Final Program

SIAM Conference on

Applications of Dynamical Systems

May 19–23, 2019
Snowbird, Utah, U.S.

Held jointly with the SIAM Workshop on Network Science (NS19)

SIAM Workshop on

Network Science

May 22–23, 2019

Sponsored by the SIAM Activity Group on Dynamical Systems
This activity group provides a forum for the exchange of ideas and information between mathematicians and applied scientists whose work involves dynamical systems. The goal of this group is to facilitate the development and application of new theory and methods of dynamical systems. The techniques in this area are making major contributions in many areas, including biology, nonlinear optics, fluids, chemistry, and mechanics.

SIAM Events Mobile App

Scan the QR code with any QR reader and download the TripBuilder EventMobile™ app to your iPhone, iPad, iTouch or Android mobile device.
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https://www.siam.org/conferences/CM/Main/ds19
https://www.siam.org/conferences/CM/Main/ns19

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Conference Themes

The scope of this conference encompasses theoretical, computational and experimental research on dynamical systems.

Highlighted systems include:
dynamics of biological systems
chemical systems
physical systems
social systems
financial systems

Highlighted areas include:
data and dynamics
applications in geophysics
fluid dynamics
materials science
engineering
other areas

SIAM Registration Desk

The SIAM registration desk is located in the Ballroom Foyer of the Cliff Lodge. It is open during the following hours:

Saturday, May 18
4:00 p.m. - 8:00 p.m.

Sunday, May 19
7:15 a.m. - 4:45 p.m.

Monday, May 20
8:00 a.m. - 6:30 p.m.

Tuesday, May 21
8:00 a.m. - 5:30 p.m.

Wednesday, May 22
7:45 a.m. - 5:30 p.m.

Thursday, May 23
8:00 a.m. - 6:15 p.m

Hotel Address

Snowbird Ski and Summer Resort
9320 S. Cliff Lodge Drive
Snowbird, UT 84092-9000
U.S.

Hotel Telephone Number

To reach an attendee or leave a message, call +1-801-742-2222. If the attendee is a hotel guest, the hotel operator can connect you with the attendee's room.

Hotel Check-in and Check-out Times

Check-in time is 4:00 p.m.
Check-out time is 11:00 a.m.

Altitude Awareness

Important Information for visitors not accustomed to Snowbird's high altitude: Utah's Wasatch Mountains are among the most beautiful in America and we hope you will enjoy every minute of your visit. But some of the very features which make the high country so attractive may cause problems unless you recognize and know how to prevent them. Visit *https://www.siam.org/conferences/CM/LS/GI/ds19-general-information* for additional information.

Child Care

As a service to SIAM attendees, SIAM has made arrangements for in-room child care. If you have not already made reservation for child care and would like to inquire about availability, please call the Mountain School at +1-801-947-8222.

Corporate Members and Affiliates

SIAM corporate members provide their employees with knowledge about, access to, and contacts in the applied mathematics and computational sciences community through their membership benefits. Corporate membership is more than just a bundle of tangible products and services; it is an expression of support for SIAM and its programs. SIAM is pleased to acknowledge its corporate members and sponsors. In recognition of their support, non-member attendees who are employed by the following organizations are entitled to the SIAM member registration rate.

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CEA/DAM
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National Institute of Standards and Technology (NIST)

National Security Agency

Oak Ridge National Laboratory

Sandia National Laboratories

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United States Department of Energy

U.S. Army Corps of Engineers, Engineer Research and Development Center

List current as of April 2019.

Funding Agencies

SIAM and the Conference Organizing Committee wish to extend their thanks and appreciation to the U.S. National Science Foundation and the DOE Office of Advanced Scientific Computing Research for their support of this conference.

Join SIAM and save!

Leading the applied mathematics community . . .

SIAM members save up to $140 on full registration for the 2019 SIAM Conference on Dynamical Systems! Join your peers in supporting the premier professional society for applied mathematicians and computational scientists. SIAM members receive subscriptions to *SIAM Review*, *SIAM News* and *SIAM Unwrapped*, and enjoy substantial discounts on SIAM books, journal subscriptions, and conference registrations.

If you are not a SIAM member and paid the *Non-Member* rate to attend, you can apply the difference of $140 between what you paid and what a member paid towards a SIAM membership. Contact SIAM Customer Service for details or join at the conference registration desk.

If you are a SIAM member, it only costs $15 to join the SIAM Activity Group on Dynamical Systems (SIAG/DS). As a SIAG/DS member, you are eligible for an additional $15 discount on this conference, so if you paid the SIAM member rate to attend the conference, you might be eligible for a free SIAG/DS membership. Check at the registration desk.

Students who paid the Student Non-Member Rate will be automatically enrolled as SIAM Student Members. Please go to *https://my.siam.org* to update your education and contact information in your profile. If you attend a SIAM Academic Member Institution or are part of a SIAM Student Chapter you will be able to renew next year for free.

Join onsite at the registration desk, go to *https://www.siam.org/Membership/Join-SIAM* to join online or download an application form, or contact SIAM Customer Service:

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Standard Audio/Visual Set-Up in Meeting Rooms

SIAM does not provide computers for any speaker. When giving an electronic presentation, speakers must provide their own computers. SIAM is not responsible for the safety and security of speakers' computers.

A data (LCD) projector and screen will be provided in all technical session meeting rooms. The data projectors support both VGA and HDMI connections. Presenters requiring an alternate connection must provide their own adaptor.

Internet Access

Complimentary wireless internet access will be available in the guest rooms, public areas, and meeting space of the Cliff Lodge.

Email stations will also be available during registration hours.

Conference Registration Fee Includes

Admission to all technical sessions *(SIAM Conference on Dynamical Systems and SIAM Workshop on Network Science)*

Business Meeting *(open to SIAM Activity Group on Dynamical Systems members)*

Coffee breaks daily

Room set-ups and audio/visual equipment

Poster Session and Dessert Receptions

Welcome Reception

Job Postings

Please check at the SIAM registration desk regarding the availability of job postings or visit *https://jobs.siam.org/*.

Poster Participant Information

Poster Session 1 is scheduled on Tuesday, May 21 from 8:30 p.m. - 10:30 p.m. Poster Session 1 presenters are requested to put up their posters between 8:00 and 8:30 p.m. on Tuesday, at which time boards and push pins will be available. **Poster displays must be removed at 10:30 p.m., the end of Poster Session 1.**

Poster Session 2 is scheduled on Wednesday, May 22, 8:30 p.m.- 10:30 p.m. Poster Session 2 presenters are requested to put up their posters between 8:00 and 8:30 p.m. on Wednesday, at which time boards and push pins will be available. **Poster displays must be removed at 10:30 p.m., the end of Poster Session 2.**

SIAM Books and Journals

Please stop by the SIAM books table to browse and purchase our selection of textbooks and monographs. Enjoy discounted prices and free shipping. Complimentary copies of selected SIAM journals are available, as well. The books booth will be staffed from 9:00 a.m. through 4:30 p.m. The books table will close at 1:30 p.m. on Thursday.

Table Top Displays

AIP Publishing

IOP Publishing

SIAM

2019 Conference Bag Sponsor

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Name Badges

A space for emergency contact information is provided on the back of your name badge. Help us help you in the event of an emergency!

Comments?

Comments about SIAM meetings are encouraged! Please send to:

Cynthia Phillips, SIAM Vice President for Programs (vpp@siam.org).

Get-togethers

Welcome Reception
Saturday, May 18
6:00 p.m. - 8:00 p.m.

SIAG/DS Business Meeting (open to SIAG/DS members)
Monday, May 20
9:00 p.m. - 9:30 p.m.
Complimentary beer and wine will be served.

PP1 Poster Session and Dessert Reception
Tuesday, May 21
8:30 p.m. - 10:30 p.m.

PP2 Poster Session and Dessert Reception
Wednesday, May 22
8:30 p.m. - 10:30 p.m.

Statement on Inclusiveness

As a professional society, SIAM is committed to providing an inclusive climate that encourages the open expression and exchange of ideas, that is free from all forms of discrimination, harassment, and retaliation, and that is welcoming and comfortable to all members and to those who participate in its activities. In pursuit of that commitment, SIAM is dedicated to the philosophy of equality of opportunity and treatment for all participants regardless of gender, gender identity or expression, sexual orientation, race, color, national or ethnic origin, religion or religious belief, age, marital status, disabilities, veteran status, field of expertise, or any other reason not related to scientific merit. This philosophy extends from SIAM conferences, to its publications, and to its governing structures and bodies. We expect all members of SIAM and participants in SIAM activities to work towards this commitment.

SIAM has partnered with NAVEX Global to provide an online portal for reporting violations of this policy. Please submit reports at *https://siam.ethicspoint.com/*.

Please Note

SIAM is not responsible for the safety and security of attendees' computers. Do not leave your laptop computers unattended. Please remember to turn off your cell phones, pagers, etc. during sessions.

Recording of Presentations

Audio and video recording of presentations at SIAM meetings is prohibited without the written permission of the presenter and SIAM.

Social Media

SIAM is promoting the use of social media, such as Facebook and Twitter, to enhance scientific discussion at its meetings and enable attendees to connect with each other prior to, during and after conferences. If you are tweeting about a conference, please use the designated hashtag to enable other attendees to keep up with the Twitter conversation and to allow better archiving of our conference discussions. The hashtag for this meeting is #SIAMDS19.

SIAM's Twitter handle is @TheSIAMNews.

Changes to the Printed Program

The printed program was current at the time of printing, however, please review the online program schedule *(http://meetings.siam.org/program.cfm?CONFCODE=ds19)* or use the mobile app for up-to-date information.

SIAM Events Mobile App Powered by TripBuilder®

To enhance your conference experience, we're providing a state-of-the-art mobile app to give you important conference information right at your fingertips. With this TripBuilder EventMobile™ app, you can:

- Create your own custom schedule
- View Sessions, Speakers, Exhibitors and more
- Take notes and export them to your email
- View Award-Winning TripBuilder Recommendations for the meeting location
- Get instant Alerts about important conference info

Scan the QR code with any QR reader and download the TripBuilder EventMobile™ app to your iPhone, iPad, iTouch or Android mobile device.

You can also visit *http://www.tripbuildermedia.com/apps/siamevents.*

SIAM Workshop on Network Science

The SIAM Workshop on Network Science will take place on Wednesday, May 22 through Thursday, May 23. Sessions will take place in the Cottonwood Room, located in the Snowbird Center.

Detailed session information is included in the content of this program. Additional workshop information is posted at *https://www.siam.org/conferences/CM/Main/ns19*.

There is no additional fee for SIAM Conference on Dynamical Systems (DS19) attendees to attend this workshop.

Prize Presentation and Special Lecture

The Prize Presentation and Special Lecture will take place in the Ballroom.

SIAM Activity Group on Dynamical Systems Prizes

Sunday, May 19

6:20 p.m. - 6:30 p.m.

Prize Presentations

Jürgen Moser and J. D. Crawford

J. D. Crawford Prize Recipient

Margaret Beck, *Boston University, U.S.*

Jürgen Moser Lecturer

Philip Holmes, *Princeton University, U.S.*

6:30 p.m. - 7:15 p.m.

SP1 Juergen Moser Lecture - Vocal Development in Marmoset Monkeys: Neuromechanics and Social Interactions

Philip Holmes, *Princeton University, U.S.*

Invited Plenary Speakers

Invited Plenary Presentations will take place in the Ballroom.

Sunday, May 19

8:30 a.m. - 9:15 a.m.

IP1 Chain Reactions

Tadashi Tokieda, *Stanford University, U.S.*

2:55 p.m. - 3:40 p.m.

IP2 Localized Pattern Formation

Bjorn Sandstede, *Brown University, U.S.*

Monday, May 20

10:45 a.m. - 11:30 a.m.

IP3 Starbursts and Flowers: When Spreading Droplets Break Bad

Karen Daniels, *North Carolina State University, U.S.*

2:55 p.m. - 3:40 p.m.

IP4 Hybrid Forecasting of Complex Systems: Combing Machine Learning with Knowledge-based Models

Michelle Girvan, *University of Maryland, College Park, U.S.*

Tuesday, May 21

10:45 a.m. - 11:30 a.m.

IP5 A Topological View of Collective Behavior Models

Chad M. Topaz, *Williams College, U.S.*

Wednesday, May 22

10:15 a.m. - 11:00 a.m.

IP6 Biological Fluid Mechanics: Hydrodynamically-coupled Oscillators

Lisa J. Fauci, *Tulane University, U.S.*

11:00 a.m. - 11:45 a.m.

IP7 Inference in Dynamical Systems: The Thermodynamic Formalism and Bayesian Inference

Sayan Mukherjee, *Duke University, U.S.*

Thursday, May 23

10:45 a.m. - 11:30 a.m.

IP8 On the Impact of Dynamics on Ensemble Data Assimilation

Marc Bocquet, *Ecole Nationale des Ponts et Chaussées, France*

6:10 p.m. - 6:55 p.m.

IP9 Networks Thinking Themselves

Danielle S. Bassett, *University of Pennsylvania, U.S.*

Minitutorials

Minitutorials will take place in Ballroom I.

Sunday, May 19

9:45 a.m. - 11:45 a.m.

MT1 Dynamic Mode Decompositions and Koopman Analysis

Organizers: Marko Budišić, *Clarkson University, U.S.*

J. Nathan Kutz, *University of Washington, U.S.*

Maziar S. Hemati, *University of Minnesota, U.S.*

4:10 p.m. - 6:10 p.m.

MT2 Stochastic Population Dynamics: Persistence, Extinction, and Quasi-stationarity

Organizer: Sebastian Schreiber, *University of California, Davis, U.S.*

SIAM Activity Group on Dynamical Systems (SIAG/DS)

www.siam.org/Activity-Groups/DS

A great way to get involved!

Collaborate and interact with mathematicians and applied scientists whose work involves dynamical systems.

Society for Industrial and Applied Mathematics

ACTIVITIES INCLUDE

- DSWeb portal
- Special sessions at SIAM meetings
- Biennial conference
- Jürgen Moser Lecture
- J. D. Crawford Prize
- Red Sock Award

BENEFITS OF SIAG/DS MEMBERSHIP

- Listing in the SIAG's online membership directory
- Additional $15 discount on registration at the SIAM Conference on Applied Dynamical Systems (excludes students)
- Dynamical Systems Magazine
- Subscription to *SIAM Journal on Applied Dynamical Systems*
- Electronic communications about recent developments in your specialty
- Eligibility for candidacy for SIAG/DS office
- Participation in the selection of SIAG/DS officers

ELIGIBILITY

- Be a current SIAM member.

COST

- $15 per year
- Student members can join two activity groups for free!

2019 SIAG/DS OFFICERS

Chair: Andrew Bernoff, *Harvey Mudd College*
Vice Chair: Ira Schwartz, *Naval Research Laboratory*
Program Director: Mason Porter, *UCLA*
Secretary: Anna Ghazaryan, *Miami University*
Co-Section Chief Editors of DSWeb Magazine: Anna Ghazaryan, *Miami University*, and Korana Burke, *University of California, Davis*
Co-Portal Editor-in-Chiefs of DSWeb: Elizabeth Cherry, *Rochester Institute of Technology*, and Danny Abrams, *Northwestern University*

SIAG/DS: *www.siam.org/Activity-Groups/DS*
SIAM: *www.siam.org/joinsiam*
DSWeb: *dsweb.siam.org*

DS19 and NS19 Program

SIAM Conference on
Applications of Dynamical Systems
May 19–23, 2019
Snowbird, Utah, U.S.

Held jointly with the SIAM Workshop on Network Science (NS19)

SIAM Workshop on
Network Science
May 22–23, 2019

Saturday, May 18

Registration

4:00 p.m.-8:00 p.m.

Room: Ballroom Foyer

Saturday, May 18

Student and Postdoc Icebreaker Session

4:30 p.m.-5:30 p.m.

Room: Primrose A

On Saturday before the opening reception, there will be an informal Student and Postdoc Icebreaker session. Through structured activities, we hope attendees leave feeling comfortable about the meeting and having made new connections as friendly faces during the conference. All who are interested are welcome, and first-time attendees are especially encouraged to attend. There is no additional cost, but to get a count on how many people to expect, we request that you register for this session when you register for the conference. Light refreshments will be available.

Organizer: Alexandria Volkening
Ohio State University, U.S.

Organizer: Heather Zinn Brooks
University of California, Los Angeles, U.S.

Welcome Reception

6:00 p.m.-8:00 p.m.

Room: Ballroom

Sunday, May 19

Registration

7:15 a.m.-4:45 p.m.

Room: Ballroom Foyer

Welcome Remarks

8:15 a.m.-8:30 a.m.

Room: Ballroom

Sunday, May 19

IP1

Chain Reactions

8:30 a.m.-9:15 a.m.

Room: Ballroom

Chair: Mason A. Porter, University of California, Los Angeles, U.S.

To every action corresponds an equal and opposite reaction. However, there turn out to exist in nature situations where the reaction seems neither equal in magnitude nor opposite in direction to the action. We will see a series of table-top demos and experimental movies, apparently in more and more violation of Newton's 3rd law, and give an analysis of what is happening, discovering in the end that the phenomenon is in a sense generic. The keys are shock, singularity in the material property, and supply of ‘critical geometry'.

Tadashi Tokieda
Stanford University, U.S.

Coffee Break

9:15 a.m.-9:45 a.m.

Room: Golden Cliff

Sunday, May 19

MT1

Dynamic Mode Decompositions and Koopman Analysis

9:45 a.m.-11:45 a.m.

Room: Ballroom 1

Chair: Marko Budišic, Clarkson University, U.S.

Chair: J. Nathan Kutz, University of Washington, U.S.

Chair: Maziar S. Hemati, University of Minnesota, U.S.

Nonlinear maps, ODEs, and PDEs can all be represented by the Koopman family of linear operators, enabling spectral analysis of nonlinear dynamics. Two seminal papers by Schmid, and by Rowley, Mezic, Bagheri, Schlatter, and Henningson sparked a vigorous development of data-driven analysis techniques under an ever-expanding umbrella of Dynamic Mode Decomposition (DMD) algorithms, now understood to be associated with the theoretical Koopman framework. Initial applications came from fluid dynamics; however, the technique has been applied in all areas of science and engineering. The session aims to introduce the Koopman/DMD framework to non-experts. The focus is on providing a balanced overview of the core ideas, rather than the latest developments. The session will be split into three 30-minute expository parts, and end with a 15 minute Q&A. The first part (M. Budišic) will serve as an introduction to the Koopman operator, placing it in the context of broader dynamical systems theory. The second part (J. N. Kutz) will discuss various algorithms for computing the DMD, with connections to the broader data-driven modeling of dynamics. The third part (M. S. Hemati) will feature a case study of applications, such as fluid flow analysis, with guidance for addressing practical challenges. The final part will be reserved for questions from the audience concerning recent results, future developments, and open problems within the Koopman/DMD analyses.

Speakers:

Marko Budišic, Clarkson University, U.S.

J. Nathan Kutz, University of Washington, U.S.

Maziar S. Hemati, University of Minnesota, U.S.

Sunday, May 19

MS1

Advances in Infectious Disease Modeling - Part I of II

9:45 a.m.-11:25 a.m.

Room: Ballroom 2

For Part 2 see MS12

Infectious diseases are spreading geographically faster now than ever before, posing a continuing threat to daily life. Mathematical modeling has become an important tool in investigating infections, providing key insights into infection dynamics and spread at both the within-host and epidemiological scales. The primary goal of this minisymposium is to provide a platform for discussion of mathematical models of infectious disease dynamics and provide a broad perspective on the strengths, and weaknesses, of disease modeling. In particular we aim to emphasize appropriate use of methodology, from deterministic to stochastic models, as we use modeling to investigate a great diversity of problems, from understanding basic disease mechanisms in-host to controlling the spread of infection between hosts.

Organizer: Alun Lloyd
North Carolina State University, U.S.

Organizer: Jessica M. Conway
Pennsylvania State University, U.S.

Organizer: Ruian Ke
Los Alamos National Laboratory, U.S.

9:45-10:05 Heterogeneous HIV Viral Rebound Dynamics Following Treatment Interruption

Jessica M. Conway, Pennsylvania State University, U.S.

10:10-10:30 On the Importance of Spatial Structure in Within-Host Models of Viral Dynamics and the Immune Responses

Ruian Ke, Los Alamos National Laboratory, U.S.

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Sunday, May 19

MS1

Advances in Infectious Disease Modeling - Part I of II

continued

10:35-10:55 Early Events During Hepatitis B Virus Infection

Stanca Ciupe, Virginia Tech, U.S.; Jonathan Forde, Hobart and William Smith Colleges, U.S.; Naveen K. Vaidya, San Diego State University, U.S.

11:00-11:20 Incorporating Infected Cell Phenotypes into Models of Within-Host Viral Dynamics

Katia Koelle, Emory University, U.S.

Sunday, May 19

MS2

Novel Directions in Network Dynamical Systems - Part I of II

9:45 a.m.-11:25 a.m.

Room: Magpie B

For Part 2 see MS15

Network dynamical systems play a major role throughout science and technology. Despite this, many important questions remain open or have unsatisfactory answers. For example, how can one determine a network structure from limited available data? And what explains the abundance of unusual phenomena in network systems, such as invariant spaces, degenerate spectra, robust heteroclinic networks, complicated bifurcation scenarios and the emergence of synchrony? Such questions are further complicated by the fact that many techniques from dynamical systems theory are unable to keep track of the underlying network structure. In an attempt to tackle these issues, numerous creative solutions and innovative techniques have been brought forward. Many of these have an interdisciplinary flavour, forming surprising bridges between multiple areas of mathematics. For instance, networks have been linked to various algebraic structures. Examples of this include the groupoid formalism, which relates synchrony-patterns to balanced equivalence relations and thus enables the use of lattice theory, and more recently the fundamental network construction, which uses the idea of hidden symmetry to connect networks to certain monoid representations. This two-part minisymposium provides an overview of many different, novel and interdisciplinary approaches to problems in network dynamical systems.

Organizer: Eddie Nijholt
University of Illinois at Urbana-Champaign, U.S.

Organizer: Sören Schwenker
Universität Hamburg, Germany

9:45-10:05 Towards a Bifurcation Theory for Network Dynamical Systems using Hidden Symmetry

Bob Rink, Vrije Universiteit Amsterdam, The Netherlands

continued in next column

10:10-10:30 Generalized Feedforward Networks: Algebraic Structure and Steady State Bifurcations

Eddie Nijholt, University of Illinois at Urbana-Champaign, U.S.; Bob Rink, Vrije Universiteit Amsterdam, The Netherlands; *Sören Schwenker*, Universität Hamburg, Germany

10:35-10:55 Effective Networks: Predicting Network Structure and Critical Transitions from Data

Deniz Eroglu, Northwestern University, U.S.

11:00-11:20 Effects of Structural Changes in Network Dynamics: More is Less

Tiago Pereira, Imperial College London, United Kingdom; Camille Poignard, University of Exeter, United Kingdom; Philipp Pade, Humboldt University Berlin, Germany

Sunday, May 19

MS3

Dynamics of Non-Gaussian Stochastic Systems - Part I of II

9:45 a.m.-11:00 a.m.

Room: Wasatch A

For Part 2 see MS16

Stochastic effects appeared in many complex phenomena or systems are often non-Gaussian (e.g., Lévy motion) rather than Gaussian (e.g., Brownian motion). For instance, in the process of transcription and translation of DNA, changes in ocean and climate, and rotating annular fluid flows, those systems present sudden, intermittent, unpredictable dynamical behaviors. Then it is more appropriate to use non-Gaussian Lévy motions to simulate fluctuations in mathematical modeling of complex systems under uncertainty. Non-Gaussian dynamical systems are useful and important in investigating the dynamical behaviors of stochastic systems. In order to better describe dynamical behaviors, we consider the stochastic differential equations with Lévy motions, mean exit time, escape probability, dimension reduction, invariant manifolds, slow manifolds, large deviations, probability density functions, and phase-space orbits to reflect the information of dynamical systems. Furthermore, these tools can be used to study the dynamical behaviors of complex systems such as gene regulation systems, molecular analysis, and atmospheric climate change. This minisymposium brings together researchers with diverse but related background suitable to study dynamics of non-Gaussian stochastic systems, and give the scientific community a flavor of the most important stochastic approaches relevant to systems in biology and meteorology, and engineering.

Organizer: Shenglan Yuan
Huazhong University of Science & Technology, China

Organizer: Jinqiao Duan
Illinois Institute of Technology, U.S.

9:45-10:05 Geometric Methods for Stochastic Dynamics

Jinqiao Duan, Illinois Institute of Technology, U.S.

continued in next column

10:10-10:30 Slow Manifolds for Stochastic Systems with Non-Gaussian Stable Lévy Noise

Shenglan Yuan, Huazhong University of Science & Technology, China

10:35-10:55 Homogenization of Periodic Linear Nonlocal Partial Differential Equations

Qiao Huang, Huazhong University of Science & Technology, China

Sunday, May 19

MS4

Complex Oscillatory Patterns in Biological Systems

9:45 a.m.-11:25 a.m.

Room: Wasatch B

Mixed-mode oscillations (MMOs) and bursting oscillations are fascinating dynamical behaviors exhibited by an array of biological systems with multiple timescale dynamics. Canards are solutions of multiple timescale systems which, after flowing close to an attracting slow manifold, remain close to a repelling slow manifold for a considerable amount of time relative to the system timescale. These solutions, especially near folded-node singularities and in the presence of a return mechanism, give an essential generating mechanism for MMOs and can describe transitions between spiking and bursting in coupled oscillator models. Canards, MMOs, bursts, and related oscillatory dynamics arise in a variety of biological systems, including in neural and cardiac dynamics. Speakers in this minisymposium will give an overview of ongoing research and current questions surrounding mathematical analysis of MMOs and bursting in biological systems. Results and examples of MMOs and bursting in four distinct models will be presented. Featured topics of this minisymposium include mechanisms surrounding the onset of MMOs or bursting as a function of changing model parameters and the role of canards in mediating complex oscillations.

Organizer: Zahra Aminzare
University of Iowa, U.S.

Organizer: Elizabeth Davison
Princeton University, U.S.

9:45-10:05 Canard-Induced Mixed Mode Oscillations in Coupled FitzHugh-Nagumo Systems with Non-Symmetric Coupling

Zahra Aminzare, University of Iowa, U.S.; Elizabeth Davison, Naomi E. Leonard, and Biswadip Dey, Princeton University, U.S.

continued on next page

Sunday, May 19

MS4

Complex Oscillatory Patterns in Biological Systems

continued

10:10-10:30 Canard-Mediated Complex Oscillations in a Rate Model

Elif Koksal Ersoz and Mathieu Desroches, Inria Sophia Antipolis, France; Antoni Guillamon, Polytechnic University of Catalonia, Spain; Joel Tabak, University of Exeter, United Kingdom

10:35-10:55 Canards as a Mechanism for Early Afterdepolarizations in Cardiac Cells

Joshua T. Kimrey, Theo Vo, and Richard Bertram, Florida State University, U.S.

11:00-11:20 Bursting in the Presence of a Locally Separating Manifold

Hinke M. Osinga, Saeed Farjami, and Vivien Kirk, University of Auckland, New Zealand

Sunday, May 19

MS5

Got Rhythm? - A Dynamical Systems Survival Guide for Biology

9:45 a.m.-11:25 a.m.

Room: Maybird

Experimental biology has revealed that the generation of rhythmic, arrhythmic, stationary, and chaotic activities are each – at certain times and in certain contexts – required to sustain life. To date, many of these discoveries are unknown to the modeling community. Meanwhile, dynamical systems modeling of related simulations is ongoing, but is largely unknown to experimentalists. Enhanced communication between these two arenas is likely to illuminate how organisms function. Some niches within biology have invested in such interactions; we are targeting those that have not. Our minisymposium will showcase insights into the role of rhythmic structure – or the lack thereof – in biology, via collaboration between experimentalists and theorists. To this end, we discuss i) dynamical systems frameworks that characterize simulated systems, which merit dissemination within the experimental community, and ii) open problems that are novel to most theorists, which show preliminary evidence of benefiting from a dynamical systems framework. The areas to be discussed are: the information content of acoustic signals, chemical reactions governing metabolism, and the means by which neurons communicate in a circuit. Moreover, we aim to attract researchers who to-date consider themselves to be either solely theorists or solely experimentalists. We will foster conversation on promising new directions for collaborative endeavors.

Organizer: Eve Armstrong
University of Pennsylvania, U.S.

Organizer: Youngmin Park
University of Pennsylvania, U.S.

9:45-10:05 What Kind of Music do Songbirds Like? A Dynamical Systems Approach to Predicting Female Song Preferences

Eve Armstrong and Alicia Zeng, University of Pennsylvania, U.S.; David White, Wilfred Lauriel University, Canada; Marc Schmidt, University of Pennsylvania, U.S.

10:10-10:30 Scalar Reduction of a Neural Field Model with Spike Frequency Adaptation

Youngmin Park, University of Pennsylvania, U.S.; G. Bard Ermentrout, University of Pittsburgh, U.S.

10:35-10:55 Bayesian Parameter Estimation in the Spatial Organization of Metabolism

Sasha Shirman, Svetlana P. Ikonomova, Taylor Nichols, Keith Tyo, Danielle Tullman-Ercek, and Niall M. Mangan, Northwestern University, U.S.

11:00-11:20 A Neuromechanistic Model for Keeping a Simple Rhythmic Beat in the Context of Music

Amitabha Bose, New Jersey Institute of Technology, U.S.; Aine Byrne, New York University, U.S.; John Rinzel, Courant Institute and Center for Neural Science, New York University, U.S.

continued in next column

Sunday, May 19

MS6

Applied Mathematical Techniques for Fluid Flow Across Scales - Part I of II

9:45 a.m.-11:25 a.m.

Room: Superior A

For Part 2 see MS19

Fluid flow is omnipresent in nature and is characterized by a wide range of actively interacting scales. While applied mathematical techniques has helped us in understanding the dynamics of fluid flow in a myriad of configurations, the collection of techniques used in this field has grown exponentially over the years. Consequently, in this minisymposium we aim to address a wide spectrum of different cutting-edge research problems in fluid dynamics where efficient applied mathematical techniques can be utilized to understand specific nontrivial aspects of the flow. This minisymposium will feature eight applied mathematicians discussing fluid dynamic problems ranging from small scale flows set in lab experiments, where classical methods such as conformal mapping and asymptotic analysis can be employed, to strongly nonlinear turbulent flows in the atmosphere and the ocean, where specialized novel techniques are coupled with state-of-the-art high resolution direct numerical simulations to understand energy and momentum transfers across spatio-temporal scales. The two sessions of this minisymposium will also serve as a generic advertisement to a general audience, including graduate students and early career scientists, the grand challenges in fluid dynamic problems at various scales and a collection of specialized applied mathematical techniques that can be used to address them.

Organizer: Pejman Sanaei
Courant Institute of Mathematical Sciences, New York University, U.S.

Organizer: Jim Thomas
Woods Hole Oceanographic Institution and Dalhousie University, U.S.

9:45-10:05 On Stability of Oriented Meteorites

Pejman Sanaei, Michael J. Shelley, and Leif Ristroph, Courant Institute of Mathematical Sciences, New York University, U.S.

continued in next column

10:10-10:30 Complex Dynamics of Unsteady Microchannel Fluid--Structure Interactions: 1D Model

Tanmay Inamdar and *Ivan C. Christov*, Purdue University, U.S.

10:35-10:55 Marangoni-Driven Motion of Particles at Liquid-Gas Interfaces

Saeed Jafari Kang, Esmaeil Dehdashti, and *Hassan Masoud*, Michigan Technological University, U.S.

11:00-11:20 Dynamical Models for Interacting Flapping Swimmers

Anand Oza, New Jersey Institute of Technology, U.S.; Eva Kanso, University of Southern California, U.S.; Michael J. Shelley, Courant Institute of Mathematical Sciences, New York University, U.S.

Sunday, May 19

MS7

Nonlinear Waves and Patterns

9:45 a.m.-11:25 a.m.

Room: Superior B

From striped clouds in the sky and vegetation patterning in drylands to salt fingers in oceans, patterns and waves arise in nature everywhere. These phenomena motivate the study of PDE models associate with convection and reaction-diffusion. Mathematical techniques can help to reveal the mechanisms of patterns and waves in various applications, and help to predict or control their generations or degradations. In this minisymposium, recent advances in mathematical analysis of pattern forming systems will be discussed, ranging from spectra, bifurcations, to existence theorem, stability and amplitude equations.

Organizer: Jichen Yang
Universität Bremen, Germany

Organizer: Jens Rademacher
Universität Bremen, Germany

9:45-10:05 Exploiting Topographic Heterogeneity to Probe Models of Dryland Vegetation Patterns

Mary Silber, University of Chicago, U.S.; Punit Gandhi, Ohio State University, U.S.; Sarah Iams, Harvard University, U.S.

10:10-10:30 Convectons and Chaos in Doubly Diffusive Convection

Cedric Beaume, University of Leeds, United Kingdom

10:35-10:55 Localized Traveling Waves in Thermosolutal Convection

Haifaa Alrihieli, University of Leeds, United Kingdom

11:00-11:20 Bifurcation of Localized Structures in Biologically Inspired Reaction-Diffusion Equations

Fahad Saif Hamood Al Saadi and Alan R. Champneys, University of Bristol, United Kingdom

Sunday, May 19

MS8

Computation of Sensitivities of Statistics in Chaotic Systems

9:45 a.m.-11:25 a.m.

Room: White Pine

Gradient information computed from numerical simulations is useful for design and optimization and uncertainty quantification in many engineering disciplines. Today's high-fidelity simulations can capture complex physics including chaotic dynamics, but sensitivity analysis on them is still nascent. The reason is that an infinitesimal perturbation applied to a chaotic system grows unbounded in time, rendering linearized perturbation solutions meaningless. The mean response of the system, i.e., the sensitivity of statistics to perturbations to system inputs, is bounded. This series of talks present methods to compute the sensitivities of chaotic statistics efficiently. This type of methods has far-reaching applications across several scientific and engineering disciplines - from climate studies to modern aircraft design. The algorithms discussed will be roughly based on two key ideas: one, computing shadowing directions and their adjoints and two, splitting the overall sensitivity into its stable and unstable contributions and devising a backward algorithm for the unstable contribution. The talks will focus on applications of these algorithms for gradient-based design optimization applications in computational fluid dynamics.

Organizer: Nisha Chandramoorthy
Massachusetts Institute of Technology, U.S.

Organizer: Qiqi Wang
Massachusetts Institute of Technology, U.S.

Organizer: Patrick J. Blonigan
Sandia National Laboratories, U.S.

Organizer: Angxiu Ni
University of California, Berkeley, U.S.

9:45-10:05 Computation of Sensitivities in Chaotic Systems: An Overview

Qiqi Wang, Massachusetts Institute of Technology, U.S.

continued in next column

10:10-10:30 Adjoint Shadowing Directions in Chaotic Dynamical Systems for Sensitivity Analysis

Angxiu Ni, University of California, Berkeley, U.S.

10:35-10:55 Space-Split Statistical Sensitivity Computation in Chaotic Systems

Nisha Chandramoorthy, Massachusetts Institute of Technology, U.S.

11:00-11:20 Adjoint Sensitivity Analysis of a Scale-Resolving Turbulent Flow Simulation

Patrick J. Blonigan, Sandia National Laboratories, U.S.

Sunday, May 19

MS9

Mapping and Modeling Cardiac Electrical Dynamics and Arrhythmias - Part I of II

9:45 a.m.-11:25 a.m.

Room: Primrose A

For Part 2 see MS21

Cardiac arrhythmias are abnormal heart rhythms underlying complex spatiotemporal electromechanical activity. Spiral and scroll waves patterns of self-organised abnormal synchronisation are known to exist in the heart. These non-linear vortices act as fast cardiac activation sources underlying cardiac arrhythmias and fatal fibrillation. Mapping and control of the rotors of rapid abnormal activation in the heart is of primary importance necessary to revert to normal heart rhythm. This minisymposium provides a sampling of the current experimental, and theoretical approaches to mapping of the rotors dynamics, locus identification, and modelling of cardiac electrical dynamics and arrhythmias.

Organizer: Irina Biktasheva
University of Liverpool, United Kingdom

Organizer: Seth Weinberg
Virginia Commonwealth University, U.S.

Organizer: Alena Talkachova
University of Minnesota, U.S.

9:45-10:05 Novel Approaches for Mapping-Specific Rotor Ablation During Atrial Fibrillation

Alena Talkachova, University of Minnesota, U.S.

10:10-10:30 Gap Junctional and Ephaptic Coupling Modulate Repolarization in Cardiac Tissue

Seth Weinberg, Virginia Commonwealth University, U.S.

10:35-10:55 Spontaneous Initiation of Ventricular Fibrillation

Hiroshi Ashikaga, Johns Hopkins University, U.S.

11:00-11:20 Sensitivity of Spiral Wave Core Formation and Transient Spiral Core Interactions

Christopher Marcotte, University of Exeter, United Kingdom

Sunday, May 19

MS10

Collective Behavior in Networks - Part I of II

9:45 a.m.-11:25 a.m.

Room: Primrose B

For Part 2 see MS22

Collective behavior in networks of dynamically linked entities is ubiquitous to many natural processes and industrial applications, including coordinated firing of neurons in the brain, synchronization of powergrids, and spreading of information or disinformation. Understanding the dynamics, the emergence and the breakdown of collective behavior is critical to the understanding and control of the relevant macroscopic dynamics of such processes. This minisymposium addresses several aspects of collective behavior in networks, including synchronization, diffusion and multilayer networks.

Organizer: Lachlan D. Smith
University of Sydney, Australia

Organizer: Georg A. Gottwald
University of Sydney, Australia

9:45-10:05 Dynamical Instabilities in Networked Systems, it is a Matter of Time and Direction

Timoteo Carletti, University of Namur, Belgium

10:10-10:30 Multifaceted Dynamics of Janus Oscillator Networks

Zachary G. Nicolaou, Deniz Eroglu, and Adilson E. Motter, Northwestern University, U.S.

10:35-10:55 Synchronization, Information, and Memory in Simplex Networks: Dynamics of Coupled Oscillators with Higher-Order Interactions

Per Sebastian Skardal, Trinity College, U.S.

11:00-11:20 Chaos and Multistability in Networks of Coupled Oscillators

Lachlan D. Smith and Georg A. Gottwald, University of Sydney, Australia

Sunday, May 19

CP1

Networks I

9:45 a.m.-11:25 a.m.

Room: Ballroom 3

Chair: Michael Gabbay, University of Washington, U.S.

9:45-10:05 A Dynamical Systems Approach to Threshold Models of Social Influence

Yi Ming Lai, University of Nottingham, United Kingdom; Mason A. Porter, University of California, Los Angeles, U.S.

10:10-10:30 Implication Avoiding Dynamics for Externally Observed Networks

Joel D. Nishimura and Oscar Goodloe, Arizona State University, U.S.

10:35-10:55 Spectral Analysis of a Non-Equilibrium Stochastic Dynamics on a Complex Network

Inbar Seroussi and Nir Sochen, Tel Aviv University, Israel

11:00-11:20 A Nonlinear Model of Opinion Network Dynamics and Its Experimental Investigation

Michael Gabbay, University of Washington, U.S.

Sunday, May 19

CP2

Hamiltonian Systems

9:45 a.m.-11:25 a.m.

Room: Magpie A

Chair: Vered Rom-Kedar, Weizmann Institute of Science, Israel

9:45-10:05 Data Driven Hamiltonian Dynamics for Hydrogen-Oxygen Combustion via Programmable Potentials

Allan Avila, University of California, Santa Barbara, U.S.

10:10-10:30 Diffusion of Medium Earth Orbits from a Hamiltonian Perturbative Approach

Jerome Daquin, University of Padova, Italy; Christos Efthymiopoulos, Academy of Athens, Greece; Ioannis Gkolias, Politecnico di Milano, Italy; Aaron Rosengren, University of Arizona, U.S.

10:35-10:55 Studying the Effect of the Solvent on the Position of the Dividing Surface with the Aid of Lagrangian Descriptors

Rafael Garcia-Meseguer, University of Bristol, United Kingdom; Barry Carpenter, Cardiff University, United Kingdom; Stephen Wiggins, University of Bristol, United Kingdom

11:00-11:20 On Exponential Fermi Accelerators and on Energy Equilibration

Vered Rom-Kedar, Weizmann Institute of Science, Israel; Kushal Shah, Indian Institute of Science Education and Research, India; Dmitry Turaev, Imperial College London, United Kingdom; Vassili Gelfreich, University of Warwick, United Kingdom

Lunch Break

11:25 a.m.-1:00 p.m.

Attendees on their own

Sunday, May 19

MS11

Nonsmooth Dynamical Systems: From Nodes to Networks

1:00 p.m.-2:40 p.m.

Room: Ballroom 1

This minisymposium aims to foster discussion around tools for handling nonsmooth or discontinuous dynamical systems, as well as networks of such systems. Nonsmooth mathematical models arise naturally in physics, engineering or biology when considering impacting or switching systems. In addition, there is increasing interest in using piecewise linear models to caricature more complex nonlinear systems. By separating phase space into regions which are each governed by linear differential equations, one can often obtain global analytical insight – with trajectories and other quantities of interest available in closed form. The price for this is the loss of many standard tools from smooth dynamical systems. Existence, uniqueness and stability must be considered carefully, and new methods developed. Even a simple planar system may display grazing, sliding and slipping bifurcations not present in smooth systems, while additional challenges appear at the network level. For some classes of nonsmooth systems, the stability of network synchrony can be determined by an extension of the Master Stability Function; while in others, such as Glass networks, the order of nodes crossing switching manifolds leads to a combinatorial explosion in the number of stability conditions. By combining expertise from network theory with analysis from (typically low-dimensional) dynamical systems, this minisymposium will encourage the development of next generation tools for network dynamical systems.

Organizer: Yi Ming Lai

University of Nottingham, United Kingdom

1:00-1:20 Non-Smooth Dynamics Perspectives for Designing Large Scale Optimization Algorithms in Stochastic Settings

Rachel Kuske, Georgia Institute of Technology, U.S.; Emmanouil Daskalakis, University of British Columbia, Canada; Felix Herrmann, Georgia Institute of Technology, U.S.

continued in next column

1:25-1:45 Nonsmooth Dynamics in Spatially Distributed Neural Systems

G. Bard Ermentrout, University of Pittsburgh, U.S.

1:50-2:10 Sleep, Dreams, and Bifurcations: REM Sleep and Nonsmooth Maps for Sleep/Wake Dynamics

Cecilia Diniz Behn, Colorado School of Mines, U.S.; Victoria Booth, University of Michigan, U.S.

2:15-2:35 A Probabilistic Regularization of Zeno Hybrid Systems by a Convolution Method

Ismail Belgacem, University of Victoria, Canada; Hamid Bensalah, University of Abou Bekr Belkaïd, Algeria; Brahim Cherki, University of Tlemcen, Algeria; Roderick Edwards, University of Victoria, Canada

Sunday, May 19

MS12

Advances in Infectious Disease Modeling - Part II of II

1:00 p.m.-2:40 p.m.

Room: Ballroom 2

For Part 1 see MS1

Infectious diseases are spreading geographically faster now than ever before, posing a continuing threat to daily life. Mathematical modeling has become an important tool in investigating infections, providing key insights into infection dynamics and spread at both the within-host and epidemiological scales. The primary goal of this minisymposium is to provide a platform for discussion of mathematical models of infectious disease dynamics and provide a broad perspective on the strengths, and weaknesses, of disease modeling. In particular we aim to emphasize appropriate use of methodology, from deterministic to stochastic models, as we use modeling to investigate a great diversity of problems, from understanding basic disease mechanisms in-host to controlling the spread of infection between hosts.

Organizer: Alun Lloyd

North Carolina State University, U.S.

Organizer: Jessica M. Conway

Pennsylvania State University, U.S.

Organizer: Ruian Ke

Los Alamos National Laboratory, U.S.

1:00-1:20 Control of Mosquito-Borne Diseases: To Spray or Not to Spray?

Alun Lloyd, North Carolina State University, U.S.

1:25-1:45 Evolution of HIV-1 Across the Within and Between-Host Scales: The Role of Transmission Bottlenecks

David Dick, University of Western Ontario, Canada

1:50-2:10 Spatial Aspects in Vaccination

Julien Arino, University of Manitoba, Canada

2:15-2:35 Application of Probability Generating Functions to Infectious Disease Modeling

Joel C. Miller, Institute for Disease Modeling, U.S. and La Trobe University, Australia

Sunday, May 19

MS13

Simple Systems with Complex Dynamics

1:00 p.m.-2:40 p.m.

Room: Ballroom 3

Lab experiments can often be very costly as they may require expensive equipment. However, research in dynamical systems can still be done using simple table top experiments at low cost. Many of these systems may seem extremely simple and mundane in set up, yet they can be very rich in their dynamics. In this minisymposium, we present four table top experiments involving mechanical, chemical and electrical oscillators and show how they can produce complex phenomena such as synchronization, period doubling bifurcation and chaos. We also demonstrate how these systems can be studied mathematically and numerically.

Organizer: Andrea J. Welsh

Georgia Institute of Technology, U.S.

1:00-1:20 The Wien Bridge Oscillator as an Archetype for Exploring Practical Applications of Nonlinear Dynamics

Randall Tagg and Masoud Asadi-Zeydabadi, University of Colorado, Denver, U.S.

1:25-1:45 Dynamics of Table-Top Fire Fronts

Niklas Manz, College of Wooster, U.S.; Hannah Phillips and Conner Herndon, Georgia Institute of Technology, U.S.; Abigail Ambrose, College of Wooster, U.S.; Flavio H. Fenton, Georgia Institute of Technology, U.S.

1:50-2:10 Continuum Mechanics of Magic

Jared Bronski, University of Illinois, U.S.; Richard McLaughlin, University of North Carolina at Chapel Hill, U.S.

2:15-2:35 Using a Micro-Controller for Dynamics Visualization

Andrea J. Welsh, Georgia Institute of Technology, U.S.; Cristian Delgado, Universidad Nacional Autónoma de México, Mexico; Casey Lee-Trimble, Mount Holyoke College, U.S.; Flavio H. Fenton, Georgia Institute of Technology, U.S.

Sunday, May 19

MS14

Understanding Spatiotemporal Dynamics through Analytical Approaches - Part I of II

1:00 p.m.-2:15 p.m.

Room: Magpie A

For Part 2 see MS25

This minisymposium will focus on analytical techniques applied to a variety of dynamical systems with the goal of understanding the emergence of various spatiotemporal behaviors arising in myriad applications. Among the approaches discussed will be several recent ideas in the use of Competitive Modes to identify and analyze chaotic regimes, complex bifurcations leading to diverse dynamical regimes, comparisons of the effects of discrete and distributed delays on various limit cycle and chaotic oscillators (including effects such as transitions between amplitude death and oscillation death), and asymptotic criteria for the emergence of spatiotemporal dynamics in reaction-diffusion systems. Other talks will emphasize applications of analytical techniques to systems arising in problems of scientific or industrial importance.

Organizer: Roy Choudhury

University of Central Florida, U.S.

Organizer: Robert Van Gorder

University of Oxford, United Kingdom

Organizer: Constance Schober

University of Central Florida, U.S.

1:00-1:20 Pattern Formation in Bulk-Surface Reaction-Diffusion Systems

Andrew Krause, University of Oxford, United Kingdom

1:25-1:45 Dynamics from a Coupled Chemical - Thermal - Microsilica Particle Formation Model

Raquel Gonzalez Farina, Andreas Münch, James Oliver, and Robert Van Gorder, University of Oxford, United Kingdom

1:50-2:10 Pattern Formation in Reaction-Diffusion Systems on Time-Evolving Domains

Robert Van Gorder, University of Oxford, United Kingdom

Sunday, May 19

MS15

Novel Directions in Network Dynamical Systems - Part II of II

1:00 p.m.-2:40 p.m.

Room: Magpie B

For Part 1 see MS2

Network dynamical systems play a major role throughout science and technology. Despite this, many important questions remain open or have unsatisfactory answers. For example, how can one determine a network structure from limited available data? And what explains the abundance of unusual phenomena in network systems, such as invariant spaces, degenerate spectra, robust heteroclinic networks, complicated bifurcation scenarios and the emergence of synchrony? Such questions are further complicated by the fact that many techniques from dynamical systems theory are unable to keep track of the underlying network structure. In an attempt to tackle these issues, numerous creative solutions and innovative techniques have been brought forward. Many of these have an interdisciplinary flavour, forming surprising bridges between multiple areas of mathematics. For instance, networks have been linked to various algebraic structures. Examples of this include the groupoid formalism, which relates synchrony-patterns to balanced equivalence relations and thus enables the use of lattice theory, and more recently the fundamental network construction, which uses the idea of hidden symmetry to connect networks to certain monoid representations. This two-part minisymposium provides an overview of many different, novel and interdisciplinary approaches to problems in network dynamical systems.

Organizer: Eddie Nijholt

University of Illinois at Urbana-Champaign, U.S.

Organizer: Sören Schwenker

Universität Hamburg, Germany

1:00-1:20 Stability of Network Dynamical Systems

Lee DeVille, University of Illinois, U.S.

continued on next page

Sunday, May 19

MS15

Novel Directions in Network Dynamical Systems - Part II of II

continued

1:25-1:45 Synchrony-Breaking Bifurcating Branches from Non-Zero Lattice Indices

Hiroko Kamei, University of Dundee, United Kingdom

1:50-2:10 Stability for Heteroclinic Dynamics of Localized Frequency Synchrony

Alexander Lohse, Universität Hamburg, Germany

2:15-2:35 Synchrony-Breaking Bifurcation in Feed-Forward Networks

Pedro Soares, Universidade do Porto, Portugal

Sunday, May 19

MS16

Dynamics of Non-Gaussian Stochastic Systems - Part II of II

1:00 p.m.-2:40 p.m.

Room: Wasatch A

For Part 1 see MS3

Stochastic effects appeared in many complex phenomena or systems are often non-Gaussian (e.g., Lévy motion) rather than Gaussian (e.g., Brownian motion). For instance, in the process of transcription and translation of DNA, changes in ocean and climate, and rotating annular fluid flows, those systems present sudden, intermittent, unpredictable dynamical behaviors. Then it is more appropriate to use non-Gaussian Lévy motions to simulate fluctuations in mathematical modeling of complex systems under uncertainty. Non-Gaussian dynamical systems are useful and important in investigating the dynamical behaviors of stochastic systems. In order to better describe dynamical behaviors, we consider the stochastic differential equations with Lévy motions, mean exit time, escape probability, dimension reduction, invariant manifolds, slow manifolds, large deviations, probability density functions, and phase-space orbits to reflect the information of dynamical systems. Furthermore, these tools can be used to study the dynamical behaviors of complex systems such as gene regulation systems, molecular analysis, and atmospheric climate change. This minisymposium brings together researchers with diverse but related background suitable to study dynamics of non-Gaussian stochastic systems, and give the scientific community a flavor of the most important stochastic approaches relevant to systems in biology and meteorology, and engineering.

Organizer: Shenglan Yuan

Huazhong University of Science & Technology, China

Organizer: Jinqiao Duan

Illinois Institute of Technology, U.S.

1:00-1:20 Asymptotic Behaviors of Several Kinds of Slow-Fast Systems Driven by Lévy Processes

Yong Xu, Northwestern Polytechnical University, China

continued in next column

1:25-1:45 Lévy Noise-Induced Transition in a Two-Dimensional Gene Regulatory System

Fengyan Wu, Chongqing University, China

1:50-2:10 Dynamics and an Averaging Principle for Completely Integrable Stochastic Hamiltonian System with Lévy Noise

Pingyuan Wei, Huazhong University of Science & Technology, China

2:15-2:35 Characterization of the Most Probable Transition Paths of Stochastic Dynamical Systems with Stable Lévy Noise

Yuanfei Huang, Huazhong University of Science & Technology, China

Sunday, May 19

MS17

Heteroclinic Attractors and Cyclic Competition of Species - Part I of II

1:00 p.m.-2:40 p.m.

Room: Wasatch B

For Part 2 see MS27

A significant progress in understanding of typical processes in multispecies ecological systems, as well as neural and cognitive networks, has been achieved using dynamical models which include heteroclinic sequences. The goal of the minisymposium is to present recent advances in that field. The talks include the description and analysis of multidimensional heteroclinic attractors, hierarchical heteroclinic networks, as well as spatially extended deterministic and stochastic rock-paper-scissors models.

Organizer: Alexander Nepomnyashchy
Technion Israel Institute of Technology, Israel

Organizer: Vladimir A. Volpert
Northwestern University, U.S.

1:00-1:20 Mathematical Modeling of Cyclic Population Dynamics

Alvin Bayliss, Northwestern University, U.S.; *Alexander Nepomnyashchy*, Technion Israel Institute of Technology, Israel; Vladimir A. Volpert, Northwestern University, U.S.

1:25-1:45 Spirals, Heteroclinic Cycles and Heteroclinic Bifurcations in a Spatially Extended Rock-Paper-Scissors Model of Cyclic Dominance

Claire M. Postlethwaite, University of Auckland, New Zealand; Alastair M. Rucklidge, University of Leeds, United Kingdom

1:50-2:10 Existence and Stability of Periodic Traveling Waves: Who Will Prevail in a Rock-Paper-Scissors Game?

Cris Hasan and Hinke M. Osinga, University of Auckland, New Zealand; Claire M. Postlethwaite, University of Auckland, New Zealand; Alastair M. Rucklidge, University of Leeds, United Kingdom

2:15-2:35 Spatially Extended Stochastic Rock-Paper-Scissors and May-Leonard Models

Uwe Tauber and Shannon R. Serrao, Virginia Tech, U.S.

Sunday, May 19

MS18

Stability and Resilience in Natural Dynamical Systems

1:00 p.m.-2:40 p.m.

Room: Maybird

Over the past decade, there has been increasing attention paid to the phenomenon of resilience in diverse scientific fields. The concept of resilience captures the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, and feedbacks. A variety of novel methods for measuring resilience of multistable complex networked dynamical systems have emerged across disciplines, largely extending the classical linear stability analysis. This minisymposium features recent trends, from foundations and models in various scientific fields to the data-driven estimation of resilience.

Organizer: Klaus Lehnertz
Universität Bonn, Germany

1:00-1:20 Assessing Resilience - An Overview of Concepts and Methodologies

Klaus Lehnertz, Universität Bonn, Germany

1:25-1:45 Dynamical Robustness and Resilience in Coupled Oscillator Networks

Kai Morino, Gouhei Tanaka, and Kazuyuki Aihara, University of Tokyo, Japan

1:50-2:10 On the Edge: Extinction Thresholds and the Periphery of Pollination Networks

Lukas Halekotte and Ulrike Feudel, University of Oldenburg, Germany

2:15-2:35 Estimating Resilience from Time Series - A Non-Perturbative Approach

Thorsten Rings, Universität Bonn, Germany; Mahmood Mazarei and Amin Akhshi, Sharif University of Technology, Iran; Christian Geier, Universität Bonn, Germany; M. Reza Rahimi Tabar, Sharif University of Technology, Iran; Klaus Lehnertz, Universität Bonn, Germany

Sunday, May 19

MS19

Applied Mathematical Techniques for Fluid Flow Across Scales - Part II of II

1:00 p.m.-2:40 p.m.

Room: Superior A

For Part 1 see MS6

Fluid flow is omnipresent in nature and is characterized by a wide range of actively interacting scales. While applied mathematical techniques has helped us in understanding the dynamics of fluid flow in a myriad of configurations, the collection of techniques used in this field has grown exponentially over the years. Consequently, in this minisymposium we aim to address a wide spectrum of different cutting-edge research problems in fluid dynamics where efficient applied mathematical techniques can be utilized to understand specific nontrivial aspects of the flow. This minisymposium will feature eight applied mathematicians discussing fluid dynamic problems ranging from small scale flows set in lab experiments, where classical methods such as conformal mapping and asymptotic analysis can be employed, to strongly nonlinear turbulent flows in the atmosphere and the ocean, where specialized novel techniques are coupled with state-of-the-art high resolution direct numerical simulations to understand energy and momentum transfers across spatio-temporal scales. The two sessions of this minisymposium will also serve as a generic advertisement to a general audience, including graduate students and early career scientists, the grand challenges in fluid dynamic problems at various scales and a collection of specialized applied mathematical techniques that can be used to address them.

Organizer: Pejman Sanaei
Courant Institute of Mathematical Sciences, New York University, U.S.

Organizer: Jim Thomas
Woods Hole Oceanographic Institution and Dalhousie University, U.S.

1:00-1:20 New Asymptotic Models for Ocean Waves

Jim Thomas, Woods Hole Oceanographic Institution and Dalhousie University, U.S.

continued on next page

Sunday, May 19

MS19

Applied Mathematical Techniques for Fluid Flow Across Scales - Part II of II

continued

1:25-1:45 A Novel Reactive Forcing Scheme for Incompressible Scalar Turbulence

Don Daniel and Daniel Livescu, Los Alamos National Laboratory, U.S.; Jaiyoung Ryu, Chung-Ang University, Korea

1:50-2:10 A Reduced Model for Partially-Ionized Atmospheric Turbulence in Jupiter

Santiago Jose Benavides and Glenn Flierl, Massachusetts Institute of Technology, U.S.

2:15-2:35 Energy Dynamics of Nonlinear Acoustic Wave Turbulence

Prateek Gupta, Purdue University, U.S.

Sunday, May 19

MS20

Existence and Stability of Nonlinear Waves: Theory and Numerical Computations - Part I of II

1:00 p.m.-2:40 p.m.

Room: Superior B

For Part 2 see MS30

The existence and stability of nonlinear waves have been of paramount importance in a diverse array of fields including optics, atomic physics, materials science, and water waves. In this session, we will showcase recent theoretical and computational work in which novel techniques are applied to a diverse array of systems. These systems include reaction-diffusion equations such as the Fisher-KPP equation; hyperbolic PDEs, such as the sine-Gordon equation; and nonlocal PDEs, such as the Smoluchowski coagulation equation. We will analyze fronts, periodic wavetrains, and shock solutions using a wide array of techniques, including spatial dynamics methods, such as Lin's method and the Evans function; topological methods, such as the as Maslov index; and more general approaches, such as semigroup methods and Whitham modulation theory. In several cases, numerical and analytical studies will be correlated with experimental results.

Organizer: Ross H. Parker
Brown University, U.S.

Organizer: Efstathios Charalampidis
University of Massachusetts, Amherst, U.S.

1:00-1:20 Stability of Planar Fronts in a Reaction-Diffusion System

Anna Ghazaryan, Miami University, U.S.; Yuri Latushkin, University of Missouri, Columbia, U.S.; Xinyao Yang, Xi'an Jiaotong - Liverpool University, China

1:25-1:45 Fronts in Inhomogeneous Wave Equations

Jacob Brooks, University of Surrey, United Kingdom

1:50-2:10 Asymptotic Stability of Pulled Fronts using Pointwise Estimates

Matt Holzer, George Mason University, U.S.

2:15-2:35 The Effect of Different Velocities on Global Existence and Stability in Nonlinear Reaction-Diffusion Systems

Björn De Rijk, Universität Stuttgart, Germany

Sunday, May 19

MS21

Mapping and Modeling Cardiac Electrical Dynamics and Arrhythmias - Part II of II

1:00 p.m.-2:40 p.m.

Room: Primrose A

For Part 1 see MS9

Cardiac arrhythmias are abnormal heart rhythms underlying complex spatiotemporal electromechanical activity. Spiral and scroll waves patterns of self-organised abnormal synchronisation are known to exist in the heart. These non-linear vortices act as fast cardiac activation sources underlying cardiac arrhythmias and fatal fibrillation. Mapping and control of the rotors of rapid abnormal activation in the heart is of primary importance necessary to revert to normal heart rhythm. This minisymposium provides a sampling of the current experimental, and theoretical approaches to mapping of the rotors dynamics, locus identification, and modelling of cardiac electrical dynamics and arrhythmias.

Organizer: Irina Biktasheva
University of Liverpool, United Kingdom

Organizer: Seth Weinberg
Virginia Commonwealth University, U.S.

Organizer: Alena Talkachova
University of Minnesota, U.S.

1:00-1:20 Cardiac Re-Entry Dynamics in MRI and Micro-CT Based Models of the Heart

Irina Biktasheva, University of Liverpool, United Kingdom; Girish Ramlugun and Belvin Thomas, Auckland BioEngineering Institute, New Zealand; Vadim N. Biktashev and Diane P. Fraser, University of Exeter, United Kingdom; Ian J. LeGrice, Bruce H. Smaill, and Jichao Zhao, Auckland BioEngineering Institute, New Zealand

1:25-1:45 Electromechanical Vortex Filaments and Vortex-Substrate Interactions During Cardiac Fibrillation

Jan Christoph, University of Göttingen, Germany

1:50-2:10 Equation-Free Approaches on Excitable Tissue Dynamics

Konstantinos Aronis and Hiroshi Ashikaga, Johns Hopkins University, U.S.

2:15-2:35 Gap Junctions Induced Bistability Conductance in Cardiac Tissue

Jean R. Bragard, Universidad de Navarra, Spain

Sunday, May 19

MS22

Collective Behavior in Networks - Part II of II

1:00 p.m.-2:40 p.m.

Room: Primrose B

For Part 1 see MS10

Collective behavior in networks of dynamically linked entities is ubiquitous to many natural processes and industrial applications, including coordinated firing of neurons in the brain, synchronization of powergrids, and spreading of information or disinformation. Understanding the dynamics, the emergence and the break-down of collective behavior is critical to the understanding and control of the relevant macroscopic dynamics of such processes. This minisymposium addresses several aspects of collective behavior in networks, including synchronization, diffusion and multilayer networks.

Organizer: Lachlan D. Smith
University of Sydney, Australia

Organizer: Georg A. Gottwald
University of Sydney, Australia

1:00-1:20 Model-Free Inference of Direct Network Interactions from Nonlinear Collective Dynamics

Sarah Hallerberg, Hamburg University of Applied Sciences, Germany; Jose Casadiego, Technische Universität Dresden, Germany; Mor Nitzan, Harvard University, U.S.; Marc Timme, Technische Universität Dresden, Germany

1:25-1:45 Diffusion Dynamics in Multilayer Networks

Yamir Moreno, University of Zaragoza, Spain

1:50-2:10 Stable Chimeras and Independently Synchronizable Clusters in Coupled Oscillator Networks

Young Sul Cho, Northwestern University, U.S. and Chonbuk National University, South Korea; *Takashi Nishikawa* and Adilson E. Motter, Northwestern University, U.S.

2:15-2:35 Urban Sensing as a Spreading Process

Kevin O'Keeffe, Massachusetts Institute of Technology, U.S.

Sunday, May 19

CP3

Delay Differential Equations I

1:00 p.m.-2:40 p.m.

Room: White Pine

Chair: Joanna Slawinska, University of Wisconsin, Milwaukee, U.S.

1:00-1:20 Bogdanov-Takens Resonance in Time-Delayed Systems

Mattia Tommaso Coccolo Bosio, Universidad Rey Juan Carlos, Spain

1:25-1:45 Comparison and Connection Between Delay Oscillators and ODE Oscillators

Lauren Lazarus, Trinity College, U.S.

1:50-2:10 Time Delay Models of Vehicular Traffic and their Comparison to Microscopic Traffic Data

Tamas G. Molnar, Budapest University of Technology and Economics, Hungary; Sergei S. Avedisov, Chaozhe He, and Gabor Orosz, University of Michigan, Ann Arbor, U.S.

2:15-2:35 Vector-Valued Spectral Analysis of Complex Flows

Joanna Slawinska, University of Wisconsin, Milwaukee, U.S.; Abbas Ourmazd, University of Wisconsin, U.S.; Dimitrios Giannakis, Courant Institute of Mathematical Sciences, New York University, U.S.; Joerg Schumacher, Technische Universitaet Ilmenau, Germany

Intermission

2:40 p.m.-2:55 p.m.

Sunday, May 19

IP2

Localized Pattern Formation

2:55 p.m.-3:40 p.m.

Room: Ballroom

Chair: Arjen Doelman, Leiden University, Netherlands

Spatially localized patterns arise in many natural processes: buckled shells, spots in autocatalytic chemical reactions, crime hotspots, localized fluid structures, and vegetation spots are prominent examples that have attracted much attention. Despite appearing on vastly different scales, spatially localized structures often share similar features and properties, and mathematical techniques can help identify the origins of such patterns across different systems. In this talk, I will highlight the use of analytical and geometric dynamical-systems techniques to better understand when localized patterns may emerge, how their shape and form is determined, and what their stability properties might be. I will also discuss open problems and challenges.

Bjorn Sandstede
Brown University, U.S.

Coffee Break

3:40 p.m.-4:10 p.m.

Room: Golden Cliff

Sunday, May 19

MT2

Stochastic Population Dynamics: Persistence, Extinction, and Quasi-stationarity

4:10 p.m.-6:10 p.m.

Room: Ballroom 1

Chair: Sebastian Schreiber, University of California, Davis, U.S.

A long standing question in biology is "what are the minimal conditions to ensure the long-term persistence of a population, or to ensure the long-term coexistence of interacting species?" The answers to this question are essential for identifying mechanisms that maintain biodiversity. Mathematical models play an important role in identifying potential mechanisms and, when coupled with data, can determine whether or not a given mechanism is operating in a specific population or community. For over a century, nonlinear difference and differential equations have been used to identify mechanisms for population persistence and species coexistence. These models, however, fail to account for intrinsic and extrinsic random fluctuations experienced by all populations. In this mini-tutorial, I will give an overview on models for accounting for both forms of stochasticity, analytical and numerical methods for studying the dynamics of these models, and theoretical and numerical challenges for future research. The overview will focus on discrete-time models: (i) random maps on compact metric spaces to account for extrinsic noise due environmental fluctuations, and (ii) Markov chains on countable state spaces to account for intrinsic noise due to populations consisting of a finite number of individuals. The models, methods, and challenges will be illustrated with data-based models of checkerspot butterflies, California annual plant communities, chaotic beetles, and more.

Speaker:

Sebastian Schreiber, University of California, Davis, U.S.

Sunday, May 19

MS23

Nonlinear Decision-Making Dynamics

4:10 p.m.-5:50 p.m.

Room: Ballroom 2

Decision-making dynamics are used to study systems in biology and engineering that operate at multiple scales and levels of complexity. A key challenge is explaining the management of critical tradeoffs such as speed-versus-accuracy and stability-versus-flexibility. This minisymposium will offer approaches that leverage nonlinear dynamics and bifurcation theory to model, analyze and design decision-making. Nonlinear dynamics will be presented that help explain how decision-makers handle both collaborative and antagonistic interactions, how agreement and disagreement can be derived from principles of symmetry, how changing environmental conditions can be accommodated through inhibition, and how tasks can be dynamically prioritized under competing objectives.

Organizer: Naomi E. Leonard
Princeton University, U.S.

Organizer: Alessio Franci
Universidad Nacional Autónoma de México, Mexico

4:10-4:30 Decision Making in Presence of Frustration on Multiagent Antagonistic Networks

Claudio Altafini and *Angela Fontan*, Linköping University, Sweden

4:35-4:55 Symmetry and Synthesis of Agreement and Disagreement Dynamics

Anastasia Bizyaeva, Princeton University, U.S.; Alessio Franci, Universidad Nacional Autónoma de México, Mexico; Naomi E. Leonard, Princeton University, U.S.

5:00-5:20 Cellular Decision-Making Models in Yeast

Aldo E. Encarnacion Segura, Thomas Bose, Andreagiovanni Reina, and James A R Marshall, University of Sheffield, United Kingdom

5:25-5:45 Motivation Dynamics for Autonomous Systems

Paul B. Reverdy, University of Arizona, U.S.; Daniel Koditschek, University of Pennsylvania, U.S.; Craig A. Thompson, University of Arizona, U.S.

Sunday, May 19

MS24

Data-Driven Approaches in the Life Sciences

4:10 p.m.-5:50 p.m.

Room: Ballroom 3

Current research in computational biology makes extensive use of data-driven methods for modeling and analysis of biological networks. The plethora of available experimental data and the growing demand to develop large-scale models require innovative methods, for example convolutional neural networks for data mining, algebraic dynamical polynomial systems for model identification and reduction for gene data-driven networks, and agent-based networks for pattern detection and control. This minisymposium will highlight the diversity of data-driven applications of dynamical systems to problems in the life sciences, with emphasis on systems biology and computational neuroscience.

Organizer: Brandilyn Stigler
Southern Methodist University, U.S.

Organizer: Anyu Zhang
Southern Methodist University, U.S.

4:10-4:30 Algebraic Design of Experiments for Discrete Models of Gene Regulatory Networks

Anyu Zhang, Southern Methodist University, U.S.

4:35-4:55 Sparse Model Selection for Structurally Challenging, Dynamic, Biological Systems

Niall M. Mangan, Northwestern University, U.S.; Travis Askham, New Jersey Institute of Technology, U.S.; Steven L. Brunton and J. Nathan Kutz, University of Washington, U.S.; Joshua L. Proctor, Institute for Disease Modeling, U.S.

5:00-5:20 Dynamically Relevant Motifs in Inhibition-Dominated Neural Networks

Katherine Morrison, University of Northern Colorado, U.S.

5:25-5:45 Measuring the Impact of Edge Controls on the Dynamics of Stochastic Discrete Networks

David Murrugarra, University of Kentucky, U.S.

Sunday, May 19

MS25

Understanding Spatiotemporal Dynamics through Analytical Approaches - Part II of II

4:10 p.m.-5:25 p.m.

Room: Magpie A

For Part 1 see MS14

This minisymposium will focus on analytical techniques applied to a variety of dynamical systems with the goal of understanding the emergence of various spatiotemporal behaviors arising in myriad applications. Among the approaches discussed will be several recent ideas in the use of Competitive Modes to identify and analyze chaotic regimes, complex bifurcations leading to diverse dynamical regimes, comparisons of the effects of discrete and distributed delays on various limit cycle and chaotic oscillators (including effects such as transitions between amplitude death and oscillation death), and asymptotic criteria for the emergence of spatiotemporal dynamics in reaction-diffusion systems. Other talks will emphasize applications of analytical techniques to systems arising in problems of scientific or industrial importance.

Organizer: Roy Choudhury
University of Central Florida, U.S.

Organizer: Robert Van Gorder
University of Oxford, United Kingdom

Organizer: Constance Schober
University of Central Florida, U.S.

4:10-4:30 Categorizing Spatiotemporal Patterns Near a Codimension-Two Point

Ranses Alfonso Rodriguez, University of Central Florida, U.S.

4:35-4:55 Various Dynamical Regimes, and Transitions from Homogeneous to Inhomogeneous Steady States in Oscillators with Delays and Diverse Couplings

Roy Choudhury, University of Central Florida, U.S.

5:00-5:20 Dynamics of the Kudryashov generalized KdV Equation

Constance Schober and William Hilton, University of Central Florida, U.S.

Sunday, May 19

MS26

Observability and Controllability of Network Dynamics

4:10 p.m.-5:50 p.m.

Room: Magpie B

Dynamical networks are increasingly useful as models of interacting systems in the physical and biological sciences and engineering. The concepts of observability and controllability are classical for linear dynamics, but the general theory is much more complicated in the nonlinear case. This session explores foundational and computational aspects of network analysis and design. Investigations of how and where to observe a network to efficiently learn its behavior will be discussed, along with questions about what determines the limits on observability. These results have applications to sensor placement and experimental design. Controlling a network to desirable dynamics raises similar issues regarding placement and activity of controllers. Speakers in this session will discuss a wide range of recent developments in network observation and control.

Organizer: Timothy Sauer
George Mason University, U.S.

Organizer: Christophe Letellier
Normandie Université, France

4:10-4:30 Controllability-Based Network Measures and their Applications in Biological Networks

Bingbo Wang and Lin Gao, Xidian University, China; *Yong Gao*, University of British Columbia, Canada

4:35-4:55 Sensor Selection and State Estimation for Nonlinear Network Dynamics

Aleksandar Haber, City University of New York, Staten Island, U.S.

5:00-5:20 Assessing Observability of Complex Networks using a Nonlinear Theory

Christophe Letellier, Normandie Université, France; Irene Sendina-Nadal, Rey Juan Carlos University, Spain

5:25-5:45 Observability Condition Number for Dynamical Networks

Jiajing Guan, Tyrus Berry, and *Timothy Sauer*, George Mason University, U.S.

Sunday, May 19

MS27

Heteroclinic Attractors and Cyclic Competition of Species - Part II of II

4:10 p.m.-5:50 p.m.

Room: Wasatch B

For Part 1 see MS17

A significant progress in understanding of typical processes in multispecies ecological systems, as well as neural and cognitive networks, has been achieved using dynamical models which include heteroclinic sequences. The goal of the minisymposium is to present recent advances in that field. The talks include the description and analysis of multidimensional heteroclinic attractors, hierarchical heteroclinic networks, as well as spatially extended deterministic and stochastic rock-paper-scissors models.

Organizer: Alexander Nepomnyashchy
Technion Israel Institute of Technology, Israel

Organizer: Vladimir A. Volpert
Northwestern University, U.S.

4:10-4:30 Two-Dimensional Heteroclinic Attractors in the Generalized Lotka-Volterra System

Valentin Afraimovich, IICO-UASLP, Mexico; Gregory Moses and *Todd Young*, Ohio University, U.S.

4:35-4:55 Non-Smooth Heteroclinic Tori in Models of Coordination Between the Human Minds

Michael Zaks, Humboldt University at Berlin, Germany; Mikhail I. Rabinovich, University of California, San Diego, U.S.

5:00-5:20 Polar Ecosystems in a Changing Climate

Kenneth M. Golden, University of Utah, U.S.; Ivan Sudakov, University of Dayton, U.S.; Sergey Vakulenko, Russian Academy of Sciences, Russia; Kyle R. Steffen, University of Texas at Austin, U.S.; Yekaterina Epshteyn, University of Utah, U.S.; Chris Horvat, Brown University, U.S.; Daniela Flocco, University of Reading, United Kingdom; David W. Rees Jones, University of Oxford, United Kingdom

5:25-5:45 Explicit Probability of Fixation Formula for Mutual Competitors in a Stochastic Population Model under Competitive Trade-Offs

Glenn S. Young and Andrew Belmonte, Pennsylvania State University, U.S.

Sunday, May 19

MS28

Statistical Analysis in Biophysics and Climate

4:10 p.m.-5:50 p.m.

Room: Maybird

The goal of this minisymposium is to bring together researchers that work on current trends in statistical analysis dealing with questions originates from biophysical systems and climate. In particular, this minisymposium focuses on various strategies improved and used in both forward and backward modeling to observe phenomena at different scales. Examples include constructing metrics to compare anatomical shapes and utilizing it to understand evolutionary process, applying existing data assimilation methods to address issues in the Earth's climate besides extracting the features in biophysics experiments by means of non parametric Bayesian methods.

Organizer: Zeliha Kilic
Arizona State University, U.S.

4:10-4:30 Monitoring Life, Just a Few Photons at a Time
Steve Presse, Arizona State University, U.S.

4:35-4:55 Biologically Relevant Features on Surfaces Representing Teeth and Bones
Shan Shan, Duke University, U.S.

5:00-5:20 Applying Lagrangian Data Assimilation to Nextsim
Colin Guider, University of North Carolina at Chapel Hill, U.S.

5:25-5:45 Bayesian Nonparametric Analysis of Transcriptional Processes
Zeliha Kilic, Arizona State University, U.S.

Sunday, May 19

MS29

Dynamics of Fibres in Turbulence

4:10 p.m.-5:50 p.m.

Room: Superior A

A fundamental problem in turbulence research is to understand the dynamics of particles suspended in turbulent flows. During the last decade substantial progress has been made in understanding the dynamics of spherical particles in turbulence. Yet most solid particles we encounter in Nature are not spherical. For such particles one must also consider their angular motion, in addition to their translation. Because of these additional degrees of freedom, the dynamics of non-spherical particles in turbulence is much more difficult to analyse. But recent experiments and direct numerical simulations can guide the mathematical analysis of such systems. The goal of this minisymposion is to bring together leading experts in the experimental, numerical, and mathematical analysis of non-spherical particles in turbulence - to report in recent progress, to document the most important open questions, and to discuss future avenues of research in this subject.

Organizer: Bernhard Mehlig
University of Gothenburg, Sweden

Organizer: Greg Voth
Wesleyan University, U.S.

4:10-4:30 Buckling of Small Inextensible Fibers in Turbulence
Jeremie Bec and Allende Sofia, CNRS, France; Christophe Henry, Inria Sophia Antipolis, France

4:35-4:55 Inertial Range Scaling of the Rotation of Fibres in Turbulence
Shima Parsa, Harvard University, U.S.

5:00-5:20 Orientation Patterns of Non-Spherical Particles in Turbulence
Bernhard Mehlig, University of Gothenburg, Sweden

5:25-5:45 Fiber Orientation Fields and Vortex Stretching in Turbulence
Greg Voth, Wesleyan University, U.S.

Sunday, May 19

MS30

Existence and Stability of Nonlinear Waves: Theory and Numerical Computations - Part II of II

4:10 p.m.-5:50 p.m.

Room: Superior B

For Part 1 see MS20

The existence and stability of nonlinear waves have been of paramount importance in a diverse array of fields including optics, atomic physics, materials science, and water waves. In this session, we will showcase recent theoretical and computational work in which novel techniques are applied to a diverse array of systems. These systems include reaction-diffusion equations such as the Fisher-KPP equation; hyperbolic PDEs, such as the sine-Gordon equation; and nonlocal PDEs, such as the Smoluchowski coagulation equation. We will analyze fronts, periodic wavetrains, and shock solutions using a wide array of techniques, including spatial dynamics methods, such as Lin's method and the Evans function; topological methods, such as the as Maslov index; and more general approaches, such as semigroup methods and Whitham modulation theory. In several cases, numerical and analytical studies will be correlated with experimental results.

Organizer: Ross H. Parker
Brown University, U.S.

Organizer: Efstathios Charalampidis
University of Massachusetts, Amherst, U.S.

4:10-4:30 Stability of Front Solutions in a Model for a Surfactant Driven Flow on an Inclined Plane
Stephane Lafortune, College of Charleston, U.S.; Anna Ghazaryan, Miami University, U.S.; Vahagn Manukian, Miami University Hamilton, U.S.

4:35-4:55 Traveling Waves and Discontinuous Shock Solutions of the Whitham Modulation Equations
Patrick Sprenger and Mark A. Hoefer, University of Colorado Boulder, U.S.

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5:00-5:20 Grassmannian Flows and Applications to Smoluchowski's Coagulation Equation

Ioannis Stylianidis, Heriot-Watt University, United Kingdom

5:25-5:45 Observation of Domain Walls in Stokes Waves on Deep Water

Fotini Tsitoura, University of Massachusetts, Amherst, U.S.

Sunday, May 19

MS31

Mathematical Modeling, Analysis, and Computation in Epidemiology

4:10 p.m.-5:50 p.m.

Room: White Pine

In this minisymposium, researchers are going to present their recent work on infectious disease modeling with detail analysis. Both vector borne and non-vector borne diseases are covered here. This minisymposium will focus not only on recent outbreaks, like Zika, Chikungunya, will also focus on important neglected tropical diseases, like Chagas disease. Outcomes of studies of this proposed minisymposium provide new information regarding disease transmissions and about policies to reduce infections in humans. Presenters in this symposium will demonstrate new ideas about disease initiation, its spread and control. They will focus on multiple transmission pathways of disease dynamics, effect of seasonality on disease transmissions, spread and control of nosocomial infections and also on how the biodiversity effects infections prevalence in humans. Deterministic or stochastic approaches are applied in these analysis. Overall, this minisymposium has lots of variety within the same field of interest and it will present various aspects of dynamics of infectious diseases. This event connects researchers or students with the same interest for further exploration of similar topics.

Organizer: Md Mondal Hasan Zahid

University of Texas at Arlington, U.S.

4:10-4:30 Decoys and Dilution: the Impact of Incompetent Hosts on Prevalence of Chagas Disease

Md Mondal Hasan Zahid and Christopher Kribs, University of Texas at Arlington, U.S.

4:35-4:55 Mathematical Modeling of Chikungunya Dynamics with Seasonality

Md Rafiul Islam and Angela Peace, Texas Tech University, U.S.

5:00-5:20 Effects of Multiple Transmission Pathways on Zika Dynamics

Omomayowa Olawoyin and Christopher Kribs, University of Texas at Arlington, U.S.

5:25-5:45 Modeling a Nosocomial Epidemic of Middle-East Respiratory Syndrome

Tamer Oraby, University of Texas, Rio Grande Valley, U.S.

Sunday, May 19

MS32

Recent Advances at the Intersection of Data Assimilation and Physiologically-Based Modeling for Clinical Applications - Part I of II

4:10 p.m.-5:50 p.m.

Room: Primrose A

For Part 2 see MS45

This minisymposium will focus on physiologic modeling in clinical settings and the use of data assimilation to iteratively estimate and validate model parameters that may inform patient-specific clinical care. We will focus on a variety of applications including the glucose-insulin system in type 2 diabetes, pulmonary (lung) dynamics in intensive care unit settings, and female endocrine (reproductive system) function in the context of pathophysiology such as endometriosis. Within these contexts the talks will address a variety of methodologic and dynamics problems, including noise-induced chaos, parameter estimation using Bayesian inverse and filtering formulations, state and parameter forecasting, and model evaluation and uncertainty quantification. In all cases the talks will focus on the dynamics of these systems and how those dynamics translate into, and impact, our understanding of physiology and our ability to personalize medical treatment. Furthermore, by anchoring and defining the mathematical approaches presented in explicit physiologic problems, the talks will highlight the interplay between dynamics-based tools and clinical applications.

Organizer: David J. Albers

Columbia University, U.S.

Organizer: Cecilia Diniz Behn

Colorado School of Mines, U.S.

4:10-4:30 Dynamics, Data, and Data Assimilation: Using Physiologic Models with Data to Understand Physiology and Impact Clinical Settings

David J. Albers, Columbia University, U.S.

4:35-4:55 Shear-Induced Reliability Failure in Physiological Systems with Delay

David J. Albers, Columbia University, U.S.; Bhargav R. Karamched and *William Ott*, University of Houston, U.S.

continued on next page

Sunday, May 19

MS32

Recent Advances at the Intersection of Data Assimilation and Physiologically-Based Modeling for Clinical Applications - Part I of II

continued

5:00-5:20 Modeling and Estimation of Glucose-Insulin Dynamics by using the Ornstein-Uhlenbeck Process

Melike Sirlanci, California Institute of Technology, U.S.

5:25-5:45 Designing Metrics to Evaluate a Clinical Forecasting System

George Hripcsak, Columbia University, U.S.

Sunday, May 19

MS33

Reduced Models of Complex Dynamical Systems: From Theory to Applications - Part I of II

4:10 p.m.-5:50 p.m.

Room: Primrose B

For Part 2 see MS46

Nonlinear dynamic phenomena often require a large number of dynamical variables for their description, only a small fraction of which are direct observable. Reduced models using only these relevant variables can be very useful for increasing computational efficiency, gaining insights into the underlying dynamics, and for data-driven modeling. As scientists and engineers become ever more reliant on computational models for prediction, inference, control, and decision making, improving model reduction techniques have a potential to impact a wide range of applications. The purpose of this minisymposium is to bring together a range of perspectives on general model reduction methodology and specific applications to physical, biological, and engineered systems.

Organizer: Kevin K. Lin

University of Arizona, U.S.

Organizer: Fei Lu

Johns Hopkins University, U.S.

4:10-4:30 Data-Driven Model Reduction in the Mori-Zwanzig Framework

Kevin K. Lin, University of Arizona, U.S.; Fei Lu, Johns Hopkins University, U.S.

4:35-4:55 Space-Time Numerical Approximations of a Nudging Algorithm

Cecilia F. Mondaini, Tulane University, U.S.

5:00-5:20 Changing Collective Behavior of Oscillators by Controlling the Destiny of their Phase Density

Bharat Monga and Jeff Moehlis, University of California, Santa Barbara, U.S.

5:25-5:45 Reduced Models for Uncertainty Quantification

Jing Li and *Panos Stinis*, Pacific Northwest National Laboratory, U.S.

Sunday, May 19

CP4

Power Systems

4:10 p.m.-5:50 p.m.

Room: Wasatch A

Chair: Larissa I. Serdukova, Georgia Institute of Technology, U.S.

4:10-4:30 Ac Response of Coupled Phase Oscillators with Inertia

Xuewei Zhang, Texas A&M University, U.S.

4:35-4:55 Structure and Physics Preserving Reductions of Power Grid Models

Colin J. Grudzien, University of Nevada, Reno, U.S.; Deepjyoti Deka, Michael Chertkov, and Scott Backhaus, Los Alamos National Laboratory, U.S.

5:00-5:20 Relativistic Chaotic Scattering

Jesus M. Seoane, Universidad Rey Juan Carlos, Spain

5:25-5:45 Stability and Bifurcation Analysis of the Period-T Motion of a Vibroimpacting Energy Generator

Larissa I. Serdukova, Georgia Institute of Technology, U.S.; Daniil Yurchenko, Heriot-Watt University, United Kingdom; Rachel Kuske, Georgia Institute of Technology, U.S.

Intermission

5:50 p.m.-6:20 p.m.

Prize Presentations - Juergen Moser and J. D. Crawford

6:20 p.m.-6:30 p.m.

Room: Ballroom

Sunday, May 19

SP1

Juergen Moser Lecture - Vocal Development in Marmoset Monkeys: Neuromechanics and Social Interactions

6:30 p.m.-7:15 p.m.

Room: Ballroom

Chair: Andrew J. Bernoff, Harvey Mudd College, U.S.

Vocal development requires adaptive coordination of the lungs and larynx, their controlling muscles, the nervous system, and social interactions. We build a bio-mechanical model of the marmoset monkey vocal apparatus and, using behavioral data and maximum entropy methods, show that combinations of growth in the vocal tract, muscles and nervous system can account for juvenile vocal development. Our analysis appeals to dynamical systems and bifurcation theory, and is based on a normal form reduction of the bio-mechanical model. In this talk I hope to display lively interactions among mathematical modeling and analysis, probabilistic methods, and bio-physical data. This is joint work with Yayoi Teramoto, Daniel Takahashi and Asif Ghazanfar.

Philip Holmes
Princeton University, U.S.

Monday, May 20

Registration

8:00 a.m.-6:30 p.m.

Room: Ballroom Foyer

Monday, May 20

MS34

Stochastic Population Dynamics in Continuous Time: Persistence, Extinction, and Quasi-Stationarity

8:30 a.m.-10:10 a.m.

Room: Ballroom 1

All populations, whether they be viruses, plants, or animals, experience environmental and demographic stochasiticty. Environmental stochasticity stems from fluctuations in environmental conditions such temperature or precipitations which influence survival, growth, and reproduction of individuals. Demographic stochasticity stems from populations consisting of a finite number of individuals whose fates are not perfectly correlated and, ultimately, results in populations going extinct. Understanding how environmental and demographic stochasticity influence population dynamics is of fundamental importance to understand what stochastic mechanisms facilitate or inhibit persistence of populations, coexistence of interacting species or genotypes, outbreaks of diseases, or maintenance of ecosystem services. This minisymposium will explore these issues for continuous-time Markov models such as stochastic differential equations, Markov processes on countable state spaces, and piece-wise deterministic Markov processes. In particular, it will highlight new mathematical advances (e.g. criteria for stochastic persistence, asymptotics for quasi-stationary distributions and intrinsic extinction times) and their applications.

Organizer: Sebastian Schreiber
University of California, Davis, U.S.

8:30-8:50 Coexistence and Extinction for Stochastic Kolmogorov Systems

Dang Nguyen Hai, University of Alabama, Tuscaloosa, U.S.; Alex Hening, Tufts University, U.S.; George Yin, Wayne State University, U.S.

8:55-9:15 The Competitive Exclusion Principle in Stochastic Environments

Alex Hening, Tufts University, U.S.; Dang H. Nguyen, University of Alabama, U.S

9:20-9:40 How Environmental Randomness Can Reverse the Trend

Edouard Strickler and Michel Benaim, Universite de Neuchatel, Switzerland

9:45-10:05 Quasi-Stationarity for Reaction Networks

Mads C. Hansen, University of Copenhagen, Denmark

Monday, May 20

MS35

Modern Approaches to Understanding Bridge Instabilities

8:30 a.m.-10:10 a.m.

Room: Ballroom 2

Modern suspension and cable-stayed bridges are typically designed to withstand static loads and to avoid certain vertical and horizontal vibration frequencies. Two significant events have inspired a focus on their nonlinear dynamics: the failure of the Tacoma Narrows Bridge in 1940 and the large horizontal vibrations of London's Millennium Bridge 60 years later. The former led to new understanding of wind-induced Hopf bifurcation and the latter to new theories of instability due to pedestrian synchronization. However, a complete engineering-scale understanding of these effects remains lacking. At the same time, the mathematical explanation of these instability mechanisms is being called into question, in the light of new data, alternative modeling techniques, and dynamical systems analyses. This minisymposium brings together applied mathematicians and mechanical engineers to discuss recent advances. Topics covered include new evidence to suggest that gait synchronization is not the primary cause of pedestrian-induced instabilities, the role of global bifurcations in bridge models and new understandings of the mechanism of wind-induced oscillations.

Organizer: Igor Belykh
Georgia State University, U.S.

Organizer: Alan R. Champneys
University of Bristol, United Kingdom

8:30-8:50 On the Synchronizarion Myth for Lateral Pedestrian-Instability of Suspension Bridges

Igor Belykh, Kevin Daley, and Russell Jeter, Georgia State University, U.S.; Alan R. Champneys and John Macdonald, University of Bristol, United Kingdom

8:55-9:15 A Nondestructive Damage Detection in Bridge Structures using Information-Theoretic Methods

Amila Sudu Ambegedara, Jie Sun, Kerop Janoyan, and Erik Bollt, Clarkson University, U.S.

continued in next column

9:20-9:40 Wind-Induced Instability of a Suspension Bridge: A Tale of Two Frequencies

Kevin Daley, Georgia State University, U.S.; Vladimir Belykh, Lobachevsky State University of Nizhny Novgorod, Russia; Igor Belykh, Georgia State University, U.S.

9:45-10:05 Homoclinic Orbits in the Suspension Bridge Equation

Jan Bouwe Van Den Berg, VU University, Amsterdam, Netherlands

Monday, May 20

MS36

Dynamics and Control of Multilayer Networks - Part I of II

8:30 a.m.-10:10 a.m.

Room: Ballroom 3

For Part 2 see MS49

The mutual interdependence of the nonlinear dynamics with the structure of the network is an important issue. Recently, multilayer networks have been suggested to offer a better representation of the topology and dynamics of real-world systems in comparison with isolated one-layer structures. The prime objective of multiplex networks is to explore multiple levels of interactions where functions of one layer get affected by the properties of other layers. One of the most promising applications of the multilayer approach is the study of the brain, or technological interdependent systems, i.e., those systems in which the correct functioning of one of them strongly depends on the status of the others. For instance, multilayer networks with interconnected layers naturally occur in electrical power grids and transportation systems. Moreover, multiplexing is important for controlling, since it is not always possible to directly access and manipulate the desired layer, while the network it is multiplexed with may be adaptable. In this minisymposium, we plan to address the following questions. What is the role of network topology in dynamical phenomena such as synchronization, diffusion of opinions, epidemics and other contagions on networks, etc.? We wish to address this question in a variety of network settings such as static, coevolving and multi-layers, etc. We will also explore these issues in environments involving the interplay of noise and dynamics.

Organizer: Anna Zakharova
Technische Universität Berlin, Germany

Organizer: Sarika Jalan
Indian Institute of Technology, Indore, India

8:30-8:50 Inhibition Induced Explosive Synchronization in Multiplex Networks

Sarika Jalan, Indian Institute of Technology, Indore, India

8:55-9:15 Explosive Synchronization in Adaptive and Multilayer Networks

Stefano Boccaletti, CNR, Italy

continued on next page

9:20-9:40 Percolation in Real Multilayer Networks

Filippo Radicchi, Indiana University, U.S.

9:45-10:05 Interdependent and Competitive Dynamics of Multilayer Networks

Michael M. Danziger, Northeastern University, U.S.

Monday, May 20

MS37

Exploring the Phase Space: From Galaxies to Molecules - Part I of II

8:30 a.m.-10:10 a.m.

Room: Magpie A

For Part 2 see MS50

This minisymposium is aimed to gather leading researchers who apply geometrical phase space approaches within various areas of science. Participants will have an opportunity to exchange analytical and computational instruments and techniques across interdisciplinary barriers and to boost multidisciplinary research. Young researchers will have a chance to develop new perspectives on phase space structures by understanding their common foundations. The focus of minisymposium is on geometrical structures involved in model construction (e.g., via machine learning) and exploration of regular and chaotic dynamics of complex classical and quantum systems. The invited talks are intended to highlight modern applications of invariant manifold analysis (e.g. NHIM and Invariant manifolds of unstable periodic orbits) to galactic morphology, dynamical astronomy, rigid body and structural mechanics as well as chemical reaction dynamics. We especially welcome applied mathematicians, astrophysicists, chemists etc.

Organizer: Matthaios Katsanikas
University of Bristol, United Kingdom

Organizer: Francisco Gonzalez Montoya
University of Bristol, United Kingdom

Organizer: Dmitry Zhdanov
University of Bristol, United Kingdom

8:30-8:50 Geometry of Escaping Dynamics in the Presence of Dissipative, Gyroscopic and Stochastic Forces

Shane D. Ross and Jun Zhong, Virginia Tech, U.S.; Shibabrat Naik, University of Bristol, United Kingdom; Amir Ebrahim Bozorg Magham, Virginia Tech, U.S.; Lawrence N. Virgin, Duke University, U.S.

continued in next column

8:55-9:15 Topological Dynamics in Three-Dimensional Volume-Preserving Maps

Kevin A. Mitchell, University of California, Merced, U.S.; Spencer A. Smith, Mount Holyoke College, U.S.; Joshua Arenson, University of California, Merced, U.S.

9:20-9:40 The Computation and Application of Quasi-Periodic Orbits in Space Trajectory Design

Daniel Scheeres, University of Colorado Boulder, U.S.; Zubin Olikara, California Institute of Technology, U.S.

9:45-10:05 The Role of NHIMs in Barred Galaxies

Christof Jung, National Autonomous University of Mexico, Mexico

Monday, May 20

MS38

Interacting Dynamical Systems on Graphs - Part I of II

8:30 a.m.-10:10 a.m.

Room: Magpie B

For Part 2 see MS51

Interacting dynamical systems on graphs feature prominently in applications in natural science and technology. This class of spatially extended dynamical systems exhibits a wealth of interesting dynamics, which pose new exciting challenges in nonlinear science community. The talks in this minisymposium describe recent advances in the theory and applications of interacting dynamical systems with spatially structured interactions. The former deal with the questions of convergence to the continuum limit, interacting diffusions, synchronization, phase-locking, and chimera states, as well as Boolean networks. The latter include applications to neuroscience and power networks. Both the theoretical and applied studies focus on the link between the structure and dynamics in large networks.

Organizer: Georgi S. Medvedev
Drexel University, U.S.

Organizer: Hayato Chiba
Kyushu University, Japan

Organizer: Matthew S. Mizuhara
College of New Jersey, U.S.

8:30-8:50 The Kuramoto Model on Random Graphs: Take it to the Limit

Georgi S. Medvedev, Drexel University, U.S.

8:55-9:15 Power Network Dynamics on Graphons

Sebastian Throm, Universidad de Granada, Spain; Christian Kuehn, Technische Universität München, Germany

9:20-9:40 Modified Theta Model Provides Analytical Insights into Network of Neuronal Networks

Kiyoshi Kotani, Akihiko Akao, and Yasuhiko Jimbo, University of Tokyo, Japan; Bard Ermentrout, University of Pittsburgh, U.S.

9:45-10:05 Dynamics of Neurons on a Random Graph

Hayato Chiba, Kyushu University, Japan

Monday, May 20

MS39

Extreme Events in Dynamical Systems - Part I of II

8:30 a.m.-10:10 a.m.

Room: Wasatch A

For Part 2 see MS52

Rare, extreme events are widespread in natural and engineering systems, with well-known examples such as ocean rogue waves, extreme weather patterns and shock waves in power grids. Over the past few years, the dynamical systems community has made several important contributions to the modeling, prediction and control of rare extreme phenomena. These efforts have led to the development of novel methods tailored specifically towards tackling extreme events. These methods rely on various mathematical tools such as probability and information theory, invariant manifold theory, uncertainty quantification, network theory and optimization. This minisymposium aims to feature the recent developments in the field and to explore the potential contributions each approach can make to the others.

Organizer: Mohammad Farazmand
Massachusetts Institute of Technology, U.S.

Organizer: Themistoklis Sapsis
Massachusetts Institute of Technology, U.S.

8:30-8:50 Extreme Events: Origins, Prediction and Mitigation

Mohammad Farazmand and Themistoklis Sapsis, Massachusetts Institute of Technology, U.S.

8:55-9:15 Towards a Generalized Theory of Rare Event Simulation for Linear Stochastic Differential Equations

Benjamin J. Zhang, Massachusetts Institute of Technology, U.S.; Tuhin Sahai, United Technologies Research Center, U.S.; Youssef M. Marzouk, Massachusetts Institute of Technology, U.S.

9:20-9:40 Rare Event Simulation via Importance Sampling for Linear SPDE's

Konstantinos Spiliopoulos, Boston University, U.S.

9:45-10:05 Tensor Decomposition Based Splitting Methods for Rare Event Simulation

Quan Long, United Technologies Research Center, U.S.; Benjamin J. Zhang and Youssef M. Marzouk, Massachusetts Institute of Technology, U.S.; Alex Gorodetsky, University of Michigan, U.S.; *Tuhin Sahai*, United Technologies Research Center, U.S.

Monday, May 20

MS40

Machine Learning and Dynamical Systems Tools for Neurophysiological Data Analysis

8:30 a.m.-10:10 a.m.

Room: Wasatch B

Large data sets can be analyzed both by techniques based on dynamical systems theory as well as by methods of machine learning. On the one hand, techniques based on coupled oscillators models and synchronization theory became a popular tool in analysis of rhythmical processes, on the other hand, modern approaches from machine learning have been proven to be successful in a number of scientific disciplines. However, these approaches are not far apart and may (and sometimes shall) be used complementary. In this minisymposium we concentrate both on techniques as well as on their applications to physiological and, in particular, neurophysiological signals like EEG, ECG, and respiration. Starting with an overview of the machine-learning tools in the first talk, we will present and compare different data analysis techniques based either on dynamical models (mostly phase dynamics models) or on computational ones. The ultimate goal is to compare the different approaches and evaluate possible successful scenarios.

Organizer: Michael Rosenblum
Universität Potsdam, Germany

Organizer: Markus W Abel
Universität Potsdam, Germany

8:30-8:50 Machine Learning vs Dynamical System Based Analysis of Neurophysiological Data: An Overview

Markus W Abel and Markus Quade, Universität Potsdam, Germany

8:55-9:15 Inferring the Connectivity of Pulse-Coupled Oscillatory Networks using Phase Modelling

Rok Cestnik, Vrije Universiteit Amsterdam, The Netherlands; Michael Rosenblum, Universität Potsdam, Germany

9:20-9:40 Dynamical Disentanglement in Analysis of Oscillatory Data

Michael Rosenblum, Universität Potsdam, Germany

9:45-10:05 Sleep Staging with General Deep Neural Models of the Eeg

Justus T. Schwabedal, Brain Electrophysiology Laboratory Cooperation, Germany

Monday, May 20

MS41

Stochastic Models in Biology - Part I of II

8:30 a.m.-10:10 a.m.

Room: Maybird

For Part 2 see MS54

Stochasticity plays a fundamental role in many biological systems, particularly when modeling small scale phenomena such as biochemical reactions, cellular processes, neurotransmission, and ion channel noise. Stochastic effects are also important at larger scales, such as disease spreading within a population or multi-species ecological interactions. This minisymposium features stochastic methods to model a variety of biological phenomena, with a focus on the mathematical challenges that arise when modeling such systems.

Organizer: Deena Schmidt
University of Nevada, Reno, U.S.

8:30-8:50 Complexity Reduction for Stochastic Network Models in Biology

Deena Schmidt, University of Nevada, Reno, U.S.; Roberto F. Galan and Peter J. Thomas, Case Western Reserve University, U.S.

8:55-9:15 Network Stabilization of Stochastic Systems using Absolutely Robust Modules

German Enciso, University of California, Irvine, U.S.

9:20-9:40 Influence of Receptor Recharge on the Statistics of Captured Particles

Gregory A. Handy, Sean Lawley, and *Alla Borisyuk*, University of Utah, U.S.

9:45-10:05 Connecting Risk Factor Prevalence to Cancer Incidence through Stochastic Carcinogenesis Models

Andrew F. Brouwer, Marisa Eisenberg, and Rafael Meza, University of Michigan, U.S.

Monday, May 20

MS42

Data-Driven Methods for Flow Sensing, Estimation, and Control - Part I of II

8:30 a.m.-10:10 a.m.

Room: Superior A

For Part 2 see MS55

The objective of flow control for complex fluid-dynamical systems involves addressing many challenging sub-problems, including: understanding the relevant flow physics, reduced-order model development, flow-feature extraction and targeting, sensor placement, sensor and data fusion, state estimation, and feedback control. Advanced tools for data-driven modeling of complex systems have arisen from the study of fluid dynamics (e.g., Dynamic Mode Decomposition and its variants) and tools from outside of fluids community have flowed in from operator-theoretic control, network theory, and machine learning. These tools, coupled with increased computational power, have created exciting possibilities for additional advances. This minisymposium brings together researchers utilizing data-driven approaches to address many challenging problems relevant to flow control in order to share experiences involving current tools and techniques and to highlight current challenges and future opportunities.

Organizer: Francis D. Lagor
State University of New York, Buffalo, U.S.

8:30-8:50 Sequential DMD Mode Selection for Reduced-Order Modeling

John Graff and Francis D. Lagor, State University of New York, Buffalo, U.S.

8:55-9:15 Blending Network Science and Fluid Mechanics for Modeling and Control of Vortical Flows

Kunihiko Taira, University of California, Los Angeles, U.S.

9:20-9:40 Interpretable Nonlinear Models of Unsteady Flow Physics

Steven Brunton and J. Nathan Kutz, University of Washington, U.S.; Jean-Christophe Loiseau, ParisTech; Bernd Noack, LIMSI-CNRS, France

9:45-10:05 Data-Driven Modeling of Unsteady Aerodynamic Systems

Scott Dawson, Illinois Institute of Technology, U.S.; Steven Brunton, University of Washington, U.S.

Monday, May 20

MS43

Recent Advances in Diffusive and Reaction-Diffusion Systems - Part I of II

8:30 a.m.-10:10 a.m.

Room: Superior B

For Part 2 see MS56

Diffusive systems have modeled phenomena observed on vast ranges of spatial scales - from population models and disease spread down to dynamics occurring on cellular levels. This session will showcase recent advances in diffusive and reaction-diffusion systems that encompass all of these scales. Both applications and new theory advances will be emphasized. Novel applications include localized solutions that arise in the SIRS model with spatial diffusion, on curved surfaces, and in systems with white noise and bulk-surface coupling. On the theoretical side, multi-body dynamical systems, pattern morphology, along with wavefront dynamics due to nonlocal competition, will be discussed. For systems both stochastic and deterministic, the talks will highlight new dynamics and instabilities, as well as the numerical and analytic methods used to study them.

Organizer: Justin Tzou
Macquarie University, Sydney, Australia

Organizer: Theodore Kolokolnikov
Dalhousie University, Canada

Organizer: David Iron
Dalhousie University, Canada

8:30-8:50 Modelling Honey Bees in Winter using a Keller-Segel Model with a Chemotactic Coefficient Changing Sign

Robbin Bastiaansen and Arjen Doelman, Leiden University, Netherlands; Frank van Langevelde, Wageningen University and Research Centre, The Netherlands; *Vivi Rottschafer*, Leiden University, Netherlands

8:55-9:15 Existence and Stability of Spike Solutions in the SIRS Model with Diffusion

Chunyi Gai, Dalhousie University, Canada

9:20-9:40 The Dynamics of a Brusselator System with Bulk-Membrane Coupling

Daniel Gomez, University of British Columbia, Canada

9:45-10:05 Localized Solutions on Curved Surfaces in Reaction-Diffusion Systems

Takashi Teramoto, Asahikawa Medical University, Japan

Monday, May 20

MS44

Computer Assisted Theorems in Dynamics - Part I of II

8:30 a.m.-10:10 a.m.

Room: White Pine

For Part 2 see MS57

Topological and variational methods provide general existence theorems for important classes of problems. Yet, information about the shape and stability of the solutions (e.g. the patterns they describe) can often be obtained only with the help of numerical calculations. Indeed, our understanding of high and infinite dimensional nonlinear dynamical systems is largely based on numerical simulations, and while these inform our intuition, they ultimately raise as many questions as they answer. In both finite and infinite dimensions, identifying the building blocks that organize the dynamics is crucial for the global analysis of the system. Computer assisted proofs can be used to find and prove these low dimensional invariant dynamical structures, e.g. fixed points, periodic orbits, heteroclinic and homoclinic orbits. In this way local, rigorously verified, numerical solutions are the seeds from which additional global understanding is gained. This double minisymposium explores recent advances in computer assisted theorems for connecting orbits, spatio-temporal periodic solutions and bifurcations in both ordinary and partial differential equations, as well as delay equations. The session is also intended to highlight the work of early career researchers in this area.

Organizer: Jason D. Mireles James
Florida Atlantic University, U.S.

Organizer: Jan Bouwe Van Den Berg
VU University, Amsterdam, Netherlands

8:30-8:50 Computer Assisted Proofs in Dynamical Systems Theory: The 1980's to the Present

Jason D. Mireles James, Florida Atlantic University, U.S.

8:55-9:15 Recent Developments for Infinite Dimensional Dynamical Systems

Jan-Philippe Lessard, McGill University, Canada

continued in next column

9:20-9:40 Computer Assisted Proofs of Wright's and Jones' Conjectures: Counting and Discounting Slowly Oscillating Periodic Solutions to a Delay Differential Equation

Jonathan C. Jaquette, Brandeis University, U.S.; Jan-Philippe Lessard, McGill University, Canada; Konstantin Mischaikow, Rutgers University, U.S.; Jan Bouwe Van Den Berg, VU University, Amsterdam, Netherlands

9:45-10:05 Rigorous Verification of Wave Stability

Blake Barker, Brigham Young University, U.S.

Monday, May 20

MS45

Recent Advances at the Intersection of Data Assimilation and Physiologically-Based Modeling for Clinical Applications - Part II of II

8:30 a.m.-10:10 a.m.

Room: Primrose A

For Part 1 see MS32

This minisymposium will focus on physiologic modeling in clinical settings and the use of data assimilation to iteratively estimate and validate model parameters that may inform patient-specific clinical care. We will focus on a variety of applications including the glucose-insulin system in type 2 diabetes, pulmonary (lung) dynamics in intensive care unit settings, and female endocrine (reproductive system) function in the context of pathophysiology such as endometriosis. Within these contexts the talks will address a variety of methodologic and dynamics problems, including noise-induced chaos, parameter estimation using Bayesian inverse and filtering formulations, state and parameter forecasting, and model evaluation and uncertainty quantification. In all cases the talks will focus on the dynamics of these systems and how those dynamics translate into, and impact, our understanding of physiology and our ability to personalize medical treatment. Furthermore, by anchoring and defining the mathematical approaches presented in explicit physiologic problems, the talks will highlight the interplay between dynamics-based tools and clinical applications.

Organizer: David J. Albers
Columbia University, U.S.

Organizer: Cecilia Diniz Behn
Colorado School of Mines, U.S.

8:30-8:50 A New Criterion for Prediabetes with a Mathematical Model

Joon Ha and Arthur Sherman, National Institutes of Health, U.S.

8:55-9:15 Discovering Reproductive Phenotypes using a New Endocrine Model

Erica J. Graham, Bryn Mawr College, U.S.; David J. Albers, Columbia University, U.S.

continued on next page

9:20-9:40 Improving Forecasts by Walking Backward

Bruce J. Gluckman, Pennsylvania State University, U.S.

9:45-10:05 Using MCMC to Quantify Insulin Resistance in Adolescent Girls

Kai Bartlette, Colorado School of Mines, U.S.; Matthew Levine, California Institute of Technology, U.S.; David J. Albers, Columbia University, U.S.; Melanie Cree-Green, University of Colorado, U.S.; Cecilia Diniz Behn, Colorado School of Mines, U.S.

Monday, May 20

MS46

Reduced Models of Complex Dynamical Systems: From Theory to Applications - Part II of II

8:30 a.m.-10:10 a.m.

Room: Primrose B

For Part 1 see MS33

Nonlinear dynamic phenomena often require a large number of dynamical variables for their description, only a small fraction of which are direct observable. Reduced models using only these relevant variables can be very useful for increasing computational efficiency, gaining insights into the underlying dynamics, and for data-driven modeling. As scientists and engineers become ever more reliant on computational models for prediction, inference, control, and decision making, improving model reduction techniques have a potential to impact a wide range of applications. The purpose of this minisymposium is to bring together a range of perspectives on general model reduction methodology and specific applications to physical, biological, and engineered systems.

Organizer: Kevin K. Lin

University of Arizona, U.S.

Organizer: Fei Lu

Johns Hopkins University, U.S.

8:30-8:50 Learning Interaction Laws in Interacting Agent-Based Systems

Mauro Maggioni, Fei Lu, Ming Zhong, and Sui Tang, Johns Hopkins University, U.S.

8:55-9:15 Representing Model Inadequacy in Interacting Systems

Rebecca E. Morrison, University of Colorado Boulder, U.S.; Youssef M. Marzouk, Massachusetts Institute of Technology, U.S.

9:20-9:40 Theoretical And Numerical Approach to Stochastic Reduction without Scale Separation

Felix X.-F. Ye, Johns Hopkins University, U.S.; Panos Stinis, Pacific Northwest National Laboratory, U.S.; Lu Fei, Johns Hopkins University, U.S.

9:45-10:05 Nonparametric Modeling of Reduced-Order Dynamical Systems

John Harlim, Pennsylvania State University, U.S.

Monday, May 20

Coffee Break

10:10 a.m.-10:40 a.m.

Room: Golden Cliff

Remarks

10:40 a.m.-10:45 a.m.

Room: Ballroom

Monday, May 20

IP3

Starbursts and Flowers: When Spreading Droplets Break Bad

10:45 a.m.-11:30 a.m.

Room: Ballroom

Chair: Elaine Spiller, Marquette University, U.S.

A droplet of pure water placed on a clean glass surface will spread axisymmetrically: there is nothing to break the symmetry. For more interesting fluids or more interesting surfaces, new patterns of spreading are possible. I will highlight two systems in which dramatic instabilities arise through the interaction of surface tension, elasticity, and the interface between them. The first example -- starburst fractures -- arises when droplets are placed on very soft substrates, such that elastic forces are in direct competition with capillary forces. The second example is the surprising case of a liquid metals, where fingering instabilities are unexpected due to typically large interfacial tensions. However, electrochemical oxidation can lower the interfacial tension of gallium-based liquid metal alloys, thereby inducing drastic shape changes including the formation of fractals.

Karen Daniels
North Carolina State University, U.S.

Lunch Break

11:30 a.m.-1:00 p.m.

Attendees on their own

Monday, May 20

Mentoring Session

11:45 a.m.-12:45 p.m.

Room: Primrose A

We are hosting a mentoring event for graduate students, postdoctoral scholars, faculty, and career scientists, with a focus on supporting a diverse and inclusive academic environment. The event will provide a welcoming and supportive atmosphere for meeting other conference attendees. Participants will be broken into mentoring groups, with each group focusing on different topics --- including, but not limited to, thriving in academia at various levels; balancing work and family life; and navigating academia as a woman, underrepresented minority, and/or LGBTQ person. We will also provide mentoring for participants interested in non-academic careers or transitioning to non-academic careers. The event will start with short icebreaker, which will include door prizes, followed by a small group discussion. We are hoping that this event will foster a more welcoming environment for everyone and will facilitate a free exchange of ideas during the conference.

Organizer: Korana Burke
University of California, Davis, U.S.

Monday, May 20

MS47

Modeling Water Flowing over the Landscape: Evolution, Form and Impact

1:00 p.m.-2:40 p.m.

Room: Ballroom 1

The minisymposium brings together researchers investigating landscape evolution and form with those investigating vegetation distribution in landscapes where water is not abundant. Water nourishes plants and shapes landscapes, creating patterns in the landscape and in the distribution of vegetation across multiple spatial and temporal scales. Our goal is for there to be an exchange of ideas between earth scientists, ecohydrologists, and applied mathematicians. At the core of the exchange is identifying appropriate mathematical modeling frameworks for the processes investigated – river networks, dryland biomass distribution, mudslides - and taking note of their commonalities. One theme of the mini-symposium is the challenge and opportunity presented by the multiple temporal and spatial scales of the processes being captured. The timescales of modeled processes range from geologic timescales to the abrupt timescale of landslides. The spatial scales range from those of river networks to those of vegetation patterns. Another theme is pattern formation, both in determining the shapes of dendritic river networks and in setting the forms of vegetation patterns arising in dryland ecosystems. Climate, and the changing timing of seasonal processes, also plays a role in shaping these systems. The modeling efforts interface mathematical models, computational models, and satellite data to investigate water-related feedbacks and the shaping of natural systems.

Organizer: Sarah Iams
Harvard University, U.S.

Organizer: Amilcare Porporato
Princeton University, U.S.

Organizer: Mary Silber
University of Chicago, U.S.

1:00-1:20 Ecohydrological Drivers of Vegetation Patterns and Landscape Evolution

Amilcare Porporato and Milad Hooshyar, Princeton University, U.S.

continued on next page

1:25-1:45 Groundwater, Climate, and the Growth of River Networks

Daniel Rothman, Alvaro Arredondo, and Yossi Cohen, Massachusetts Institute of Technology, U.S.; Olivier Devauchelle, Institut de Physique du Globe de Paris, France; Hanjoerg Seybold, ETH Zürich, Switzerland; Eric Stansifer and Robert Yi, Massachusetts Institute of Technology, U.S.

1:50-2:10 Water Transport in Models of Dryland Vegetation Patterns

Punit Gandhi, Ohio State University, U.S.; Sarah Iams, Harvard University, U.S.; Sara Bonetti, ETH Zürich, Switzerland; Amilcare Porporato, Princeton University, U.S.; Mary Silber, University of Chicago, U.S.

2:15-2:35 Applications of Erosion to Debris and Mudflows

Bjorn Birnir, University of California, Santa Barbara, U.S.

Monday, May 20

MS48

Koopman Operator Techniques in Dynamical Systems: Theory

1:00 p.m.-2:40 p.m.

Room: Ballroom 2

The Koopman operator offers an alternative description of nonlinear dynamical systems by looking at the evolution of functions (observables) on the state space rather than tracking state variables. The benefit of this viewpoint is that the nonlinear dynamics is embedded in a linear (albeit infinite-dimensional) framework without loss of information. The linear setting allows one to leverage tools from functional analysis and spectral theory to study a problem. Recent research efforts have focused on data-driven approximations of the Koopman operator through the development and refinement of Dynamic Mode Decomposition algorithms for autonomous, time-varying, and stochastic systems. All of these algorithms, however, focus on the singular part of the spectrum (eigenvalues and eigenfunctions), ignoring the continuous part of the spectrum. Another important, but quite new, direction in current research efforts is the use of the Koopman operator in data analysis/machine learning and the incorporation of Koopman operator theory within AI architectures. This minisymposium will address recent advances in research efforts pertaining to the characterization and numerical computation of the continuous spectrum; the use of Koopman operator theory in data analysis, machine learning, and artificial intelligence; and the prediction and control of nonlinear dynamical systems.

Organizer: Ryan Mohr

University of California, Santa Barbara, U.S.

1:00-1:20 Spectral Theory of the Koopman Operator and Fundamentals of Physics

Igor Mezic, University of California, Santa Barbara, U.S.

1:25-1:45 Approximations of the Fractal Spectrum of the Koopman Operator

Marko Budišic, Clarkson University, U.S.

continued in next column

1:50-2:10 Koopman Operator Theory in Artificial Intelligence

Ryan Mohr and Igor Mezic, University of California, Santa Barbara, U.S.; Ioannis Kevrekidis, Johns Hopkins University, U.S.; Ruslan Salakhutdinov, Carnegie Mellon University, U.S.

2:15-2:35 Learning Koopman Eigenfunctions for Prediction and Control: The Transient Case

Milan Korda, LAAS-CNRS, Toulouse, France; Igor Mezic and *Poorva Shukla*, University of California, Santa Barbara, U.S.

Monday, May 20

MS49

Dynamics and Control of Multilayer Networks - Part II of II

1:00 p.m.-2:40 p.m.

Room: Ballroom 3

For Part 1 see MS36

The mutual interdependence of the nonlinear dynamics with the structure of the network is an important issue. Recently, multilayer networks have been suggested to offer a better representation of the topology and dynamics of real-world systems in comparison with isolated one-layer structures. The prime objective of multiplex networks is to explore multiple levels of interactions where functions of one layer get affected by the properties of other layers. One of the most promising applications of the multilayer approach is the study of the brain, or technological interdependent systems, i.e., those systems in which the correct functioning of one of them strongly depends on the status of the others. For instance, multilayer networks with interconnected layers naturally occur in electrical power grids and transportation systems. Moreover, multiplexing is important for controlling, since it is not always possible to directly access and manipulate the desired layer, while the network it is multiplexed with may be adaptable. In this minisymposium, we plan to address the following questions. What is the role of network topology in dynamical phenomena such as synchronization, diffusion of opinions, epidemics and other contagions on networks, etc.? We wish to address this question in a variety of network settings such as static, coevolving and multi-layers, etc. We will also explore these issues in environments involving the interplay of noise and dynamics.

Organizer: Anna Zakharova
Technische Universität Berlin, Germany

Organizer: Sarika Jalan
Indian Institute of Technology, Indore, India

1:00-1:20 Control of Neural Networks by Weak Multiplexing
Anna Zakharova, Technische Universität Berlin, Germany

continued in next column

1:25-1:45 Explosive Synchronization in Multiplex Networks
Inmaculada Leyva, Universidad Rey Juan Carlos, Spain; Sarika Jalan and Anil Kumar, Indian Institute of Technology, Indore, India

1:50-2:10 Tweezer Control for Chimera States in Multilayer Networks
Iryna Omelchenko, Technische Universität Berlin, Germany

2:15-2:35 Delay Controls Chimera Relay Synchronization in Multiplex Networks
Jakub Sawicki, Berlin Institute of Technology, Germany

Monday, May 20

MS50

Exploring the Phase Space: From Galaxies to Molecules - Part II of II

1:00 p.m.-2:40 p.m.

Room: Magpie A

For Part 1 see MS37

This minisymposium is aimed to gather leading researchers who apply geometrical phase space approaches within various areas of science. Participants will have an opportunity to exchange analytical and computational instruments and techniques across interdisciplinary barriers and to boost multidisciplinary research. Young researchers will have a chance to develop new perspectives on phase space structures by understanding their common foundations. The focus of minisymposium is on geometrical structures involved in model construction (e.g., via machine learning) and exploration of regular and chaotic dynamics of complex classical and quantum systems. The invited talks are intended to highlight modern applications of invariant manifold analysis (e.g. NHIM and Invariant manifolds of unstable periodic orbits) to galactic morphology, dynamical astronomy, rigid body and structural mechanics as well as chemical reaction dynamics. We especially welcome applied mathematicians, astrophysicists, chemists etc.

Organizer: Matthaios Katsanikas
University of Bristol, United Kingdom

Organizer: Francisco Gonzalez Montoya
University of Bristol, United Kingdom

Organizer: Dmitry Zhdanov
University of Bristol, United Kingdom

1:00-1:20 Phase Space Geometry and Chemical Reaction Dynamics
Tamiki Komatsuzaki, Hokkaido University, Japan

1:25-1:45 Use of Direct Dynamics Simulations and Classical Power Spectra to Study the Intramolecular and Unimolecular Dynamics of Vibrationally Excited Molecules
William Hase, Texas Tech University, U.S.

continued on next page

1:50-2:10 Machine-Learning Transition State Theory and the Descent of Organic Reactions into Chaos

Daniel Singleton, Texas A&M University, U.S.

2:15-2:35 Time Series Analysis of Dynamical Systems

Mikito Toda, Nara Women's University, Japan

Monday, May 20

MS51

Interacting Dynamical Systems on Graphs - Part II of II

1:00 p.m.-2:40 p.m.

Room: Magpie B

For Part 1 see MS38

Interacting dynamical systems on graphs feature prominently in applications in natural science and technology. This class of spatially extended dynamical systems exhibits a wealth of interesting dynamics, which pose new exciting challenges in nonlinear science community. The talks in this minisymposium describe recent advances in the theory and applications of interacting dynamical systems with spatially structured interactions. The former deal with the questions of convergence to the continuum limit, interacting diffusions, synchronization, phase-locking, and chimera states, as well as Boolean networks. The latter include applications to neuroscience and power networks. Both the theoretical and applied studies focus on the link between the structure and dynamics in large networks.

Organizer: Georgi S. Medvedev
Drexel University, U.S.

Organizer: Hayato Chiba
Kyushu University, Japan

Organizer: Matthew S. Mizuhara
College of New Jersey, U.S.

1:00-1:20 Pattern Formation in the Kuramoto Model on Random Graphs

Matthew S. Mizuhara, College of New Jersey, U.S.

1:25-1:45 Quasiperiodic Chimera States

Oleh Omel'chenko, University of Potsdam, Germany

1:50-2:10 Fixed Points and Information Flow in Boolean Networks

Fumito Mori, RIKEN, Japan

2:15-2:35 On the Landscape of Synchronization Networks: A Perspective from Nonconvex Optimization

Shuyang Ling, Ruitu Xu, and Afonso Bandeira, Courant Institute of Mathematical Sciences, New York University, U.S.

Monday, May 20

MS52

Extreme Events in Dynamical Systems - Part II of II

1:00 p.m.-2:40 p.m.

Room: Wasatch A

For Part 1 see MS39

Rare, extreme events are widespread in natural and engineering systems, with well-known examples such as ocean rogue waves, extreme weather patterns and shock waves in power grids. Over the past few years, the dynamical systems community has made several important contributions to the modeling, prediction and control of rare extreme phenomena. These efforts have led to the development of novel methods tailored specifically towards tackling extreme events. These methods rely on various mathematical tools such as probability and information theory, invariant manifold theory, uncertainty quantification, network theory and optimization. This minisymposium aims to feature the recent developments in the field and to explore the potential contributions each approach can make to the others.

Organizer: Mohammad Farazmand
Massachusetts Institute of Technology, U.S.

Organizer: Themistoklis Sapsis
Massachusetts Institute of Technology, U.S.

1:00-1:20 Reduced-Order Statistical Models for Predicting Mean Responses and Extreme Events in Barotropic Turbulence

Di Qi, New York University, U.S.; Andrew Majda, Courant Institute of Mathematical Sciences, New York University, U.S.

1:25-1:45 Data-Driven Spatio-Temporal Prediction of High-Dimensional Geophysical Turbulence

Pedram Hassanzadeh and Amin Khodkar, Rice University, U.S.

1:50-2:10 Simultaneous Learning of Dynamics and Signal-Noise Decomposition

Samuel Rudy, University of Washington, U.S.

2:15-2:35 A Gaussian Process Regression Method for Sampling Tail Events in Dynamical Systems

Mustafa A. Mohamad, Courant Institute of Mathematical Sciences, New York University, U.S.

Monday, May 20

MS53

Neuronal Excitability in the Lenses of Dynamical Systems

1:00 p.m.-2:40 p.m.

Room: Wasatch B

One of the most important features of neurons is their ability to produce various patterns of electrical activity that are spontaneous or triggered by external inputs (such as pre-synaptic inputs). These activities are involved in many important physiological processes such as motor control, attention, memory and hormone release. Modeling such activities at the single cell and network levels help illustrate how they are generated and elucidate their underlying dynamics. That ranges from using Hodgkin-Huxley type models and applying slow fast analysis, to developing neuronal network models with certain coupling topologies. In this minisymposium, speakers will provide an overview of how they use such modeling approaches to decipher neuronal excitability and the role it plays in defining network behaviour.

Organizer: Anmar Khadra
McGill University, Canada

1:00-1:20 Excitability of Cerebellar Stellate Cells, a New Perespective

Saeed Farjami, Ryan Alexander, Derek Bowie, and *Anmar Khadra*, McGill University, Canada

1:25-1:45 Homoclinic Structure in Fold/hom Bursting Models

Roberto Barrio, University of Zaragoza, Spain; Santiago Ibanez and Lucia Perez, University of Oviedo, Spain

1:50-2:10 Spontaneous Excitability in the Morris-Lecar Model with Ion Channel Noise

Jay Newby, University of Alberta, Canada

2:15-2:35 Domino-Like Transient Dynamics at Seizure onset in Epilepsy

Jennifer Creaser, University of Exeter, United Kingdom; Congping Lin, Huazhong University of Science & Technology, China; Thomas Ridler and Jonathan Brown, University of Exeter, United Kingdom; Wendyl D'Souza, Udaya Seneviratne, and Mark Cook, University of Melbourne, Australia; John Terry and Krasimira Tsaneva-Atanasova, University of Exeter, United Kingdom

Monday, May 20

MS54

Stochastic Models in Biology - Part II of II

1:00 p.m.-2:10 p.m.

Room: Maybird

For Part 1 see MS41

Stochasticity plays a fundamental role in many biological systems, particularly when modeling small scale phenomena such as biochemical reactions, cellular processes, neurotransmission, and ion channel noise. Stochastic effects are also important at larger scales, such as disease spreading within a population or multi-species ecological interactions. This minisymposium features stochastic methods to model a variety of biological phenomena, with a focus on the mathematical challenges that arise when modeling such systems.

Organizer: Deena Schmidt
University of Nevada, Reno, U.S.

1:00-1:20 Modeling Particle Tracking Experiments that Reveal Intracellular Transport Mechanisms

Scott McKinley, Tulane University, U.S.

1:25-1:45 Estimating Kinetic Rates of Prion Replication from a Structured Population Model

Suzanne Sindi and Fabian Santiago, University of California, Merced, U.S.

1:50-2:10 Generalizations of the 'Linear Chain Trick': Incorporating More Flexible Dwell Time Distributions into Mean Field ODE Models

Paul J. Hurtado, University of Nevada, Reno, U.S.

Monday, May 20

MS55

Data-Driven Methods for Flow Sensing, Estimation, and Control - Part II of II

1:00 p.m.-2:40 p.m.

Room: Superior A

For Part 1 see MS42

The objective of flow control for complex fluid-dynamical systems involves addressing many challenging sub-problems, including: understanding the relevant flow physics, reduced-order model development, flow-feature extraction and targeting, sensor placement, sensor and data fusion, state estimation, and feedback control. Advanced tools for data-driven modeling of complex systems have arisen from the study of fluid dynamics (e.g., Dynamic Mode Decomposition and its variants) and tools from outside of fluids community have flowed in from operator-theoretic control, network theory, and machine learning. These tools, coupled with increased computational power, have created exciting possibilities for additional advances. This minisymposium brings together researchers utilizing data-driven approaches to address many challenging problems relevant to flow control in order to share experiences involving current tools and techniques and to highlight current challenges and future opportunities.

Organizer: Francis D. Lagor
State University of New York, Buffalo, U.S.

1:00-1:20 DMD-Based Estimation of the Unsteady Flow Field Around an Actuated Airfoil

Daniel F. Gomez, University of Maryland, U.S.; Francis D. Lagor, State University of New York, Buffalo, U.S.; Phillip B. Kirk, University of Maryland, Baltimore County, U.S.; Andrew Lind and Anya Jones, University of Maryland, College Park, U.S.; Derek A. Paley, University of Maryland, U.S.

1:25-1:45 A Discrete Empirical Interpolation Method for Nonlinear Manifolds

Sam Otto and Clarence Rowley, Princeton University, U.S.

continued on next page

1:50-2:10 Multi-Rate and Multi-Fidelity Sensor Fusion for Turbulent Flow Reconstruction

Maziar S. Hemati and *Mengying Wang*, University of Minnesota, U.S.; C Vamsi Krishna and Mitul Luhar, University of Southern California, U.S.

2:15-2:35 Data-Driven Refinements of Physics-Based Models with Application to Turbulence Modeling

Armin Zare and *Mihailo Jovanovic*, University of Southern California, U.S.; Tryphon Georgiou, University of California, Irvine, U.S.

Monday, May 20

MS56

Recent Advances in Diffusive and Reaction-Diffusion Systems - Part II of II

1:00 p.m.-2:40 p.m.

Room: Superior B

For Part 1 see MS43

Diffusive systems have modeled phenomena observed on vast ranges of spatial scales - from population models and disease spread down to dynamics occurring on cellular levels. This session will showcase recent advances in diffusive and reaction-diffusion systems that encompass all of these scales. Both applications and new theory advances will be emphasized. Novel applications include localized solutions that arise in the SIRS model with spatial diffusion, on curved surfaces, and in systems with white noise and bulk-surface coupling. On the theoretical side, multi-body dynamical systems, pattern morphology, along with wavefront dynamics due to nonlocal competition, will be discussed. For systems both stochastic and deterministic, the talks will highlight new dynamics and instabilities, as well as the numerical and analytic methods used to study them.

Organizer: Justin Tzou
Macquarie University, Sydney, Australia

Organizer: Theodore Kolokolnikov
Dalhousie University, Canada

Organizer: David Iron
Dalhousie University, Canada

1:00-1:20 White Noise and Spike Dynamics

David Iron, Dalhousie University, Canada

1:25-1:45 Blowup from Randomly Switching Between Stable Boundary Conditions for the Diffusion Equation

Sean Lawley, University of Utah, U.S.

1:50-2:10 The Role of Receptor Clustering in Chemoreception and Directional Sensing

Alan E. Lindsay, University of Notre Dame, U.S.

2:15-2:35 The Bramson Delay in Non-Local KPP Type Problems

Emeric Bouin, Université Paris Dauphine, France

Monday, May 20

MS57

Computer Assisted Theorems in Dynamics - Part II of II

1:00 p.m.-2:40 p.m.

Room: White Pine

For Part 1 see MS44

Topological and variational methods provide general existence theorems for important classes of problems. Yet, information about the shape and stability of the solutions (e.g. the patterns they describe) can often be obtained only with the help of numerical calculations. Indeed, our understanding of high and infinite dimensional nonlinear dynamical systems is largely based on numerical simulations, and while these inform our intuition, they ultimately raise as many questions as they answer. In both finite and infinite dimensions, identifying the building blocks that organize the dynamics is crucial for the global analysis of the system. Computer assisted proofs can be used to find and prove these low dimensional invariant dynamical structures, e.g. fixed points, periodic orbits, heteroclinic and homoclinic orbits. In this way local, rigorously verified, numerical solutions are the seeds from which additional global understanding is gained. This double minisymposium explores recent advances in computer assisted theorems for connecting orbits, spatio-temporal periodic solutions and bifurcations in both ordinary and partial differential equations, as well as delay equations. The session is also intended to highlight the work of early career researchers in this area.

Organizer: Jason D. Mireles James
Florida Atlantic University, U.S.

Organizer: Jan Bouwe Van Den Berg
VU University, Amsterdam, Netherlands

1:00-1:20 Computer Assisted Analysis of Hopf Bifurcations

Elena Queirolo, Vrije Universiteit Amsterdam, The Netherlands

1:25-1:45 A Method of Reducing Validation Errors when Integrating Smooth Vector Fields

Shane Kepley, Rutgers University, U.S.

1:50-2:10 Smale Tangles in the Circular Restricted Four Body Problems

Maxime Murray, Florida Atlantic University, U.S.

2:15-2:35 Bifurcations of Homoclinic Orbits in the Circular Restricted Four Body Problem

Wouter A. Hetebrij, Vrije Universiteit Amsterdam, The Netherlands

Monday, May 20

MS58

Understanding Dynamical Phenomena through System Reductions

1:00 p.m.-2:40 p.m.

Room: Primrose A

Modeling is a key to understanding the dynamics of many real-world systems, from networks of coupled oscillators to interacting climate systems. Often the original models are high-dimensional with many degrees of freedom because of the complexity and the number of interacting subsystems. Reducing such systems to the ingredients essential to the dynamic phenomenon of interest makes them more accessible to rigorous mathematical analysis. The main aim of this minisymposium is to bring together experts with different approaches to system reductions. These approaches include (a) mathematical reductions through the structure of equations and (b) reductions informed by data or real-world constraints. Cutting across disciplines, these distinct perspectives may lead to new approaches to be developed in the future.

Organizer: Alexander Lohse
Universität Hamburg, Germany

Organizer: Christian Bick
University of Exeter, United Kingdom

1:00-1:20 Model Reduction in Complex Networks of Kuramoto Oscillators with Collective Coordinates
Georg A. Gottwald, University of Sydney, Australia

1:25-1:45 Macroscopic Models for the Mammalian Circadian System
Kevin Hannay, Schriener University, U.S.

1:50-2:10 Asymptotic Reduction of Large Order Dynamical Systems
Andrew Fowler, Oxford University, United Kingdom

2:15-2:35 Purposeful Modeling of Physical Systems: A Grand Challenge for Systems Engineering
Robert E. Skelton, Texas A&M University, U.S.

Monday, May 20

MS59

Recent Advances in Modeling of Complex Processes in Large Dynamical Systems and Nonlinear Optics

1:00 p.m.-2:40 p.m.

Room: Primrose B

We present some recent developments in modeling of complex phenomena in large dynamical systems and nonlinear optics. The first speaker will report on the problem of statistical behavior of a large system with energy potential in the presence of a random forcing. The second speaker will address the issue of reducing the dimension of a large system via stochastic parameterization. The third speaker will talk about a random model of rigid sphere dynamics. The fourth speaker will elaborate on the effects of active optical media on light propagation.

Organizer: Rafail Abramov
University of Illinois, Chicago, U.S.

Organizer: Gregor Kovacic
Rensselaer Polytechnic Institute, U.S.

1:00-1:20 Statistical Network Representations of Energy Landscapes in Soft-Sphere Models
Katherine Newhall, University of North Carolina at Chapel Hill, U.S.

1:25-1:45 Stochastic Subgrid-Scale Parameterization for One-Dimensional Shallow Water Dynamics using Stochastic Mode Reduction
Ilya Timofeyev, University of Houston, U.S.

1:50-2:10 The Random Gas of Hard Spheres
Rafail Abramov, University of Illinois, Chicago, U.S.

2:15-2:35 Slow Light Propagation in Active Optical Media
Gregor Kovacic, Rensselaer Polytechnic Institute, U.S.

Intermission

2:40 p.m.-2:55 p.m.

Monday, May 20

IP4

Hybrid Forecasting of Complex Systems: Combining Machine Learning with Knowledge-based Models

2:55 p.m.-3:40 p.m.

Room: Ballroom

Chair: Juan G. Restrepo, University of Colorado Boulder, U.S.

In recent years, machine learning methods such as "deep learning" have proven enormously successful for tasks such as image classification, voice recognition, and more. Despite their effectiveness for big-data classification problems, these methods have had limited success for time series prediction, especially for complex systems like those we see in weather, solar activity, and brain dynamics. In this talk, I will discuss how a Reservoir Computer (RC) - a special kind of machine learning system that offers a "universal" dynamical system - can draw on its own internal complex dynamics in order to forecast systems like the weather, beyond the time horizon of other methods. The RC provides a knowledge-free approach because it builds forecasts purely from past measurements without any specific knowledge of the system dynamics. By building a new hybrid approach that judiciously combines the knowledge-free prediction of the RC with a knowledge-based, mechanistic model, we demonstrate a further, dramatic, improvement in forecasting complex systems. This hybrid approach can given us new insights into the weaknesses of our knowledge-based models and also reveal limitations in our machine learning system, guiding improvements in both knowledge-free and knowledge-based prediction techniques.

Michelle Girvan
University of Maryland, College Park, U.S.

Coffee Break

3:40 p.m.-4:10 p.m.

Room: Golden Cliff

Monday, May 20

MS60

Theoretical Aspects of Spiral Waves and Traveling Waves in a Cardiac or Neuroscience Context - Part I of II

4:10 p.m.-5:50 p.m.

Room: Ballroom 1

For Part 2 see MS73

Spiral and scroll waves are the most common types of solutions characterizing the dynamics of 2- and 3-dimensional excitable media such as the cardiac tissue. This minisymposium presents a sampling of recent analytical, numerical and data-driven studies focusing on the interaction of scroll waves, spiral waves and other patterns with perturbations such as structural heterogeneities, spatially varying anisotropy of the medium, and external stimuli as well as self or mutual interactions.

Organizer: Hans Dierckx
Ghent University, Belgium

Organizer: Stephanie Dodson
Brown University, U.S.

Organizer: Benjamin Ambrosio
Normandie University, France & Courant Institute, NY, U.S.

Organizer: Roman Grigoriev
Georgia Institute of Technology, U.S.

4:10-4:30 Some Bifurcations and Wave Patterns Arising in Excitable and Oscillatory Models of Neuroscience Context

Benjamin Ambrosio, Normandie University, France & Courant Institute, NY, U.S.

4:35-4:55 Role of Specta in Period-Doubling Instabilities of Spiral Waves

Stephanie Dodson and Bjorn Sandstede, Brown University, U.S.

5:00-5:20 St. Petersburg Paradox for Quasiperiodically Hypermeandering Spiral Waves

Vadim N. Biktashev, University of Exeter, United Kingdom; Ian Melbourne, University of Warwick, United Kingdom

5:25-5:45 Geometry of Wave Propagation on Active Deformable Surfaces

Pearson Miller and Joern Dunkel, Massachusetts Institute of Technology, U.S.

Monday, May 20

MS61

Advanced Data-Driven Techniques and Numerical Methods in Koopman Operator Theory - Part I of II

4:10 p.m.-5:50 p.m.

Room: Ballroom 2

For Part 2 see MS74

The Koopman operator approach studies nonlinear dynamical systems through the lens of the associated Koopman operator, which is an infinite-dimensional linear operator governing the evolution of observable functions defined on the state-space. The linearity of this operator allows for the deployment of a large array of tools from functional analysis, operator theory and linear algebra to study, both theoretically and numerically, the underlying dynamical system, allowing one to recover the underlying state-space structures (e.g., invariant sets) from the spectrum of this operator as well as facilitating various model reduction techniques (e.g., Dynamic Mode Decomposition). The key step in applying the Koopman operator approach is a finite-dimensional numerical approximation of the infinite dimensional operator, which is the topic of the proposed minisymposium. The session collects leading developments in the field from the past two years. The topics are machine learning and reproducing kernel Hilbert space techniques within the Koopman operator framework (1,2), advanced linear algebra techniques for enhancing Dynamic Mode Decomposition (3), sample complexity of Koopman operator approximations (4), robust extraction of spatio-temporal patterns (5,6), model reduction of stochastic systems (7), spectrally convergent approximations of the Koopman operator (8).

Organizer: Milan Korda
LAAS-CNRS, Toulouse, France

Organizer: Stefan Klus
Freie Universität Berlin, Germany

Organizer: Zlatko Drmac
University of Zagreb, Croatia

4:10-4:30 Data-Driven Analysis of Koopman Spectra with Reproducing Kernels

Yoshinobu Kawahara, Osaka University and RIKEN, Japan

continued in next column

4:35-4:55 Eigendecompositions of Transfer Operators in Reproducing Kernel Hilbert Spaces

Stefan Klus, Freie Universität Berlin, Germany

5:00-5:20 Numerical Methods for Data Driven Koopman Spectral Analysis

Zlatko Drmac, University of Zagreb, Croatia; Igor Mezic and Ryan Mohr, University of California, Santa Barbara, U.S.

5:25-5:45 Sample Complexity of Optimal Nonlinear Regulation using Koopman Operator

Umesh Vaidya, Iowa State University, U.S.

Monday, May 20

MS62

Dynamics and Topology of Vascular Networks - Part I of II

4:10 p.m.-5:50 p.m.

Room: Ballroom 3

For Part 2 see MS75

Animals, plants and even some slime molds need a vasculature system to survive. It provides nutrients, collects waste and transfers information, enabling the transport of substances at larger distances and speeds compared to simple diffusion. Current research on vascular systems tries to decipher the basic rules that drive their development and the processes that control their activity. Due to the continuous improvement of experimental techniques, researchers have been uncovering a wealth of phenomena related to vascular systems, ranging from the brain vasculature and its coupling with neural activity, to the morphogenesis and self-organization of vessels in chicken embryo, Physarum polycephalum or jellyfish. Their findings have dispelled the naive picture of a vascular network as a linear and passive transport system and have motivated a recent burst of theoretical work, utilizing tools from dynamical systems, graph theory and network topology. Nevertheless, many questions are still open, including the particularly active fronts of self-regulation and morphogenesis, dynamics, fluctuations, and interactions with the external environment. This minisymposium will gather applied mathematicians, physicists and experimentalists with theoretical interest in the modeling of vascular phenomena. It is intended for researchers with an interest in biological applications of dynamical systems and it will present a strong synergy with the Workshop on Network Science.

Organizer: Miguel Ruiz Garcia
University of Pennsylvania, U.S.

Organizer: Eleni Katifori
University of Pennsylvania, U.S.

4:10-4:30 Making Microvascular Networks Work: Angiogenesis, Remodeling and Pruning

Timothy W. Secomb, University of Arizona, U.S.

4:35-4:55 Dissecting the Contributions of Neuronal and Non-Neuronal Processes to Cerebral Vascular Dynamics

Patrick Drew, Pennsylvania State University, U.S.

continued in next column

5:00-5:20 Mapping Brain-Wide Vascular Networks with Capillary Resolution: Topological Features and Functional Correlates

Christoph Kirst, Rockefeller University, U.S.

5:25-5:45 Modeling Hemodynamic Fluctuations: The Brain Vasculature as an Excitable Network

Miguel Ruiz Garcia and Eleni Katifori, University of Pennsylvania, U.S.

Monday, May 20

MS63

High Dimensional Phase Space Structures in Chemical Reaction Dynamics - Part I of II

4:10 p.m.-5:50 p.m.

Room: Magpie A

For Part 2 see MS76

Following the success of transition state theory, dynamical systems theory has played a fundamental role in understanding nonstatistical properties of chemical reactions since its introduction in the 1980s. This has lead to a cross-fertilization between theoretical chemistry and dynamical systems theory. Chemistry profited from qualitative and quantitative tools, for example, lobes and reactive islands, to understand chemical phenomena such as product ratios and roaming. Chemical reaction problems stimulated, among others, the research of transition states and dividing surfaces, normally hyperbolic invariant manifolds (NHIMs) and their stable/unstable manifolds on the dynamical systems side. All of these contributions are based on dynamical structures in phase space that govern transport in the respective systems. Recent developments in the field show demand for tools to treat higher dimensional phase space structures and understand the implications for chemical reactions arising from bifurcations of NHIMs. Further development and combination of methods from phase space transport, model reduction, neural networks, and computational chemistry is of the essence. To do this, we propose to bring together leading researchers in theoretical chemistry and dynamical systems theory to identify new questions that will deepen this interdisciplinary collaboration. Moreover, this meeting is an opportunity to discuss ways to convey new methods and results to a broader scientific audience.

Organizer: Vladimir Krajnak
University of Bristol, United Kingdom

Organizer: Shibabrat Naik
University of Bristol, United Kingdom

Organizer: Rafael Garcia-Meseguer
University of Bristol, United Kingdom

4:10-4:30 A Dynamical Systems Perspective on the Definition of a Reaction Path

Holger Waalkens, University of Groningen, Netherlands

continued on next page

4:35-4:55 The Transition Manifold Approach to Molecular Coarse Graining

Andreas Bittracher, Freie Universität Berlin, Germany

5:00-5:20 Non-adiabatic Dynamics from Classical Equations of Motion

Joshua Kretchmer, California Institute of Technology, U.S.

5:25-5:45 Detailed Dynamics Study of the Linc/licn Isomerization Reaction in a Bath

Rosa M. Benito, Universidad Pólitecnica de Madrid, Spain

Monday, May 20

MS64

Influence of Network Structure and Symmetry on Dynamics - Part I of II

4:10 p.m.-5:50 p.m.

Room: Magpie B

For Part 2 see MS77

Network dynamical systems arise in many branches of science. Examples include gene expression, population dynamics and neural networks. The network structure, i.e. which nodes a given node receives input from, often influences what bifurcations and dynamics are possible in these systems. Modeling assumptions about symmetry can also play a key role in determining dynamics. This minisymposium will address modeling and mathematical analyses relevant to homeostasis, patterns of synchrony, decision making, and more broadly, the role of symmetry and network structure in determining the generic behaviors of dynamical systems on networks.

Organizer: Yangyang Wang

Ohio State University, U.S.

Organizer: Punit Gandhi

Ohio State University, U.S.

4:10-4:30 Network Admissible Systems: Symmetries and Bifurcations

Martin Golubitsky, Ohio State University, U.S.

4:35-4:55 Bifurcations on Fully Inhomogeneous Networks

Yangyang Wang, Punit Gandhi, and Martin Golubitsky, Ohio State University, U.S.; Claire M. Postlethwaite, University of Auckland, New Zealand; Ian Stewart, University of Warwick, United Kingdom

5:00-5:20 Singularities and Homeostasis in Gene Regulatory Networks

Fernando Antoneli, Universidade Federal de São Paulo, Brazil; Martin Golubitsky, Ohio State University, U.S.; Ian Stewart, University of Warwick, United Kingdom

5:25-5:45 Coincidence of Homeostasis and Bifurcation Points in Feedforward Networks

William Duncan, Duke University, U.S.

Monday, May 20

MS65

Rare Events in Interacting Many-Body Systems

4:10 p.m.-5:50 p.m.

Room: Wasatch A

Systems containing a discrete, large yet finite, population of interacting agents or dynamical units experience constant fluctuations, due to the discreteness of agents and the stochastic nature of the inter-agent interactions. Most of the time, such systems dwell in the vicinity of some attractor, undergoing small random excursions around it, while large fluctuations, on the order of the typical system size, are extremely rare. Yet, it is precisely these extreme, rare events, giving rise e.g. to population extinction, disease eradication, the arrival of biomolecules at small cellular receptors, or power-grid desynchronization, which may be of key practical importance. As such systems are often far from equilibrium, standard techniques of statistical mechanics are defied. Especially challenging is dealing with spatially extended systems or systems mediated through complex networks, where the spatial arrangement and topology strongly affect the long-time behavior. Our aim is to present novel analytical and numerical techniques that enable the accurate and efficient computation of rare event statistics in complex, many-body problems. The purpose of this minisymposium is to expose the audience to recent progress in the field of large-deviation theory in spatially-extended and networked systems, as well as to bring together researchers developing new analytical and numerical techniques for the analysis of complex, stochastic dynamics.

Organizer: Michael Assaf

Hebrew University of Jerusalem, Israel

4:10-4:30 Fluctuation Pathways to Desynchronization in Coupled Oscillator Networks

Jason M. Hindes, US Naval Research Laboratory, U.S.; Ira B. Schwartz, Naval Research Laboratory, U.S.

4:35-4:55 Extinction Risk of a Metapopulation under the Allee Effect

Michael Assaf and Ohad Vilk, Hebrew University of Jerusalem, Israel

continued on next page

Monday, May 20

MS65

Rare Events in Interacting Many-Body Systems

continued

5:00-5:20 Narrow Escape of Interacting Diffusing Particles

Baruch Meerson and Tal Agranov, Hebrew University of Jerusalem, Israel

5:25-5:45 Extinction and Survival in Two-Species Annihilation

Eli Ben Naim, Los Alamos National Laboratory, U.S.

Monday, May 20

MS66

Neuromechanics of Locomotion - Part I of II

4:10 p.m.-5:50 p.m.

Room: Wasatch B

For Part 2 see MS79

Effective and efficient locomotion is essential for survival for most animals and requires the robust coordination of rhythmic body movements. These coordinated body movements emerge from complex interactions between pattern generating circuits in the animal's nervous system, feedback via sensory systems, muscle-body dynamics, and the environment. Thus, understanding the fundamental mechanisms underlying locomotive behavior requires application of concepts from neurophysiology and biomechanics, and the application of network theory, control theory, and dynamical systems theory. This minisymposium brings together a diverse set of scientists using integrative approaches to understand locomotion in a variety of organisms, from worms and insects to fish and mammals.

Organizer: Tim Lewis
University of California, Davis, U.S.

Organizer: Robert Guy
University of California, Davis, U.S.

4:10-4:30 An Interdisciplinary Approach to Understanding Lamprey Locomotion

Kathleen A. Hoffman, University of Maryland, Baltimore County, U.S.; Eric Tytell, Tufts University, U.S.; Tim Kiemel, University of Maryland, U.S.; Lisa J. Fauci and Christina Hamlet, Tulane University, U.S.; Megan C. Leftwich, George Washington University, U.S.; Nicole Massarelli, University of Maryland, Baltimore County, U.S.

4:35-4:55 Perturbing Muscle: Exploring Muscle Force Production as a Dynamical System

Eric Tytell, James Miller, and Ben Tidswell, Tufts University, U.S.; Jennifer Carr, Salem State University, U.S.; Nicole Danos, University of San Diego, U.S.; M. Mert Ankarali, Middle East Technical University, Turkey; Noah J. Cowan, Johns Hopkins University, U.S.; Tim Kiemel, University of Maryland, U.S.

5:00-5:20 The Role of Phase Shifts of Sensory Inputs in Walking Revealed by Means of Phase Reduction

Silvia Daun, Tibor Toth, and Azamat Yeldesbay, University of Cologne, Germany

5:25-5:45 Metachronal Propulsion at Low to Intermediate Reynolds Numbers

Shawtaroh Granzier-Nakajima, University of Arizona, U.S.; Robert D. Guy, University of California, Davis, U.S.; *Calvin Zhang*, University of Arizona, U.S.

continued in next column

Monday, May 20

MS67

Complex Nonlinear and Stochastic Dynamics in Ecology and Neuroscience: Confluences and Influences - Part I of II

4:10 p.m.-5:50 p.m.

Room: Maybird

For Part 2 see MS80

Outstanding advances in biology in the last decades have stimulated the development of new mathematical models and methods in dynamical systems, networks, and stochastic dynamics. Despite the variety of questions current biology raises from ecology to biophysics and neuroscience, simple mathematical models often provide deep insight, and show tremendously complex dynamics often relying on a few universal mechanisms. Despite this strong confluence of ideas and methodologies, the dialogue between mathematical biologists of various domains remains limited, and theories explore complementary directions. This minisymposium will bring together the mathematical ecology and neuroscience communities to exchange ideas on key novel aspects of theories and data integration techniques that could be of great influence to the other community. In particular, ecologists have made important breakthroughs in models of spatial interactions and stochastic behavior of competitive systems that could directly benefit the computational neuroscience community. Reciprocally, in neuroscience, emphasis on multiple timescales dynamics, excitable systems, mean-field theory and nonlocal integrodifferential equations could provide important tools for ecological systems. This session will highlight several cutting-edge findings in these domains combining in particular networks theory, dynamical systems, multiscale methods, stochastic and functional analysis, and data integration in dynamical models.

Organizer: Jonathan D. Touboul
Collège de France, France

Organizer: Simon Levin
Princeton University, U.S.

4:10-4:30 Noisy Competition for Percept Dominance Amidst Ambiguity

John Rinzel, Courant Institute and Center for Neural Science, New York University, U.S.

continued in next column

4:35-4:55 Stochastic Hybrid Biological Oscillators

Paul C. Bressloff, University of Utah, U.S.; James Maclaurin, New Jersey Institute of Technology, U.S.

5:00-5:20 Positional Information Effects on the Schelling's Model of Segregation: Applications to Neurodevelopment

Cristobal Quininao, Universidad de O'Higgins, Chile; Victor Verdugo, Universidad de Chile, Chile and École Normale Supérieure, France

5:25-5:45 Emergence and Persistence of Microbial Consortia at Steady State

Thibaud Taillefumier, University of Texas at Austin, U.S.

Monday, May 20

MS68

Polynomial Optimization Methods for Nonlinear Dynamics - Part I of II

4:10 p.m.-5:50 p.m.

Room: Superior A

For Part 2 see MS81

The double minisymposium will survey recently developed methods for using polynomial optimization to study nonlinear dynamical systems. The methods are implemented computationally using semidefinite programming and related convex optimization tools. The first talk will present background material and give an overview of the types of questions that can be studied in this way, with a few examples including the estimation of extreme values on attractors. Several other talks illustrate different properties that can be studied in this way: transient growth, control, Fourier spectra, and time averages. Two talks will present recent applications of these ideas to machine learning and accelerated simulation. The talks will together illustrate that approaches based on polynomial optimization, when applicable and tractable, often produce stronger results than any other existing methods. On the other hand, application to very high-dimensional dynamics requires further work on computational scalability and numerical conditioning. Some speakers will discuss approaches for improving scalability.

Organizer: David Goluskin
University of Victoria, Canada

4:10-4:30 Studying Dynamics using Polynomial Optimization

David Goluskin, University of Victoria, Canada

4:35-4:55 Convex Analysis of Maximal Transient Growth Phenomena

Giovanni Fantuzzi, Imperial College London, United Kingdom; David Goluskin, University of Victoria, Canada

5:00-5:20 Moments and Convex Optimization for Analysis and Control of Nonlinear Partial Differential Equations

Milan Korda, Didier Henrion, and Jean-Bernard Lasserre, LAAS-CNRS, Toulouse, France

5:25-5:45 Power and Limitations of Sum of Squares Programming for Stability Analysis of Dynamical Systems

Amir Ali Ahmadi and Bachir El Khadir, Princeton University, U.S.

Monday, May 20

MS69

Nonlinear Patterns and Waves - Part I of II

4:10 p.m.-5:50 p.m.

Room: Superior B

For Part 2 see MS82

This minisymposium will focus on recent results in the area of of pattens, traveling waves and related structures, obtained by either numerical or analytic techniques. Existence, stability, dynamic properties, and bifurcations of these special solutions will be addressed.

Organizer: Anna Ghazaryan
Miami University, U.S.

Organizer: Vahagn Manukian
Miami University Hamilton, U.S.

4:10-4:30 Pulse Solutions for an Extended Klausmeier Model with Spatially Varying Coefficients

Robbin Bastiaansen, Martina Chirilus-Bruckner, and *Arjen Doelman*, Leiden University, Netherlands

4:35-4:55 One-Dimensional Periodic Solutions in a Three-Component Reaction-Diffusion System

Gianne Derks, University of Surrey, United Kingdom; Peter van Heijster, Queensland University of Technology, Australia; David Lloyd, University of Surrey, United Kingdom

5:00-5:20 Grassmannian/Riccati Flows and Applications to Nonlinear Systems

Simon Malham, Heriot-Watt University, United Kingdom

5:25-5:45 Growing Stripes, with and Without Wrinkles

Montie Avery, University of Minnesota, U.S.; Ryan Goh, Boston University, U.S.; Oscar Goodloe, Arizona State University, U.S.; Alexandre Milewski, University of Bristol, United Kingdom; *Arnd Scheel*, University of Minnesota, Twin Cities, U.S.

Monday, May 20

MS70

Stability and Tipping in Ecosystems

4:10 p.m.-5:50 p.m.

Room: White Pine

The study of the stability of ecosystems under the impact of climate change is closely related with the occurrence of tipping phenomena. Tipping refers either to sudden or to gradual changes in the ecosystem dynamics as environmental parameters or external forcing are varied. In the minisymposium we will discuss the ecological consequences of different tipping scenarios. Rate-induced tipping leads to a sudden change in an ecosystem due to a decline or an increase of resources with a certain rate. Taking the spatial distribution into account tipping can be viewed as a gradual rather than a sudden process. Pattern formation processes can lead to local tipping, which only slowly develops into a global tipping. Furthermore, in an ecological system, spatially arranged in a network of patches or habitats, we show that unstable chaotic sets play a fundamental role in the stability of synchronized behavior among the ecological patches. Finally, we discuss the role of the behavior of individuals for collective dynamics.

Organizer: Ulrike Feudel
University of Oldenburg, Germany

Organizer: Ehud Meron
Ben-Gurion University, Israel

4:10-4:30 Nonlinear Dynamics of Desertification

Ehud Meron, Ben-Gurion University, Israel

4:35-4:55 Rapid Evolution Prevents Rate-Induced Critical Transition in a Predator-Prey System

Anna Vanselow and Ulrike Feudel, University of Oldenburg, Germany; Sebastian M. Wieczorek, University College Cork, Ireland

5:00-5:20 Boundaries of Synchronization in Ecological Networks

Everton S. Medeiros, University of Sao Paulo, Brazil

5:25-5:45 On the Influence of Inter-Individual Differences on Herding Behavior

Chiranjit Mitra, Daniel Rey, and Adilson E. Motter, Northwestern University, U.S.

Monday, May 20

MS71

Mixing and Transport in Fluid Flows: Advective, Diffusive and Stochastic Aspects - Part I of II

4:10 p.m.-5:50 p.m.

Room: Primrose A

For Part 2 see MS84

Transport and mixing of scalar fields in fluids, such as temperature, salinity and two-dimensional vorticity, are fundamentally important physical processes. Motivated by the ever increasing availability of global observational data on geophysical flows, major theoretical and computational development has taken place in the understanding of transport barriers, which are material flow structures that shape the transport processes and generate mixing. Identifying transport barriers eliminates the need for detailed and costly diffusive and stochastic simulations, enabling one to focus on a simplified geometric skeleton that governs the important features on the transported scalar field. This two-part minisymposium brings together theoreticians, computational experts and experimentalists to survey recent progress and challenges in the description, prediction, and computation of advective, diffusive and stochastic transport processes. Part I focuses on theoretical results and computational methods, while Part II focuses on experimental and observational techniques.

Organizer: Daniel Karrasch
Technische Universität München, Germany

Organizer: George Haller
ETH Zürich, Switzerland

4:10-4:30 Coherent Patterns using Space-Time Koopman Analysis

Suddhasattwa Das and Dimitrios Giannakis, Courant Institute of Mathematical Sciences, New York University, U.S.

4:35-4:55 Material Barriers to Diffusive and Stochastic Transport

George Haller, ETH Zürich, Switzerland

5:00-5:20 Computational Aspects of the Detection of Material Barriers to Diffusive Transport

Daniel Karrasch, Technische Universität München, Germany

continued on next page

5:25-5:45 Finite-Time Averaging of Advection-Diffusion in Lagrangian Coordinates

Alvaro de Diego, Oliver Junge, Daniel Karrasch, and *Nathanael Schilling*, Technische Universität München, Germany

Monday, May 20

MS72

Novel Approaches to Transient Dynamics

4:10 p.m.-5:50 p.m.

Room: Primrose B

Mathematical models of excitable cells, such as neurones, are often characterized by different dynamic regimes, for example coexising stable states. The transient dynamics responsible for sequential transitions between dynamics states are often discounted or overlooked in favour of the long term asymptotic behaviour. The spacial and temporal properties of the transient behaviour are emergent dynamics of the system and may be quite different from the long-term behaviour. Analysis of the behaviour of such transitions is instrumental in understanding problems in contemporary scientific applications including neuroscience, developmental biology and climate modelling. Advances in nonlinear-dynamics and imaging have allowed novel tools to be developed to tackle this regime. This minisymposium will showcase a variety of novel mathematical frameworks developed to explore and characterise deterministic and stochastic transient dynamics.

Organizer: Jennifer Creaser

University of Exeter, United Kingdom

4:10-4:30 Understanding Transients Associated with Periodic Dynamics using the LOR Coordinate Transformation

Benjamin G. Letson and *Jonathan E. Rubin*, University of Pittsburgh, U.S.

4:35-4:55 Nonautonomous Network Attractors: A New Paradigm to Model the Behaviour of Recurrent Neural Networks

Andrea Ceni, Peter Ashwin, and Lorenzo Livi, University of Exeter, United Kingdom; Claire M. Postlethwaite, University of Auckland, New Zealand

5:00-5:20 Predicting Deterministic Transient Responses via Expectation Values

Malte Schröder, Justine Wolter, Raoul Schmidt, Xiaozhu Zhang, and Marc Timme, Technische Universität Dresden, Germany

continued in next column

5:25-5:45 A Bounded-Time Approach to Dynamics Analysis

Julian Newman, Maxime Lucas, and Aneta Stefanovska, Lancaster University, United Kingdom

Intermission

5:50 p.m.-6:00 p.m.

Monday, May 20

MS73

Theoretical Aspects of Spiral Waves and Traveling Waves in a Cardiac or Neuroscience Context - Part II of II

6:00 p.m.-7:40 p.m.

Room: Ballroom 1

For Part 1 see MS60

Spiral and scroll waves are the most common types of solutions characterizing the dynamics of 2- and 3-dimensional excitable media such as the cardiac tissue. This minisymposium presents a sampling of recent analytical, numerical and data-driven studies focusing on the interaction of scroll waves, spiral waves and other patterns with perturbations such as structural heterogeneities, spatially varying anisotropy of the medium, and external stimuli as well as self or mutual interactions.

Organizer: Hans Dierckx
Ghent University, Belgium

Organizer: Stephanie Dodson
Brown University, U.S.

Organizer: Benjamin Ambrosio
Normandie University, France & Courant Institute, NY, U.S.

Organizer: Roman Grigoriev
Georgia Institute of Technology, U.S.

6:00-6:20 Drift of Cardiac Scroll Waves Due to Anisotropy Gradients in the Cardiac Wall

Hans Dierckx, Ghent University, Belgium

6:25-6:45 Reconstructing Rotor Dynamics from Sparse Noisy Data

Daniel Gurevich and Roman Grigoriev, Georgia Institute of Technology, U.S.

6:50-7:10 The Role of Higher Order Scroll Wave Filament Dynamics in Terminating Fibrillation

Niels Otani, Rochester Institute of Technology, U.S.

7:15-7:35 A Simple Parameter can Switch Between Different Weak-Noise-Induced Phenomena in a Simple Neuron Model

Marius E. Yamakou, Max Planck Institute for Mathematics in the Sciences, Germany

Monday, May 20

MS74

Advanced Data-Driven Techniques and Numerical Methods in Koopman Operator Theory - Part II of II

6:00 p.m.-7:40 p.m.

Room: Ballroom 2

For Part 1 see MS61

The Koopman operator approach studies nonlinear dynamical systems through the lens of the associated Koopman operator, which is an infinite-dimensional linear operator governing the evolution of observable functions defined on the state-space. The linearity of this operator allows for the deployment of a large array of tools from functional analysis, operator theory and linear algebra to study, both theoretically and numerically, the underlying dynamical system, allowing one to recover the underlying state-space structures (e.g., invariant sets) from the spectrum of this operator as well as facilitating various model reduction techniques (e.g., Dynamic Mode Decomposition). The key step in applying the Koopman operator approach is a finite-dimensional numerical approximation of the infinite dimensional operator, which is the topic of the proposed minisymposium. The session collects leading developments in the field from the past two years. The topics are machine learning and reproducing kernel Hilbert space techniques within the Koopman operator framework (1,2), advanced linear algebra techniques for enhancing Dynamic Mode Decomposition (3), sample complexity of Koopman operator approximations (4), robust extraction of spatio-temporal patterns (5,6), model reduction of stochastic systems (7), spectrally convergent approximations of the Koopman operator (8).

Organizer: Milan Korda
LAAS-CNRS, Toulouse, France

Organizer: Stefan Klus
Freie Universität Berlin, Germany

Organizer: Zlatko Drmac
University of Zagreb, Croatia

6:00-6:20 Data-Driven Discovery of Koopman Embeddings for Spatio-Temporal Systems

J. Nathan Kutz, Bethany Lusch, and Steven L. Brunton, University of Washington, U.S.

continued in next column

6:25-6:45 Extracting Robust Constituents in Fluid and Combustion Flow

Gemunu H. Gunaratne, University of Houston, U.S.; Sukesh Roy, Spectral Energiels, LLC, U.S.; Jia-Chen Hua, Norwegian University of Science and Technology, Norway

6:50-7:10 Analysis and Model Reduction of Stochastic Dynamics using Koopman Operators

Feliks Nüske, Rice University, U.S.

7:15-7:35 Periodic Approximation for the Spectral Analysis of the Koopman Operator

Nithin Govindarajan, University of California, Santa Barbara, U.S.

Monday, May 20

MS75

Dynamics and Topology of Vascular Networks - Part II of II

6:00 p.m.-7:40 p.m.

Room: Ballroom 3

For Part 1 see MS62

Animals, plants and even some slime molds need a vasculature system to survive. It provides nutrients, collects waste and transfers information, enabling the transport of substances at larger distances and speeds compared to simple diffusion. Current research on vascular systems tries to decipher the basic rules that drive their development and the processes that control their activity. Due to the continuous improvement of experimental techniques, researchers have been uncovering a wealth of phenomena related to vascular systems, ranging from the brain vasculature and its coupling with neural activity, to the morphogenesis and self-organization of vessels in chicken embryo, Physarum polycephalum or jellyfish. Their findings have dispelled the naive picture of a vascular network as a linear and passive transport system and have motivated a recent burst of theoretical work, utilizing tools from dynamical systems, graph theory and network topology. Nevertheless, many questions are still open, including the particularly active fronts of self-regulation and morphogenesis, dynamics, fluctuations, and interactions with the external environment. This minisymposium will gather applied mathematicians, physicists and experimentalists with theoretical interest in the modeling of vascular phenomena. It is intended for researchers with an interest in biological applications of dynamical systems and it will present a strong synergy with the Workshop on Network Science.

Organizer: Miguel Ruiz Garcia
University of Pennsylvania, U.S.

Organizer: Eleni Katifori
University of Pennsylvania, U.S.

6:00-6:20 Mutual Couplings and Constraints in Space-Sharing Complex Networks

Carl Modes, Max Planck Institute of Molecular Cell Biology and Genetics, Germany

continued in next column

6:25-6:45 An Adaptation Model for Slime Mold Physarum Polycephalum

Dan Hu, Shanghai Jiao Tong University, China

6:50-7:10 Blood Flow and Solute Transfer in Feto-Placental Capillary Networks

Philip Pearce, Massachusetts Institute of Technology, U.S.; Alexander Erlich, University of Manchester, United Kingdom; Romina Plitman Mayo, University of Cambridge, United Kingdom; Oliver E. Jensen and Igor Chernyavsky, University of Manchester, United Kingdom

7:15-7:35 Dduq: An Uncertainty Quantification/Model Reduction Technique for the Vascular Network

Alessandro Veneziani and Sofia Guzzetti, Emory University, U.S.; Kevin T. Carlberg, Sandia National Laboratories, U.S.; Pablo J. Blanco and Alonso Alvarez, Laboratorio Nacional de Computacao Cientifica, Brazil

Monday, May 20

MS76

High Dimensional Phase Space Structures in Chemical Reaction Dynamics - Part II of II

6:00 p.m.-7:40 p.m.

Room: Magpie A

For Part 1 see MS63

Following the success of transition state theory, dynamical systems theory has played a fundamental role in understanding nonstatistical properties of chemical reactions since its introduction in the 1980s. This has lead to a cross-fertilization between theoretical chemistry and dynamical systems theory. Chemistry profited from qualitative and quantitative tools, for example, lobes and reactive islands, to understand chemical phenomena such as product ratios and roaming. Chemical reaction problems stimulated, among others, the research of transition states and dividing surfaces, normally hyperbolic invariant manifolds (NHIMs) and their stable/unstable manifolds on the dynamical systems side. All of these contributions are based on dynamical structures in phase space that govern transport in the respective systems. Recent developments in the field show demand for tools to treat higher dimensional phase space structures and understand the implications for chemical reactions arising from bifurcations of NHIMs. Further development and combination of methods from phase space transport, model reduction, neural networks, and computational chemistry is of the essence. To do this, we propose to bring together leading researchers in theoretical chemistry and dynamical systems theory to identify new questions that will deepen this interdisciplinary collaboration. Moreover, this meeting is an opportunity to discuss ways to convey new methods and results to a broader scientific audience.

Organizer: Vladimir Krajnak
University of Bristol, United Kingdom

Organizer: Shibabrat Naik
University of Bristol, United Kingdom

Organizer: Rafael Garcia-Meseguer
University of Bristol, United Kingdom

continued on next page

Monday, May 20

MS76

High Dimensional Phase Space Structures in Chemical Reaction Dynamics - Part II of II

continued

6:00-6:20 What is "Roaming" in Chemical Reaction Dynamics and Why is it so Challenging to Model Theoretically?

Joel Bowman, The Emerson Center, U.S.

6:25-6:45 Roaming Radicals in Unimolecular and Bimolecular Reactions

Artur Suits, University of Missouri, Columbia, U.S.

6:50-7:10 Unveiling the Chaotic Structure in Phase Space of Molecular Systems using Lagrangian Descriptors

Florentino Borondo, Universidad Autonoma de Madrid, Spain

7:15-7:35 Phase Space of Discrete and Time Continuous Dynamical Systems

Ana M. Mancho, Instituto de Ciencias Matemáticas, Spain

Monday, May 20

MS77

Influence of Network Structure and Symmetry on Dynamics - Part II of II

6:00 p.m.-7:40 p.m.

Room: Magpie B

For Part 1 see MS64

Network dynamical systems arise in many branches of science. Examples include gene expression, population dynamics and neural networks. The network structure, i.e. which nodes a given node receives input from, often influences what bifurcations and dynamics are possible in these systems. Modeling assumptions about symmetry can also play a key role in determining dynamics. This minisymposium will address modeling and mathematical analyses relevant to homeostasis, patterns of synchrony, decision making, and more broadly, the role of symmetry and network structure in determining the generic behaviors of dynamical systems on networks.

Organizer: Yangyang Wang

Ohio State University, U.S.

Organizer: Punit Gandhi

Ohio State University, U.S.

6:00-6:20 Dynamically Relevant Motifs in Inhibition-Dominated Networks

Carina Curto, Pennsylvania State University, U.S.

6:25-6:45 Heteroclinic Cycles and Networks of Localized Frequency Synchrony in Coupled Oscillator Populations

Christian Bick, University of Exeter, United Kingdom

6:50-7:10 The Role of Symmetries in Making Collective Decisions

Alessio Franci, Universidad Nacional Autónoma de México, Mexico; Martin Golubitsky, Ohio State University, U.S.; Naomi E. Leonard, Princeton University, U.S.

7:15-7:35 (Linear) Consequences of the Fundamental Network

Eddie Nijholt, University of Illinois at Urbana-Champaign, U.S.

Monday, May 20

MS78

Novel Noise-Driven Dynamics in Far-from-Equilibrium Systems

6:00 p.m.-7:40 p.m.

Room: Wasatch A

Recently, there has been impressive experimental and theoretical progress concerning the dynamical properties of noise-driven systems that are far-from-equilibrium. These efforts span a broad array of fields including biophysics, condensed and soft matter physics, materials science, climate science, and even the social sciences. This minisymposium will bring together experimentalists and theorists from condensed matter physics and applied mathematics to explore novel dynamical systems methods and experimental techniques that are enhancing the understanding of noise-driven phenomena of current importance and interest. Systems to be treated in this session include biophysical problems such as protein folding and the growth of blood vessels and vascular networks, defect dynamics in low-dimensional crystalline materials, and noise-driven charge transport in electronic systems with novel approaches to applications such as random number generation.

Organizer: Stephen Teitsworth

Duke University, U.S.

Organizer: Luis Bonilla

Universidad Carlos III de Madrid, Spain

6:00-6:20 Dynamics Driven by Noise in Condensed Matter and Active Matter Systems

Luis Bonilla, Universidad Carlos III de Madrid, Spain

6:25-6:45 Chaos in Semiconductor Superlattices: Coherence and Stochastic Resonances and Random Number Generation

Holger T. Grahn, Paul-Drude-Institut, Germany; Yaohui Zhang, Key Laboratory of Nanodevices and Applications, Suzhou, China

6:50-7:10 Folding and Unfolding of Proteins

Ana Carpio, Universidad Complutense de Madrid, Spain

7:15-7:35 Fluctuations and Heat Transfer Induced by Degenerate Noise

John Neu, University of California, Berkeley, U.S.; Stephen Teitsworth, Duke University, U.S.

Monday, May 20

MS79

Neuromechanics of Locomotion - Part II of II

6:00 p.m.-7:40 p.m.

Room: Wasatch B

For Part 1 see MS66

Effective and efficient locomotion is essential for survival for most animals and requires the robust coordination of rhythmic body movements. These coordinated body movements emerge from complex interactions between pattern generating circuits in the animal's nervous system, feedback via sensory systems, muscle-body dynamics, and the environment. Thus, understanding the fundamental mechanisms underlying locomotive behavior requires application of concepts from neurophysiology and biomechanics, and the application of network theory, control theory, and dynamical systems theory. This minisymposium brings together a diverse set of scientists using integrative approaches to understand locomotion in a variety of organisms, from worms and insects to fish and mammals.

Organizer: Tim Lewis
University of California, Davis, U.S.

Organizer: Robert Guy
University of California, Davis, U.S.

6:00-6:20 Evolution and Analysis of Integrated Neuromechanical Models of *C. Elegans* Locomotion

Eduardo J. Izquierdo, Erick Olivares, and Randall D. Beer, Indiana University, U.S.

6:25-6:45 Analysis of the Relative Roles of Neural and Mechanical Coupling in C. Elegans Gait Modulation

Carter Johnson, Tim Lewis, and Robert D. Guy, University of California, Davis, U.S.

6:50-7:10 Signatures of Central and Peripheral Control in Nematode Locomotion: When Neurons Meet Biomechanics

Netta Cohen, *Jack Denham*, and Thomas Ranner, University of Leeds, United Kingdom

7:15-7:35 The Nematode C Elegans as a Control System

Charles Fieseler and Nathan Kutz, University of Washington, U.S.

Monday, May 20

MS80

Complex Nonlinear and Stochastic Dynamics in Ecology and Neuroscience: Confluences and Influences - Part II of II

6:00 p.m.-7:40 p.m.

Room: Maybird

For Part 1 see MS67

Outstanding advances in biology in the last decades have stimulated the development of new mathematical models and methods in dynamical systems, networks, and stochastic dynamics. Despite the variety of questions current biology raises from ecology to biophysics and neuroscience, simple mathematical models often provide deep insight, and show tremendously complex dynamics often relying on a few universal mechanisms. Despite this strong confluence of ideas and methodologies, the dialogue between mathematical biologists of various domains remains limited, and theories explore complementary directions. This minisymposium will bring together the mathematical ecology and neuroscience communities to exchange ideas on key novel aspects of theories and data integration techniques that could be of great influence to the other community. In particular, ecologists have made important breakthroughs in models of spatial interactions and stochastic behavior of competitive systems that could directly benefit the computational neuroscience community. Reciprocally, in neuroscience, emphasis on multiple timescales dynamics, excitable systems, mean-field theory and nonlocal integrodifferential equations could provide important tools for ecological systems. This session will highlight several cutting-edge findings in these domains combining in particular networks theory, dynamical systems, multiscale methods, stochastic and functional analysis, and data integration in dynamical models.

Organizer: Jonathan D. Touboul
Collège de France, France

Organizer: Simon Levin
Princeton University, U.S.

6:00-6:20 Transients in Ecological Systems

Alan M. Hastings, University of California, Davis, U.S.

continued in next column

6:25-6:45 Vegetation Distributions in Tropical Ecosystems: Correspondence Between Models and Reality

Carla Stave, Yale University, U.S.

6:50-7:10 Influences of Nonlinear Feedbacks on the Evolution of Self-Organized Landscapes

Xiaoli Dong, University of California, Davis, U.S.

7:15-7:35 Nonlinear and Stochastic Models to Link the Dynamics of Preindustrial Human Populations with their Environment

Charlotte Lee, Duke University, U.S.

Monday, May 20

MS81

Polynomial Optimization Methods for Nonlinear Dynamics - Part II of II

6:00 p.m.-7:40 p.m.

Room: Superior A

For Part 1 see MS68

The double minisymposium will survey recently developed methods for using polynomial optimization to study nonlinear dynamical systems. The methods are implemented computationally using semidefinite programming and related convex optimization tools. The first talk will present background material and give an overview of the types of questions that can be studied in this way, with a few examples including the estimation of extreme values on attractors. Several other talks illustrate different properties that can be studied in this way: transient growth, control, Fourier spectra, and time averages. Two talks will present recent applications of these ideas to machine learning and accelerated simulation. The talks will together illustrate that approaches based on polynomial optimization, when applicable and tractable, often produce stronger results than any other existing methods. On the other hand, application to very high-dimensional dynamics requires further work on computational scalability and numerical conditioning. Some speakers will discuss approaches for improving scalability.

Organizer: David Goluskin
University of Victoria, Canada

6:00-6:20 Bounding Periodically Driven Non-Autonomous Dynamical Systems via Convex Optimization

Charles R. Doering, University of Michigan, Ann Arbor, U.S.; Andrew McMillan, University of Michigan, U.S.

6:25-6:45 Accelerating Time Averaging of the Parameters of Dynamical Systems

Sergei I. Chernyshenko, Imperial College London, United Kingdom; Owen Tutty, University of Southampton, United Kingdom; Hanying Yang, Imperial College London, United Kingdom

continued in next column

6:50-7:10 Verification of Partially Observable Markov Decision Processes via Lyapunov Functions and Barrier Certificates

Mohamedreza Ahmadi, University of Texas at Austin, U.S.

7:15-7:35 Rigorous and Numerical Bounds on the Heat Transport for Rotating Rayleigh-Bénard Convection

Jared P. Whitehead, Brigham Young University, U.S.

Monday, May 20

MS82

Nonlinear Patterns and Waves - Part II of II

6:00 p.m.-7:40 p.m.

Room: Superior B

For Part 1 see MS69

This minisymposium will focus on recent results in the area of patterns, traveling waves and related structures, obtained by either numerical or analytic techniques. Existence, stability, dynamic properties, and bifurcations of these special solutions will be addressed.

Organizer: Anna Ghazaryan
Miami University, U.S.

Organizer: Vahagn Manukian
Miami University Hamilton, U.S.

6:00-6:20 A Maslov Index for Non-Hamiltonian Systems

Graham Cox, Memorial University of Newfoundland, Canada

6:25-6:45 Normalized Ground States of Second Order PDEs with Mixed Power Non-Linearities

Atanas Stefanov, University of Kansas, U.S.

6:50-7:10 Spectral Stability of Hydraulic Shock Profiles

Alim Sukhtayev, Miami University, U.S.

7:15-7:35 Long-Range Interactions of Kinks

Aslihan Demirkaya, University of Hartford, U.S.

Monday, May 20

MS83

Reduced Order Models and Spectral Submanifolds - Theory and Applications

6:00 p.m.-7:40 p.m.

Room: White Pine

Model reduction in engineering is an essential technique to understand the qualitative nature of systems' behaviour. Model reduction in purely dissipative systems, based on the theory of spectral submanifolds, is similar to a center manifold reduction in systems with conservative modes. One prominent feature of this method is the uniqueness of the obtained reduced model – a characteristic usually missing in the center manifold reduction. In this session we will bring together talks that address finding unique reduced order models. The talks will range from the theoretical background of model reduction to its practical implementation in numerical calculations and experiments.

Organizer: Robert Szalai
University of Bristol, United Kingdom

Organizer: Florian Kogelbauer
ETH Zürich, Switzerland

6:00-6:20 Spectral Submanifolds and their Conservative Limit

Florian Kogelbauer, ETH Zürich, Switzerland

6:25-6:45 Numerical Calculation of Spectral Submanifolds

Robert Szalai, University of Bristol, United Kingdom

6:50-7:10 Exact Model Reduction of Nonlinear Thermo-Mechanical Systems from a Slow-Fast Analysis

Shobhit Jain, ETH Zürich, Switzerland

7:15-7:35 Control-Based Continuation Applied to Wind-Tunnel Experiments with an Aerofoil

Irene Tartaruga, University of Bristol, United Kingdom

Monday, May 20

MS84

Mixing and Transport in Fluid Flows: Advective, Diffusive and Stochastic Aspects - Part II of II

6:00 p.m.-7:40 p.m.

Room: Primrose A

For Part 1 see MS71

Transport and mixing of scalar fields in fluids, such as temperature, salinity and two-dimensional vorticity, are fundamentally important physical processes. Motivated by the ever increasing availability of global observational data on geophysical flows, major theoretical and computational development has taken place in the understanding of transport barriers, which are material flow structures that shape the transport processes and generate mixing. Identifying transport barriers eliminates the need for detailed and costly diffusive and stochastic simulations, enabling one to focus on a simplified geometric skeleton that governs the important features on the transported scalar field. This two-part minisymposium brings together theoreticians, computational experts and experimentalists to survey recent progress and challenges in the description, prediction, and computation of advective, diffusive and stochastic transport processes. Part I focuses on theoretical results and computational methods, while Part II focuses on experimental and observational techniques.

Organizer: Daniel Karrasch
Technische Universität München, Germany

Organizer: George Haller
ETH Zürich, Switzerland

6:00-6:20 Transport Properties of the Slope Sea with Application to Atlantic Bluefin Tuna Spawning

Irina I. Rypina, Larry Pratt, Ke Chen, Christina Hernandez, and Joel Llopiz, Woods Hole Oceanographic Institution, U.S.; Samuel Entner, Wentworth Institute of Technology, U.S.

6:25-6:45 Dynamic Morphoskeleton

Mattia Serra, ETH Zürich, Switzerland; L Mahadevan, Harvard University, U.S.

continued in next column

6:50-7:10 Understanding Ocean Dynamics through Lagrangian Ocean Drifters and Deep Neural Networks

Nikolas Aksamit, ETH Zürich, Switzerland

7:15-7:35 Application of Lagrangian Clustering to Submesoscale Ensemble Forecasts

Michael Allshouse and G. Salvador-Vieira, Northeastern University, U.S.

Monday, May 20

MS85

Unusual Complexity in Applied Dynamical Models

6:00 p.m.-7:40 p.m.

Room: Primrose B

There is a plethora of nonlinear continuous and discrete dynamical system models that have been developed to predict applied phenomena of current interest ranging from population dynamics to machine learning. It is found that these systems, arising in areas that are currently being actively investigated, often exhibit extremely complex and rather unusual dynamics related to combinations of bifurcations and chaotic regimes. The unusual nature of the behavior of these systems is in many cases the key to understanding the evolution of the phenomena being modeled, so it is important to find tools and techniques – some old and some new – enabling effective analysis of the dynamics. Four researchers who are studying these kinds of systems shall report on their investigations, which are drawn from the following application areas: population dynamics; walking droplet phenomena; machine learning models in neuroscience; and chaotic logical circuits.

Organizer: Aminur Rahman
Texas Tech University, U.S.

Organizer: Denis Blackmore
New Jersey Institute of Technology, U.S.

6:00-6:20 Analyzing Chaos in Walking Droplet Models

Denis Blackmore, New Jersey Institute of Technology, U.S.

6:25-6:45 Extreme Dynamical Complexity in Recurrent Neural Networks

Ian D. Jordan, State University of New York, Stony Brook, U.S.

6:50-7:10 Complexity and Chaos in Higher Dimensional Lotka—Volterra Dynamics

Michelle Savescu, Kutztown University, U.S.; Yogesh Joshi, Kingsborough Community College, U.S.

7:15-7:35 Simple Proofs of Chaos for Logical Circuit and Walking Droplet Models

Aminur Rahman, Texas Tech University, U.S.

Monday, May 20

Dinner Break

7:40 p.m.-9:00 p.m.

Attendees on their own

SIAG/DS Business Meeting (complimentary beer and wine will be served)

9:00 p.m.-9:30 p.m.

Room: Ballroom 2

Tuesday, May 21

Registration

8:00 a.m.-5:30 p.m.

Room: Ballroom Foyer

Tuesday, May 21

MS86

Applications of Koopman Operator Theory in Dynamical Systems: From Fluids, through Machine Learning to Energy - Part I of II

8:30 a.m.-10:10 a.m.

Room: Primrose A

For Part 2 see MS97

The Koopman operator approach to dynamical systems has been applied to fluid mechanics and enjoyed success due to its model-reduction capability that captured complex coherent dynamics better than previous techniques. The approach is experiencing a high degree of co-development between theorems, numerical approaches (algorithms) and applications in natural science and technology. In fact, very interesting questions are arising for researchers on theory and algorithms side from practical applications in diverse domains. The two-part minisymposium will contribute to the overall goal of advancing the Koopman operator approach by fostering interaction between theory, numerical algorithms and applications. Fluid applications are still primarily important in this interaction, talked by Caulfield, McKeon, and Arbabi. Dynamical systems in brains are one of the novel application in talks by Liegeois and Li. Machine learning is currently the hottest topic of the interaction of Koopman operator approach in talks by Li, Yeung, and Martinez-Ramon. Energy is a direct application to technology for solving social issues in the world, talked by Martinez-Ramon and Netto. The series of the talks will provide not only new insights into the diverse application domains but also new requirement in the development of mathematical theorems.

Organizer: Yoshihiko Susuki
Osaka Prefecture University, Japan

Organizer: Igor Mezic
University of California, Santa Barbara, U.S.

Organizer: Steven Brunton
University of Washington, U.S.

continued in next column

8:30-8:50 Koopman Operator Theory for Turbulence Transition in Plane Couette Flow

Tom Eaves, University of British Columbia, Canada; Igor Mezic, University of California, Santa Barbara, U.S.; *Colm-cille Caulfield*, University of Cambridge, United Kingdom

8:55-9:15 Koopman Analysis of Oscillating Cylinder Flow

Beverley McKeon and Maysam Shamai, California Institute of Technology, U.S.; Scott Dawson, Illinois Institute of Technology, U.S.; Igor Mezic, University of California, Santa Barbara, U.S.

9:20-9:40 Data-Driven Modeling of Spatio-Temporal Systems with Continuous Spectrum

Hassan Arbabi and Themistoklis Sapsis, Massachusetts Institute of Technology, U.S.

9:45-10:05 Dynamic Mode Decomposition in Functional Magnetic Resonance Imaging

Raphael Liegeois, École Polytechnique Fédérale de Lausanne, Switzerland; Jeremy Casorso, Xialu Kong, and Wang Chi, National University of Singapore, Singapore; Dimitri Van De Ville, École Polytechnique Fédérale de Lausanne, Switzerland; B. T. Thomas Yeo, National University of Singapore, Singapore

Tuesday, May 21

CP5

Human Dynamics

8:30 a.m.-10:10 a.m.

Room: Ballroom 1

Chair: Mason A. Porter, University of California, Los Angeles, U.S.

8:30-8:50 Evolutionary Dynamics in a Group Population Structure with Barriers to Group Entry

Olivia J. Chu, Vítor Vasconcelos, and Corina Tarnita, Princeton University, U.S.

8:55-9:15 Fitting In and Breaking Up: Two Versions of Coevolving Voter Models

Yacoub H. Kureh and Mason A. Porter, University of California, Los Angeles, U.S.

9:20-9:40 Voter Dynamics and Non-Equilibrium Behaviour in a Two-Population Voter Model with Zealotry

Andrew Mellor, University of Oxford, United Kingdom; Mauro Mobilia, University of Leeds, United Kingdom; R.K.P. Zia, Virginia Tech and Iowa State University, U.S.

9:45-10:05 Punctuating Literature with Time-Series Analysis

Mason A. Porter, University of California, Los Angeles, U.S.; Alexandra Darmon, Marya Bazzi, and Sam Howison, University of Oxford, United Kingdom

Tuesday, May 21

CP6

Epidemiology

8:30 a.m.-9:45 a.m.

Room: Ballroom 2

Chair: Steven J. Schiff, Pennsylvania State University, U.S.

8:30-8:50 Stochastic Spatial Model for Yeast Biofilm Social Interactions: Investigating the Fitness Benefits of Within-Strain Cooperation

Adrienna Bingham, Aparajita Sur, Helen Murphy, and Leah Shaw, College of William & Mary, U.S.

8:55-9:15 Stochastic Hiv Rebound During Post Treatment-Interruption: the Role of Immune Pressure

Garrett T. Nieddu, Yen Ting Lin, Alan S. Perelson, and Ruian Ke, Los Alamos National Laboratory, U.S.

9:20-9:40 The Spatiotemporal Dynamics of African Infant Infections

Steven J. Schiff, Pennsylvania State University, U.S.

Tuesday, May 21

CP7

Coupled Oscillators I

8:30 a.m.-10:10 a.m.

Room: Ballroom 3

Chair: Wenqi Yue, University of Sydney, Australia

8:30-8:50 The Unruly Effective Diffusion Coefficient of Phase-Locked Bursters

Avinash J. Karamchandani and Hermann Riecke, Northwestern University, U.S.

8:55-9:15 Long-Lasting Desynchronization by Decoupling Stimulation

Justus A. Kromer and Peter Tass, Stanford University, U.S.

9:20-9:40 Non-Reciprocal Dynamics and Bifurcation Analysis of Coupled Bilinear Oscillators

Behrooz Yousefzadeh, Brian J. Ramirez, and CHIARA Daraio, California Institute of Technology, U.S.

9:45-10:05 Reduced Dynamics for the Kuramoto-Sakaguchi Model Using Collective Coordinates

Wenqi Yue, University of Sydney, Australia

Tuesday, May 21

CP8

Fluid Dynamics I

8:30 a.m.-10:10 a.m.

Room: Magpie A

Chair: Jack Shi, Columbia University, U.S.

8:30-8:50 Modeling and Dynamics of Planar Swimmers Coupled through Wake Vorticity

Blake R. Buchanan, Carnegie Mellon University, U.S.; Scott D. Kelly, University of North Carolina, Charlotte, U.S.

8:55-9:15 Ferrofluid Lubrication of Circular Squeeze Film Bearings Controlled by Variable Magnetic Field

Rajesh Shah and *Rajiv B. Shah*, Maharaja Sayajirao University of Baroda, India

9:20-9:40 Bounds on Lyapunov Exponents for Random and Deterministic Products of Shears

Rob Sturman, Jitse Niesen, and Patrick Wright, University of Leeds, United Kingdom

9:45-10:05 Deep Reinforcement Learning for Robot Locomotion

Jack Shi and Tony Dear, Columbia University, U.S.

Tuesday, May 21

CP9

Bifurcations I

8:30 a.m.-10:10 a.m.

Room: Magpie B

8:30-8:50 On the Onset of Hysteresis and Hopf-Bifurcation in Thermally Convective Spherical Couette Flow

Paul M. Mannix, Imperial College of London, United Kingdom

8:55-9:15 : Is the Mid-Pleistocene Transition (mpt) a Grazing Bifurcation?

Kgomotso Susan Morupisi and Chris Budd, University of Bath, United Kingdom

9:20-9:40 Keeping Automated Vehicles on the Road Using Bifurcation Analysis

Sanghoon Oh, Sergei S. Avedisov, and Gabor Orosz, University of Michigan, Ann Arbor, U.S.

9:45-10:05 Bifurcation Analysis for Breast Cancer Model with Control Strategies

Segun I. Oke, Maba Matadi, and Sibusiso Xulu, University of Zululand, South Africa

Tuesday, May 21

CP10

Data and Koopman Analysis

8:30 a.m.-10:10 a.m.

Room: Wasatch A

Chair: Ned J. Corron, U.S. Army AMRDEC, U.S.

8:30-8:50 Energy Models and Koopman Operator Analysis of Thermal Data

Ljuboslav Boskic, University of California, Santa Barbara, U.S.; Milan Korda, CNRS, France; Cory Brown and Igor Mezic, University of California, Santa Barbara, U.S.

8:55-9:15 Dynamic Modes of Ignition Phenomena: Learning Chemistry from Data

Cory N. Brown and Ryan Mohr, University of California, Santa Barbara, U.S.; Mohammad Alaghemandi and Jason Green, University of Massachusetts, Boston, U.S.; Igor Mezic, University of California, Santa Barbara, U.S.

9:20-9:40 Local Ensemble Transform Kalman Filtering Implemented on 2D and 3D Dynamo Flows

Sarah C. Burnett, University of Maryland, College Park, U.S.; Nathanaël Schaeffer, Institut des Sciences de la Terre de Grenoble, France; Kayo Ide, University of Maryland, College Park, U.S.

9:45-10:05 Nonlinear-Linear Alchemy: Koopman Operators and Tape Recorders

Ned J. Corron, U.S. Army AMRDEC, U.S.

Tuesday, May 21

CP11

Stochastic Dynamical Systems

8:30 a.m.-9:45 a.m.

Room: Wasatch B

Chair: Gnana M. Subramaniam, University of Oklahoma, U.S.

8:30-8:50 A Numerical Method for Solving the Non-Local Problems Related to Stochastic Dynamic Systems Driven by Levy Noise

Xiaoli Chen, Huazhong University of Science & Technology, China

8:55-9:15 Most Probable Evolution Trajectories in a Genetic Regulatory System Excited by Stable Lévy Noise

Xiujun Cheng, Zhejiang Sci-tech University, China

9:20-9:40 A Generalized Transformed Path Integral Approach for Stochastic Dynamical Systems

Gnana M. Subramaniam and Prakash Vedula, University of Oklahoma, U.S.

Tuesday, May 21

CP12

Hamiltonian Systems and Mixing

8:30 a.m.-10:10 a.m.

Room: Maybird

Chair: Rocio I. Paez, Università degli Studi di Padova, Italy

8:30-8:50 Hill Four-Body Problem with Oblate Tertiary: With Application to the Sun-Jupiter-Hektor-Skamandrios System

Wai Ting Lam and Marian Gidea, Yeshiva University, U.S.; Alessandra Celletti, Università degli Studi di Roma Tor Vergata, Italy; Catalin Gales, University Al.I.Cuza Iasi, Romania; Jaime Burgos-Garcia, Autonomous University of Coahuila, Saltillo, Mexico

8:55-9:15 Characterizing Fractal Mixing with Ergodic Subsets

Thomas F. Lynn, Julio Ottino, Paul Umbanhowar, and Richard M. Lueptow, Northwestern University, U.S.

9:20-9:40 Finding Nhim: Identifying High Dimensional Phase Space Structures using Lagrangian Descriptors

Shibabrat Naik, University of Bristol, United Kingdom; Stephen Wiggins, University of Bristol, United Kingdom

9:45-10:05 The Speed of Arnold Diffusion Along Single Resonances: A Predictive Semi-Analytic Approach

Rocio I. Paez and Massimiliano Guzzo, Università degli Studi di Padova, Italy; Christos Efthymiopoulos, Academy of Athens, Greece

Tuesday, May 21

CP13

Mathematical Biology I

8:30 a.m.-9:45 a.m.

Room: Superior A

Chair: Justin Faber, University of California, Los Angeles, U.S.

8:30-8:50 Response-Signaling Feedback with Diffusive Coupling Leads to Division Waves in a Model of *Drosophila* Embryogenesis

Richard Buckalew and Sarah Pierro, University of Minnesota, Duluth, U.S.

8:55-9:15 Energy and Phased Based Movement Recovery

George W. Council, University of Michigan, U.S.

9:20-9:40 Chaotic Dynamics Enhance the Sensitivity of Inner Ear Hair Cells

Justin Faber, University of California, Los Angeles, U.S.

Tuesday, May 21

CP14

Pattern-Forming Systems

8:30 a.m.-10:10 a.m.

Room: Superior B

Chair: Anton Pershin, University of Leeds, United Kingdom

8:30-8:50 Pattern Formation on Cubic Superlattices

Timothy K. Callahan, Embry-Riddle Aeronautical University, U.S.

8:55-9:15 Effects of Strain Rate on Fronts in Advection-Reaction-Diffusion Systems

Thomas D. Nevins and *Douglas H. Kelley*, University of Rochester, U.S.

9:20-9:40 Weakly Nonlinear Theory for Spatio-Temporal Patterns in Coupled Bulk-Surface Reaction-Diffusion Systems

Frederic Paquin-Lefebvre, Michael Ward, and Wayne Nagata, University of British Columbia, Canada

9:45-10:05 Dynamics of Exact Localized States in Plane Couette Flow

Anton Pershin, Cedric Beaume, and Steven Tobias, University of Leeds, United Kingdom

Tuesday, May 21

CP15

Maps

8:30 a.m.-10:10 a.m.

Room: White Pine

Chair: Rasa Smidtaite, Kaunas University of Technology, Lithuania

8:30-8:50 Theoretical Analysis of Information Content of the Dynamics of One Dimensional Chaotic Maps

Aliyu H. Danladi, Federal Polytechnic Bauchi, Nigeria

8:55-9:15 Billiards Inside, Circles Outside: Dynamics of a Charged Particle in a Piecewise Constant Magnetic Field

Sean Gasiorek, University of California, Santa Cruz, U.S.

9:20-9:40 Template Iterations of Quadratic Maps and Hybrid Mandelbrot Sets

Anca R. Radulescu and Kelsey Butera, State University of New York, New Paltz, U.S.; Brandee Williams, Orange County Community College, U.S.

9:45-10:05 The Effect of Explosive Divergence in a 2D Coupled Map Lattice of Matrices

Rasa Smidtaite and Minvydas Ragulskis, Kaunas University of Technology, Lithuania

Tuesday, May 21

CP16

Nonlinear Waves

8:30 a.m.-10:10 a.m.

Room: Primrose B

Chair: Jennie D'Ambroise, State University of New York College at Old Westbury, U.S.

8:30-8:50 Self-Similar, Blow-Up Solutions of the Generalised Korteweg-De Vries Equation Near Criticality

Chris Budd, University of Bath, United Kingdom; Vivi Rottschafer, Leiden University, Netherlands; Othmar Koch and Ewa Weinmuller, Technische Universität Wien, Austria

8:55-9:15 On Boundary Layers for the Burgers Equations in a Bounded Domain

Junho Choi, Chang-Yeol Jung, and Hoyeon Lee, Ulsan National Institute of Science and Technology, South Korea

9:20-9:40 2D Solutions of the Hyperbolic Discrete Nonlinear Schrödinger Equation

Jennie D'Ambroise, State University of New York College at Old Westbury, U.S.; Panayotis Kevrekidis, University of Massachusetts, Amherst, U.S.

9:45-10:05 The Effects of Shear Currents on Oceanic Rogue Waves

Qing Pan and Kwok Wing Chow, University of Hong Kong, Hong Kong

Coffee Break

10:10 a.m.-10:40 a.m.

Room: Golden Cliff

Remarks

10:40 a.m.-10:45 a.m.

Room: Ballroom

Tuesday, May 21

IP5

A Topological View of Collective Behavior Models

10:45 a.m.-11:30 a.m.

Room: Ballroom

Chair: Andrew J. Bernoff, Harvey Mudd College, U.S.

From nanoparticle assembly to synchronized neurons to locust swarms, collective behaviors abound anywhere in nature that objects or agents interact. Investigators modeling collective behavior face a variety of challenges involving data from simulation and/or experiment. These challenges include exploring large, complex data sets to understand and characterize the system, inferring the model parameters that most accurately reflect a given data set, and assessing the goodness-of-fit between experimental data sets and proposed models. Topological data analysis provides a lens through which these challenges may be addressed. This talk consists of three parts. First, I introduce the core ideas of topological data analysis for newcomers to the field. Second, I highlight how these topological techniques can be applied to models arising from the study of groups displaying collective motion, such as bird flocks, fish schools, and insect swarms. The key approach is to characterize a system's dynamics via the time-evolution of topological invariants called Betti numbers, accounting for persistence of topological features across multiple scales. Finally, moving towards a theory of reduced topological descriptions of complex behavior, I present open questions on the topology of random data, complementing research in random geometric graph theory.

Chad M. Topaz
Williams College, U.S.

Lunch Break

11:30 a.m.-1:00 p.m.

Attendees on their own

Tuesday, May 21

MS87

Topological Data Analysis and Applications in Dynamical Systems - Part I of II

1:00 p.m.-2:40 p.m.

Room: Ballroom 1

For Part 2 see MS99

Complex systems that evolve over time can be challenging to analyze or even summarize. Recent topological techniques have proven powerful in characterizing and exploring complex simulation and experimental data, as well as in determining the influence of parameters on model outputs. The intersection of dynamical systems modeling and topological data analysis is fruitful for questions arising in both contexts. Problems in the topological community, such as determining low-dimensional representations of persistence diagrams or handling data with multiple channels, are motivated by questions in model validation or parameter inference in dynamical systems. This minisymposium will highlight work applying and extending topological techniques in the context of applications and expands on the techniques described in Chad Topaz's plenary talk at this conference. Some of the talks in this session will specifically address these techniques in the context of spatio-temporal pattern formation and time-series data in biological applications.

Organizer: Rachel Neville
University of Arizona, U.S.

Organizer: Maria-Veronica Ciocanel
Ohio State University, U.S.

1:00-1:20 Curves in Diagram Space

Samir Chowdhury and Facundo Mémoli, Ohio State University, U.S.

1:25-1:45 Investigating Sleep-Wake Signals: A Persistent Homology Approach

Yu-Min Chung, University of North Carolina at Greensboro, U.S; Yu-Lun Lo, Chang Gung University, Taiwan; Hau-Tieng Wu, Duke University, U.S.

continued in next column

1:50-2:10 Topological Data Analysis for Ring Channels in Intracellular Transport

Maria-Veronica Ciocanel, Ohio State University, U.S.

2:15-2:35 Topological Data Analysis for Investigation of Dynamics and Biological Networks

Heather Harrington, University of Oxford, United Kingdom

Tuesday, May 21

MS88

Beyond the Kuramoto Model

1:00 p.m.-2:40 p.m.

Room: Ballroom 2

The Kuramoto model was introduced in 1975 by Yoshiki Kuramoto as a model for analyzing the dynamics of weakly coupled phase oscillators. This model proved to be simple enough to allow for a detailed mathematical analysis while remaining sufficiently complex to display nontrivial behavior. Despite its utility, the model as originally stated has its limitations, due to the simplifying assumptions made in its setup. Since its introduction, the Kuramoto model has been extended in a variety of forms, enabling it to be applicable to study the dynamics of systems in a range of physical, chemical, biological and technological contexts. As a result, the Kuramoto model has become a paradigmatic model in the study of coupled oscillators and synchronization dynamics. In this minisymposium, we will discuss recent impactful extensions of this line of modeling.

Organizer: Michelle Girvan
University of Maryland, College Park, U.S.

Organizer: Edward Ott
University of Maryland, U.S.

1:00-1:20 Volcano Transition in a Solvable Model of Frustrated Oscillators

Bertrand Ottino-Löffler, Cornell University, U.S.; S.H. Strogatz, Cornell University, U.S.

1:25-1:45 Connecting the Kuramoto Model and the Chimera State

Daniel M. Abrams, Northwestern University, U.S.

1:50-2:10 The Generalized Kuramoto Model: Odd Dimensions are Different; Even Dimensions are Deceptively Similar

Sarthak Chandra, University of Maryland, U.S.; Michelle Girvan, University of Maryland, College Park, U.S.; Edward Ott, University of Maryland, U.S.

2:15-2:35 Phase Approximation Beyond the First Order: The Kuramoto Model with Non-Pairwise Interactions

Iván León and *Diego Pazó*, Universidad de Cantabria, Spain

Tuesday, May 21

MS89

Experiments on Networks of Coupled Oscillators

1:00 p.m.-2:40 p.m.

Room: Ballroom 3

Theoretical studies of networks of oscillators predict rich emergent behavior; they describe fully synchronized states, clustered synchronization or chimera states, with varied waveforms (periodic, quasi-periodic, or chaotic). Relatively few experimental works exist to provide feedback. We will introduce experiments in a variety of systems to better understand which theoretically predicted behaviors are robust to the non-idealities present in real-world situations. We explore the relationship between experiment and model, and the implementation of observation based models.

Organizer: Karen Blaha
University of New Mexico, U.S.

Organizer: Fabio Della Rossa
Politecnico di Milano, Italy

1:00-1:20 Exploring Synchronization in Networks of Coupled Oscillators

Fabio Della Rossa, Politecnico di Milano, Italy; Francesco Sorrentino and Karen Blaha, University of New Mexico, U.S.

1:25-1:45 Experiments with Symmetric Networks of Heterogeneous Electronic Oscillators

Karen Blaha, University of New Mexico, U.S.

1:50-2:10 Weak Chimera States in Modular Electrochemical Oscillator Networks

Jorge Ocampo, Saint Louis University, U.S.; Christian Bick, University of Exeter, United Kingdom; *Istvan Z. Kiss*, Saint Louis University, U.S.

2:15-2:35 Experiments on Networks of Coupled Chemical Oscillators

Seth Fraden and Michael M. Norton, Brandeis University, U.S.; Ian M. Hunter, Fraden Lab, U.S.

Tuesday, May 21

MS90

Collective Behaviors in Complex Systems with Noise and Delays

1:00 p.m.-2:40 p.m.

Room: Magpie B

Collective behaviors are widely observed in many applications of complex systems, ranging from bacterial colonies to smart materials and networked systems. Even despite the fact that stochasticity and delays often play a key role in determining the behavior of such systems, those are often neglected when modeling their dynamics. The goal of this minisymposium is to discuss different approaches to study the effects of noise and delays on the behavior of complex systems. This is crucial for many applications ranging from bacteria coordination (where noise and delays are intrinsic in the underlying biochemical processes) to network control (where noise/delays often affect system performance) and smart materials (where stochasticity determines the behavior of certain structures). Within the minisymposium we bring together a mix of experts from different domains that will discuss the role of noise and delays in the behavior of complex systems from different angles, ranging from the study of stability in stochastic networks with relative-state-dependent noise diffusion, to more experimental studies in synthetic biological populations, to the analysis of stiff polymer networks and the reconstruction of delayed interactions in multi-agent systems. Bringing together scientists with such a mix of expertise will allow the minisymposium to provide an organic view of recent approaches to study the onset of collective behaviors in complex systems in the presence of noise and delays.

Organizer: Nicole Abaid
Virginia Tech, U.S.

Organizer: Giovanni Russo
University College Dublin, Ireland

1:00-1:20 Synchronization in Quorum-Sensing Networks with Noise Diffusion

Gaoyang Fan, University of Utah, U.S.; *Giovanni Russo*, University College Dublin, Ireland; Paul C. Bressloff, University of Utah, U.S.

continued in next column

1:25-1:45 Synchronization and Multicellular Control in Quorum Sensing Networks of Toggle Switches in Synthetic Biology

Mario Di Bernardo, Università di Napoli Federico II, Italy

1:50-2:10 Emergence of Metachronal Waves in Networked Systems of Stiff Polymer and Axonemal Structures

Davide Spinello, George Mason University, U.S.

2:15-2:35 A Transfer Entropy-Based Network Reconstruction Scheme Recognizing Time-Delayed Interactions Between Indirectly Connected Nodes

Rifat Sipahi, Northeastern University, U.S.; Maurizio Porfiri, New York University Tandon School of Engineering, U.S.

Tuesday, May 21

MS91

Stochastic Methods for Multiscale Dynamical Systems

1:00 p.m.-2:40 p.m.

Room: Wasatch A

Complex systems in various fields, for example, classical physics,biology, and material sciences, can be described as multiscale dynamical systems. Currently, many stochastic methods provide an effective path for understanding multiscale dynamical systems. We often use Monto-Carlo methods, moments for solution paths, mean exit time, escape probability, probability density functions, most probable trajectories and random manifolds to quantify dynamical behavior of stochastic dynamical systems. Furthermore, these tools can be used to study the dynamical behaviors of complex systems such as gene regulation network, molecular diffusion, and atmospheric climate change. We invite speakers with diverse but related background suitable to study multi-scale dynamical systems. This minisymposium will provide a glimpse of recent developments concerning the general topics of stochastic methods for multi-scale dynamical systems.

Organizer: Xiaoli Chen
Huazhong University of Science & Technology, China

1:00-1:20 Characterization of Non-Local and Non-Markovian Nature in the Tracer Diffusion of a Molecular Fluid

Changho Kim, University of California, Merced, U.S.

2:15-2:35 A Minimum Action Method for Dynamical Systems with Constant Time Delays

Xiaoliang Wan, Louisiana State University, U.S.

1:25-1:45 Homogenization of Spatial Stationary Gaussian Random Flow

Zhiwen Zhang and *Junlong Lyu*, University of Hong Kong, Hong Kong

Patterns with Stochasticity?

Yuchi Qiu, University of California, Irvine, U.S.

Tuesday, May 21

MS92

Rhythm-Generating Neural Circuits

1:00 p.m.-2:40 p.m.

Room: Wasatch B

This session is focused on rhythm-generating neural circuits that can maintain a single oscillatory regime independent of sensory feedback or, depending on the external drive, produce and switch between multiple activity patterns or gaits with distinct phase-lags of the constituent neurons. Of particular interest are regulation, resilience, and multi-functionality and interplay between their states, connectivity and the dynamics of individual neurons and synapses in such circuits.

Organizer: Andrey Shilnikov
Georgia State University, U.S.

Organizer: Marco Storace
University of Genoa, Italy

1:00-1:20 Title Not Available

Ilya Rybak, Drexel University, U.S.

1:25-1:45 Bifurcational Study of Reduced Model of Tadpole CPG

Roman M. Borisyuk, Andrea Ferrario, and Robert Merrison-Hort, Plymouth University, United Kingdom; Stephen Soffe, University of Bristol, United Kingdom; Wen-Chang Li, University of St. Andrews, United Kingdom

1:50-2:10 Modeling the Emergent Network Bursting in Swim Neural Circuits

Andrey Shilnikov, Georgia State University, U.S.

2:15-2:35 Design of Central Pattern Generator for Locomotion

Matteo Lodi, University of Genoa, Italy

Tuesday, May 21

MS93

Coupling Marine Ecosystem Dynamics to Environmental Change - Part I of II

1:00 p.m.-2:40 p.m.

Room: Maybird

For Part 2 see MS111

Most existing (mathematical/statistical) models for assessing marine ecosystem state are premised on gradual changes in the marine enviroment and in the response of the biological systems. However, recent changes in marine ecosystems are either anomalous (high-frequency, short-lived) or catastrophic (low-frequency, long-lived) perturbations. The application of most existing models, either for state projections or as premonitory tools, is therefore severely limited. This minisymposium will focus on theoretical and computational frameworks that integrate system dynamical models and empirical data, to provide information on current marine ecosystem state, and projections of its shortand long-term response to environmental change. We particularly encourage presentation of recent frameworks based on the use of (discrete or continuous time) Ordinary Differential (OD), Partial Differential (PD), and Delay Differential (DD) equations, and involve Individual-Based Modeling (IBM), spatial movement (ecology) simulations, and Dynamic Energy Budget (DEB) models. Because marine systems are complex and difficult to observe, comprehensive monitoring programs for entire systems are necessarily limited. We therefore encourage papers that deal with metamodels and innovative approaches for model integration for marine ecosystems.

Organizer: Sam Subbey
Institute of Marine Research, Bergen, Norway

Organizer: Bjorn Birnir
University of California, Santa Barbara, U.S.

1:00-1:20 Linking Fish Migration Patterns to Change in the Marine Environment - A Review of Concepts and Mathematical Models

Salah Alrabeei, Western Norway University of Applied Sciences, Norway; Sam Subbey, Institute of Marine Research, Bergen, Norway

continued on next page

1:25-1:45 Computational Topology and the Prediction of Critical Transitions in Spatially Extended Marine Populations

Laura Storch and *Sarah Day*, College of William & Mary, U.S.

1:50-2:10 Data-Driven Modeling of Phytoplankton Blooms in the Ocean

Seth Cowall, Matthew Oliver, and Pamela Cook, University of Delaware, U.S.

2:15-2:35 An Interacting Particle Model for the Capelin: Incorporating a Changing Climate

Alethea Barbaro, Case Western Reserve University, U.S.; Bjorn Birnir, University of California, Santa Barbara, U.S.

Tuesday, May 21

MS94

Geometric Approaches to Point Vortex Dynamics and Applications

1:00 p.m.-2:15 p.m.

Room: Superior A

This session aims to give an overview of recent advances in point vortex dynamics due to geometric perspectives in a variety of applications. The most well-known point vortex equations are due to Helmholtz and Kirchhoff, and arise from the two-dimensional equations for inviscid, incompressible flow. In recent years, new point vortex models have been developed for applications ranging from geophysics (e.g. the Surface Quasigeostrophic Equations) to quantum physics (e.g. for vortices in Bose-Einstein condensates). However, the models each take a similar Hamiltonian form and therefore often benefit from similar analytical approaches, such as methods for identification of invariant manifolds and symmetries. This session brings together new and established researchers to discuss these and other related topics.

Organizer: Alanna Hoyer-Leitzel
Mount Holyoke College, U.S.

Organizer: Anna M. Barry
University of Auckland, New Zealand

Organizer: Gareth E. Roberts
College of the Holy Cross, U.S.

1:00-1:20 Discrete Symmetries and Homographic Invariant Manifolds

Cristina Stoica, Wilfrid Laurier University, Canada

1:25-1:45 Noether Theorem for Magnetized Plasmas

Natalia Tronko, Max Planck Institute for Plasma Physics, Germany

1:50-2:10 Co-Rotating Vortex Filament Knots and their Stability

Theodore Kolokolnikov, Dalhousie University, Canada

Tuesday, May 21

MS95

Simple and Complex Patterns in Coupled Systems

1:00 p.m.-2:40 p.m.

Room: Superior B

Presentations in this minisymposium will be about existence and qualitative properties of wave trains, pulses, fronts and shocks and more complex structures that are key solutions in coupled systems of partial differential equations from physics and biology.

Organizer: Stephane Lafortune
College of Charleston, U.S.

1:00-1:20 Existence of Transition Fronts between a Singular State and Steady State Solutions in Diffusive Holling-Tanner Model

Vahagn Manukian, Miami University Hamilton, U.S.; Stephen Schecter, North Carolina State University, U.S.

1:25-1:45 Bifurcation Analysis in NLS Systems using Deflated Continuation

Efstathios Charalampidis, University of Massachusetts, Amherst, U.S.

1:50-2:10 Stable Planar Vegetation Stripe Patterns on Sloped Terrain in Dryland Ecosystems

Paul Carter, University of Arizona, U.S.

2:15-2:35 Spectral Stability of Periodic Multi-Pulses in the 5th Order KdV Equation

Ross H. Parker and Bjorn Sandstede, Brown University, U.S.

Tuesday, May 21

MS96

Relax, Oscillator: Novel Approaches for Understanding Relaxation Oscillation

1:00 p.m.-2:40 p.m.

Room: White Pine

Relaxation oscillations are periodic solutions which evolve on two or more timescales. They occur in a wide variety of applications, from the physiological rhythms involved in the human heartbeat, or firing of a neuron, to the periodic sliding responsible for earthquake faulting. In this minisymposium, attention is drawn to relaxation oscillations arising in recent applications, with a particular emphasis on biological systems, circuit theory, and mechanical systems with friction. In each case the relaxation oscillations being considered are novel, in the sense that they differ qualitatively from the classic relaxation oscillation typified by the well known van der Pol oscillator. We also explore some of the recent advances in geometric singular perturbation theory (GSPT) that have been prompted by the study of new kinds of relaxation oscillation. In particular, their study leads naturally to questions surrounding the extension of GSPT to the study of non-smooth dynamical systems, systems evolving on more than two timescales, and systems for which there is no obvious separation of slow and fast variables. These questions and others relating to the future of GSPT are addressed in the minisymposium, both in generality, and in the context of relaxation oscillation in applications.

Organizer: Samuel Jelbart
University of Sydney, Australia

1:00-1:20 Existence of Relaxation Oscillations in Models with Rate-and-State Friction

Kristian U. Kristiansen, Technical University of Denmark, Denmark

1:25-1:45 Switch-Like Oscillations in an NF -κB Signaling Model

Ilona Kosiuk, Max Planck Institute for Mathematics in the Sciences, Germany

1:50-2:10 Multiple Time Scales in a Calcium Dynamics Model

Nathan Pages, University of Auckland, New Zealand

2:15-2:35 Relaxation Oscillation in Mechanical Oscillators, and Stick-Slip with Ducks

Samuel Jelbart, University of Sydney, Australia

Tuesday, May 21

MS97

Applications of Koopman Operator Theory in Dynamical Systems: From Fluids, through Machine Learning to Energy - Part II of II

1:00 p.m.-2:40 p.m.

Room: Primrose A

For Part 1 see MS86

The Koopman operator approach to dynamical systems has been applied to fluid mechanics and enjoyed success due to its model-reduction capability that captured complex coherent dynamics better than previous techniques. The approach is experiencing a high degree of co-development between theorems, numerical approaches (algorithms) and applications in natural science and technology. In fact, very interesting questions are arising for researchers on theory and algorithms side from practical applications in diverse domains. The two-part minisymposium will contribute to the overall goal of advancing the Koopman operator approach by fostering interaction between theory, numerical algorithms and applications. Fluid applications are still primarily important in this interaction, talked by Caulfield, McKeon, and Arbabi. Dynamical systems in brains are one of the novel application in talks by Liegeois and Li. Machine learning is currently the hottest topic of the interaction of Koopman operator approach in talks by Li, Yeung, and Martinez-Ramon. Energy is a direct application to technology for solving social issues in the world, talked by Martinez-Ramon and Netto. The series of the talks will provide not only new insights into the diverse application domains but also new requirement in the development of mathematical theorems.

Organizer: Yoshihiko Susuki
Osaka Prefecture University, Japan

Organizer: Igor Mezic
University of California, Santa Barbara, U.S.

Organizer: Steven Brunton
University of Washington, U.S.

1:00-1:20 Reconstruction and Control of Nonlinear Dynamics using Koopman Theory

Jr-Shin Li, Washington University, St. Louis, U.S.

continued in next column

1:25-1:45 Theoretical Guarantees of Convergence and Approximate Subspace Closure for Deep Koopman Operator Learning

Enoch Yeung, University of California, Santa Barbara, U.S.

1:50-2:10 Gaussian Process for Koopman Spectral Analysis with Application to Smart Grids

Manel Martinez-Ramon, University of New Mexico, U.S.; Yoshihiko Susuki and Akitoshi Masuda, Osaka Prefecture University, Japan; Satomi Sugaya and Andrea Mammoli, University of New Mexico, U.S.; Atsushi Ishigame, Osaka Prefecture University, Japan

2:15-2:35 Data-Driven Participation Factors for Nonlinear Systems Based on Koopman Mode Decomposition

Marcos Netto, Virginia Tech, U.S.; Yoshihiko Susuki, Osaka Prefecture University, Japan; Lamine Mili, Virginia Tech, U.S.

Tuesday, May 21

MS98

Probabilistic and Geometric Analysis of Time-Dependent Dynamics

1:00 p.m.-2:40 p.m.

Room: Primrose B

This minisymposium explores new probabilistic and geometric methodologies for understanding time-dependent fluid flow. The opening speaker Thiffeault will use the time-dependent motion of microswimmers to estimate the motion of fluid parcels from their exit times through a domain boundary. Rock will detail a technique to automatically identify and separate large numbers of coherent fluid parcels (coherent sets) from the eigenvectors of a dynamic Laplacian or transfer operator over several spatial scales. Padberg-Gehle will describe the application of coherent set methodologies to analyse fluid motion in turbulent convection problems. Gonzalez-Tokman concludes the minisymposium by reporting on a specific time-dependent dynamics where one has full knowledge of the transfer operator Lyapunov spectrum, and illustrates a bifurcation in a time-dependence parameter.

Organizer: Gary Froyland
University of New South Wales, Australia

Organizer: Cecilia Gonzalez Tokman
University of Queensland, Australia

1:00-1:20 Exit Time Problems for Microswimmers
Jean-Luc Thiffeault, University of Wisconsin, Madison, U.S.

1:25-1:45 Sparse Eigenbasis Approximation: Multiple Feature Extraction Across Spatiotemporal Scales with Application to Coherent Set Identification
Gary Froyland and *Christopher Rock*, University of New South Wales, Australia; Konstantinos Sakellariou, University of Western Australia, Australia

continued in next column

1:50-2:10 Trajectory-Based Study of Coherent Behavior in Turbulent Convection
Christiane Schneide, Leuphana University of Lüneburg, Germany; Ambrish Pandey, Technische Universität Ilmenau, Germany; *Kathrin Padberg-Gehle*, Leuphana University Lueneburg, Germany; Joerg Schumacher, Technische Universitaet Ilmenau, Germany

2:15-2:35 Characterization and Perturbations of the Lyapunov Spectrum of a Class of Perron-Frobenius Operator Cocycles
Cecilia Gonzalez Tokman, University of Queensland, Australia; Anthony Quas, University of Victoria, Canada

Tuesday, May 21

CP17

Networks and Synchronization

1:00 p.m.-2:40 p.m.

Room: Magpie A

Chair: Stanley R. Huddy, Fairleigh Dickinson University, U.S.

1:00-1:20 Emergent Explosive Synchronization in Adaptive Complex Networks
Juan A. Almendral, Universidad Rey Juan Carlos, Spain; Vanesa Avalos-Gaytan, Universidad Autonoma de Cohauila, Mexico; Inmaculada Leyva, Universidad Rey Juan Carlos, Spain

1:25-1:45 Synchronization Sensitivity of a Nonlocal Network
Ibere L. Caldas and Everton S. Medeiros, University of Sao Paulo, Brazil; Rene Medrano-T, Universidade Federal de São Paulo, Brazil; Ulrike Feudel, University of Oldenburg, Germany

1:50-2:10 Noise-Induced Synchronization in Circulant Networks of Weakly Coupled Commensurate Oscillators
Barbara Gentz and Christian Wiesel, University of Bielefeld, Germany

2:15-2:35 Using Critical Curves to Compute Master Stability Islands for Amplitude Death in Networks of Delay-Coupled Oscillators
Stanley R. Huddy, Fairleigh Dickinson University, U.S.

Coffee Break

2:40 p.m.-3:10 p.m.

Room: Golden Cliff

Tuesday, May 21

MS99

Topological Data Analysis and Applications in Dynamical Systems - Part II of II

3:10 p.m.-4:50 p.m.

Room: Ballroom 1

For Part 1 see MS87

Complex systems that evolve over time can be challenging to analyze or even summarize. Recent topological techniques have proven powerful in characterizing and exploring complex simulation and experimental data, as well as in determining the influence of parameters on model outputs. The intersection of dynamical systems modeling and topological data analysis is fruitful for questions arising in both contexts. Problems in the topological community, such as determining low-dimensional representations of persistence diagrams or handling data with multiple channels, are motivated by questions in model validation or parameter inference in dynamical systems. This minisymposium will highlight work applying and extending topological techniques in the context of applications and expands on the techniques described in Chad Topaz's plenary talk at this conference. Some of the talks in this session will specifically address these techniques in the context of spatio-temporal pattern formation and time-series data in biological applications.

Organizer: Rachel Neville
University of Arizona, U.S.

Organizer: Maria-Veronica Ciocanel
Ohio State University, U.S.

3:10-3:30 A Topological Study of Spatio-Temporal Pattern Formation
Melissa R. McGuirl, Brown University, U.S.

3:35-3:55 Topological Techniques for Chracterization of Pattern Forming Systems
Rachel Neville, University of Arizona, U.S.

4:00-4:20 Analyzing Spatial Patterns and Critical Transitions in Stochastic Populations with Cubical Homology
Laura Storch and Sarah Day, College of William & Mary, U.S.

4:25-4:45 Topological Data Analysis of Biological Images using Persistence Landscapes
Peter Bubenik, University of Florida, U.S.

Tuesday, May 21

MS100

Dynamics of Democracy - Part I of II

3:10 p.m.-4:50 p.m.

Room: Ballroom 2

For Part 2 see MS112

Democracies provide a source of rich mathematical questions and broad-interest societal issues surrounding the interactions of individuals, different social movements, voting districts, and countries. Social media and the popular press further add to the complexity of these dynamics and provide new ways for communities at various scales to interact with each other. Here we bring together researchers working on a range of topics arising from democracy – e.g. the evolution of political opinions, the dynamics of social engagement, the emergence of conflict, the organization of voting districts, and the impact of immigration on a population. These problems are studied using tools from network analysis, statistics, dynamical systems, and topology. The goal of this session is to lead to cross-fertilization between these fields, highlight mathematical questions in social science, and motivate new areas of interdisciplinary research.

Organizer: Heather Z. Brooks
University of California, Los Angeles, U.S.

Organizer: Alexandria Volkening
Ohio State University, U.S.

3:10-3:30 Influence of Media on Opinion Dynamics in Social Networks
Heather Zinn Brooks and Mason A. Porter, University of California, Los Angeles, U.S.

3:35-3:55 'Very Fine People on Both Sides' of Twitter: Analyzing the Network Structure of the Online Conversation about #Charlottesville
Joseph Tien, Ohio State University, U.S.

4:00-4:20 The Effect of the Convergence Parameter in the Deffuant Model of Opinion Dynamics
Susan Fennell, University of Limerick, Ireland

4:25-4:45 A Network Model of Immigration: Enclave Formation vs. Cultural Integration
Maria D'Orsogna, California State University, Northridge, U.S.; Tom Chou and Yao-li Chuang, University of California, Los Angeles, U.S.

Tuesday, May 21

MS101

Effects of Symmetries and Partitions on Dynamics in Networks - Part I of II

3:10 p.m.-4:50 p.m.

Room: Ballroom 3

For Part 2 see MS113

The behavior of dynamical systems (nodes) that are coupled together in complex networks are greatly affected by the structure of those networks. Various patterns of synchronization and delayed synchronization among subsets of nodes are possible when the network has symmetries and input or balanced partitions. Symmetries and partitions will be introduced along with the dynamical patterns they can support. We will also present ways to find these patterns using linear programming and for creating networks with predetermined numbers of symmetries. The effect of symmetries on the efficacy of reservoir computing will be covered along with the surprising case of nodes that are not symmetrically interchangeable (asymmetric), yet support synchronous behavior in which the dynamical patterns are identical. Lack of symmetry will be shown to not necessarily be a road block to synchronous patterns and the role of symmetry and partitions in the dynamics of central pattern generators will be demonstrated. Transient patterns are also important in such networks. These will be presented in the form of large fluctuations that are rare, but which can change the form of the dynamics of the network.

Organizer: Louis M. Pecora
Naval Research Laboratory, U.S.

Organizer: Francesco Sorrentino
University of New Mexico, U.S.

3:10-3:30 Symmetries, Partitions, and Dynamics in Networks
Louis M. Pecora, Naval Research Laboratory, U.S.

3:35-3:55 Cluster Synchronization in Multilayer Networks
Francesco Sorrentino, University of New Mexico, U.S.

4:00-4:20 Algorithms and Experiments for the Approximate Balanced Coloring Problem
David Phillips, US Naval Academy, U.S.

4:25-4:45 Generating Graphs with Symmetry
Isaac Klickstein, University of New Mexico, U.S.

Tuesday, May 21

MS102

Spatiotemporally Complex Patterns - Part I of II

3:10 p.m.-4:50 p.m.

Room: Magpie A

For Part 2 see MS114

This minisymposium brings together experimentalists and theorists studying spatiotemporally complex patterns. Mathematical methods include amplitude and phase equations, machine learning, and topological data analysis.

Organizer: Patrick Shipman
Colorado State University, U.S.

Organizer: Iuliana Oprea
Colorado State University, U.S.

3:10-3:30 Amplitude and Phase Equations in Anisotropic Systems

Gerhard Dangelmayr, Colorado State University, U.S.

3:35-3:55 Pace and Patterns of Magnetic Swimmers in a Billiard Pool

Florian J. Maier, Markus Sesselmann, and Ingo Rehberg, Universität Bayreuth, Germany; *Reinhard Richter*, University of Bayreuth, Germany

4:00-4:20 Stationary and Moving Defects in Oscillatory Media

Gabriela Jaramillo, University of Houston, U.S.

4:25-4:45 Evidence of an Intrinsic Clock and Host-Parasite Coupling in the Intraerythrocytic Developmental Cycle of Plasmodium

Francis C. Motta, Florida Atlantic University, U.S.

Tuesday, May 21

MS103

Neuronal Computations in Brain Networks - Part I of II

3:10 p.m.-4:50 p.m.

Room: Magpie B

For Part 2 see MS115

The integration of information in the brain occurs through the communication of neurons whose activity transitions between many dynamical states. The successful transmission of information in the brain often relies on precise neuronal activity; however, it remains unclear how neurons in different networks coordinate to produce this activity and how much information is transmitted by the activity of neurons operating in different regimes. Mathematical modeling of neuronal networks is a powerful tool used to uncover the mechanisms underlying various dynamical regimes, as well as understand the nature of information processing in the brain. In this minisymposium, the speakers will draw particular attention to recent mathematical approaches in characterizing the neuronal computations underlying cognition, with an emphasis on the structure-function relationship in the brain.

Organizer: Jennifer Crodelle
Courant Institute of Mathematical Sciences, New York University, U.S.

Organizer: Douglas Zhou
Shanghai Jiao Tong University, China

3:10-3:30 The Role of Synchrony in Pattern Formation

Aine Byrne, New York University, U.S.

3:35-3:55 Linearity in Neuronal Networks

Yanyang Xiao and Yaoyu Zhang, New York University Abu Dhabi, United Arab Emirates; Zhiqin J. Xu, Courant Institute New York University, U.S. and New York University Abu Dhabi, United Arab Emirates; Zhongqi Tian and Douglas Zhou, Shanghai Jiao Tong University, China

4:00-4:20 Metastable Transitions in a Bistable Oscillator

Brett J. Geiger and Andrea Barreiro, Southern Methodist University, U.S.

4:25-4:45 Chaotic or Nonchaotic Dynamics in Neuronal Networks?

Douglas Zhou, Shanghai Jiao Tong University, China

Tuesday, May 21

MS104

When Stochasticity Meets Delay: Rendezvous in Infinite Dimension

3:10 p.m.-4:50 p.m.

Room: Wasatch A

Mathematical models including time delays are essential in many applications from engineering to biology. The corresponding governing equations are delay differential equations (DDE) that describe these systems in infinite dimensional phase spaces. The presence of time delays are considered as additional complication in applied mathematical models, but a relevant advantage of these models is that complex and intricate nonlinear dynamical behavior can be described with relatively low number of physical parameters. Stochastic processes also have mathematical models in infinite dimensional phase spaces, and the corresponding mathematical models, the stochastic differential equations (SDE) also appear in many engineering and biological applications. Since both DDE and SDE models are difficult to handle due to their infinite dimensional nature, one can rarely meet mathematical models where both effects are equally important, and both delay and stochasticity must appear in the governing equations. The minisymposium gives an overview of such dynamical problems from connected vehicles through biochemical reactions and random walk problems to machine tool vibrations, while the different approaches, the developed theoretical and numerical methods are also discussed and compared to each other.

Organizer: Gabor Stepan
Budapest University of Technology and Economics, Hungary

Organizer: Gabor Orosz
University of Michigan, Ann Arbor, U.S.

3:10-3:30 Retrospective Bayesian Updating to Compensate Delays in Connected Vehicle Systems

Wei Liu, Tsinghua University, China; Jeff Scruggs, University of Michigan, U.S.; *Gabor Orosz*, University of Michigan, Ann Arbor, U.S.

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Tuesday, May 21

MS104

When Stochasticity Meets Delay: Rendezvous in Infinite Dimension

continued

3:35-3:55 Bayesian Methods for Inferring Delay Distributions in Biochemical Reaction Networks

Choi Boseung, Korea University, South Korea; Mehdi Sadeghpour, University of Michigan, Ann Arbor, U.S.; William Ott and Selahittin Cinar, University of Houston, U.S.; Jae Kyoung Kim, Korea Advanced Institute of Science and Technology, Korea; *Kresimir Josic*, University of Houston, U.S.

4:00-4:20 Random Walking Around Delays

Toru Ohira, Nagoya University, Japan; John Milton, Claremont College, U.S.

4:25-4:45 Stochastic Semi-Discretization for Stochastic Systems with Delay

Henrik Sykora, Daniel Bachrathy, and Gabor Stepan, Budapest University of Technology and Economics, Hungary

Tuesday, May 21

MS105

Recent Advances in Multiple-Timescale Dynamics with Applications to Neural Systems - Part I of II

3:10 p.m.-4:50 p.m.

Room: Wasatch B

For Part 2 see MS117

Multiple timescales are underpinning complex oscillatory dynamics in many application areas, including and especially in neuroscience. Dynamical systems with multiple timescales are able to display a vast repertoire of complex oscillations: spikes, bursts, mixed-mode oscillations, as well as combinations of them. This two-part minisymposium will present recent results on multi-timescale dynamics in ODEs and network systems with a clear focus towards neural models. In these examples, phenomena such as canards and dynamic bifurcations are key to understand and control non-trivial behaviors near the boundaries between different activity regimes at many scales ranging from single neurons to micro-circuits and populations.

Organizer: Elif Koksal Ersoz
Inria Sophia Antipolis, France

Organizer: Mathieu Desroches
Inria Sophia Antipolis, France

Organizer: Daniele Avitabile
University of Nottingham, United Kingdom

Organizer: G. Bard Ermentrout
University of Pittsburgh, U.S.

3:10-3:30 Smooth Fenichel Manifolds through Gevrey Analysis

Peter De Maesschalck and Karel Kenens, Hasselt University, Belgium

3:35-3:55 Multiple Time Scales Underlying Pauses, Bursting and Depolarization Block in Midbrain Dopamine Neurons

Carmen Canavier and Christopher Knowlton, Louisiana State University Health Sciences Center, U.S.

continued in next column

4:00-4:20 Relaxation Oscillations and Canards in the Jirsa-Kelso Excitator Model: Global Flow Perspective

Krasimira Tsaneva-Atanasova, Piotr Slowinski, and Sohaib Al-Ramadhani, University of Exeter, United Kingdom

4:25-4:45 Bottom-Up Approach to Torus Bifurcation in Neuron Models

Huiwen Ju, Georgia State University, U.S.; Alexander Neiman, Ohio University, U.S.; Andrey Shilnikov, Georgia State University, U.S.

Tuesday, May 21

MS106

Novel Perspectives on Turbulence Modeling and Control - Part I of II

3:10 p.m.-4:50 p.m.

Room: Superior A

For Part 2 see MS118

Turbulent flows comprise a broad range of spatiotemporal scales and associated complex dynamical behavior. The ability to characterize, model and control turbulent fluid flows is critical for the economy and environment, e.g. to reduce drag for more efficient and greener transportation, to stabilize combustion processes and reduce pollutants, or to understand global planetary processes. There has been significant progress in theoretical and data-driven advances to address challenges in identifying spatiotemporal structures, efficient representation of high-dimensional time series, discovering intrinsic physical information (e.g. conservations laws, symmetries), and control. This minisymposium brings together leading experts who are integrating ideas from dynamical systems, statistical physics, optimization and machine learning to facilitate a deeper understanding of the underlying flow physics and provide tools for pattern identification, discovery of dynamics, and control, which may be useful in applications beyond fluid dynamics.

Organizer: Eurika Kaiser

University of Washington, U.S.

3:10-3:30 A Spatiotemporal Theory of Turbulence in Terms of Exact Coherent Structures

Predrag Cvitanovic and Matthew Gudorf, Georgia Institute of Technology, U.S.

3:35-3:55 Dynamical Description of Transient Processes in Shear Flows

Nazmi Burak Budanur, Institute of Science and Technology Austria, Austria

4:00-4:20 Discovery of High-Order PDE Models with Latent Variables

Roman Grigoriev, Patrick Reinbold, Logan Kageorge, and Michael F. Schatz, Georgia Institute of Technology, U.S.

4:25-4:45 Design of Feedback Control Laws for Turbulent Post-Stall Separated Flows

Aditya Nair, University of Washington, U.S.; Chi-An Yeh, Florida State University, U.S.; Eurika Kaiser, University of Washington, U.S.; Bernd Noack, LIMSI-CNRS, France; Steven Brunton, University of Washington, U.S.; Kunihiko Taira, University of California, Los Angeles, U.S.

Tuesday, May 21

MS107

Recent Advances in Lattice Dynamical Systems - Part I of II

3:10 p.m.-4:50 p.m.

Room: Superior B

For Part 2 see MS119

In this minisymposium we wish to showcase recent work on both the theory and applications of lattice dynamical systems (LDSs) using modern techniques from mathematical and numerical analysis. LDSs often arise as spatial discretizations of partial differential equations, but have further been applied to problems in chemical reaction theory, quantum mechanics, models of neural networks, optics, and material science. Therefore, it is our intention to provide a forum for which a diverse range of researchers can demonstrate how such differential equations can be applied to understand real-world phenomena, as well as present the techniques in which they were able to establish their results. In particular, we will focus on the existence, stability, and bifurcations of nonlinear waves and coherent structures as solutions to LDSs using modern dynamical systems techniques. This includes implementing tools from infinite-dimensional real and functional analysis to understand dynamic behaviour of propagating or periodic solutions in the discrete spatial medium endowed by the underlying lattice structure of the dynamical system. In all of this, we aim to highlight the work of both experienced and early-career researchers in an effort to foster a community of theoreticians and experimentalists interested in similar problems in dynamical systems, thus developing a stronger relationship between the relatively small, but diverse, researchers working in the study of LDSs.

Organizer: Jason J. Bramburger

Brown University, U.S.

Organizer: Timothy E. Faver

Leiden University, Netherlands

3:10-3:30 Pinning and Depinning in Dynamically Generated Media

Noah Ankney, Michigan State University, U.S.; *Montie Avery*, University of Minnesota, U.S.; Tali Khain, University of Michigan, U.S.; Arnd Scheel, University of Minnesota, Twin Cities, U.S.

continued in next column

3:35-3:55 Snakes and Lattices: Understanding the Bifurcation Structure of Localized Solutions to Lattice Dynamical Systems

Jason J. Bramburger, Brown University, U.S.

4:00-4:20 Dispersive Shock Waves in Nonlinear Lattices

Chris Chong, Bowdoin College, U.S.

4:25-4:45 Traveling Pulses in Discrete FitzHugh-Nagumo Systems

Willem M. Schouten-Straatman, Leiden University, Netherlands

Tuesday, May 21

MS108

Thermodynamic Laws from Nonequilibrium Dynamics - Part I of II

3:10 p.m.-4:50 p.m.

Room: White Pine

For Part 2 see MS120

The main theme of this minisymposium is the derivation of thermodynamic laws from nonequilibrium dynamics. A physical (or biological) system is said to be nonequilibrium if it is irreversible due to external forces or boundary effects. Many fundamental questions related to thermodynamic properties can be asked. Dynamical systems generated by these nonequilibrium physical processes are usually inherently high dimensional and noisy, which makes these problems both challenging and interesting. In addition to their mathematical value, complex nonequilibrium dynamics can arise from numerous applied areas. We believe that the proposed mini-symposium will promote fruitful interaction between dynamical systems and nonequilibrium statistical physics and fields such as mathematical biology, fluid dynamics, control theory, and material sciences. We propose this mini-symposium to address the recent advances and challenges of nonequilibrium dynamical systems.
Eight speakers who are experts in this area, including two from underrepresented groups, are invited to present their research related to the derivation of thermodynamic laws (or related global properties) from nonequilibrium dynamical systems. These presentations include new techniques in dynamical systems, probabilistic approaches for dynamical systems, and novel numerical methods for high-dimensional problems. We expect an audience from diverse areas to be interested in our mini-symposium.

Organizer: Yao Li

University of Massachusetts, Amherst, U.S.

Organizer: Timothy Chumley

Mount Holyoke College, U.S.

Organizer: Jianyu Chen

University of Massachusetts, Amherst, U.S.

3:10-3:30 Thermodynamic Laws from Interacting Kinetic Particles

Yao Li, University of Massachusetts, Amherst, U.S.

continued in next column

3:35-3:55 The Kac Model and (Non-) Equilibrium Statistical Mechanics

Federico Bonetto, Georgia Institute of Technology, U.S.

4:00-4:20 Mathematicothermodynamics: Stochastic Laws and Emergent Behavior of Population Kinetic Systems

Hong Qian, University of Washington, U.S.

4:25-4:45 Local Immunodeficiency: Minimal Network and Stability

Longmei Shu, Georgia Institute of Technology, U.S.

Tuesday, May 21

MS109

Complex Dynamics from the Perspective of Geometry, Spectral Theory, and Data - Part I of II

3:10 p.m.-4:50 p.m.

Room: Primrose A

For Part 2 see MS121

The understanding and reduced-order modeling of complex dynamical systems from a data-driven perspective poses new and exciting research challenges. These challenges stem from dynamical complexity of different types, including chaotic mixing, stochastic forcing, high- or infinite-dimensionality, and turbulence—often present simultaneously. The need to perform reduced-order modeling in the presence of these behaviors has spurred the development of a diverse range of geometric, set-oriented, and operator-theoretic approaches. The purpose of this minisyposium is to bring together experts from these fields working on different aspects of these problems, and to engage them in a discussion on transferring and combining their knowledge.

Organizer: Peter Koltai

Freie Universität Berlin, Germany

Organizer: Dimitrios Giannakis

Courant Institute of Mathematical Sciences, New York University, U.S.

3:10-3:30 Spectral Approximation of Evolution Operators in Reproducing Kernel Hilbert Space

Dimitrios Giannakis and Suddhasattwa Das, Courant Institute of Mathematical Sciences, New York University, U.S.; Joanna Slawinska, University of Wisconsin, Milwaukee, U.S.

3:35-3:55 Long-Time Dynamical Estimates from Short-Time Data using Dynamical Galerkin Approximation

Erik Thiede, University of Chicago, U.S.; Dimitrios Giannakis, Courant Institute of Mathematical Sciences, New York University, U.S.; Aaron Dinner, University of Chicago, U.S.; Jonathan Weare, Courant Institute of Mathematical Sciences, New York University, U.S.

continued on next page

4:00-4:20 Stability of the Malvinas Current

Francisco J. Beron-Vera, University of Miami, U.S.; Nicolas Bodnariuk and Martin Saraceno, Universidad de Buenos Aires, Argentina; M. Josefina Olascoaga, University of Miami, U.S.; Claudia Simionato, Universidad de Buenos Aires, Argentina

4:25-4:45 How do Coherent Sets Respond to Perturbations and how can I Separate Many Coherent Sets?

Gary Froyland, University of New South Wales, Australia; Oliver Junge, Technische Universität München, Germany; Christopher Rock, University of New South Wales, Australia; Konstantinos Sakellariou, University of Western Australia, Australia

Tuesday, May 21

MS110

Invariant Manifolds, Global Structures and Bifurcations

3:10 p.m.-4:50 p.m.

Room: Primrose B

The minisymposium is intended for a discussion of topics related to invariant manifolds of dynamical systems. This relates, for example to stable and unstable manifolds of equilibria, periodic orbits and other solutions. Being global, the manifolds can be embedded into the phase space in a very complicated way, thus revealing complex dynamics. The interaction of these sets can lead to drastic reconstructions of the structure of solutions, creating homoclinic and heteroclinic connections, attractors and even chaos. This minisymposium features a collection of new advances in ODE and PDE dynamics, ranging from analytic results to numerical simulations and applications, both in continuous- and discrete-time systems.

Organizer: Lars Siemer
Universität Bremen, Germany

Organizer: Ivan Ovsyannikov
University of Hamburg, Germany

3:10-3:30 Statistics Meets Geometry: Extreme Value Laws in Dynamical Systems

Alef E. Sterk, University of Groningen, The Netherlands

3:35-3:55 Dynamics Near a Periodically Forced Attracting Heteroclinic Cycle

Alexandre A. Rodrigues, University of Porto, Portugal; Isabel Labouriau, Universidade do Porto, Portugal

4:00-4:20 Application of Manifolds to an Aperiodic 3D Flow: the Western Alboran Gyre

Genevieve Brett, University of Hawaii, Manoa, U.S.; Lawrence Pratt and Irina I. Rypina, Woods Hole Oceanographic Institution, U.S.

4:25-4:45 The Role of Advection for Patterns Near Turing Instabilities in Planar Reaction-Diffusion Systems

Jichen Yang and Jens Rademacher, Universität Bremen, Germany; Eric Siero, University of Oldenburg, Germany

Tuesday, May 21

CP18

Coupled Oscillators II

3:10 p.m.-4:50 p.m.

Room: Maybird

3:10-3:30 Coarse-Graining for Coupled Oscillators: A Case Study in Discovering Low-Dimensional Dynamics

Jordan Snyder, University of California, Davis, U.S.; Andrey Lokhov and Anatoly Zlotnik, Los Alamos National Laboratory, U.S.

3:35-3:55 Drive-Based Motivation Dynamics for Coordination of Limit-Cycle Behaviors

Craig A. Thompson and Paul B. Reverdy, University of Arizona, U.S.

4:00-4:20 Critical Switching Behavior in Globally Attractive Chimera States

Yuanzhao Zhang and Zachary Nicolaou, Northwestern University, U.S.; Joseph Hart, University of Maryland, U.S.; Rajarshi Roy, University of Maryland, College Park, U.S.; Adilson E. Motter, Northwestern University, U.S.

4:25-4:45 Extreme Events in Delay-Coupled Relaxation Oscillators

Arindam Saha and Ulrike Feudel, University of Oldenburg, Germany

Intermission

4:50 p.m.-5:00 p.m.

Tuesday, May 21

MS111

Coupling Marine Ecosystem Dynamics to Environmental Change - Part II of II

5:00 p.m.-6:40 p.m.

Room: Ballroom 1

For Part 1 see MS93

Most existing (mathematical/statistical) models for assessing marine ecosystem state are premised on gradual changes in the marine enviroment and in the response of the biological systems. However, recent changes in marine ecosystems are either anomalous (high-frequency, short-lived) or catastrophic (low-frequency, long-lived) perturbations. The application of most existing models, either for state projections or as premonitory tools, is therefore severely limited. This minisymposium will focus on theoretical and computational frameworks that integrate system dynamical models and empirical data, to provide information on current marine ecosystem state, and projections of its shortand long-term response to environmental change. We particularly encourage presentation of recent frameworks based on the use of (discrete or continuous time) Ordinary Differential (OD), Partial Differential (PD), and Delay Differential (DD) equations, and involve Individual-Based Modeling (IBM), spatial movement (ecology) simulations, and Dynamic Energy Budget (DEB) models. Because marine systems are complex and difficult to observe, comprehensive monitoring programs for entire systems are necessarily limited. We therefore encourage papers that deal with metamodels and innovative approaches for model integration for marine ecosystems.

Organizer: Sam Subbey

Institute of Marine Research, Bergen, Norway

Organizer: Bjorn Birnir

University of California, Santa Barbara, U.S.

5:00-5:20 Oyster Population Persistence with Fluctuating Dispersal Rates

Rachel Wilson and Junping Shi, College of William & Mary, U.S.; Rom Lipcius, Virginia Institute of Marine Science, U.S.

continued in next column

5:25-5:45 Small Organisms Causing Big Problems: Modeling Heterosigma Akashiwo

Nicholas J. Russell and Louis F. Rossi, University of Delaware, U.S.

5:50-6:10 An Integrated Approach to Coral-Algal Phase Shift Modeling: Numerical Methods Meets Data Science

Rosanna Neuhausler, University of California, Berkeley, U.S.; Martin Robinson and Maria Bruna, University of Oxford, United Kingdom; Laurel Larsen, University of California, Berkeley, U.S.

6:15-6:35 Using Plankton as Biosensor

Vito Pastore, Thomas Zimmerman, Sujoy K. Biswas, and *Simone Bianco*, IBM Research, U.S.

Tuesday, May 21

MS112

Dynamics of Democracy - Part II of II

5:00 p.m.-6:40 p.m.

Room: Ballroom 2

For Part 1 see MS100

Democracies provide a source of rich mathematical questions and broad-interest societal issues surrounding the interactions of individuals, different social movements, voting districts, and countries. Social media and the popular press further add to the complexity of these dynamics and provide new ways for communities at various scales to interact with each other. Here we bring together researchers working on a range of topics arising from democracy – e.g. the evolution of political opinions, the dynamics of social engagement, the emergence of conflict, the organization of voting districts, and the impact of immigration on a population. These problems are studied using tools from network analysis, statistics, dynamical systems, and topology. The goal of this session is to lead to cross-fertilization between these fields, highlight mathematical questions in social science, and motivate new areas of interdisciplinary research.

Organizer: Heather Z. Brooks

University of California, Los Angeles, U.S.

Organizer: Alexandria Volkening

Ohio State University, U.S.

5:00-5:20 Interdisciplinary Inclusive Communities of Undergraduates doing Social-Justice Inspired Research

Carlos Castillo-Chavez, Arizona State University, U.S.

5:25-5:45 Quantifying Gerrymandering using Random Dynamics

Jonathan C. Mattingly and Gregory J. Herschlag, Duke University, U.S.

5:50-6:10 A Topological Approach to Detecting Neighborhood Segregation

Michelle Feng, University of California, Los Angeles, U.S.

6:15-6:35 Forecasting U.S. Elections using Compartmental Models

Alexandria Volkening, Ohio State University, U.S.; Daniel Linder, Augusta University, U.S.; Mason A. Porter, University of California, Los Angeles, U.S.; Grzegorz Rempala, Ohio State University, U.S.

Tuesday, May 21

MS113

Effects of Symmetries and Partitions on Dynamics in Networks - Part II of II

5:00 p.m.-6:40 p.m.

Room: Ballroom 3

For Part 1 see MS101

The behavior of dynamical systems (nodes) that are coupled together in complex networks are greatly affected by the structure of those networks. Various patterns of synchronization and delayed synchronization among subsets of nodes are possible when the network has symmetries and input or balanced partitions. Symmetries and partitions will be introduced along with the dynamical patterns they can support. We will also present ways to find these patterns using linear programming and for creating networks with predetermined numbers of symmetries. The effect of symmetries on the efficacy of reservoir computing will be covered along with the surprising case of nodes that are not symmetrically interchangeable (asymmetric), yet support synchronous behavior in which the dynamical patterns are identical. Lack of symmetry will be shown to not necessarily be a road block to synchronous patterns and the role of symmetry and partitions in the dynamics of central pattern generators will be demonstrated.

Organizer: Louis M. Pecora
Naval Research Laboratory, U.S.

Organizer: Francesco Sorrentino
University of New Mexico, U.S.

5:00-5:20 Benefits of Heterogeneity: Random Beats Design in Network Synchronization

Yuanzhao Zhang and *Adilson E. Motter*, Northwestern University, U.S.

5:25-5:45 Converse Symmetry Breaking: Demonstration and Application to Network Optimization

Ferenc Molnar, University of Notre Dame, U.S.; Takashi Nishikawa and Adilson E. Motter, Northwestern University, U.S.

5:50-6:10 The Effect of Symmetry on Reservoir Computing

Thomas L. Carroll and Louis M. Pecora, Naval Research Laboratory, U.S.

6:15-6:35 Large Fluctuations and Rare Events in Complex Networks

Ira B. Schwartz, Naval Research Laboratory, U.S.

Tuesday, May 21

MS114

Spatiotemporally Complex Patterns - Part II of II

5:00 p.m.-6:40 p.m.

Room: Magpie A

For Part 1 see MS102

This minisymposium brings together experimentalists and theorists studying spatiotemporally complex patterns. Mathematical methods include amplitude and phase equations, machine learning, and topological data analysis.

Organizer: Patrick Shipman
Colorado State University, U.S.

Organizer: Iuliana Oprea
Colorado State University, U.S.

5:00-5:20 Chevron Structures in Passive and Active Liquid Crystals

Lidia Mrad, University of Arizona, U.S.

5:25-5:45 Complex and Disordered Patterns in Pattern Formation with Two Length Scales

Alastair M. Rucklidge, University of Leeds, United Kingdom

5:50-6:10 Effects of Anisotropies in the Complex Ginzburg-Landau Equation

Derek Handwerk, Colorado State University, U.S.

6:15-6:35 Taming the Spatiotemporal Chaos in Nanoscale Topographies Produced by Ion Bombardment

R Mark Bradley, Colorado State University, U.S.

Tuesday, May 21

MS115

Neuronal Computations in Brain Networks - Part II of II

5:00 p.m.-6:40 p.m.

Room: Magpie B

For Part 1 see MS103

The integration of information in the brain occurs through the communication of neurons whose activity transitions between many dynamical states. The successful transmission of information in the brain often relies on precise neuronal activity; however, it remains unclear how neurons in different networks coordinate to produce this activity and how much information is transmitted by the activity of neurons operating in different regimes. Mathematical modeling of neuronal networks is a powerful tool used to uncover the mechanisms underlying various dynamical regimes, as well as understand the nature of information processing in the brain. In this minisymposium, the speakers will draw particular attention to recent mathematical approaches in characterizing the neuronal computations underlying cognition, with an emphasis on the structure-function relationship in the brain.

Organizer: Jennifer Crodelle
Courant Institute of Mathematical Sciences, New York University, U.S.

Organizer: Douglas Zhou
Shanghai Jiao Tong University, China

5:00-5:20 Mathematical Model of Pain Processing in the Spinal Cord

Sofia H. Piltz, University of Michigan, U.S.; Jennifer Crodelle, Courant Institute of Mathematical Sciences, New York University, U.S.; Megan Hagenauer and Victoria Booth, University of Michigan, U.S.

5:25-5:45 A Role for Electrical Coupling in Cortical Networks

Jennifer Crodelle, Courant Institute of Mathematical Sciences, New York University, U.S.

5:50-6:10 Network Reconstruction in the Cerebral Cortex: Architectural and Functional Connectivity with Matrix Completion

Paulina Volosov and Gregor Kovacic, Rensselaer Polytechnic Institute, U.S.

6:15-6:35 Reconstruction of Digital Systems by Transfer Entropy

Zhongqi Tian, Shanghai Jiao Tong University, China

Tuesday, May 21

MS116

Exiting Problems and Quasi-Stationarity in Stochastic Dynamics

5:00 p.m.-6:40 p.m.

Room: Wasatch A

Stochastic dynamics are ubiquitous to natural phenomena such as neuronal networks, molecular dynamics, chemical reactions and climate dynamics. In many cases, such phenomena are modelled by Stochastic Differential Equations (SDEs) which describe globally diffusive systems. However, the underlying determinstic parts of the equation may have strong stability properties that prevail on long time scales such that the behaviour may be dominated by dissipative dynamics or certain coherent structures despite the noise. The challenge of understanding deterministic and diffusive interactions has lead to intensive mathematical research on exiting problems, almost invariant or metastable sets, escape rates of mass in open systems and quasi-stationarity of stochastic processes. Many mathematical methods such as Markov process theory, spectral analysis of PDEs, ergodic theory or invariant manifold theory have been used to tackle such problems. The aim of this minisymposium is to gather researchers actively working on the theory and applications of stochastic processes exiting bounded domains, combining dynamical and stochastic aspects of this highly challenging problem field.

Organizer: Maximilian Engel
Technische Universität München, Germany

5:00-5:20 Exit Problems and Rare Transitions in Noisy Heteroclinic Networks

Yuri Bakhtin, Courant Institute of Mathematical Sciences, New York University, U.S.

5:25-5:45 Dynamical Systems with Fast Switching and Slow Diffusion: Hyperbolic Equilibria and Stable Limit Cycles

Alexandru Hening, Tufts University, U.S.

5:50-6:10 Center Manifolds for Rough Differential Equations

Alexandra Neamtu and Christian Kuehn, Technische Universität München, Germany

continued in next column

6:15-6:35 Quasi-Stationary Monte Carlo Methods

Andi Wang, University of Oxford, United Kingdom; Martin Kolb, Universität Paderborn, Germany; Gareth O. Roberts, Warwick University, United Kingdom; David Steinsaltz, University of Oxford, United Kingdom

Tuesday, May 21

MS117

Recent Advances in Multiple-Timescale Dynamics with Applications to Neural Systems - Part II of II

5:00 p.m.-6:40 p.m.

Room: Wasatch B

For Part 1 see MS105

Multiple timescales are underpinning complex oscillatory dynamics in many application areas, including and especially in neuroscience. Dynamical systems with multiple timescales are able to display a vast repertoire of complex oscillations: spikes, bursts, mixed-mode oscillations, as well as combinations of them. This two-part minisymposium will present recent results on multi-timescale dynamics in ODEs and network systems with a clear focus towards neural models. In these examples, phenomena such as canards and dynamic bifurcations are key to understand and control non-trivial behaviors near the boundaries between different activity regimes at many scales ranging from single neurons to micro-circuits and populations.

Organizer: Elif Koksal Ersoz
Inria Sophia Antipolis, France

Organizer: Mathieu Desroches
Inria Sophia Antipolis, France

Organizer: Daniele Avitabile
University of Nottingham, United Kingdom

Organizer: G. Bard Ermentrout
University of Pittsburgh, U.S.

5:00-5:20 Mathematical Tools for Phase Control in Transient States of Neuronal Oscillators

Gemma Huguet and Alberto Perez-Cervera, Universitat Politecnica de Catalunya, Spain; Tere M. Seara, Universitat Politecnica de Catalunya, Spain

5:25-5:45 Leveraging Machine Learning to Control Neural Oscillators

Jeff Moehlis, Timothy Matchen, and Bharat Monga, University of California, Santa Barbara, U.S.

5:50-6:10 Cellular Control of Network Rhythmic Activity

Guillaume Drion, University of Liege, Belgium

continued on next page

6:15-6:35 When Three is a Crowd: Chaos from Clusters in Networks of Phase Oscillators with Inertia

Barrett N. Brister, Georgia State University, U.S.; Vladimir Belykh, Lobachevsky State University of Nizhny Novgorod, Russia; Igor Belykh, Georgia State University, U.S.

Tuesday, May 21

MS118

Novel Perspectives on Turbulence Modeling and Control - Part II of II

5:00 p.m.-6:15 p.m.

Room: Superior A

For Part 1 see MS106

Turbulent flows comprise a broad range of spatiotemporal scales and associated complex dynamical behavior. The ability to characterize, model and control turbulent fluid flows is critical for the economy and environment, e.g. to reduce drag for more efficient and greener transportation, to stabilize combustion processes and reduce pollutants, or to understand global planetary processes. There has been significant progress in theoretical and data-driven advances to address challenges in identifying spatiotemporal structures, efficient representation of high-dimensional time series, discovering intrinsic physical information (e.g. conservations laws, symmetries), and control. This minisymposium brings together leading experts who are integrating ideas from dynamical systems, statistical physics, optimization and machine learning to facilitate a deeper understanding of the underlying flow physics and provide tools for pattern identification, discovery of dynamics, and control, which may be useful in applications beyond fluid dynamics.

Organizer: Eurika Kaiser
University of Washington, U.S.

5:00-5:20 Probability r-Forms in Exterior Calculus, Lie Symmetries and a Generalized Liouville Equation

Robert K. Niven, University of New South Wales, Australia

5:25-5:45 A New Scalable Algorithm for Computational Optimal Control Under Uncertainty

Daniele Venturi, University of California, Santa Cruz, U.S.

5:50-6:10 Optimizing Finite-Time Coherence in Non-Autonomous Systems without Trajectory Integration

Gary Froyland, University of New South Wales, Australia; Peter Koltai and *Martin Plonka*, Freie Universität Berlin, Germany

Tuesday, May 21

MS119

Recent Advances in Lattice Dynamical Systems - Part II of II

5:00 p.m.-6:40 p.m.

Room: Superior B

For Part 1 see MS107

In this minisymposium we wish to showcase recent work on both the theory and applications of lattice dynamical systems (LDSs) using modern techniques from mathematical and numerical analysis. LDSs often arise as spatial discretizations of partial differential equations, but have further been applied to problems in chemical reaction theory, quantum mechanics, models of neural networks, optics, and material science. Therefore, it is our intention to provide a forum for which a diverse range of researchers can demonstrate how such differential equations can be applied to understand real-world phenomena, as well as present the techniques in which they were able to establish their results. In particular, we will focus on the existence, stability, and bifurcations of nonlinear waves and coherent structures as solutions to LDSs using modern dynamical systems techniques. This includes implementing tools from infinite-dimensional real and functional analysis to understand dynamic behaviour of propagating or periodic solutions in the discrete spatial medium endowed by the underlying lattice structure of the dynamical system. In all of this, we aim to highlight the work of both experienced and early-career researchers in an effort to foster a community of theoreticians and experimentalists interested in similar problems in dynamical systems, thus developing a stronger relationship between the relatively small, but diverse, researchers working in the study of LDSs.

Organizer: Jason J. Bramburger
Brown University, U.S.

Organizer: Timothy E. Faver
Leiden University, Netherlands

5:00-5:20 Nanopteron Traveling Waves for Mass-in-Mass Lattices in the Small Mass Limit

Timothy E. Faver, Leiden University, Netherlands

continued on next page

Tuesday, May 21

MS119

Recent Advances in Lattice Dynamical Systems - Part II of II

continued

5:25-5:45 Traveling Waves, Discrete Breathers and Shock Waves in Granular Crystals: Theory, Simulation and Experiments

Panos Kevrekidis, University of Massachusetts, Amherst, U.S.

5:50-6:10 Wave Propagation in Peridynamical Media

Michael Herrmann, Technische Universität Braunschweig, Germany; Karsten Matthies, University of Bath, United Kingdom

6:15-6:35 Dynamics on Planar Lattices

Mia Jukic, University of Leiden, The Netherlands; Hermen Jan Hupkes, Leiden University, Netherlands; Leonardo Morelli, University of Leiden, The Netherlands

Tuesday, May 21

MS120

Thermodynamic Laws from Nonequilibrium Dynamics - Part II of II

5:00 p.m.-6:40 p.m.

Room: White Pine

For Part 1 see MS108

The main theme of this minisymposium is the derivation of thermodynamic laws from nonequilibrium dynamics. A physical (or biological) system is said to be nonequilibrium if it is irreversible due to external forces or boundary effects. Many fundamental questions related to thermodynamic properties can be asked. Dynamical systems generated by these nonequilibrium physical processes are usually inherently high dimensional and noisy, which makes these problems both challenging and interesting. In addition to their mathematical value, complex nonequilibrium dynamics can arise from numerous applied areas. We believe that the proposed mini-symposium will promote fruitful interaction between dynamical systems and nonequilibrium statistical physics and fields such as mathematical biology, fluid dynamics, control theory, and material sciences. We propose this mini-symposium to address the recent advances and challenges of nonequilibrium dynamical systems.
Eight speakers who are experts in this area, including two from underrepresented groups, are invited to present their research related to the derivation of thermodynamic laws (or related global properties) from nonequilibrium dynamical systems. These presentations include new techniques in dynamical systems, probabilistic approaches for dynamical systems, and novel numerical methods for high-dimensional problems. We expect an audience from diverse areas to be interested in our mini-symposium.

Organizer: Yao Li

University of Massachusetts, Amherst, U.S.

Organizer: Timothy Chumley

Mount Holyoke College, U.S.

Organizer: Jianyu Chen

University of Massachusetts, Amherst, U.S.

5:00-5:20 Entropy Production in Random Billiards and the Second Law of Thermodynamics

Timothy Chumley, Mount Holyoke College, U.S.

continued in next column

5:25-5:45 Thermodynamics of Random Billiards

Renato Feres, Washington University in St. Louis, U.S.

5:50-6:10 Diffusive Scaling Limit in a Slow-Fast Standard Map

Ke Zhang, University of Toronto, Canada

6:15-6:35 Averaging in Billiard-Like Systems

Alexander Grigo, University of Oklahoma, U.S.

Tuesday, May 21

MS121

Complex Dynamics from the Perspective of Geometry, Spectral Theory, and Data - Part II of II

5:00 p.m.-6:40 p.m.

Room: Primrose A

For Part 1 see MS109

The understanding and reduced-order modeling of complex dynamical systems from a data-driven perspective poses new and exciting research challenges. These challenges stem from dynamical complexity of different types, including chaotic mixing, stochastic forcing, high- or infinite-dimensionality, and turbulence—often present simultaneously. The need to perform reduced-order modeling in the presence of these behaviors has spurred the development of a diverse range of geometric, set-oriented, and operator-theoretic approaches. The purpose of this minisyposium is to bring together experts from these fields working on different aspects of these problems, and to engage them in a discussion on transferring and combining their knowledge.

Organizer: Peter Koltai
Freie Universität Berlin, Germany

Organizer: Dimitrios Giannakis
Courant Institute of Mathematical Sciences, New York University, U.S.

5:00-5:20 On the Large Scale Flow Structure in Rayleigh--Bénard Convection: Manifold Learning and Transition Matrix Analysis

Peter Koltai, Freie Universität Berlin, Germany; Stephan Weiss, Max-Planck-Institute for Dynamics and Self-Organization, Germany

5:25-5:45 Lyapunov Vector Fields and Coarse-Grained Dynamics via the Spectral Exterior Calculus

Tyrus Berry, George Mason University, U.S.; Dimitrios Giannakis, Courant Institute of Mathematical Sciences, New York University, U.S.

5:50-6:10 On the Slow Dynamics of Superstructures in Turbulent Convection

Joerg Schumacher, Technische Universitaet Ilmenau, Germany

6:15-6:35 The Computation of Invariant Sets via Observations

Michael Dellnitz, University of Paderborn, Germany

Tuesday, May 21

MS122

Noise in Spatially Extended Systems

5:00 p.m.-6:40 p.m.

Room: Primrose B

Stochastic partial differential equations have become a standard tool for modellers to study the effect of mesoscopic random fluctuations on the dynamics. The inclusion of noise has been shown to significantly modify the dynamics and occurrence of spatio-temporal patterns such as noise-induced phase transitions, noise-induced traveling waves and patterns and stochastic spatiotemporal intermittency. This minisymposium presents recent results on how noise affects spatial patterns such as travelling waves in reaction-diffusion equations and in what way the wave solutions of the associated deterministic partial differential equation form a skeleton for the stochastically perturbed environment.

Organizer: Madeleine C. Cartwright
University of Sydney, Australia

5:00-5:20 Dynamics of Reaction-Diffusion SPDEs

Christian Kuehn, Technische Universität München, Germany; Nils Berglund, University of Orléans, France; Karna V. Gowda, Northwestern University, U.S.; Patrick Kürschner, Max Planck Institute, Magdeburg, Germany; Alexandra Neamtu, Technische Universität München, Germany; Francesco Romano, Ludwig-Maximilians-Universität München, Germany

5:25-5:45 A Collective Coordinate Framework to Study the Dynamics of Travelling Waves in Stochastic Partial Differential Equations

Madeleine C. Cartwright and Georg A. Gottwald, University of Sydney, Australia

5:50-6:10 Travelling Waves in Reaction-Diffusion Equations Forced by Translation Invariant Noise

Christian Hamster and Hermen Jan Hupkes, Leiden University, Netherlands

6:15-6:35 Effect of Noise on Emergent Patterns in Reaction-Diffusion Systems and Neural Fields

James Maclaurin, New Jersey Institute of Technology, U.S.

Tuesday, May 21

CP19

Neuroscience

5:00 p.m.-6:40 p.m.

Room: Maybird

Chair: Helmut Schmidt, Max Planck Institute for Human Cognitive and Brain Sciences, Germany

5:00-5:20 Modeling Gnrh Neuronal Dynamics in Response to Kisspeptin Stimulation

Jonas Lehnert and Anmar Khadra, McGill University, Canada

5:25-5:45 A GSPT Approach in a Breakspear & Friston Like Model

Jose Mujica and Pablo Aguirre, Universidad Técnica Federico Santa María, Chile; Patricio Orio, Universidad de Valparaiso, Chile

5:50-6:10 Computational Approaches for Multistable Rhythms in Modular Neural Networks

Krishna Pusuluri, Sunitha Basodi, and Andrey Shilnikov, Georgia State University, U.S.

6:15-6:35 Mathematical Treatment of Action Potential Propagation in Axonal Fibre Bundles

Helmut Schmidt and Thomas Knoesche, Max Planck Institute for Human Cognitive and Brain Sciences, Germany

SIADS Editorial Board Meeting

6:30 p.m.-8:30 p.m.

Room: Twin Peaks A - 10th Floor

Dinner Break

6:40 p.m.-8:30 p.m.

Attendees on their own

Tuesday, May 21

PP1

Poster Session and Dessert Reception

8:30 p.m.-10:30 p.m.

Room: Ballroom

A Mathematical Model for Sea Slug Swim CPGs

Deniz Alacam, Uludag University, Turkey; Akira Sakurai, Georgia State University, U.S.; Paul Katz, University of Massachusetts, Amherst, U.S.; Andrey Shilnikov, Georgia State University, U.S.

Dynamics of a Producer-Grazer Model Incorporating the Effects of Phosphorus Loading on Grazer's Growth

Lale Asik and Angela Peace, Texas Tech University, U.S.

Symbolic Representation of Neuronal Dynamics and Network Behaviors

Sunitha Basodi, Krishna Pusuluri, and Andrey Shilnikov, Georgia State University, U.S.

Adaptive Models for Collective Decision Making in Swarms

Subekshya Bidari, University of Colorado Boulder, U.S.

Synaptic Dynamics and Bursting in Neural Networks

Jassem N. Bourahmah, Georgia State University, U.S.

The 3D Painlevé Paradox

Noah D. Cheesman, University of Bristol, United Kingdom; John Hogan, Bristol Centre for Applied Nonlinear Mathematics and University of Bristol, United Kingdom

Sampling Centrality Measures of Temporal Networks with Continuous Time Scales

Regino Criado Herrero, Julio Flores Álvarez, and Miguel Romance del Río, Universidad Rey Juan Carlos, Spain

Dynamics of Delayed Mathematical Model of Tumor Growth

Parthasakha Das, Indian Institute of Engineering Science and Technology, India

Leveraging Topological and Geometric Features of Sunspots for Solar Flare Prediction

Elizabeth Bradley, University of Colorado, Boulder and Santa Fe Institute, U.S.; *Varad Deshmukh*, University of Colorado, U.S.; James D. Meiss, University of Colorado Boulder, U.S.; Thomas Berger and Maxine Hartnett, University of Colorado, U.S.

continued in next column

Macroscopic Analysis of a Neural Network in the Olfactory Bulb Using Equation-Free Methods

Anna Dittus, University of Rostock, Germany; Jens Starke, Technical University of Denmark, Denmark

Reconstruction a 2D Incompressible Flow Field Based on Sparse Frequency-Domain Measurements

Mojtaba F. Fathi and Roshan Dsouza, University of Wisconsin, Milwaukee, U.S.

Principles for Making Half-Center Oscillators

Huiwen Ju, Georgia State University, U.S.; *Luwei Ge*, Georgia Institute of Technology, U.S.; Andrey Shilnikov, Georgia State University, U.S.

The Efficiency of Food Distribution via Trophallaxis in Honeybees: An Agent-Based Model Approach

Elizabeth Bradley, University of Colorado, Boulder and Santa Fe Institute, U.S.; *Golnar Gharooni*, University of Colorado, U.S.; Charlotte Gorgemans, Boulder High School, U.S.; Orit Peleg, BioFrontiers Institute, University of Colorado, U.S.

Dynamic Complexity of Two Coupled Photonic Crystal Nanocavities

Andrus A. Giraldo, Bernd Krauskopf, and Neil Broderick, University of Auckland, New Zealand; Alejandro Giacomotti and Ariel Levenson, Center Nanosciences Et Nanotechnologies, France

Data-Driven Order Parameters for Coupled Oscillator Models

Oscar Goodloe and Joel D. Nishimura, Arizona State University, U.S.

A Closed-Form Solution of How the Differential Equation for Tendon Dynamics Affects Kinematic Approximations of Muscle Lengths

Daniel A. Hagen, University of Southern California, U.S.

Adapting Foraging Strategies in a Heterogeneous Environment

Samantha C. Hill and Frederick Adler, University of Utah, U.S.

continued in next column

A Wave of Locusts

Maryann Hohn, University of California, Santa Barbara, U.S.; Andrew J. Bernoff, Harvey Mudd College, U.S.; Michael Culshaw-Maurer, University of California, Davis, U.S.; Rebecca Everett, Haverford College, U.S.; Christopher Strickland, University of Tennessee, Knoxville, U.S.; Jasper Weinburd, University of Minnesota, Twin Cities, U.S.

Teaching Dynamical Systems: a Flipped Class with Limited Prerequisites

Sarah Iams, Harvard University, U.S.

Frequency Response Analysis of Mosquito Swarming over a Marker

Puneet Jain, Brigham Young University, U.S.; Sachit Butail, Northern Illinois University, U.S.

Parameter Estimation in ODEs with Neural Networks

Manu Kalia, University of Twente, Netherlands

Computational Techniques for Analytic Solution of Delay Differential Equations

Rajinder Kaur, Trinity College, Jalandhar, India

A Transfer-Operator Based Computational Study of Periodically Forced Mixers

Anna Klünker, Leuphana University of Lüneburg, Germany; Kathrin Padberg-Gehle, Leuphana University Lueneburg, Germany

Data Assimilation with Adaptive Moving Meshes

Cassidy Krause, University of Kansas, U.S.; Colin Guider, University of North Carolina at Chapel Hill, U.S.; Nikhil Shankar, University of Michigan, Ann Arbor, U.S.; Erik Van Vleck, University of Kansas, U.S.

Mixing in Cutting and Shuffling Systems with Diffusion

Hannah E. Kreczak, Rob Sturman, and Mark C.T. Wilson, University of Leeds, United Kingdom

Numerical Continuation of Amplitude Vacillating Flow in Sheared Annular Electroconvection

Gregory M. Lewis, University of Ontario Institute of Technology, Canada; Mary Pugh and Stephen Morris, University of Toronto, Canada

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Mathematical Models and Tools for Understanding the Entrainment of Hierarchical Circadian Systems

Guangyuan Liao, Casey Diekman, and Amitabha Bose, New Jersey Institute of Technology, U.S.

A Reduced Order Mathematical Model of Platelet Aggregation in an Extravascular Injury and the Effects of ADP-Dependent Platelet Activation

Kathryn G. Link and Aaron L. Fogelson, University of Utah, U.S.; Karin Leiderman and Nicholas A. Danes, Colorado School of Mines, U.S.

A Pharmacokinetic Model of Lead-Calcium Interactions

Tucker Lundgren and Anca Radulescu, State University of New York, New Paltz, U.S.

Host-Pathogen Dynamics: Quantifying Process-Level Variation using a System-Specific Dynamical Model in a Non-Linear Mixed Effects Modeling Framework

Catalina M. Medina, Paul J. Hurtado, and Deena Schmidt, University of Nevada, Reno, U.S.

The Dynamical and Biophysical Mechanism for Camp Overshoot in Ventricular Myocytes Following β_1-Adrenergic Stimulation

Emily E. Meyer, Tim Lewis, and Colleen Clancy, University of California, Davis, U.S.

Dynamics from Ranking Problems

William G. Mitchener, College of Charleston, U.S.

Community Structure and Structural Balance in Signed Networks

Megan J. Morrison and Michael Gabbay, University of Washington, U.S.

Topological Vortex Dynamics Described with Bifurcation Theory

Anne R. Nielsen, Technical University of Denmark, Denmark; Matthias Heil, University of Manchester, United Kingdom; Morten Andersen, Roskilde University, Denmark; Morten Brøns, Technical University of Denmark, Denmark

Sensing Environmental Changes using Plankton

Vito Pastore, IBM Research, U.S.

Relaxation Oscillations in the MAPK-Cascade

Stefan Portisch and Peter Szmolyan, Technische Universität Wien, Austria

continued in next column

Melnikov Theory for 2D Manifolds of Three Dimensional Non-Volume Preserving Flows

Kanaththa G. Priyankara and Erik Bollt, Clarkson University, U.S.; Sanjeeva Balasuriya, University of Adelaide, Australia

Data Fusion Reconstruction of Spatially Embedded Complex Networks

Fernando J. Quevedo, Jie Sun, and Erik Bollt, Clarkson University, U.S.

On Edge's PageRank, Hashimoto Non-Backtracking Matrix and Multilayer Networks

Regino Criado Herrero, Julio Flores Álvarez, Alejandro García del Amo Jiménez, and *Miguel Romance del Río*, Universidad Rey Juan Carlos, Spain

Temporal Patterning of Intermittent Synchronization Between Coupled Predator-Prey Oscillators

Leonid Rubchinsky, Indiana University-Purdue University Indianapolis (IUPUI), U.S.; Sungwoo Ahn, East Carolina University, U.S.

Management Practices on Flow Kick Dynamics

Maria I. Sanchez Muniz, Kate Meyer, and Andrew Brettin, University of Minnesota, Twin Cities, U.S.; Richard McGehee, University of Minnesota, U.S.; Mary Lou Zeeman and James Broda, Bowdoin College, U.S.; Sarah Iams, Harvard University, U.S.; John Mangles, University of Kansas, U.S.; Alana Hoyer-Leitzel, Mount Holyoke College, U.S.

Synchrony: From Franklin Bells to Brain Dynamics

Mustafa Sayli, Yi Ming Lai, Rüdiger Thul, and Stephen Coombes, University of Nottingham, United Kingdom

A New Computational Approach for the Solutions of Dynamical Systems with Impulsive Effects

Palwinder Singh, Lyallpur Khalsa College, Jalandhar, India

The Lotka Model: One Century Later

Gessner A. Soto, University of Colorado, U.S.

Data-Driven Reduced-Order Modeling for Select Features of Complex Flows

Vivian Steyert and Clarence Rowley, Princeton University, U.S.

On the Analysis of Earthquakes using Mutual Information

Amila N. Sudu Ambegedara, Jie Sun, and Erik Bollt, Clarkson University, U.S.

continued in next column

Finding Complete Characterizations Of Explicit Symmetry Breaking

Calley L. Tinsman and Timothy K. Callahan, Embry-Riddle Aeronautical University, U.S.

A Mathematical Model of Flagellar Gene Regulation and Construction in *Salmonella Enterica*

Kiersten Utsey and James P. Keener, University of Utah, U.S.

Network Analyses of 4D Genome Polymer Models Automate Detection of Community-Scale Gene Organization

Benjamin L. Walker, University of North Carolina at Chapel Hill, U.S.; Dane Taylor, State University of New York, Buffalo, U.S.; Josh Lawrimore, University of North Carolina at Chapel Hill, U.S.; Caitlin Hult, University of Michigan, U.S.; David Adalsteinsson, University of North Carolina at Chapel Hill, U.S.; Kerry Bloom, University of North Carolina, U.S.; Gregory Forest, University of North Carolina at Chapel Hill, U.S.

Multilevel Monte Carlo for Spiking Networks

Zhuocheng Xiao, University of Arizona, U.S.; Kevin K. Lin, University of Arizona, U.S.

The Initiation of Cytoplasmic Streaming and Locomotion by Mechanochemical Instability

Hongtao Xue and Robert D. Guy, University of California, Davis, U.S.

A Nonlinear Dynamical Systems Approach to Bird Song Analysis

Xiao Zeng, Eve Armstrong, and Marc Schmidt, University of Pennsylvania, U.S.; David White, Wilfrid Laurier University, Canada; Vijay Balasubramanian, University of Pennsylvania, U.S.

Logic Behind Neural Control of Breathing Pattern

Yunjiao Wang, Texas Southern University, U.S.; Alona Ben-Tal, Massey University, New Zealand; Maria Leite, University of South Florida, St. Petersburg, U.S.

Wednesday, May 22

Registration

7:45 a.m.-5:30 p.m.

Room: Ballroom Foyer

Wednesday, May 22

MS123

Complex Systems Science Meets Machine Learning - Part I of II

8:00 a.m.-9:40 a.m.

Room: Ballroom 3

For Part 2 see MS127

Complex dynamical systems in various fields, from engineering to neuroscience and climatology to social science are typically high-dimensional and often their known mathematical models are incomplete. Therefore, the treatment of basic modelling issues, as dimension reduction, forecasting, or detection of special features, for such systems by means of established techniques from complex systems science often fails. There is a broad activity today across the sciences to combine and complement existing techniques with insights and algorithms from machine learning. In this MS different hybrid methods will be presented for data-based modelling, model reduction, forecasting of even extreme events and controlling of such systems. Such exploratory approaches, even though increasingly popular and truly promising, are in many ways "in its infancy" and there are several crucial open problems which will be also emphasized.

Organizer: Juergen Kurths

Potsdam Institute for Climate Impact Research and Humboldt University Berlin, Germany

8:00-8:20 Emergent Space, Emergent Time - Data with Hidden Internal Order and Manifold Learning

Ioannis Kevrekidis, Johns Hopkins University, U.S.

8:25-8:45 Complex Network and Machine Learning Techniques for Extreme Climatic Events

Juergen Kurths, Potsdam Institute for Climate Impact Research and Humboldt University Berlin, Germany

8:50-9:10 Machine Learning Analysis and Prediction of Chaotic Systems

Edward Ott, University of Maryland, U.S.

9:15-9:35 Machine Learning in Controlling Coupled Complex Systems

Yang Tang, East China University of Science and Technology, China

Wednesday, May 22

MS124

Mathematical Modeling of Human Dynamics - Part I of II

8:00 a.m.-9:40 a.m.

Room: Magpie B

For Part 2 see MS128

The dynamics of social human interaction shape everything from our response to emergency situations to how we evolve as a society. However, the ability to predict how an individual or a group will react to a certain situation is a difficult feat. In this respect, mathematical models of individual and collective human behavior form a first step in testing and postulating complex hypotheses. These models have applications in the design of emergency response systems and in building evacuation, management of large crowds, and in drafting public policies. This two-part minisymposium brings together recent theoretical and empirical approaches in the study of human individual and social dynamics across a variety of contexts. On the theoretical side we will discuss agent-based and continuum models of pedestrian movement, lost person dynamics, and emotional contagion in high-stress crowds. On the experimental side we will tease out the dependence of human movement on bottlenecks and social influence, analyze the dynamics of opinion formation in social networks, and discuss human emotion generation in the presence of aversive stimuli.

Organizer: Alethea Barbaro

Case Western Reserve University, U.S.

Organizer: Sachit Butail

Northern Illinois University, U.S.

8:00-8:20 Temporal Dynamics of Human Emotional Response to Aversive Stimuli

Sachit Butail, Joseph Kempel, and David Bridgett, Northern Illinois University, U.S.

8:25-8:45 A Kinetic Contagion Model for Fearful Crowds

Daniel Balagué, Case Western Reserve University, U.S.

8:50-9:10 How Curvature Measures and Geometric Structure Influence the Movement of Information in Social Groups

James E. McClure, Virginia Tech, U.S.

continued on next page

9:15-9:35 Influence of Social Information on Network Dynamics in Human Groups

Shinnosuke Nakayama and Elizabeth Krasner, New York University Tandon School of Engineering, U.S.; Lorenzo Zino, Politecnico di Torino, Italy; Maurizio Porfiri, New York University Tandon School of Engineering, U.S.

Wednesday, May 22

CP20

Entropy and Information

8:00 a.m.-9:40 a.m.

Room: Ballroom 1

Chair: Alice C. Schwarze, University of Oxford, United Kingdom

8:00-8:20 A Dynamical Systems Based Hierarchy for Shannon, Metric and Topological Entropy

Raymond Addabbo, Vaughn College of Aeronautica and Technology, U.S.; Denis Blackmore, New Jersey Institute of Technology, U.S.

8:25-8:45 On the Automatic Parameter Selection for Permutation Entropy

Audun D. Myers and Firas A. Khasawneh, Michigan State University, U.S.

8:50-9:10 Framework for An Ensemble-Based Topological Entropy Calculation in Three Dimensions

Eric Roberts and Suzanne Sindi, University of California, Merced, U.S.; Spencer Smith, Mount Holyoke College, U.S.; Kevin Mitchell, University of California, Merced, U.S.

9:15-9:35 Entropy and Functional Redundancy in Biological Networks

Alice C. Schwarze, University of Oxford, United Kingdom; Jonny Wray, e-Therapeutics Plc, United Kingdom; Mason A. Porter, University of California, Los Angeles, U.S.

Wednesday, May 22

CP21

Data and Dynamics

8:00 a.m.-9:40 a.m.

Room: Ballroom 2

Chair: Jeffrey Tithof, University of Rochester, U.S.

8:00-8:20 On the Continuous Time Limit of the Ensemble Kalman Filter

Theresa Lange and Wilhelm Stannat, Technische Universität Berlin, Germany

8:25-8:45 Identification of Distributed Parameters in Size-Structured Aerosol Populations Using Bayesian State Estimation

Matthew Ozon, University of Eastern Finland, Finland; Jari Kaipio, University of Auckland, New Zealand; Aku Seppänen and Kari Lehtinen, University of Eastern Finland, Finland

8:50-9:10 Efficiently Quantifying Chaotic Advection in Sparse Trajectory Data

Spencer A. Smith, Sue Shi, and Nguyen Nguyen, Mount Holyoke College, U.S.; Eric Roberts, Kevin Mitchell, and Suzanne Sindi, University of California, Merced, U.S.

9:15-9:35 Temporal Asymmetry of Lagrangian Coherent Structures

Jeffrey Tithof, University of Rochester, U.S.; Balachandra Suri, Institute of Science and Technology, Austria; Michael Schatz and Roman Grigoriev, Georgia Institute of Technology, U.S.; Douglas H. Kelley, University of Rochester, U.S.

Wednesday, May 22

CP22

Fluid Dynamics and Geophysics

8:00 a.m.-9:40 a.m.

Room: Magpie A

Chair: Roland Welter, Boston University, U.S.

8:00-8:20 Theory and Computation of Nonlinear Deformation Spectra of Flows with Geophysical Applications

Siavash Ameli and Shawn Shadden, University of California, Berkeley, U.S.

8:25-8:45 Stability Analysis of the Maas Ocean Model

Siddhartha Bishnu, Florida State University, U.S.; Joseph Schoonover, Fluid Numerics LLC, U.S.

8:50-9:10 Well-Posedness and Long-Time Dynamics of the Rotating Boussinesq and Quasigeostrophic Equations: Recent Past and Proximate Future

Maleafisha S. Tladi, University of Limpopo, South Africa

9:15-9:35 Decay Profiles of a Linear System Associated with the Compressible Navier Stokes Equations

Roland Welter, Eugene Wayne, and Ryan Goh, Boston University, U.S.

Wednesday, May 22

CP23

Chaos and Related Topics

8:00 a.m.-9:40 a.m.

Room: Wasatch A

Chair: Jim Wiseman, Agnes Scott College, U.S.

8:00-8:20 Using Machine Learning to Separate Chaotic Signals: A Chaos Version of the Cocktail Party Problem

Sanjukta Krishnagopal, University of Maryland, College Park, U.S.; Edward Ott, University of Maryland, U.S.; Michelle Girvan, University of Maryland, College Park, U.S.; Brian Hunt, University of Maryland, U.S.

8:25-8:45 Exploring Chaotic Motion Through Dynamically-Evolving Reference Frames

Matthew A. Morena, Christopher Newport University, U.S.

8:50-9:10 Bounding Lyapunov Exponents Using Semidefinite Programming

Hans Oeri and David Goluskin, University of Victoria, Canada

9:15-9:35 Generalized Transitivity and Mixing

Jim Wiseman, Agnes Scott College, U.S.

Wednesday, May 22

CP24

Numerics and PDEs

8:00 a.m.-9:40 a.m.

Room: Wasatch B

Chair: Sarita Nandal, Indian Institute of Technology Roorkee, India

8:00-8:20 Error Estimates and 2nd Order Corrections to Approximate Fluid Models

Bin Cheng, University of Surrey, United Kingdom

8:25-8:45 A Deferred Correction with Penalty Projection Method for Magnetohydrodynamics

Dilek Erkmen, Michigan Technological University, U.S.; Songul Kaya Merdan, Middle East Technical University Ankara, Turkey

8:50-9:10 Blade-Vortex Interaction Numerical Study Using Potential Flow Theory and Neural Networks

Ionut E. Iacob, Marcel Ilie, and Alex Stokolos, Georgia Southern University, U.S.

9:15-9:35 A New Compact Difference Scheme of Second Order for Variable Order Fractional Sub-Diffusion Wave Equation

Sarita Nandal and Dwijendra Narian Pandey, Indian Institute of Technology Roorkee, India

Wednesday, May 22

CP25

Bifurcations II

8:00 a.m.-9:40 a.m.

Room: Maybird

Chair: Shreya Sehgal, Liverpool Hope University, United Kingdom

8:00-8:20 The Geometry of Rest-Spike Bistability

Giuseppe Ilario Cirillo and Rodolphe Sepulchre, University of Cambridge, United Kingdom

8:25-8:45 Homoclinic Saddle to Saddle-Focus Transitions in Four Dimensional Systems

Hil Meijer and Manu Kalia, University of Twente, Netherlands; Yuri Kuznetsov, Utrecht University and University of Twente, Netherlands

8:50-9:10 On the Effect of Invisibility of Stable Periodic Orbits at Homoclinic Bifurcations

Ivan Ovsyannikov, University of Hamburg, Germany; Sergey Gonchenko, Lobachevsky State University of Nizhny Novgorod, Russia; Dmitry Turaev, Imperial College London, United Kingdom

9:15-9:35 Bifurcation Analysis of Spiral Waves

Shreya Sehgal and Andrew Foulkes, Liverpool Hope University, United Kingdom

Wednesday, May 22

CP26

Nonsmooth Systems

8:00 a.m.-8:50 a.m.

Room: Superior A

8:00-8:20 One-Dimensional Stochastic Reaction Networks: Classification and Dynamics

Mads Christian Hansen, Carsten Wiuf, and *Chuang Xu*, University of Copenhagen, Denmark

8:25-8:45 Most Probable Tipping Events in a Noisy Piecewise Linear System with Periodic Forcing

Jessica Zanetell, University of Arizona, U.S.; John Gemmer, Wake Forest University, U.S.

Wednesday, May 22

CP27

Networks II

8:00 a.m.-9:40 a.m.

Room: Superior B

Chair: Ben Z. Webb, Brigham Young University, U.S.

8:00-8:20 D-Chain Tomography: a New Structure Spectrum for the Study of Network Dynamics

Ricky X. Chen, University of Virginia, U.S.; *Andrei Bura*, Virginia Tech, U.S.; Christian Reidys, Biocomplexity Institute, U.S.

8:25-8:45 Optimal Control of Stochastic Temporal Networks

Anna Di Meglio, Pietro De Lellis, Franco Garofalo, and Francesco Lo Iudice, University of Naples Federico II, Italy

8:50-9:10 Exoplanetary Mass Constraints Based on Topology of Interacting Networks

Tamás Kovács, Eötvös University, Hungary

9:15-9:35 Specialization Models of Network Growth

Ben Z. Webb, Brigham Young University, U.S.; Leonid Bunimovich, Georgia Institute of Technology, U.S.; Dallas Smith, Brigham Young University, U.S.

Wednesday, May 22

CP28

Delay Differential Equations II

8:00 a.m.-9:40 a.m.

Room: White Pine

Chair: Adam K. Kiss, Budapest University of Technology and Economics, Hungary

8:00-8:20 Periodic and Quasi-Periodic Orbit Optimization in Dynamical Systems with Delay

Zaid Ahsan and Mingwu Li, University of Illinois, Urbana-Champaign, U.S.; Harry Dankowicz, University of Illinois at Urbana-Champaign, U.S.; Jan Sieber, University of Exeter, United Kingdom

8:25-8:45 A Recipe for State Dependent Distributed Delay Differential Equations

Tyler Cassidy and Antony Humphries, McGill University, Canada; Morgan Craig, Université de Montréal, Canada

8:50-9:10 Centre Manifolds for Impulsive Delay Differential Equations: Approximation and Applications

Kevin Church, University of Waterloo, Canada

9:15-9:35 Bistabilities in Nonlinear Delayed Systems: Saturation Effects in Connected Automated Vehicle Design

Adam K. Kiss, Budapest University of Technology and Economics, Hungary; Sergei S. Avedisov, University of Michigan, Ann Arbor, U.S.; Daniel Bachrathy, Budapest University of Technology and Economics, Hungary; Gábor Orosz, University of Michigan, Ann Arbor, U.S.

Wednesday, May 22

CP29

Topological Data Analysis

8:00 a.m.-9:15 a.m.

Room: Primrose A

Chair: Sarah J. Tymochko, Michigan State University, U.S.

8:00-8:20 Featurization of Persistence Diagrams for Classifying Attractors

Elizabeth Munch, Firas A. Khasawneh, and Jose Perea, Michigan State University, U.S.

8:25-8:45 Chaos Detection Through Persistent Homology

Josh R. Tempelman and Firas A. Khasawneh, Michigan State University, U.S.

8:50-9:10 Using Persistent Homology to Quantify Periodic Circular Structures in Dynamic Image Data

Sarah J. Tymochko and Elizabeth Munch, Michigan State University, U.S.; Jason Dunion, University of Miami, U.S.; Kristen Corbosiero and Ryan Torn, State University of New York, Albany, U.S.

Wednesday, May 22

CP30

Ecology

8:00 a.m.-9:40 a.m.

Room: Primrose B

8:00-8:20 Fitness Dependence of the Fixation Time Distribution in Solvable Evolutionary Birth-Death Processes

David Hathcock and Steven H. Strogatz, Cornell University, U.S.

8:25-8:45 Number and Stability of Relaxation Oscillations for Predator-Prey Systems with Small Death Rates

Ting-Hao Hsu, University of Miami, U.S.; Gail S. K. Wolkowicz, McMaster University, Canada

8:50-9:10 Spatial Effects in Savanna Dynamics

Denis D. Patterson and Jonathan Touboul, Brandeis University, U.S.; Carla Staver, Yale University, U.S.; Simon Levin, Princeton University, U.S.

9:15-9:35 Evolutionary Dynamics of a Spatiotemporal Stoichiometric Producer-Grazer Systems

Md Masud Rana, Texas Tech University, U.S.; Chandani Dissanayake, Sri Lanka Technological Campus, Sri Lanka; Lourdes Juan, Kevin Long, and Angela Peace, Texas Tech University, U.S.

Workshop on Network Science: Welcome Remarks

8:50 a.m.-9:00 a.m.

Room: Cottonwood C & D - Snowbird Center

Wednesday, May 22

IP100

Workshop on Network Science: From Single Networks to Networks of Networks

9:00 a.m.-9:45 a.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

Network science has been focused on the properties of a single isolated network that does not interact or depends on other networks. I will present several applications of networks in physiology, traffic, climate, and epidemics. In reality, many real networks, such as the power grid, protein networks, transportation, and communication infrastructures interact and depend on each other. I will present a framework for studying the vulnerability of networks of interacting networks. In interdependent networks, when nodes in one network fail, they cause dependent nodes in other networks to also fail. This may lead to a cascade of failures and to a sudden fragmentation of the system. I will present analytical solutions for the critical threshold and the giant component of a network of N interdependent networks. I will show, that the general theory has many novel features that are not present in the classical network theory. I will also show that interdependent networks embedded in space are significantly more vulnerable compared to random networks.

Shlomo Havlin
Bar-Ilan University, Israel

Coffee Break

9:40 a.m.-10:10 a.m.

Room: Golden Cliff

Wednesday, May 22

CP100

Workshop on Network Science: Contributed Session 1

9:50 a.m.-10:40 a.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

9:50-10:10 A Preferential Attachment Graph Model with Triangles

Nicole Eikmeier and David F. Gleich, Purdue University, U.S.

10:15-10:35 Optimal Structure and Parameter Learning of Ising Models

Andrey Lokhov, Marc Vuffray, Sidhant Misra, and Michael Chertkov, Los Alamos National Laboratory, U.S.

Remarks

10:10 a.m.-10:15 a.m.

Room: Ballroom

Wednesday, May 22

IP6

Biological Fluid Mechanics: Hydrodynamically-coupled Oscillators

10:15 a.m.-11:00 a.m.

Room: Ballroom

Chair: Lennaert van Veen, University of Ontario Institute of Technology, Canada

Respiratory cilia that transport mucus in the lungs, spermatozoa that collectively move through the female reproductive tract, paddling appendages that propel a crawfish, and fish swimming in a school are all examples of oscillators that exert force on a surrounding fluid. Do the synchronous or phase-shifted periodic motions that we observe arise due to hydrodynamic coupling? We will discuss experiments and models of the self-organized pattern of beating flagella and cilia — from minimal models of colloidal particles driven by optical traps to more detailed models that include dynamics of the molecular motors driving the motion. We will also examine the role of fluid inertia on the dynamics of synchronization of such systems.

Lisa J. Fauci
Tulane University, U.S.

Workshop on Network Science: Coffee Break

10:40 a.m.-11:00 a.m.

Room: Cottonwood A & B - Snowbird Center

Wednesday, May 22

CP101

Workshop on Network Science: Contributed Session 2

11:00 a.m.-11:50 a.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

11:00-11:20 Node Connectivity and Centrality Drive Pathogen Spread in Human Mobility Networks

Brandon A. Lieberthal, University of Maine, U.S.; Aiman Soliman, University of Illinois at Urbana-Champaign, U.S.; Sandra De Urioste-Stone, University of Maine, U.S.; Shaowen Wang, University of Illinois at Urbana-Champaign, U.S.; Allison Gardner, University of Maine, U.S.

11:25-11:45 Concurrency and Reachability in Tree-Like Temporal Networks

Eun Lee, Scott Emmons, and Ryan Gibson, University of North Carolina at Chapel Hill, U.S.; James Moody, Duke University, U.S.; Peter J. Mucha, University of North Carolina, U.S.

Wednesday, May 22

IP7

Inference in Dynamical Systems: The Thermodynamic Formalism and Bayesian Inference

11:00 a.m.-11:45 a.m.

Room: Ballroom

Chair: Scott McKinley, Tulane University, U.S.

We consider inference of dynamical systems from ergodic observations using a general Bayesian framework for updating belief distributions using a loss function, called Gibbs posterior inference. Suppose that make observations of an ergodic system, and we attempt to model the system by a parametrized family of Gibbs measures on a mixing shift of finite type. For fixed loss function and prior distribution on the parameter space, we characterize the asymptotic behavior of the Gibbs posterior distribution on the parameter space as the number of observations tends to infinity In particular, we de fine a limiting variational problem over the space of joinings of the model system with the observed system, and we show that the Gibbs posterior distributions concentrate around the solution set of this variational problem. Our convergence results hold in general misspecified settings, and our examples illustrate that in the properly specified case they may be used to establish posterior consistency. This work establishes tight connections between Gibbs posterior inference and the thermodynamic formalism, which may inspire new proof techniques in the study of Bayesian posterior consistency for dependent processes. Joint work with Kevin McGoff, UNC Charlotte and Andrew Nobel, UNC Chapel Hill.

Sayan Mukherjee
Duke University, U.S.

Lunch Break

11:45 a.m.-1:00 p.m.

Attendees on their own

Workshop on Network Science: Lunch Break

11:50 a.m.-1:20 p.m.

Attendees on their own

Wednesday, May 22

MS125

Feedback Mechanisms in Climate: The Maths and the Consequences - Part I of II

1:00 p.m.-2:40 p.m.

Room: Ballroom 1

For Part 2 see MS136

In many climate systems, processes interact to form positive (destabilising) or negative (stabilising) feedback loops, which play pivotal roles for the stability and sensitivity of climate phenomena. The importance of feedback mechanisms cannot be overstated. The speeds of the processes involved determine important timescales of the climate system and it has been suggested that feedback mechanisms are behind many, possibly most, of the nonlinearities in the climate. In this minisymposium, several studies of climate systems driven by feedback mechanisms will be presented, including planetary energy balance and the El Niño Southern Oscillation. The presentations will showcase a variety of mathematical modelling and analysis techniques, such as delay differential equation and slow-fast reductions, each delivering valuable insights into the inner-workings of complex climate systems.

Organizer: Andrew Keane
University of Auckland, New Zealand

Organizer: Bernd Krauskopf
University of Auckland, New Zealand

1:00-1:20 Climate System Feedbacks and Their Role in Projections of Future Climate Change

Henk A. Dijkstra, Utrecht University, The Netherlands

1:25-1:45 A Mid Pleistocene Transition by Frequency Locking in a Zonal Energy Balance Model with Ice Extent

Esther Widiasih, University of Hawaii, West Oahu, U.S.; Anna M. Barry, University of Auckland, New Zealand; Malte Stuecker, Pusan National Univeristy, South Korea; Andrew Keane, University of Auckland, New Zealand

1:50-2:10 Bifurcations and Multi-Frequency Tipping in a Periodically Forced Delay Differential Equation

Andrew Keane and Bernd Krauskopf, University of Auckland, New Zealand

2:15-2:35 Stable Asymmetric Ice Belts in An Energy Balance Model of Pluto

Alice Nadeau and Emma Jaschke, University of Minnesota, U.S.

Wednesday, May 22

MS126

Numerical Measures of Chaos and Regularity

1:00 p.m.-2:40 p.m.

Room: Ballroom 2

Hamiltonian systems and low-dimensional maps often have a complex mixture of regular and chaotic orbits. In this minisymposium the speakers will discuss numerical methods for computing properties of these orbits. It is common to classify orbits as chaotic using positive Lyapunov exponents. Accurate computation of these exponents is difficult, and a number of finite-time techniques, such as the Fast Lyapunov Indicators give more efficient methods for distinguishing chaotic orbits and various classes of regular orbits. Regular orbits in these systems often lie on invariant tori and have dynamics that is conjugate to a rigid rotation. Though invariant tori are known to exist for systems that are nearly integrable (by KAM theory), the parameterization method gives a computationally efficient, provably convergent method for computing tori with given rotation vectors, even far from integrability. By contrast, if one wants to find the set of rotation vectors for which there are regular orbits, methods of frequency analysis based on smoothed Fourier techniques can be used. More recently, regularized Birkhoff average techniques have been shown to give highly accurate computations of rotation vectors, when they exist, and to give a sharp distinction between initial conditions on tori and those that are chaotic. Such methods can lead to a better understanding of the set of phase space foliated by tori and the properties of the rotation vectors that correspond to robust tori.

Organizer: Evelyn Sander
George Mason University, U.S.

Organizer: James D. Meiss
University of Colorado Boulder, U.S.

1:00-1:20 The Parameterization Method for Computing Periodic and Quasi-Periodic Orbits in Symplectic Maps without Using Symmetries

Renato Calleja, Universidad Nacional Autónoma de México, Mexico; Diego Del Castillo-Negrete, Oak Ridge National Laboratory, U.S.; David Martínez del Río and Olvera Arturo, IIMAS - UNAM, Mexico

continued in next column

1:25-1:45 Numerical Measures of Heterogeneity and Regularity of Chaotic Systems

James A. Yorke, University of Maryland, U.S.

1:50-2:10 Rotation Vectors for Invariant Tori Using Weighted Birkhoff Averages

Evelyn Sander, George Mason University, U.S.

2:15-2:35 Visualizing Chaotic and Regular Orbits in Three and Four Dimensional Maps

James D. Meiss, University of Colorado Boulder, U.S.; Arnd Baecker, Institut für Theoretische Physik, Germany; Nathan Guillery, University of Colorado Boulder, U.S.

Wednesday, May 22

MS127

Complex Systems Science Meets Machine Learning - Part II of II

1:00 p.m.-2:40 p.m.

Room: Ballroom 3

For Part 1 see MS123

Complex dynamical systems in various fields, from engineering to neuroscience and climatology to social science are typically high-dimensional and often their known mathematical models are incomplete. Therefore, the treatment of basic modelling issues, as dimension reduction, forecasting, or detection of special features, for such systems by means of established techniques from complex systems science often fails. There is a broad activity today across the sciences to combine and complement existing techniques with insights and algorithms from machine learning. In this MS different hybrid methods will be presented for data-based modelling, model reduction, forecasting of even extreme events and controlling of such systems. Such exploratory approaches, even though increasingly popular and truly promising, are in many ways “in its infancy” and there are several crucial open problems which will be also emphasized.

Organizer: Juergen Kurths
Potsdam Institute for Climate Impact Research and Humboldt University Berlin, Germany

1:00-1:20 A New View on Integrability: On Matching Dynamical Systems Through Koopman Operator Eigenfunctions

Erik Bollt, Clarkson University, U.S.; Li Qianxiao, Institute of High Performance Computing, Agency for Science, Singapore; Felix Dietrich, Johns Hopkins University, U.S.; Yannis Kevrekidis, Princeton University, U.S.

1:25-1:45 On the Koopman Operator of Algorithms

Felix Dietrich, Johns Hopkins University, U.S.; Thomas N. Thiem, Princeton University, U.S.; Ioannis Kevrekidis, Johns Hopkins University, U.S.

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Wednesday, May 22

MS127

Complex Systems Science Meets Machine Learning - Part II of II

continued

1:50-2:10 Data-Assisted Reduced-Order Modelling of Complex Dynamical Systems

Themistoklis Sapsis and Zhong Yi Wan, Massachusetts Institute of Technology, U.S.; Pantelis Vlachas and Petros Koumoutsakos, ETH Zürich, Switzerland

2:15-2:35 Dynamical Aspects of Reservoir Computing

Thomas Lymburn, Thomas Jungling, Thomas Stemler, Debora Correa, and *Michael Small*, University of Western Australia, Australia

Wednesday, May 22

MS128

Mathematical Modeling of Human Dynamics - Part II of II

1:00 p.m.-2:40 p.m.

Room: Magpie B

For Part 1 see MS124

The dynamics of social human interaction shape everything from our response to emergency situations to how we evolve as a society. However, the ability to predict how an individual or a group will react to a certain situation is a difficult feat. In this respect, mathematical models of individual and collective human behavior form a first step in testing and postulating complex hypotheses. These models have applications in the design of emergency response systems and in building evacuation, management of large crowds, and in drafting public policies. This two-part minisymposium brings together recent theoretical and empirical approaches in the study of human individual and social dynamics across a variety of contexts. On the theoretical side we will discuss agent-based and continuum models of pedestrian movement, lost person dynamics, and emotional contagion in high-stress crowds. On the experimental side we will tease out the dependence of human movement on bottlenecks and social influence, analyze the dynamics of opinion formation in social networks, and discuss human emotion generation in the presence of aversive stimuli.

Organizer: Sachit Butail

Northern Illinois University, U.S.

Organizer: Alethea Barbaro

Case Western Reserve University, U.S.

1:00-1:20 Queuing Or Pushing: Pedestrian Behavior in Front of Bottlenecks

Juliane Adrian, Forschungszentrum Jülich, Germany

1:25-1:45 Robust Social Forces in Agent-Based Models of Crowds

Poul G. Hjorth, Frank Schilder, and Jens Starke, Technical University of Denmark, Denmark

1:50-2:10 Modeling Lost Person Dynamics for Wilderness Search and Rescue

Nicole Abaid and Amanda Hashimoto, Virginia Tech, U.S.

2:15-2:35 An Experimental Evaluation of the Social Force Model

Hye Rin Lindsay Lee, Case Western Reserve University, U.S.

Wednesday, May 22

MS129

Nonlinear and Nonsmooth Problems in Rotordynamics

1:00 p.m.-2:40 p.m.

Room: Wasatch A

Modern engineered systems are dominated by the dynamics of rotating machines; from large scale gas turbine engines, power generators and mineral extraction drills, to automotive transmission systems, wheeled locomotion and braking systems, to laboratory-scale manufacturing devices and electrical motors. At high rotation speeds, gyroscopic effects lead to large non-normal terms that can cause mode-coupling instabilities in the presence of small eccentricities. In addition, contact between rotor and stator leads to violent exchanges of energy and persistent forward and backward whirling motion. Transitions between non-contacting and either permanently or intermittently contacting (bouncing motion) are poorly understood, as are the ensuing complex dynamics that is observed. Recent advances include understanding instabilities due to additional moving parts (bearings or autobalancers), grazing due to internal resonance between forward and backward whirling modes, the effects of friction dampers on freely oscillating components, and the presence of intrinsic localised modes of circular arrays of fan or turbine blades. This minisymposium will specifically focus on how modern dynamical phenomena - for example, nonsmooth bifurcations, discrete breathers, frequency locking and chaos - naturally occur in rotordynamic systems, but with a twist. At the same time, modern dynamical analyses appear to provide new methods for monitoring, designing and controling practical mechanical systems.

Organizer: Alan R. Champneys

University of Bristol, United Kingdom

1:00-1:20 Nonlinear and Nonsmooth Problems in Rotordynamics

Alan R. Champneys, University of Bristol, United Kingdom

1:25-1:45 Rotordynamics Near Internal Resonance - When Impacting Orbits Degenerately Graze into Existence

Karin Mora, University of Paderborn, Germany; Alan R. Champneys, University of Bristol, United Kingdom; Alexander Shaw and Michael Friswell, Swansea University, United Kingdom

continued on next page

1:50-2:10 Nonlinear Vibration Localisation in Rotors

Norbert P. Hoffmann, Technische Universität Hamburg, Germany; Filipe Fontanela, Imperial College London, United Kingdom; Antonio Papangelo, Università e Politecnico di Bari, Italy

2:15-2:35 Blade-Tip/Casing Interaction: Phenomena Underlying Rub-Induced Vibrations in Turbomachinery

Alessandra Vizzaccaro and Loic Salles, Imperial College London, United Kingdom

Wednesday, May 22

MS130

Phase-Amplitude Coordinate Systems for Oscillators

1:00 p.m.-2:40 p.m.

Room: Wasatch B

Phase reduction has been an essential tool in the study of weakly perturbed limit cycle oscillators. However, particularly as perturbations become larger, phase dynamics alone are often insufficient to characterize an oscillator's behavior. This minisymposium will highlight recent advances in the development of coordinate systems which characterize both the asymptotic phase and the transient decay of solutions with respect to a limit cycle. Phase-amplitude coordinate systems in reaction-diffusion equations and nonsmooth dynamical systems will be discussed, as will applications to biological systems.

Organizer: Dan D. Wilson

University of Tennessee, U.S.

Organizer: Jeff Moehlis

University of California, Santa Barbara, U.S.

1:00-1:20 Understanding the Mechanisms of the East-West Asynchrony in Jet-Lag Recovery

Dan D. Wilson, University of Tennessee, U.S.; G. Bard Ermentrout, University of Pittsburgh, U.S.

1:25-1:45 Hybrid Oscillators: Phase and Amplitude in a Class of Non-Smooth Systems

Shai Revzen and Matthew D. Kvalheim, University of Michigan, U.S.

1:50-2:10 Phase-Amplitude Reduction of Rhythmic Patterns in Reaction-Diffusion Systems

Hiroya Nakao, Tokyo Institute of Technology, Japan

2:15-2:35 Isochrons: from Lie Symmetries to the Parameterization Method and Beyond

Toni Guillamon, Gemma Huguet, and Oriol Castejon, Universitat Politecnica de Catalunya, Spain

Wednesday, May 22

MS131

Dynamical Systems Software

1:00 p.m.-2:40 p.m.

Room: Maybird

The SIAM Dynamical Systems community has a long tradition of software development. By now classical tools, developed and championed by our members, have impacted fields far outside of our core discipline. As a result, sophisticated modeling and analysis techniques with origin in dynamical systems theory have been applied to the behavioral, biological, engineering, environmental, medical, physical, and sociological sciences. New perspectives on real-world problems, e.g., graph-theoretic approaches or tools for analyzing slow-fast systems, have prompted innovative translational efforts that sustain the relevance of dynamical systems theory as a key enabling discipline. The experience of building general-purpose software for use outside of a research group can be very rewarding, even if the effort may be considerable. The Dynamical Systems community has recognized both the utility of such tools and the need to make this effort visible through the DSWeb Dynamical Systems Software pages, celebrating their 20th anniversary in 2018. The DSWeb 2018 software contest sought to “promote the development of novel and creative software-based methods to analyze dynamical systems.” In 2019, a similar contest focuses on software tutorials will promote the associated development of useful pedagogical documentation. This minisymposium will highlight several examples of software development, spanning both theory and application.

Organizer: Harry Dankowicz

University of Illinois at Urbana-Champaign, U.S.

Organizer: Jan Sieber

University of Exeter, United Kingdom

1:00-1:20 Multidimensional Manifold Continuation for Adaptive Boundary-Value Problems with COCO

Harry Dankowicz and Yuqing Wang, University of Illinois at Urbana-Champaign, U.S.

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Wednesday, May 22

MS131

Dynamical Systems Software continued

1:25-1:45 Emergence and Macroscopic Behavioural ExtRaction (EMBER): Challenges and Opportunities

Anne C. Skeldon, University of Surrey, United Kingdom; Spencer Thomas, National Physical Laboratory, United Kingdom; David Lloyd, University of Surrey, United Kingdom

1:50-2:10 The Brain Dynamics Toolbox

Stewart Heitmann, Victor Chang Cardiac Research Institute, Australia

2:15-2:35 Applications of Spectral Submanifolds in Nonlinear Modal Analysis using SSMtool

Sten Ponsioen and George Haller, ETH Zürich, Switzerland

Wednesday, May 22

MS132

Modeling and Simulation of Fluid--Structure Interactions of Internal Flows in Soft Conduits

1:00 p.m.-2:40 p.m.

Room: Superior A

This minisymposium will showcase current research on theory, computation and key applications of fluid--structure interactions (FSIs) involving internal fluid flows in compliant conduits. This topic is at the forefront of mechanics research, with the current challenges lying in the formulation of tractable mathematical models for these multi-field problems, and the development of accurate and stable numerical methods to simulate dynamics of internal FSIs. Applications of this work range from the microscopic (flow in blood vessels and soft microfluidic devices) to the macroscopic (large-scale flows in porous media or industrial piping systems). To highlight the frontiers of the field, four talks are planned in the minisymposium, covering 1) viscous-elastic FSIs with applications to soft robotic actuation, 2) efficient direct numerical simulation of FSIs through boundary update via resolvents, 3) a nonlinear ALE-FSI solver for cardiovascular applications, and 4) variational theory for flexible and expandable tubes conveying compressible fluids.

Organizer: Ivan C. Christov
Purdue University, U.S.

1:00-1:20 Control of Multiple Elastic Actuators by a Single Input via Interaction Between Viscosity and Bi-Stability

Eran Ben-Haim, Lior Salem, Yizhar Or, and *Amir D. Gat*, Technion Israel Institute of Technology, Israel

1:25-1:45 Boundary Update via Resolvent for Fluid-Structure Interaction

Martina Bukac, University of Notre Dame, U.S.; Catalin S. Trenchea, University of Pittsburgh, U.S.

continued in next column

1:50-2:10 A Nonlinear ALE-FSI Solver for Cardiovascular Applications within the CRIMSON Framework

Nitesh Nama, University of Michigan, U.S.; Miquel Aguirre, Ecole des Mines de St Etienne, France; Alberto Figueroa, University of Michigan, U.S.

2:15-2:35 Geometric Theory of Flexible and Expandable Tubes Conveying Fluid: Equations, Solutions and Shock Waves

Francois Gay-Balmaz, Ecole Normale Superieure, France

Wednesday, May 22

MS133

Nonlinear Energy Transport, Non-Reciprocity and Control in Dynamical and Acoustical Systems - Part I of II

1:00 p.m.-2:40 p.m.

Room: Superior B

For Part 2 see MS145

This Minisymposium will focus on recent developments and challenges related to nonlinear energy transfer, non-reciprocity and control of energy distribution in dynamical and acoustical systems . Topics will include, but will not be limited to: - Intense non-stationary energy transfers - Nonlinear non-reciprocity in dynamics and acoustics - Acoustic sonic vacua - Energy transport in non-smooth systems and granular media - Nonlinear phononics - Nonlinear energy harvesting - Intentional nonlinearity for energy transfer and control - Applications of strong nonlinear energy transfers

Organizer: Oleg Gendelman
Technion Israel Institute of Technology, Israel

Organizer: Alexander Vakakis
University of Illinois, U.S.

1:00-1:20 Non-Reciprocal Acoustics in Nonlinear Lattices

Alireza Mojahed, University of Illinois at Urbana-Champaign, U.S.; Oleg Gendelman, Technion Israel Institute of Technology, Israel; Alexander Vakakis, University of Illinois, U.S.

1:25-1:45 Dynamic Response of Non-Linearly Coupled Chain of Parametrically Forced Oscillators

Yuli Starosvetsky, Technion - Israel Institute of Technology, Israel

1:50-2:10 Nonlinear Wave-Particle Resonances and Energy Exchange in the Earth's Magnetosphere

Dmitri Vainchtein, Drexel University, U.S.; Anton Artemyev, University of California, Los Angeles, U.S.

2:15-2:35 Influence of Nonlinear Pump-Signal Wave Interaction on Non-Reciprocal Behavior in Modulated Spring-Mass Chains

Michael R. Haberman and Samuel P. Wallen, University of Texas at Austin, U.S.

Wednesday, May 22

MS134

Bacterial Motility: From Agent-Based Models to Nonlocal PDEs

1:00 p.m.-2:40 p.m.

Room: Primrose A

Various strains of bacteria are known to move along substrates or "swim" suspended in liquid. Some use flagella, others extend microscopic grappling hooks called pili; some use chemotaxis to self-organise, others detect the trails of their kin. It is well-known that both communication and steric interaction like collision and alignment, can result in the formation of coherent patterns. Such patterns are important for the functioning of the bacteria, for instance for the formation of biofilms. Since bacteria can be observed under microscopes, their individual dynamics have been studied and used in Agent Based Modelling (ABM). However, even with the aid of GPU-based simulations, the reproduction of macroscopic pattern formation in ABM remains a formidable task. Other approaches are the coarse-graining of ABM using tools of non-equilibrium statistical physics and the formulation of phenomenological models in the form of non-local PDEs. These PDEs may look like modified Navier-Stokes equations or have convolution terms modelling sensory perception and the effect of steric interaction. In this minisymposium, several forms of discrete and continuous modelling of bacterial motility will be presented and compared, with a focus on collective motion and pattern formation.

Organizer: Lennaert van Veen
University of Ontario Institute of Technology, Canada

1:00-1:20 Stigmergic Social Behaviors Facilitate the Active Expansion of Pseudomonas Aeruginosa Interstitial Biofilms

Erin S. Gloag, Ohio State University, U.S.; Awais Javed, Swinburne University of Technology, Australia

1:25-1:45 Modeling of Microswimmers: Hydrodynamics and Steric Effects

Marco G. Mazza, Loughborough University, United Kingdom; Fabian Schwarzendahl, Max Planck Institute for Dynamics and Self-Organization, Germany

continued in next column

1:50-2:10 A Mathematical Investigation of the Local/Nonlocal Interactions Behind the Sorting and Collective Movement of Dictyostelium Discoideum Aggregations

Raluca Eftimie, University of Dundee, United Kingdom

2:15-2:35 Emergent Flows in Confined Incipient Active Nematics

Minu Varghese, Brandeis University, U.S.; Arvind Baskaran, ; Michael Hagan and Aparna Baskaran, Brandeis University, U.S.

Wednesday, May 22

MS135

Geometric Singular Perturbation Theory Beyond the Standard Form - Part I of II

1:00 p.m.-2:40 p.m.

Room: Primrose B

For Part 2 see MS148

Many scientific models across fields as diverse as climate, pituitary cell, and combustion dynamics have a fundamental element in common: they all involve the interplay of mechanisms operating on vastly different timescales. Studies of the corresponding multiple-timescale dynamical systems have typically been confined to the so-called standard form, where the distinction between slow and fast components of the vector field is made explicit. This minisymposium concerns the future of geometric singular perturbation theory (GSPT)---the paradigm used to study these systems---in the nonstandard setting. This includes systems where slow and fast directions mix nonlinearly throughout the phase space, where more than two distinct timescales appear in the dynamics, where no explicit small parameters appear to characterize the timescales, and so on. Our speakers will discuss new challenges in nonstandard GSPT in a variety of important applications, including aircraft ground dynamics, the Olsen model of peroxidase-oxidase reaction, and excitatory networks. An important aspect of our story is to analyze nonstandard versions of canard explosion and relaxation oscillations by adapting standard GSPT techniques and blow-up methods. We will also discuss recent computational advances to detect slow manifolds and bifurcations in nonstandard systems. These advances include zero curvature methods, iterative schemes, numerical boundary value problems, and manifold learning.

Organizer: Ian M. Lizarraga
University of Sydney, Australia

1:00-1:20 Advances in GSPT: Teaching New Tricks to an Old Dog

Peter Szmolyan, Technische Universität Wien, Austria

continued in next column

1:25-1:45 Canards in Excitatory Networks

Daniele Avitabile, University of Nottingham, United Kingdom; *Mathieu Desroches*, Inria Sophia Antipolis, France; G. Bard Ermentrout, University of Pittsburgh, U.S.

1:50-2:10 Pseudo Singularities and Canards and Non-Standard Singular Perturbation Problems

Martin Wechselberger, University of Sydney, Australia

2:15-2:35 Mind the Canard: Taking An Aircraft for a Spin on the Ground

Bernd Krauskopf, University of Auckland, New Zealand; James Rankin, University of Exeter, United Kingdom; Mathieu Desroches, Inria Sophia Antipolis, France; Mark Lowenberg, University of Bristol, United Kingdom

Wednesday, May 22

CP31

Collective Behavior

1:00 p.m.-2:40 p.m.

Room: Magpie A

1:00-1:20 A Generalized Model of Flocking

Guy A. Djokam and Muruhan Rathinam, University of Maryland, Baltimore County, U.S.

1:25-1:45 Stability Analysis for an N-Particle System in the Plane with Spring-Like Coupling

Constantine N. Medynets and Irina Popovici, US Naval Academy, U.S.; Cark Kolon, United States Navy, U.S.

1:50-2:10 Collective Mechanical Adaptation of Honeybee Swarms

Orit Peleg, BioFrontiers Institute, University of Colorado, U.S.; Jacob Peters, Mary Salcedo, and L. Mahadevan, Harvard University, U.S.

2:15-2:35 Emergent Pattern Forming Swarms and the Physics of Mixed Reality Experiments

Klimka Szwaykowska, Syntek Corporation, U.S.; Ira B. Schwartz, Naval Research Laboratory, U.S.; Thomas W. Carr, Southern Methodist University, U.S.; Jason M. Hindes, US Naval Research Laboratory, U.S.

Wednesday, May 22

CP32

Ecology and Evolutionary Biology

1:00 p.m.-2:40 p.m.

Room: White Pine

Chair: Darlington David, University of Liberia, Liberia

1:00-1:20 Role of Additional Food on the Local and Global Dynamics of a Diffusive Predator-Prey System

Vandana Tiwari, Kamla Nehru Institute of Technology, India

1:25-1:45 On Volterra Quadratic Stochastic Operators of a Two-Sex Population on S^1 x S^1

Oscar Castanos, California State University, Fresno, U.S.; Utkir Rozikov and Uygun Jamilov, Academy of Sciences of Uzbekistan, Uzbekistan

1:50-2:10 The Replicator Dynamics for Multilevel Selection in Evolutionary Games

Daniel B. Cooney, Princeton University, U.S.

2:15-2:35 Mathematical Modeling of Cancer Self Remission and Tumor Instabilty as a Prey - Predator System

Darlington David and Michael Gboneh, University of Liberia, Liberia; Melvin Kollie, Florida International University, U.S.

Wednesday, May 22

CP102

Workshop on Network Science: Contributed Session 3

1:20 p.m.-2:35 p.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

1:20-1:40 Recovering Planted Hitting Sets in Hypergraphs

Austin Benson, *Ilya Amburg*, and Jon M. Kleinberg, Cornell University, U.S.

1:45-2:05 Configuration Models of Random Hypergraphs and their Applications

Philip S. Chodrow, Massachusetts Institute of Technology, U.S.

2:10-2:30 From Connections to Relationships with Cellular Sheaves

Jakob Hansen, University of Pennsylvania, U.S.

Workshop on Network Science: Coffee Break

2:35 p.m.-3:00 p.m.

Room: Cottonwood A& B - Snowbird Center

Coffee Break

2:40 p.m.-3:10 p.m.

Room: Golden Cliff

Wednesday, May 22

CP103

Workshop on Network Science: Contributed Session 4

3:00 p.m.-3:50 p.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

3:00-3:20 Critical Network Cascades: Why Locally Tree-Like Approximations Work, when they Breakdown, and how to Correct Them

Sarthak Chandra and Edward Ott, University of Maryland, U.S.; Michelle Girvan, University of Maryland, College Park, U.S.

3:25-3:45 Coupled Point Processes and Network Evolution Dynamics

Yacoub H. Kureh, Mason A. Porter, and Jeffrey Brantingham, University of California, Los Angeles, U.S.

Wednesday, May 22

MS136

Feedback Mechanisms in Climate: The Maths and the Consequences - Part II of II

3:10 p.m.-4:50 p.m.

Room: Ballroom 1

For Part 1 see MS125

In many climate systems, processes interact to form positive (destabilising) or negative (stabilising) feedback loops, which play pivotal roles for the stability and sensitivity of climate phenomena. The importance of feedback mechanisms cannot be overstated. The speeds of the processes involved determine important timescales of the climate system and it has been suggested that feedback mechanisms are behind many, possibly most, of the nonlinearities in the climate. In this minisymposium, several studies of climate systems driven by feedback mechanisms will be presented, including planetary energy balance and the El Niño Southern Oscillation. The presentations will showcase a variety of mathematical modelling and analysis techniques, such as delay differential equation and slow-fast reductions, each delivering valuable insights into the inner-workings of complex climate systems.

Organizer: Andrew Keane
University of Auckland, New Zealand

Organizer: Bernd Krauskopf
University of Auckland, New Zealand

3:10-3:30 Dynamical Systems Analysis of the Maasch–Saltzman Model for Glacial Cycles

Hans Engler, Georgetown University, U.S.; *Hans G. Kaper*, Argonne National Laboratory and Georgetown University, U.S.; Tasso J. Kaper, Boston University, U.S.; Theodore Vo, Florida State University, U.S.

3:35-3:55 Permafrost Melt and its Effects on Planetary Energy Balance

Kaitlin Hill and Richard McGehee, University of Minnesota, U.S.

continued in next column

4:00-4:20 Derivation of Delay Equation Climate Models using Projection Methods

Swinda Falkena, Utrecht University, The Netherlands; Courtney Quinn and Jan Sieber, University of Exeter, United Kingdom; Jason Frank and Henk A. Dijkstra, Utrecht University, The Netherlands

4:25-4:45 Noise-Induced Tipping in a Periodically Forced System: The Noise-Drift Balanced Regime

John Gemmer, Wake Forest University, U.S.; Yuxin Chen, Northwestern University, U.S.; Alexandria Volkening, Ohio State University, U.S.; Mary Silber, University of Chicago, U.S.

Wednesday, May 22

MS137

Modeling Female and Minority Representation in Society

3:10 p.m.-4:50 p.m.

Room: Ballroom 2

The representation of women and minorities in society is constantly evolving. Sociological models of gender and racial dynamics seek to understand and predict the role of women and minorities in professional and popular culture, as well as forces at play in the dynamics of segregation. Such models are inherently data-driven and seek to capture phenomenological information, such as the relative impact of sociological factors or time to gender parity in a field. In this minisymposium, speakers will discuss models of the evolution of women and minorities in the workplace, in leadership positions, and in media. These models are a critical tool in striving for equity in society.

Organizer: Kaitlin Hill
University of Minnesota, U.S.

Organizer: Sara M. Clifton
University of Illinois at Urbana-Champaign, U.S.

3:10-3:30 Mathematical Model of Gender Bias and Homophily in Professional Hierarchies

Sara M. Clifton, University of Illinois at Urbana-Champaign, U.S.; Kaitlin Hill, University of Minnesota, U.S.; Avinash Karamchandani, Northwestern University, U.S.; Eric Autry, Duke University, U.S.; Patrick McMahon and Grace Sun, University of Illinois at Urbana-Champaign, U.S.

3:35-3:55 Lessons from a Systematic Cross-Industry Exploration of Historic Changes in Female Representation

Luis Amaral, Northwestern University, U.S.

4:00-4:20 The Dynamics of Unorganized Segregation

S. John Hogan, University of Bristol, United Kingdom

4:25-4:45 Creating Predictive Models for Racial Affirmative Action Policies in U.S. Undergraduate Admissions

Daniel P. Maes, University of Michigan, U.S.

Wednesday, May 22

MS138

New Directions in Simultaneous State and Parameter Estimation - Part I of II

3:10 p.m.-4:50 p.m.

Room: Ballroom 3

For Part 2 see MS151

A ubiquitous problem that arises in many areas of science and engineering is to estimate the parameters of a model from data. In dynamical systems, these parameters include the state of the model, as well as static quantities or functional terms which account for systematic and random errors arising from various sources, such as model misspecification or unresolved scales. In data assimilation (DA), these estimates are made by coupling prior assumptions in the form of SDE models and statistical distributions or processes for uncertain states, parameters, and model terms to data in the form of partial, noisy observations of the state of the system. This is an especially challenging problem with a high-dimensional state and parameter space in combination with sparse data and nonlinear dynamical and measurement models, a scenario often encountered in realistic physical and machine learning inference settings. A recent trend is to combine tools and theory from DA and machine learning, which also deals with nonlinear and high-dimensional numerical inference, in order to address the problems arising in the context of non-Gaussian likelihood and posterior estimation. In this vein, the aim of this minisymposium is to present various novel methods and theoretical advancements for model selection and simultaneous state, parameter, and functional estimation.

Organizer: Jana de Wiljes
Universität Potsdam, Germany

Organizer: Paul Rozdeba
Universität Potsdam, Germany

3:10-3:30 State and Parameter Estimation for Sonar Bias Mitigation in Autonomous Underwater Navigation
Erin M. Linebarger, University of Utah, U.S.

continued in next column

3:35-3:55 Sequential Bayesian Drift Estimation and Model Selection in Stochastic Dynamical Systems
Paul Rozdeba, Universität Potsdam, Germany

4:00-4:20 Projected Data Assimilation
John Maclean, University of Adelaide, Australia

4:25-4:45 Tikhonov Regularization within Ensemble Kalman Inversion
Neil Chada, National University of Singapore, Singapore; Andrew Stuart, California Institute of Technology, U.S.; Xin T. Tong, National University of Singapore, Singapore

Wednesday, May 22

MS139

Geometric Mechanics and Robotics - Part I of II

3:10 p.m.-4:50 p.m.

Room: Magpie A

For Part 2 see MS152

Modern robotic systems are dynamical systems evolving on nonlinear configuration manifolds that benefit from global geometric techniques arising in geometric mechanics and geometric control theory. While there have been significant advances in the hardware capabilities of robots, the functionality of such systems are constrained by the use of local coordinate descriptions of the dynamics and the associated controllers that cannot adequately describe the aggressive time and cost optimal trajectories that arise in contemporary engineering applications. In addition, there are topological obstructions to controllability that cannot be addressed at the local level. The scope of this minisymposium is a synthesis of coordinate-independent differential-geometric approaches to mechanics and control and applications to real-world problems in dynamics and robotics.

Organizer: Tomoki Ohsawa
University of Texas at Dallas, U.S.

Organizer: Vakhtang Putkaradze
University of Alberta, Canada

3:10-3:30 Dynamics of Mechanically Coupled Nonholonomic Systems
Scott D. Kelly, University of North Carolina, Charlotte, U.S.

3:35-3:55 Variational Methods for the Dynamics of Porous Media
Tagir Farkhutdinov and Vakhtang Putkaradze, University of Alberta, Canada; Francois Gay-Balmaz, École Normale Supérieure Paris, France

4:00-4:20 The Connections Between Discrete Geometric Mechanics, Information Geometry and Machine Learning
Melvin Leok, University of California, San Diego, U.S.

4:25-4:45 Stabilization of Mechanical Systems with Broken Symmetry
Cesar Contreras and Tomoki Ohsawa, University of Texas at Dallas, U.S.

Wednesday, May 22

MS140

New Directions in Multiple Time Scale Dynamics - Part I of II

3:10 p.m.-4:50 p.m.

Room: Magpie B

For Part 2 see MS153

Multiple time scales are ubiquitous to natural phenomena such as neuron dynamics, chemical reactions, population dynamics, social interactions, among many others. The behaviour of such phenomena can be quite complicated and exhibit, for example, relaxation and mixed-mode oscillations. Although the theory of multiple time scale dynamical systems has had great progress in the past years, especially in the context of ordinary differential equations, there is still a vast spectrum of challenges that require further efforts such as desingularization of high co-dimension singularities, fast-slow dynamic networks, fast-slow stochastic differential equations and discrete time systems particularly with singularities, to mention a few. The aim of this minisymposium is to gather researchers actively working on the theory and applications of multiple time scale dynamical systems, disseminate recent results, and to discuss novel research directions and their mathematical challenges.

Organizer: Hildeberto Jardon
Technische Universität München, Germany

Organizer: Christian Kuehn
Technische Universität München, Germany

3:10-3:30 Dynamic Networks with Two Timescales

Hildeberto Jardon and Christian Kuehn, Technische Universität München, Germany

3:35-3:55 Analysis and Simulation of Multiscale Stochastic Intracellular Bio-Chemical Reacting Networks

Di Liu, Michigan State University, U.S.

continued in next column

4:00-4:20 Singular Perturbation Analysis of a Regularized MEMS Model

Annalisa Iuorio, Technische Universität Wien, Austria; Nikola Popovic, University of Edinburgh, United Kingdom; Peter Szmolyan, Technische Universität Wien, Austria

4:25-4:45 Mixed-Mode Oscillations and Bistability in a Predator-Prey Model with Two Time-Scales

Susmita Sadhu, Georgia College & State University, U.S.

Wednesday, May 22

MS141

Theory and Application of Piecewise-Smooth ODEs - Part I of II

3:10 p.m.-4:50 p.m.

Room: Wasatch A

For Part 2 see MS154

Systems involving switches, impacts, thresholds, etc are naturally modeled by equations that are piecewise-smooth. Such equations readily admit novel dynamics and bifurcations that do not conform to the theory of smooth dynamical systems. The speakers in this minisymposium will discuss new advances in the theory of piecewise-smooth ODEs, and demonstrate implications of the theory in applications including electronic systems, mechanics and agricultural systems. On the theoretical part, bifurcations for equilibria of piecewise-smooth ODEs, networks of piecewise-smooth systems, slow-fast systems with non-smooth control, and rotation sets in the framework of non-smooth systems will be presented. Some of the talks are quite general for a brief introduction in the respective areas. On the applications, mechanical systems such as pendulums, or applications of piecewise-smooth control and bifurcations to coffee crops, and some electronic systems with hysteresis and memristors oscillations will be shown.

Organizer: Gerard Olivar Tost
Universidad Nacional de Colombia, Colombia

Organizer: David J. Simpson
Massey University, New Zealand

3:10-3:30 Towards a General Bifurcation Theory for Equilibria of Piecewise-Smooth Odes

David J. Simpson, Massey University, New Zealand

3:35-3:55 Rotation Theory and Applications of Piecewise-Smooth Maps

Deissy M. Sotelo C, National University of Colombia, Colombia

4:00-4:20 Swings, Spiders and Piecewise-Smooth Models of Actuated Pendulums

Paul Glendinning and Brigid Murphy, University of Manchester, United Kingdom

4:25-4:45 A Multilayer Discontinuous Approach to Achieve Convergence in Networks of Piecewise-Smooth Systems

Marco Coraggio, Pietro De Lellis, and Mario di Bernardo, University of Naples Federico II, Italy

Wednesday, May 22

MS142

The Dynamics and Structure of Neuronal Networks - Part I of II

3:10 p.m.-4:50 p.m.

Room: Wasatch B

For Part 2 see MS155

The dynamics of neuronal networks provide rich information regarding the nature of computation and information encoding in the brain. This minisymposium highlights recent studies that analyze dynamical system network models in neuroscience, emphasizing implications in learning, connectivity reconstruction, sensory processing, and synchronization. The speakers will draw particular attention to new mathematical advances in characterizing the structure-function relationship for complex neuronal networks and techniques for understanding the biophysical processes underlying observed network activity.

Organizer: Victor Barranca
Swarthmore College, U.S.

Organizer: Songting Li
Shanghai Jiao Tong University, China

3:10-3:30 Network Microstructure Dominates Global Network Connectivity in Synchronous Event Initiation

Duane Nykamp and Brittany Baker, University of Minnesota, U.S.

3:35-3:55 Dynamical and Coupling Structure of Pulse-Coupled Networks in Maximum Entropy Analysis

Zhiqin J. Xu, Courant Institute New York University, U.S. and New York University Abu Dhabi, United Arab Emirates; Douglas Zhou, Shanghai Jiao Tong University, China; David Cai, Shanghai Jiao Tong University, China and Courant Institute of Mathematical Sciences, New York University, U.S.

4:00-4:20 Balanced Neuronal Dynamics Facilitate Reconstruction of Recurrent Network Connectivity

Victor Barranca, Swarthmore College, U.S.; Douglas Zhou, Shanghai Jiao Tong University, China

4:25-4:45 Role of the Locus Coeruleus in the Emergence of Power Law Wake Bouts in a Model of the Brainstem Sleep-Wake System Through Early Infancy

Mainak Patel, College of William & Mary, U.S.

Wednesday, May 22

MS143

Julia: Computational Tools for Dynamical Systems

3:10 p.m.-4:50 p.m.

Room: Maybird

Julia is a relatively new high-level programming language that excels at numerical computing (see Julia: A Fresh Approach to Numerical Computing, SIAM Review 2017). It is well known for its speed and expressiveness and offers many benefits for researchers in the dynamical systems, such as a wide suite of best-of-breed numerical integrators for ODEs, DDEs, and SDEs in the form of DifferentialEquations.jl. In this mini-symposium, we explore how the ecosystem of Julia can be leveraged to enable the exploration of dynamical systems, with features such as arbitrary-precision or rigorous (interval arithmetic) calculations easily added with just a few lines of code. The performance of Julia means that large-scale computations coded without resorting needing to vectorise each calculation; similarly, we will show that mathematically convenient abstractions can be used directly in computational codes without performance penalties and so enable tighter links between the mathematics and the code. The minisymposium will begin with a brief introduction to the Julia language and ecosystem, followed by more in depth talks on different approaches to dynamical systems.

Organizer: David A. Barton
University of Bristol, United Kingdom

3:10-3:30 A Brief Introduction to Julia and Applications to Dynamical Systems

David A. Barton, University of Bristol, United Kingdom

3:35-3:55 Handling Multiscale Stochastic Differential Equations in Julia

Chris Rackauckas, University of California, Irvine, U.S.

4:00-4:20 Rigorous Location of Periodic Orbits with Interval Methods

David P. Sanders, Universidad Nacional Autónoma de México, Mexico

4:25-4:45 Large-Scale Numerical Investigations into the Dynamics of Nonlinear Classical Systems

Sebastian M. Micluta-Campeanu, University of Bucharest, Romania

Wednesday, May 22

MS144

Analysis and Computation of Polymer and Lipid Suspensions - Part I of II

3:10 p.m.-4:50 p.m.

Room: Superior A

For Part 2 see MS157

The complex interactions of charged polymers and lipids with solvent sets up a hugely mutable system that affords subtle mechanisms to control the dynamics and curvature of membranes and higher codimensional structures. This minisymposium will feature contributions to the investigation of intrinsically multi-dimensional aspects of the dynamics of polymer and lipid suspensions, including the existence, stability, instability, slow evolution, and interaction of phase separated profiles. We expect to bring together researchers with a variety of backgrounds, employing diffusive stability estimates, energy methods from the calculus of variations, spatial dynamics, and bifurcation methods, and sophisticated time stepping schemes for the models of these complex systems.

Organizer: Noa Kraitzman
University of Utah, U.S.

Organizer: Keith Promislow
Michigan State University, U.S.

3:10-3:30 Amphiphilic Structures in Multiphase Density Functional Models

Karl Glasner, University of Arizona, U.S.

3:35-3:55 Toll Roads and Freeways: Defects in Bilayer Interfaces in the Multi-Component Functionalised Cahn-Hilliard Equation

Frits Veerman, Universität Heidelberg, Germany; Keith Promislow, Michigan State University, U.S.; Arjen Doelman, Leiden University, Netherlands

4:00-4:20 Computational, Asymptotic, and Rigorous Analysis of Fully Implicit Time Stepping for Allen-Cahn Dynamics

Xinyu Cheng, University of British Columbia, Canada; Dong Li, Hong Kong University of Science and Technology, Hong Kong; Keith Promislow, Michigan State University, U.S.; Brian R. Wetton, University of British Columbia, Canada

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Wednesday, May 22

MS144

Analysis and Computation of Polymer and Lipid Suspensions - Part I of II

continued

4:25-4:45 Micro-Macro Models for Two-Phase Flow of Dilute Polymeric Solutions

Stefan Metzger and *Shuwang Li*, Illinois Institute of Technology, U.S.

Wednesday, May 22

MS145

Nonlinear Energy Transport, Non-Reciprocity and Control in Dynamical and Acoustical Systems - Part II of II

3:10 p.m.-4:50 p.m.

Room: Superior B

For Part 1 see MS133

This Minisymposium will focus on recent developments and challenges related to nonlinear energy transfer, non-reciprocity and control of energy distribution in dynamical and acoustical systems . Topics will include, but will not be limited to: - Intense non-stationary energy transfers - Nonlinear non-reciprocity in dynamics and acoustics - Acoustic sonic vacua - Energy transport in non-smooth systems and granular media - Nonlinear phononics - Nonlinear energy harvesting - Intentional nonlinearity for energy transfer and control - Applications of strong nonlinear energy transfers

Organizer: Oleg Gendelman

Technion Israel Institute of Technology, Israel

Organizer: Alexander Vakakis

University of Illinois, U.S.

3:10-3:30 Escape Dynamics in Harmonically Forced Systems

Oleg Gendelman, Technion Israel Institute of Technology, Israel

3:35-3:55 Strongly Nonlinear Periodic System Exhibiting Giant Breaking of Reciprocity with Robust Signal Integrity

Michael J. Leamy and Amir Darabi, Georgia Institute of Technology, U.S.; Alexander Vakakis, University of Illinois, U.S.; Lezheng Fang, Georgia Institute of Technology, U.S.

4:00-4:20 Vibration Absorption of a Two Degree-of-Freedom Pendulum with a Nonlinear Energy Sink

Gabriel Hurel, Alireza Ture Savadkoohi, and Claude - Henri Lamarque, Université de Lyon, France

4:25-4:45 Geomaterial-Inspired Nonlinear Mechanical Meta-Structures

Itay Grinberg and *Kathryn Matlack*, University of Illinois at Urbana-Champaign, U.S.

Wednesday, May 22

MS146

Nonlocal Dynamical Systems and Applications - Part I of II

3:10 p.m.-4:50 p.m.

Room: White Pine

For Part 2 see MS159

Nonlocal Dynamical Systems, including delay differential equations, integro-differential equations, ordinary differential equations and partial differential equations, are extremely important tools in the large area of mathematical biology, image processing, and phase transitions. The simulation and analysis of Nonlocal Dynamical Systems are very successful in understanding the mechanisms that generate interesting and significant phenomenas in a variety of scientific subjects. The purpose of this minisymposium is to bring together researchers working in different directions to discuss recent advances in the modeling by nonlocal operators of emerging phenomena, numerical simulation and mathematical analysis of related Dynamical Systems.

Organizer: Xiaoxia Xie

Idaho State University, U.S.

3:10-3:30 Turing Type Bifurcation in Reaction-Diffusion Model with Nonlocal Interactions

Junping Shi and Shanshan Chen, College of William & Mary, U.S.

3:35-3:55 An Advection and Age-Structured Approach to Modeling Bird Migration and Indirect Transmission of Avian Influenza

Rongsong Liu, University of Wyoming, U.S.; Stephen Gourley, University of Surrey, United Kingdom; Rachel L. Jennings, University of Wyoming, U.S.

4:00-4:20 Mimetic Method on Reaction Diffusion Equation of the Tumor Growth in Cornea

Zachariah Sinkala and Hugh B. Matlock, Middle Tennessee State University, U.S.

4:25-4:45 Spreading Speeds in Random Environments

Zhongwei Shen, University of Alberta, Canada

Wednesday, May 22

MS147

Control Techniques based on Koopman Operator Theory - Part I of II

3:10 p.m.-4:50 p.m.

Room: Primrose A

For Part 2 see MS160

The Koopman operator framework is an alternative approach to the classical pointwise description of dynamical systems. It provides a global description in terms of the evolution of "observable-functions" and turns nonlinear systems into linear (but infinite-dimensional) systems. This framework is directly connected to data-driven requirements for analysis and design of complex dynamics emerging in real-world applications. Recently, it has become increasingly popular in the context of control of dynamical systems, as a powerful tool to apply systematic linear control methods to nonlinear systems. This minisymposium aims to report on recent developments of Koopman operator techniques for controlling dynamical systems. A general introduction to the topic will be given in the first talk. Other presentations will develop more specific topics: control of multiway dynamical systems (talk 2), controllability and observability (talks 3,4), feedback control of partial differential equations (talk 5), identification and estimation (talk 6), optimal control (talks 3,6), sensor placement (talk 7), and signal processing (talk 8).

Organizer: Alexandre Mauroy
University of Namur, Belgium

Organizer: Alexandre Mauroy
University of Namur, Belgium

Organizer: Amit Surana
United Technologies Research Center, U.S.

Organizer: Sebastian Peitz
University of Paderborn, Germany

3:10-3:30 Controlling Dynamical Systems with the Koopman Operator: An Overview

Alexandre Mauroy, University of Namur, Belgium

continued in next column

3:35-3:55 DMD Based Control of Multiway Dynamical Systems

Can Chen, University of Michigan, Ann Arbor, U.S.; Anthony M. Bloch and Indika Rajapakse, University of Michigan, U.S.; Amit Surana, United Technologies Research Center, U.S.

4:00-4:20 Koopman Based Control: Bilinearization, Controllability and Optimal Control of Control-Affine Nonlinear Systems

Debdipta Goswami and Derek A. Paley, University of Maryland, U.S.

4:25-4:45 Systems Theoretic Aspects of Koopman Operator Theoretic Frameworks

Zeng Shen, Washington University in St. Louis, U.S.

Wednesday, May 22

MS148

Geometric Singular Perturbation Theory Beyond the Standard Form - Part II of II

3:10 p.m.-4:50 p.m.

Room: Primrose B

For Part 1 see MS135

Many scientific models across fields as diverse as climate, pituitary cell, and combustion dynamics have a fundamental element in common: they all involve the interplay of mechanisms operating on vastly different timescales. Studies of the corresponding multiple-timescale dynamical systems have typically been confined to the so-called standard form, where the distinction between slow and fast components of the vector field is made explicit. This minisymposium concerns the future of geometric singular perturbation theory (GSPT)---the paradigm used to study these systems---in the nonstandard setting. This includes systems where slow and fast directions mix nonlinearly throughout the phase space, where more than two distinct timescales appear in the dynamics, where no explicit small parameters appear to characterize the timescales, and so on. Our speakers will discuss new challenges in nonstandard GSPT in a variety of important applications, including aircraft ground dynamics, the Olsen model of peroxidase-oxidase reaction, and excitatory networks. An important aspect of our story is to analyze nonstandard versions of canard explosion and relaxation oscillations by adapting standard GSPT techniques and blow-up methods. We will also discuss recent computational advances to detect slow manifolds and bifurcations in nonstandard systems. These advances include zero curvature methods, iterative schemes, numerical boundary value problems, and manifold learning.

Organizer: Ian M. Lizarraga
University of Sydney, Australia

3:10-3:30 Computational Singular Perturbation Method for Nonstandard Slow-Fast Systems

Ian M. Lizarraga, University of Sydney, Australia

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Wednesday, May 22

MS148

Geometric Singular Perturbation Theory Beyond the Standard Form - Part II of II

continued

3:35-3:55 A Surface of Heteroclinic Connections in a 4D Slow-Fast System

Elle Musoke, Hinke M. Osinga, and Bernd Krauskopf, University of Auckland, New Zealand

4:00-4:20 Manifold Learning and Detection of Sloppiness

Mahdi Kooshkbaghi, Princeton University, U.S.; Alexander Holiday, Google, Inc., U.S.; Juan M. Bello-Riva, Schrodinger, Inc., U.S.; C. William Gear, Princeton University, U.S.; Antonios Zagaris, Wageningen University and Research Centre, The Netherlands; Yannis Kevrekidis, Johns Hopkins University, U.S.

4:25-4:45 Using the Zero-Curvature Set to Organize Phase Space

Benjamin G. Letson, University of Pittsburgh, U.S.

Wednesday, May 22

PP100

Workshop on Network Science: Poster Session

3:50 p.m.-5:00 p.m.

Room: Cottonwood A& B - Snowbird Center

3:50 p.m.-4:25 p.m. Demos of Software for Local Graph Clustering - In lieu of a poster, this presentation will be a demo presented in *Cottonwood C&D*

David F. Gleich, Purdue University, U.S.; Michael Mahoney, Stanford University, U.S.; Kimon Fountoulakis, University of Waterloo, Canada

Inferring Dynamical Systems through Active Queries

Abhijin Adiga, Chris J. Kuhlman, Madhav Marathe, and S S Ravi, University of Virginia, U.S.; Daniel J RosenKrantz and Richard E. Stearns, State University of New York, Albany, U.S.

Modeling the Evolution of Discriminatory Biomarkers in the Immune Response to Infection with Transcriptomics Data

Manuchehr Aminian, Nathan Mankovich, Shannon Stiverson, and Michael Kirby, Colorado State University, U.S.

Action-Based Model for Network Data with Errors

Viplove Arora and Mario Ventresca, Purdue University, U.S.

Inhibitory Synapses Are Central to Structural Balance in *C. Elegans* Neuronal Network

Rahul Badhwar, Lovely Professional University, India; Ganesh Bagler, Indraprastha Institute of Information Technology Delhi, India

On the Statistical Detection of Clusters in Directed Networks

Alan Ballard, Naval Postgraduate School, U.S.; Marcus Perry, University of Alabama, U.S

Robustness and Vulnerability of Coupled Interdependent Networks: Mathematical Optimization Aspects

Vladimir Boginski, University of Central Florida, U.S.

Analytical Formulation of the Block-Constrained Configuration Model

Giona Casiraghi, ETH Zürich, Switzerland

continued in next column

Competition Graph Variants for Characterizing Coordinated Automation in Social Networks

Bryan Ek, Lucas Overbey, and Kevin Pinzhoffer, Naval Information Warfare Center Atlantic, U.S.

Non-Random Teleportation in Random Walk Based Network Sampling

Trenton W. Ford, Jermaine Marshall, Ronald Metoyer, and Nitesh Chawla, University of Notre Dame, U.S.

Spanning Tree Modulus for Secure Broadcast Games

Kapila G. Kottegoda, Nathan Albin, and Pietro Poggi-Corradini, Kansas State University, U.S.

A Dynamical Systems Approach to Threshold Models of Social Influence

Yi Ming Lai, University of Nottingham, United Kingdom; Mason A. Porter, University of California, Los Angeles, U.S.

Topologies That Favor Synchronization in Second Order Kuramoto Oscillator Networks

Elbert E. Macau, Laboratory for Computing and Applied Mathematics and Brazilian Institute for Space Research, Brazil; Juliana Lacerda and Celso Freitas, Brazilian National Institute for Space Research - INPE, Brazil

Cooperation in the Shadow of Self-Interest: A Coevolving Network Model of Public Goods Games

Nishant Malik, Rochester Institute of Technology, U.S.; Hsuan-Wei Lee, Academia Sinica, Taiwan; Huan-Kai Tseng, National Taiwan University, Taiwan

Dynamic Behaviour of Distributed Generation DC Network and Stabilization with Passivity-Based Control

Rutvika N. Manohar and Takashi Hikihara, Kyoto University, Japan

Community Detection, the No Free Lunch Theorem, and Attack Games

Arya D. McCarthy, Johns Hopkins University, U.S.

Graph Comparison via the Non-Backtracking Spectrum

Andrew Mellor and Angelica Grusovin, University of Oxford, United Kingdom

GeoNet: A Framework for Intrinsic Geospatial Anomaly Detection

Jameson D. Morgan and Derek Doran, Wright State University, U.S.

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Structural Balance Dynamics and Community Structure

Megan J. Morrison and Michael Gabbay, University of Washington, U.S.

Topology Identification in Conservative Distribution Networks

Satya Jayadev Pappu, Indian Institute of Tecnology Madras, India; Aravind Rajeswaran, University of Washington, U.S. and Indian Institute of Technology, Madras, India; Shankar Narasimhan and Nirav Bhatt, Indian Institute of Tecnology Madras, India

Idealized Models of Insect Olfaction

Pamela B. Pyzza, Ohio Wesleyan University, U.S.; Gregor Kovacic, Rensselaer Polytechnic Institute, U.S.; Katherine Newhall, University of North Carolina at Chapel Hill, U.S.; Douglas Zhou, Shanghai Jiao Tong University, China

Estimation in the Popularity Adjusted Stochastic Blockmodel

Ramchandra Rimal and Marianna Pensky, University of Central Florida, U.S.

On the Bottleneck Structure of Positive Linear Programming

Jordi Ros-Giralt, Richard Lethin, and Aditya Gudibanda, Reservoir Labs, U.S.

Modeling Graphs with Vertex Replacement Grammars

Satyaki Sikdar, Justus Hibshman, and Tim Weninger, University of Notre Dame, U.S.

Opinion Model for Distributed Anomaly Detection on Smart Grids

Gonzalo P. Suarez, University of Tennessee, U.S.; Lazaros Gallos, Rutgers University, U.S.; Nina Fefferman, Tufts University, U.S.; Shlomo Havlin, Bar-Ilan University, Israel

Motif Signatures of Social Networks are Function of Hierarchy and Homophily

Malgorzata Turalska, U.S. Army Research Laboratory, U.S.

Neuronal Network Reconstruction of the Cerebral Cortex

Paulina Volosov and Gregor Kovacic, Rensselaer Polytechnic Institute, U.S.

Cascade Dynamics on Multiplex Networks

Yaofeng Desmond Zhong, Princeton University, U.S.; Vaibhav Srivastava, Michigan State University, U.S.; Naomi E. Leonard, Princeton University, U.S.

Intermission

4:50 p.m.-5:00 p.m.

Wednesday, May 22

MS149

Planetary Motion and its Effects on Climate - Part I of II

5:00 p.m.-6:40 p.m.

Room: Ballroom 1

For Part 2 see MS162

This session reviews recent research into the relationship between planetary motion and climate. Some scholars have used low-dimensional and conceptual models to test hypotheses about how climate is affected by different elements of a planet's motion. Others rely on large-scale global circulation models to understand how orbital parameters affect the detailed structure of a planet's climate.On the other hand, recent studies have investigated how climate signatures from Earth's sediment cores can be used to understand the chaotic behavior of the solar system. Results from these research areas will be presented in this session, with specific focus on climate of exoplanets and Earth's past climate.

Organizer: Alice Nadeau

University of Minnesota, U.S.

Organizer: Harini Chandramouli

University of Minnesota, U.S.

5:00-5:20 The Snowball Bifurcation on Tidally Influenced Planets

Dorian S. Abbot and *Jade Checlair*, University of Chicago, U.S.; Kristen Menou, University of Toronto, Canada; Jonah Bloch-Johnson and Navah X. Farahat, University of Chicago, U.S.; R. J. Graham, ; David Plotkin and Predrag Popovic, University of Chicago, U.S.; Francisco Spaulding-Astudillo, University of California, Los Angeles, U.S.; Thaddeus D. Komacek, Stephanie L. Olson, Andrea Salazar, and Olivia Alcabes, University of Chicago, U.S.

5:25-5:45 Ice Caps and Ice Belts: The Effects of Obliquity on Ice-Albedo Feedback

Brian Rose, State University of New York, Albany, U.S.; Timothy Cronin, Massachusetts Institute of Technology, U.S.; Cecilia Bitz, University of Washington, U.S.

5:50-6:10 Modeling Martian Climate with Low-Dimensional Energy Balance Models

Gareth E. Roberts, College of the Holy Cross, U.S.; Alice Nadeau, University of Minnesota, U.S.

6:15-6:35 Effects of a Rogue Star on Earth's Climate

Harini Chandramouli, University of Minnesota, U.S.

Wednesday, May 22

MS150

Rare Events in Complex Systems - Part I of II

5:00 p.m.-6:40 p.m.

Room: Ballroom 2

For Part 2 see MS163

Complex systems such as the earth, brain, human society, and infrastructure systems experience events which are rare in frequency but at times have catastrophic consequences. Understanding the dynamics of these events has become a pressing challenge. For example, the most significant impact of climate change appears to be the shift in the frequency of rare events such as the floods, droughts, hurricanes, and forest fires. However, the dynamical processes responsible for these disastrous events are yet to be fully understood. Examples of rare events in biological systems include heart attacks, strokes, and seizures whereas, stock and commodity market crashes are examples of rare events in financial systems. Reliable predictions of all these events is still a challenge. Rare events in infrastructure systems occur in the form of large-scale failures of these systems, some of the well-known examples are black-outs in power grids and traffic jams in transportation networks. While the increased connectivity in society has played a constructive role, the spread of misinformation in online social networks has also lead to the rare occurrences of widespread rioting and violence. In this minisymposium, we discuss different tools from network science and dynamical systems that could not only assist in improving our understanding of rare events in complex systems but also provide us the ability to predict them, so to mitigate the unpleasant outcomes associated with them.

Organizer: Nishant Malik

Rochester Institute of Technology, U.S.

Organizer: Ugur Ozturk

Potsdam Institute for Climate Impact Research and University of Potsdam, Germany

5:00-5:20 Detecting Rare Dynamical Regime Shifts in Complex Systems

Nishant Malik, Rochester Institute of Technology, U.S.

5:25-5:45 Rare Events Associated with Human Mobility

Naoya Fujiwara, Tohoku University, Japan

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Wednesday, May 22

MS150

Rare Events in Complex Systems - Part I of II

continued

5:50-6:10 Phase Coherence Between Precipitation in South America and Rossby Waves

Maximilian Gelbrecht, Humboldt University at Berlin, Germany; Niklas Boers, Ecole Normale Supérieure, France; Jürgen Kurths, Potsdam Institute for Climate Impact Research and Free University of Berlin, Germany

6:15-6:35 Early Warning and Diagnosis in Complex High Dimensional Systems

Jie Sun and Erik Bollt, Clarkson University, U.S.

Wednesday, May 22

MS151

New Directions in Simultaneous State and Parameter Estimation - Part II of II

5:00 p.m.-6:40 p.m.

Room: Ballroom 3

For Part 1 see MS138

A ubiquitous problem that arises in many areas of science and engineering is to estimate the parameters of a model from data. In dynamical systems, these parameters include the state of the model, as well as static quantities or functional terms which account for systematic and random errors arising from various sources, such as model misspecification or unresolved scales. In data assimilation (DA), these estimates are made by coupling prior assumptions in the form of SDE models and statistical distributions or processes for uncertain states, parameters, and model terms to data in the form of partial, noisy observations of the state of the system. This is an especially challenging problem with a high-dimensional state and parameter space in combination with sparse data and nonlinear dynamical and measurement models, a scenario often encountered in realistic physical and machine learning inference settings. A recent trend is to combine tools and theory from DA and machine learning, which also deals with nonlinear and high-dimensional numerical inference, in order to address the problems arising in the context of non-Gaussian likelihood and posterior estimation. In this vein, the aim of this minisymposium is to present various novel methods and theoretical advancements for model selection and simultaneous state, parameter, and functional estimation.

Organizer: Jana de Wiljes
Universität Potsdam, Germany

Organizer: Paul Rozdeba
Universität Potsdam, Germany

5:00-5:20 Gaussian Processes for Nonparametric Inference in Continuous Time Markov Processes

Manfred Opper, Technische Universität Berlin, Germany

5:25-5:45 Ensemble Kalman Inversion: A Derivative-Free Technique for Machine Learning Tasks

Nikola Kovachki, California Institute of Technology, U.S.

5:50-6:10 Feature-Based Data Assimilation Example: Estimating Parameters of the Nonlinear Cloud and Rain Equation from Large-Eddy Simulations

Spencer C. Lunderman, University of Arizona, U.S.

6:15-6:35 A Bayesian Approach to Quantifying Uncertainty in Divergence-Free Flows

Nathan Glatt-Holtz, Tulane University, U.S.; Jeff Borggaard and Justin Krometis, Virginia Tech, U.S.

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Wednesday, May 22

MS152

Geometric Mechanics and Robotics - Part II of II

5:00 p.m.-6:40 p.m.

Room: Magpie A

For Part 1 see MS139

Modern robotic systems are dynamical systems evolving on nonlinear configuration manifolds that benefit from global geometric techniques arising in geometric mechanics and geometric control theory. While there have been significant advances in the hardware capabilities of robots, the functionality of such systems are constrained by the use of local coordinate descriptions of the dynamics and the associated controllers that cannot adequately describe the aggressive time and cost optimal trajectories that arise in contemporary engineering applications. In addition, there are topological obstructions to controllability that cannot be addressed at the local level. The scope of this minisymposium is a synthesis of coordinate-independent differential-geometric approaches to mechanics and control and applications to real-world problems in dynamics and robotics.

Organizer: Tomoki Ohsawa
University of Texas at Dallas, U.S.

Organizer: Vakhtang Putkaradze
University of Alberta, Canada

5:00-5:20 Dynamics of Circulant Systems of ODE's

Anthony M. Bloch and Matthew D. Kvalheim, University of Michigan, U.S.

5:25-5:45 Geometric Kinematic Control of a Spherical Rolling Robot

Tomoki Ohsawa, University of Texas at Dallas, U.S.

5:50-6:10 Integrability and Chaos in Figure Skating

Vaughn Gzenda and Vakhtang Putkaradze, University of Alberta, Canada

6:15-6:35 Reduced-Order Models for Locomotion in the Perturbed Stokes Regime

Matthew D. Kvalheim, Brian Bittner, and Shai Revzen, University of Michigan, U.S.

Wednesday, May 22

MS153

New Directions in Multiple Time Scale Dynamics - Part II of II

5:00 p.m.-6:40 p.m.

Room: Magpie B

For Part 1 see MS140

Multiple time scales are ubiquitous to natural phenomena such as neuron dynamics, chemical reactions, population dynamics, social interactions, among many others. The behaviour of such phenomena can be quite complicated and exhibit, for example, relaxation and mixed-mode oscillations. Although the theory of multiple time scale dynamical systems has had great progress in the past years, especially in the context of ordinary differential equations, there is still a vast spectrum of challenges that require further efforts such as desingularization of high co-dimension singularities, fast-slow dynamic networks, fast-slow stochastic differential equations and discrete time systems particularly with singularities, to mention a few. The aim of this minisymposium is to gather researchers actively working on the theory and applications of multiple time scale dynamical systems, disseminate recent results, and to discuss novel research directions and their mathematical challenges.

Organizer: Hildeberto Jardon
Technische Universität München, Germany

Organizer: Christian Kuehn
Technische Universität München, Germany

5:00-5:20 Slow-fast systems on a Möbius band

Renato Huzak, University of Hasselt, Belgium

5:25-5:45 Temporal Multiscale Methods for a Plaque Model

Florian Sonner, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

5:50-6:10 Discretized Fast-Slow Systems Near Singularities

Maximilian Engel, Christian Kuehn, and Luca Arcidiacono, Technische Universität München, Germany; Matteo Petrera and Yuri Suris, Technische Universität, Berlin, Germany

6:15-6:35 Multi-Cluster Structures in Slowly Adapting Networks of Coupled Oscillators

Rico Berner, Serhiy Yanchuk, and Eckehard Schöll, Technische Universität Berlin, Germany

Wednesday, May 22

MS154

Theory and Application of Piecewise-Smooth ODEs - Part II of II

5:00 p.m.-6:40 p.m.

Room: Wasatch A

For Part 1 see MS141

Systems involving switches, impacts, thresholds, etc are naturally modeled by equations that are piecewise-smooth. Such equations readily admit novel dynamics and bifurcations that do not conform to the theory of smooth dynamical systems. The speakers in this minisymposium will discuss new advances in the theory of piecewise-smooth ODEs, and demonstrate implications of the theory in applications including electronic systems, mechanics and agricultural systems. On the theoretical part, bifurcations for equilibria of piecewise-smooth ODEs, networks of piecewise-smooth systems, slow-fast systems with non-smooth control, and rotation sets in the framework of non-smooth systems will be presented. Some of the talks are quite general for a brief introduction in the respective areas. On the applications, mechanical systems such as pendulums, or applications of piecewise-smooth control and bifurcations to coffee crops, and some electronic systems with hysteresis and memristors oscillations will be shown.

Organizer: Gerard Olivar Tost
Universidad Nacional de Colombia, Colombia

Organizer: David J. Simpson
Massey University, New Zealand

5:00-5:20 Linearising Nonsmooth Flows with Stochastic Discontinuity Boundaries

Eoghan J. Staunton and Petri T. Piiroinen, National University of Ireland, Galway, Ireland

5:25-5:45 Periodic Orbits Bifurcation in Hysteretic Systems with Real Eigenvalues

Francisco Torres, Enrique Ponce, and Marina Esteban, Universidad de Sevilla, Spain

continued on next page

Wednesday, May 22

MS154

Theory and Application of Piecewise-Smooth ODEs - Part II of II

continued

5:50-6:10 Fake Discontinuities in Piecewise Linear Memristor Oscillators

Enrique Ponce, Universidad de Sevilla, Spain; Andres Amador, Pontificia Universidad Javeriana Cali, Colombia; Javier Ros, Universidad de Sevilla, Spain

6:15-6:35 Filippov System that Models the Interaction Between CBB Affected by Capture and a Natural Predator

Gerard Olivar Tost, Universidad Nacional de Colombia, Colombia; Carlos Andres Trujillo Salazar, Universidad del Quindio, Colombia

Wednesday, May 22

MS155

The Dynamics and Structure of Neuronal Networks - Part II of II

5:00 p.m.-6:40 p.m.

Room: Wasatch B

For Part 1 see MS142

The dynamics of neuronal networks provide rich information regarding the nature of computation and information encoding in the brain. This minisymposium highlights recent studies that analyze dynamical system network models in neuroscience, emphasizing implications in learning, connectivity reconstruction, sensory processing, and synchronization. The speakers will draw particular attention to new mathematical advances in characterizing the structure-function relationship for complex neuronal networks and techniques for understanding the biophysical processes underlying observed network activity.

Organizer: Victor Barranca

Swarthmore College, U.S.

Organizer: Songting Li

Shanghai Jiao Tong University, China

5:00-5:20 Dendritic Computation Captured by An Effective Point Neuron Model

Songting Li, Shanghai Jiao Tong University, China

5:25-5:45 Binocular Rivalry in Macaque V1

Wei Dai, Shanghai Jiao Tong University, China

5:50-6:10 Structural Reorganizations During Continuous Learning and Sleep in Spiking Neural Networks

Yury Sokolov, Oscar Gonzalez, Giri Krishnan, and Maxim Bazhenov, University of California, San Diego, U.S.

6:15-6:35 Nonuniform Sampling Granger Causality Analysis for Pulse-Coupled Nonlinear Network Dynamics

Yaoyu Zhang, Courant Institute New York University, U.S. and New York University Abu Dhabi, United Arab Emirates

Wednesday, May 22

MS156

Lightning-Fast Interactive Simulations of Reaction Diffusion Systems

5:00 p.m.-6:15 p.m.

Room: Maybird

Over the past few years, central processing units (CPUs) have reached their speed limit due to thermodynamic constraints. However, the computational need has been skyrocketing as with every problem that we solve we open the door to more intricate realms that would entail even more intensive computations. To keep up with the computational demands, CPU manufacturers pack more compute cores into the CPU to offer some level of parallelization. Once even the small number of cores in a single CPU is not enough, we cluster a number of CPUs in a supercomputer to solve our computationally intensive problems. Unfortunately, supercomputers are expensive, not really user-friendly, and hard to maintain. In this minisymposium, we present the application of Graphics Processing Units (GPUs) as an alternative to traditional supercomputing for reaction-diffusion systems. Modern GPUs have thousands of computational cores and are already included in any personal computer or even cell-phone. We will showcase the leading edge application of GPUs to solve highly complex reaction-diffusion systems as model systems that can benefit from high levels of parallelism that is offered by the modern GPU without which the use of supercomputer would be inevitable due to the computational costs. With the aid of the GPU the speakers achieve high levels of speed-ups of lightning-fast real-time interactive simulations on personal computers or even cell-phones.

Organizer: Abouzar Kaboudian

Georgia Institute of Technology, U.S.

5:00-5:20 GPU-Accelerated Implicit/Explicit Solvers for Cardiac Modeling

Shahriar Iravanian, Emory University, U.S.

5:25-5:45 Real-time Interactive Computations of Fractals, Turing Patterns, and Cardiac Arrhythmias using WebGL 2.0

Abouzar Kaboudian, Georgia Institute of Technology, U.S.

5:50-6:10 Improving Low-Energy Defibrillation Using WebGL

Yanyan Ji, Abouzar Kaboudian, Hector Augusto Velasco Perez, and Flavio H. Fenton, Georgia Institute of Technology, U.S.

Wednesday, May 22

MS157

Analysis and Computation of Polymer and Lipid Suspensions - Part II of II

5:00 p.m.-6:40 p.m.

Room: Superior A

For Part 1 see MS144

The complex interactions of charged polymers and lipids with solvent sets up a hugely mutable system that affords subtle mechanisms to control the dynamics and curvature of membranes and higher codimensional structures. This minisymposium will feature contributions to the investigation of intrinsically multi-dimensional aspects of the dynamics of polymer and lipid suspensions, including the existence, stability, instability, slow evolution, and interaction of phase separated profiles. We expect to bring together researchers with a variety of backgrounds, employing diffusive stability estimates, energy methods from the calculus of variations, spatial dynamics, and bifurcation methods, and sophisticated time stepping schemes for the models of these complex systems.

Organizer: Noa Kraitzman
University of Utah, U.S.

Organizer: Keith Promislow
Michigan State University, U.S.

5:00-5:20 Codimension One Minimizers of Highly Amphiphilic Mixtures
Shibin Dai, University of Alabama, U.S

5:25-5:45 A Two-Component Functionalized Cahn-Hilliard Equation with Generic Pearling Inhibition
Qiliang Wu, Ohio University, U.S.; Keith Promislow, Michigan State University, U.S.

5:50-6:10 Curve Lengthening and Shortening in Strongly FCH
Yuan Chen and Keith Promislow, Michigan State University, U.S.

6:15-6:35 Bifurcation and Competitive Evolution of Network Morphologies in the Functionalized Cahn-Hilliard
Noa Kraitzman, University of Utah, U.S.; Keith Promislow, Michigan State University, U.S.

Wednesday, May 22

MS158

Recent Developments in Dynamics of Localized Patterns - Part I of II

5:00 p.m.-6:40 p.m.

Room: Superior B

For Part 2 see MS169

Driving mechanisms in the formation and dynamics of spatially localized patterns, can be elucidated by studying existence, stability, bifurcations and interactions of fronts, pulses, and spots arising in multi-component reaction-diffusion systems. This minisymposium will showcase resent developments in this direction, connecting researchers working on various types of model equations to extract key features of rich dynamics of localized patterns from dynamical system view point. The goal is to identify future challenges and new directions. Multi-faceted nature of the subject will be discussed from analytic results to numerical simulations or combination to those. Some potential subtopics include spatial heterogeneity and their effect on localized patterns.

Organizer: Shin-Ichiro Ei
Hokkaido University, Japan

Organizer: Takashi Teramoto
Asahikawa Medical University, Japan

Organizer: Peter van Heijster
Queensland University of Technology, Australia

5:00-5:20 On the Interplay between Intrinsic and Extrinsic Instabilities of Spatially Localized Patterns
Yasumasa Nishiura, Tohoku University, Japan

5:25-5:45 Dynamics of Fronts in 1D Allen-Cahn Equations with Large Scale Coupling
Jens Rademacher, Universität Bremen, Germany

5:50-6:10 Using Geometry to Detect Stability: The Riccati-Evans Function
Timothy Roberts, University of Sydney, Australia

6:15-6:35 Limit Classfication on Eigenfunctions for 1-Dimensional Reaction-Diffusion System
Tohru Wakasa, Kyushu Institute of Technology, Japan

Wednesday, May 22

MS159

Nonlocal Dynamical Systems and Applications - Part II of II

5:00 p.m.-6:40 p.m.

Room: White Pine

For Part 1 see MS146

Nonlocal Dynamical Systems, including delay differential equations, integro-differential equations, ordinary differential equations and partial differential equations, are extremely important tools in the large area of mathematical biology, image processing, and phase transitions. The simulation and analysis of Nonlocal Dynamical Systems are very successful in understanding the mechanisms that generate interesting and significant phenomenas in a variety of scientific subjects. The purpose of this minisymposium is to bring together researchers working in different directions to discuss recent advances in the modeling by nonlocal operators of emerging phenomena, numerical simulation and mathematical analysis of related Dynamical Systems.

Organizer: Xiaoxia Xie
Idaho State University, U.S.

5:00-5:20 The Role of Shelter
Guangyu Zhao, Auburn University, U.S.

5:25-5:45 Spreading Solutions of a Reaction Diffusion Equation with Free Boundaries in Time-Periodic Environment.
Fang Li, Shanghai Normal University, China

5:50-6:10 Effects of the Climate Change on the Nonlocal Population
Xiaoxia Xie, Idaho State University, U.S.; Zhongwei Shen, University of Alberta, Canada

6:15-6:35 Homogenization for Some Nonlocal Stochastic Partial Differential Equations
Li Lin, Huazhong University of Science & Technology, China

Wednesday, May 22

MS160

Control Techniques based on Koopman Operator Theory - Part II of II

5:00 p.m.-6:40 p.m.

Room: Primrose A

For Part 1 see MS147

The Koopman operator framework is an alternative approach to the classical pointwise description of dynamical systems. It provides a global description in terms of the evolution of "observable-functions" and turns nonlinear systems into linear (but infinite-dimensional) systems. This framework is directly connected to data-driven requirements for analysis and design of complex dynamics emerging in real-world applications. Recently, it has become increasingly popular in the context of control of dynamical systems, as a powerful tool to apply systematic linear control methods to nonlinear systems. This minisymposium aims to report on recent developments of Koopman operator techniques for controlling dynamical systems. A general introduction to the topic will be given in the first talk. Other presentations will develop more specific topics: control of multiway dynamical systems (talk 2), controllability and observability (talks 3,4), feedback control of partial differential equations (talk 5), identification and estimation (talk 6), optimal control (talks 3,6), sensor placement (talk 7), and signal processing (talk 8).

Organizer: Alexandre Mauroy
University of Namur, Belgium

Organizer: Amit Surana
United Technologies Research Center, U.S.

Organizer: Sebastian Peitz
University of Paderborn, Germany

5:00-5:20 Data Driven Feedback Control of Nonlinear PDEs using the Koopman Operator

Sebastian Peitz, University of Paderborn, Germany; Stefan Klus, Freie Universität Berlin, Germany

5:25-5:45 Discovering Conservation Laws from Data for Control

Eurika Kaiser, Steven L. Brunton, and J. Nathan Kutz, University of Washington, U.S.

continued in next column

5:50-6:10 Optimal Sensor and Actuator Placement using Balanced Model Reduction

Krithika Manohar, California Institute of Technology, U.S.; J. Nathan Kutz and Steven L. Brunton, University of Washington, U.S.

6:15-6:35 Expansion Formula of the Resolvents of Koopman Operators: Towards Applications in Analysis and Synthesis of Nonlinear Dynamical Systems

Yoshihiko Susuki, Osaka Prefecture University, Japan; Igor Mezic, University of California, Santa Barbara, U.S.; Alexandre Mauroy, University of Namur, Belgium

Wednesday, May 22

MS161

Reduced Order Models for Fluid Flows

5:00 p.m.-6:40 p.m.

Room: Primrose B

This minisymposium aims at giving a survey of recent developments in the reduced order modeling of fluid flows. Computational modeling, numerical analysis, and applications to realistic engineering and geophysical flow problems will be covered in this minisymposium. Both achievements and open problems in the reduced order modeling of fluid flows will be discussed.

Organizer: Traian Iliescu
Virginia Tech, U.S.

Organizer: Shane D. Ross
Virginia Tech, U.S.

5:00-5:20 Data-Driven Correction Reduced Order Models for Fluid Flows

Traian Iliescu, Virginia Tech, U.S.; Leo Rebholz, Clemson University, U.S.; Muhammad Mohebujjaman, Virginia Tech, U.S.; Xuping Xie, Oak Ridge National Laboratory, U.S.; Birgul Koc and Changhong Mou, Virginia Tech, U.S.

5:25-5:45 Frequency-Ranked Data-Driven Stochastic Modeling, and Applications to Climate Dynamics

Mickael Chekroun, University of California, Los Angeles, U.S.

5:50-6:10 An Artificial Compression Based Reduced Order Model

Michael Schneier, University of Pittsburgh, U.S.

6:15-6:35 Dynamic Stochastic Model Order Reduction with Adaptive Data-Driven Closures for Geophysical Flows

Pierre F. Lermusiaux, Jing Lin, and Abhinav Gupta, Massachusetts Institute of Technology, U.S.

Dinner Break

6:40 p.m.-8:30 p.m.

Attendees on their own

DSWeb Editorial Board Meeting

7:00 p.m.-8:30 p.m.

Room: Twin Peaks A - 10th Floor

Wednesday, May 22

PP2

Poster Session and Dessert Reception

8:30 p.m.-10:30 p.m.

Room: Ballroom

Synaptic Plasticity in Correlated Balanced Networks

Alan E. Akil, University of Houston, U.S.; Robert Rosenbaum, University of Notre Dame, U.S.; Krešimiv Josić, University of Houston, U.S.

Towards Understanding the Genetic Divergence of Shellfish Symbionts using Ocean Models

Aishah Albarakati, Marko Budišic, and Andrew David, Clarkson University, U.S.

Stability Analysis of Abstract Ecological Networks and the Beaufort Sea Food Web

Stefan Awender, Renate A. Wackerbauer, and Greg Breed, University of Alaska, Fairbanks, U.S.

Dynamics Near the Leapfrogging Vortex Quartet

Brandon Behring, New Jersey Institute of Technology, U.S.

Encoding Plankton Behavior in Videos for Environmental Health Monitoring

Sujoy K. Biswas, Thomas Zimmerman, and Vito Pastore, IBM Research, U.S.; Lucrezia Maini, ETH Zürich, Switzerland; Simone Bianco, IBM Research, U.S.

Identifying Important Edges in Complex Networks

Timo Broehl and Klaus Lehnertz, Universität Bonn, Germany

Are the SDGs Self-Consistent and Mutually Achievable?

Jonathan Dawes, University of Bath, United Kingdom

A Novel Explanation for Young's Single Photon Experiment

Jorge Diaz-Castro, University of Puerto Rico, Puerto Rico

Molding the Asymmetry of Localized

continued in next column

Frequency-Locking Waves by a Generalized Forcing and Implications to the Inner Ear

Yuval Edri, Ben-Gurion University of the Negev, Israel; Dolores Bozovic, University of California, Los Angeles, U.S.; Ehud Meron, Ben-Gurion University, Israel; Arik Yochelis, Ben Gurion University Negev, Israel

Invasion and Extinction in Stochastic Food Webs

Dunia Fernandez and Eric Forgoston, Montclair State University, U.S.

Machine Learning to Improve Data Assimilation for Arctic Sea Ice

Ty Frazier, University of Minnesota, U.S.; Siyang Jing and Christian Sampson, University of North Carolina at Chapel Hill, U.S.

Combining Diffusion Maps and Set Oriented Numerics for the Approximation of Invariant Sets

Raphael Gerlach, Universität Paderborn, Germany; Peter Koltai, Freie Universität Berlin, Germany; Michael Dellnitz, University of Paderborn, Germany

Dynamics of Dual Strain Toggle Consortium

Deepjyoti Ghosh, University of Houston, U.S.; Mehdi Sadeghpour, University of Michigan, Ann Arbor, U.S.; Razan Alnahhas, Rice University, U.S.; William Ott, University of Houston, U.S.; Matthew Bennett, Rice University, U.S.; Krešimiv Josić, University of Houston, U.S.

Characterization of Chaos in Random Neural Networks

Richard Janis Goldschmidt, University of Potsdam, Germany and University of Aberdeen, United Kingdom; Antonio Politi, University of Aberdeen, United Kingdom; Arkady Pikovsky, Universität Potsdam, Germany

Using Exact Coherent Structures to Tile the Infinite Spacetime Kuramoto-Sivashinsky Equation

Matthew Gudorf, Georgia Institute of Technology, U.S.

Influence of Astrocytes in Neuronal Network Synchrony

Gregory A. Handy and Alla Borisyuk, University of Utah, U.S.

continued in next column

Existence of Blenders in a H\'enon-Like Family: Geometric Insights from Invariant Manifold Computations

Stefanie Hittmeyer, Bernd Krauskopf, and Hinke M. Osinga, University of Auckland, New Zealand; Katsutoshi Shinohara, Hitotsubashi University, Japan

Nonlinear and Branching Dynamics of Terrestrial Landscape Evolution

Milad Hooshyar, Princeton University, U.S.; Sara Bonetti, ETH Zürich, Switzerland; Amilcare Porporato, Princeton University, U.S.

Periodic and Quasiperiodic Dynamics of Optoelectronic Oscillators with Narrowband Time-Delayed Feedback

Lucas Illing and Yunjia Bao, Reed College, U.S.; Ella Banyas, University of California, Berkeley, U.S.

Heteroclinic Networks with Noise and Input

Valerie J. Jeong, University of Auckland, New Zealand

A Computer-Assisted Study of Red Coral Population Dynamics

Sayomi Kamimoto, Evelyn Sander, and Thomas Wanner, George Mason University, U.S.; Hye Kyung Kim, University of Minnesota, U.S.

Mechanisms of Frequency and Intensity Regulation in Spinal Cord Central Pattern Generator

Lae U. Kim and Hermann Riecke, Northwestern University, U.S.

Stable Stripe Patterns in a Generalized Gierer-Meinhardt Model

David Kok, University of Leiden, The Netherlands

Mixed Global Dynamics of Harmonically Forced Vibro-Impact Oscillator with Dry Friction

Pavel Kravetc, University of Texas at Dallas, U.S.; Oleg Gendelman, Technion Israel Institute of Technology, Israel; Dmitri Rachinskii, University of Texas at Dallas, U.S.

Pedestrian-Induced Vertical Vibrations of Footbridges

Ratislav Krylov and Kevin Daley, Georgia State University, U.S.; Vladimir Belykh, Lobachevsky State University of Nizhny Novgorod, Russia; Igor Belykh, Georgia State University, U.S.

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Wednesday, May 22

PP2

Poster Session and Dessert Reception

continued

Contagion Dynamics on Adaptive Networks: Norovirus as a Case Study

Brittany Lemmon and Deena Schmidt, University of Nevada, Reno, U.S.

Robustness of Planar Target Patterns

Ang Li, Brown University, U.S.

Model Order Reduction in the Frequency Domain via Spectral Proper Orthogonal Decomposition

Cong Lin and Maciej Balajewicz, University of Illinois at Urbana-Champaign, U.S.

Analysis of Reaction-Diffusion PDE Models for Localized Pattern Formation in Cells

Yue Liu and Leah Edelstein-Keshet, University of British Columbia, Canada

Noisy Heteroclinic Networks

Gray T. Manicom, University of Auckland, New Zealand

Hebbian Model of the Structural Plasticity in the Olfactory System

Hermann Riecke and *John Meng*, Northwestern University, U.S.

From Theory to Application: Case Studies of Resilience Metrics

Katherine Meyer, University of Minnesota, U.S.; Andrew Brettin, University of Minnesota, Twin Cities, U.S.; Alanna Hoyer-Leitzel, Mount Holyoke College, U.S.; Sarah Iams, Harvard University, U.S.; John Mangles, University of Kansas, U.S.; Richard McGehee and Maria Sanchez-Muniz, University of Minnesota, U.S.; Mary Lou Zeeman, Bowdoin College, U.S.

Cardio-Respiratory Interactions: Neural Mechanisms

Yaroslav Molkov, William Barnett, Robert Capps, and Elizaveta Latash, Georgia State University, U.S.; David Baekey, University of Florida, U.S.; Thomas Dick, Case Western Reserve University, U.S.; Julian Paton, University of Auckland, New Zealand

continued in next column

Optimizing Sequential Decisions in the Drift-Diffusion Model

Khanh Nguyen, University of Houston, U.S.; Zachary P. Kilpatrick, University of Colorado Boulder, U.S.; Kresimir Josic, University of Houston, U.S.

Convergence of Ginelli's Algorithm for Covariant Lyapunov Vectors

Florian Noethen, Universität Hamburg, Germany

Modelling Blood and the Dynamics of Hematopoietic Stem Cells

Rasmus K. Pedersen, Johnny T. Ottesen, and Morten Andersen, Roskilde University, Denmark; Thomas Stiehl, Universität Heidelberg, Germany

A Dynamical Systems Approach to Questionnaire Data

Aviva Prins, University of California, Los Angeles, U.S.; Jiazhong Mei, University of California, Berkeley, U.S.; Qinyi Zeng, Omri Azencot, Michael Lindstrom, Jeff Brantingham, and Andrea Bertozzi, University of California, Los Angeles, U.S.

Stability and Nonlinear Waves in Damped Driven Rotating Shallow Water Models

Artur Prugger and Jens Rademacher, Universität Bremen, Germany

On the Effect of Forcing on Fold Bifurcations and Early-Warning Signals in Population Dynamics

Flavia Remo, Friedrich-Schiller-Universität Jena, Germany

Parametrically Excited Bi-Rhythmic Generalised Van Der Pol Model

Sandip Saha and Gautam Gangopadhyay, Bose National Centre for Basic Sciences, India

Using Diffusion Maps in Equation-Free Modeling

Rebecca Santorella, Brown University, U.S.

Nonequilibrium Statistical Mechanics and Data Assimilation of Sudden Stratospheric Warming

Justin M. Finkel, University of Chicago, U.S.; Jonathan Weare, Courant Institute of Mathematical Sciences, New York University, U.S.; Dorian S. Abbot and Mary Silber, University of Chicago, U.S.

continued in next column

Analysis of Some Non-Smooth Bifurcations with Applications to Ship Maneuvering

Miriam Steinherr Zazo and Jens Rademacher, Universität Bremen, Germany; Ivan Ovsyannikov, University of Hamburg, Germany

Mode Interactions and Superlattice Patterns

Priya Subramanian, University of Leeds, United Kingdom; Pakwan Riyapan, Prince of Songkla University, Thailand; Alastair M. Rucklidge, University of Leeds, United Kingdom

Transient Activity Patterns in Synaptically Coupled Morris-Lecar Neuron Networks

Jeremy Thomas and Renate A. Wackerbauer, University of Alaska, Fairbanks, U.S.

Analysis of Hippocampal Calcium Imaging Data

Duc P. Truong, Southern Methodist University, U.S.; Jun Guo and Wei Xu, University of Texas Southwestern Medical School, U.S.; Andrea Barreiro, Southern Methodist University, U.S.

Inherently Complex Quantum Dynamics

Ariadna E. Venegas-Li, Fabio Anza, and James Crutchfield, University of California, Davis, U.S.

Nontwist Maps with Even Power Winding Number Profiles

Alexander Wurm, Western New England University, U.S.

Exploring Reversible EMT using DSGRN

Ying Xin, Bree Cummins, and Tomas Gedeon, Montana State University, U.S.

Refractory Dynamics on Networks: Role of Network Structure

Daniel R. Zavitz and Alla Borisyuk, University of Utah, U.S.

Dynamics and Topological Entropy of 1D Greenberg-Hastings Cellular Automata

Dennis Ulbrich, University of Bremen, Germany; *Jens Rademacher*, Universität Bremen, Germany; Marc Kesseboehmer, University of Bremen, Germany

How Entropic Regression Beats the Outliers Problem in Nonlinear System Identification

Abd Alrahman R. Almomani, Jie Sun, and Erik Bollt, Clarkson University, U.S.

Thursday, May 23

Registration

8:00 a.m.-6:15 p.m.

Room: Ballroom Foyer

Thursday, May 23

MS162

Planetary Motion and its Effects on Climate - Part II of II

8:30 a.m.-10:10 a.m.

Room: Ballroom 1

For Part 1 see MS149

This session reviews recent research into the relationship between planetary motion and climate. Some scholars have used low-dimensional and conceptual models to test hypotheses about how climate is affected by different elements of a planet's motion. Others rely on large-scale global circulation models to understand how orbital parameters affect the detailed structure of a planet's climate.On the other hand, recent studies have investigated how climate signatures from Earth's sediment cores can be used to understand the chaotic behavior of the solar system. Results from these research areas will be presented in this session, with specific focus on climate of exoplanets and Earth's past climate.

Organizer: Alice Nadeau
University of Minnesota, U.S.

Organizer: Harini Chandramouli
University of Minnesota, U.S.

8:30-8:50 The Geological Orrery: Mapping the Chaotic History of the Solar System using Earth's Geological Record

Paul Olsen, Columbia University, U.S.; Jacques Laskar, Paris Observatory, France; Dennis Kent and Sean Kinney, Columbia University, U.S.; Jingeng Sha, Nanjing Institute of Geology and Palaeontology, China; Jessica Whiteside, University of Southampton, United Kingdom

8:55-9:15 Forcing-Induced Transitions in a Paleoclimate Delay Model

Courtney Quinn and Jan Sieber, University of Exeter, United Kingdom; Anna von der Heydt, Utrecht University, The Netherlands; Timothy Lenton, University of Exeter, United Kingdom

continued in next column

9:20-9:40 Modeling the Mid Pleistocene Transition in a Budyko-Sellers Type Energy Balance Model using the LR04 Benthic Stack

Esther Widiasih, University of Hawaii, West Oahu, U.S.; Malte Stuecker, Pusan National Univeristy, South Korea; *Somyi Baek*, University of Minnesota, U.S.

9:45-10:05 A Conceptual Glacial Cycle Model with Diffusive Heat Transport

James Walsh, Oberlin College, U.S.; Esther Widiasih, University of Hawaii, West Oahu, U.S.

Thursday, May 23

MS163

Rare Events in Complex Systems - Part II of II

8:30 a.m.-10:10 a.m.

Room: Ballroom 2

For Part 1 see MS150

Complex systems such as the earth, brain, human society, and infrastructure systems experience events which are rare in frequency but at times have catastrophic consequences. Understanding the dynamics of these events has become a pressing challenge. For example, the most significant impact of climate change appears to be the shift in the frequency of rare events such as the floods, droughts, hurricanes, and forest fires. However, the dynamical processes responsible for these disastrous events are yet to be fully understood. Examples of rare events in biological systems include heart attacks, strokes, and seizures whereas, stock and commodity market crashes are examples of rare events in financial systems. Reliable predictions of all these events is still a challenge. Rare events in infrastructure systems occur in the form of large-scale failures of these systems, some of the well-known examples are black-outs in power grids and traffic jams in transportation networks. While the increased connectivity in society has played a constructive role, the spread of misinformation in online social networks has also lead to the rare occurrences of widespread rioting and violence. In this minisymposium, we discuss different tools from network science and dynamical systems that could not only assist in improving our understanding of rare events in complex systems but also provide us the ability to predict them, so to mitigate the unpleasant outcomes associated with them.

Organizer: Nishant Malik

Rochester Institute of Technology, U.S.

Organizer: Ugur Ozturk

Potsdam Institute for Climate Impact Research and University of Potsdam, Germany

8:30-8:50 Enhancing the Rarity of Arrhythmic Events: Personalized Approaches to Medical Treatment and Prevention

Niels Wessel, Humboldt University at Berlin, Germany

continued in next column

8:55-9:15 Prediction of Abnormal Cardiac Rhythms with a 1D Dynamical Model

Laura Munoz, Rochester Institute of Technology, U.S.

9:20-9:40 Signatures of Rare and Unseasonal Flood Dynamics

Dadiyorto Wendi, Universität Potsdam, Germany; Bruno Merz, German Research Centre for Geosciences, Germany; Norbert Marwan, Potsdam Institute for Climate Impact Research, Germany

9:45-10:05 Mechanisms of the Emergence of Extreme Harmful Algal Blooms

Ulrike Feudel, University of Oldenburg, Germany; Subhendu Chakraborty, DTU Aqua, Denmark; Stefanie Moorthi, University of Oldenburg, Germany; Rajat Karnatak, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Germany

Thursday, May 23

MS164

Theory and Application of Koopman Operator Methods in Molecular Simulation

8:30 a.m.-10:10 a.m.

Room: Ballroom 3

Molecular Dynamics (MD) has emerged as a powerful tool to study macromolecular systems using computer simulations. A key challenge to the routine use of MD is the need to automatically extract biologically relevant information from simulation data. A number of powerful methods have emerged over the past 15 years, including Markov State Models [Schütte et al, J. Comput. Phys., 1999] and Diffusion Maps [Coifman et al, Appl. Comput. Harmon. Anal., 2006]. The commonality of these methods is that they all attempt to approximate dominant spectral components of the infinitesimal generator of the underlying stochastic dynamics, or its associated semigroup of Koopman operators. Recently, the connection between this research and methods known in the dynamical systems community, such as (Extended) Dynamic Mode Decomposition, has been explored [Klus et al, J. Nonlinear Sci., 2018]. These discoveries have prompted significant follow-up research. In particular, the application of previously established methods to systems away from thermal equilibrium has been investigated [Koltai et al, Computation, 2018]. However, challenges and open questions remain, such as error analysis, uncertainty quantification, choice of feature functions, physical interpretation of results, and many more. This symposium aims at bringing together researchers working on Koopman operator theory and data-driven methods derived from it, as well as practitioners from biophysics, biochemistry and related fields.

Organizer: Feliks Nüske

Rice University, U.S.

8:30-8:50 Variational Approach to Markov Processes and Its Applications in Molecular Dynamics

Hao Wu, Tongji University, China

8:55-9:15 Forecasting Nonlinear Time Series with Koopman Shifted Kernel Regression

Romeo Alexander and Dimitrios Giannakis, Courant Institute of Mathematical Sciences, New York University, U.S.

continued on next page

9:20-9:40 A Local Metastability Detection Method Using Koopman Operators

Danny Perez, Los Alamos National Laboratory, U.S.

9:45-10:05 Hierarchical Dynamics Encoders Learning of Collective Variables to Understand and Accelerate Biomolecular Folding

Wei Chen, University of Illinois at Urbana-Champaign, U.S.; Hythem Sidky and *Andrew L. Ferguson*, University of Chicago, U.S.

Thursday, May 23

MS165

Dynamical Systems with Critical Rates: Beyond Classical Bifurcations

8:30 a.m.-10:10 a.m.

Room: Magpie A

Many systems from the natural world and technology have to adapt to continuously changing external conditions. Some systems have dangerous levels of external conditions, defined by catastrophic bifurcations, above which they undergo a critical transition (B-tipping) to a different state; e.g. power-grid blackouts or forest-desert transitions. Other systems can be very sensitive to how fast the external conditions change and have dangerous rates - they undergo an unexpected critical transition (R-tipping) if the external conditions change slowly but faster than some critical rate; e.g. species failing to adapt to rapid climatic changes. This genuine non-autonomous instability is very relevant for modern applications, generalises the notions of excitability and edge states, but remains far less explored than classical bifurcations. The main reasons are that R-tipping is more challenging mathematically and often puzzles applied scientists because there is no classical bifurcation or `obvious’ loss of stability. This minisymposium highlights recent advances in the theory and applications of R-tipping including concepts of compactification, connecting orbits, threshold instability and shifting chaotic attractors, together with examples from climate science, ecology and technology.

Organizer: Sebastian M. Wieczorek

University College Cork, Ireland

8:30-8:50 Rate-Induced Tipping: Beyond Classical Bifurcations in Ecology

Sebastian M. Wieczorek, Paul O'Keeffe, and Chun Xie, University College Cork, Ireland; Peter Ashwin, University of Exeter, United Kingdom; Chris K.R.T. Jones, University of North Carolina, Chapel Hill, U.S.

8:55-9:15 Rate-Induced Tipping in Multi-Dimensional Phase Space: Is this how a Hurricane Dies?

Claire Kiers and Chris Jones, University of North Carolina, Chapel Hill, U.S.

continued in next column

9:20-9:40 Tipping Phenomena in Typical Dynamical Systems Subjected to Parameter Drift

Tamas Tel and Balint Kaszas, Eötvös Loránd University, Hungary; Ulrike Feudel, University of Oldenburg, Germany

9:45-10:05 Buckling of Spherical Shells under Dynamically Increasing Pressure

Jan Sieber, University of Exeter, United Kingdom; J.M.T. Thompson, University College London, United Kingdom; John Hutchinson, Harvard University, U.S.

Thursday, May 23

MS166

Biological Signaling in Cellular Collectives - Part I of II

8:30 a.m.-10:10 a.m.

Room: Magpie B

For Part 2 see MS176

Single cells are capable of performing a plethora of extraordinary tasks, from adapting to a variety of environments to replicating genetic material. Yet, cells rarely act alone. They are typically part of a larger collective in which constituent cells communicate via signaling. This is specifically true for microbial colonies. The result is a complex community where cells distribute responsibilities and coordinate activities across populations, even in spatially extended domains. The mechanisms underlying such coordinated activity, however, are still largely not understood. Even in large spatial domains whose sizes are vastly greater than the typical diffusion correlation lengths of microbial quorum sensing molecules, cells are capable of coordination. Understanding how this is achieved is crucial to the progress of experimental disciplines such as synthetic biology, wherein emergent behaviors must be controlled to optimize efficiency of synthetic biocircuit function. This minisymposium will feature talks describing models of the mechanical and chemical mechanisms cellular collectives use to coordinate the activities of their constituent cells. Emphasis will be placed both on achievements to date and the exciting challenges ahead.

Organizer: William Ott
University of Houston, U.S.

Organizer: Bhargav R. Karamched
University of Houston, U.S.

8:30-8:50 Moran Model of Spatial Alignment in Microbial Colonies

Bhargav R. Karamched, William Ott, and Ilya Timofeyev, University of Houston, U.S.; Razan Alnahhas and Matthew Bennett, Rice University, U.S.; Krešimir Josic, University of Houston, U.S.

8:55-9:15 Microbial Population Dynamics via Cell-Shape Modulation in Negative-Feedback Networks

James J. Winkle, Rice University, U.S.

continued in next column

9:20-9:40 Spatial Patterning from a Toggle Switch

Marcella M. Gomez, University of California, Santa Cruz, U.S.

9:45-10:05 Modeling the Role of Feedback in the Adaptive Response of Bacterial Quorum Sensing

Gaoyang Fan and Paul C. Bressloff, University of Utah, U.S.

Thursday, May 23

MS167

Modelling and Analysis of Pedestrian Flow Experiments

8:30 a.m.-10:10 a.m.

Room: Wasatch B

Pedestrian flows typically represent a challenging research area as they consist of a discrete structure with many degrees of freedom which cannot be modelled as continuum. Several aspects of particle based models will be discussed and analyzed. This includes the modelling of collision avoidance, conflicts between target selection and group behavior. Pedestrian flow experiments under controlled conditions will be presented including hysteresis behavior and unstable flow situations. Feedback control methods will be presented which finally allow to perform a control based continuation of unstable states in particle based pedestrian models.

Organizer: Jens Starke
Technical University of Denmark, Denmark

8:30-8:50 Control Based Continuation of Unstable States in Particle Based Pedestrian Models

Ilias Panagiotopoulos, University of Rostock, Germany; Jens Starke, Technical University of Denmark, Denmark

8:55-9:15 Hysteresis and Unstable Pedestrian Flow Situations in Experiments

Jens Starke, Technical University of Denmark, Denmark; Ilias Panagiotopoulos, University of Rostock, Germany

9:20-9:40 Pattern Formation in an Annular Corridor of Repulsive Particles Modelling Pedestrian Flow Dynamics

Christian Marschler, Jens Starke, and *Mads Peter Sørensen*, Technical University of Denmark, Denmark; Yuri Gaididei, Bogolyubov Institute for Theoretical Physics, Ukraine; Peter Leth Christiansen, Technical University of Denmark, Denmark

9:45-10:05 Time Delayed Feedback: Control, Synchronisation, and Spectroscopy

Wolfram Just, Queen Mary University of London, United Kingdom

Thursday, May 23

MS168

Applications of Nonlinear Dynamical Systems to Kinetic Plasmas - Part I of II

8:30 a.m.-10:10 a.m.

Room: Superior A

For Part 2 see MS178

We propose a two-part minisymposium focusing on the connection between particle orbit dynamics in electric, magnetic and electromagnetic fields and the coherent field structures that produce and sustain them. Self-consistent plasma response to sculpted electric and magnetic high frequency waves or imposed external fields will be elucidated vis a vis stable structures that may not be stationary but which are robust. Numerical methods needed to fine tune such searches and designs will also be given.

Organizer: Jon Wilkening
University of California, Berkeley, U.S.

Organizer: Bedros Afeyan
Polymath Research Inc., U.S.

8:30-8:50 New Algorithms for Refinable, Adaptive Tracking of Self-Consistent Coherent Kinetic Structures in High Energy Density Plasmas: Physics Based Machine Learning

Bedros Afeyan, Polymath Research Inc., U.S.; Richard Sydora, University of Alberta, Canada

8:55-9:15 Symplectic Methods for Drifting Instabilities in Magnetized High Energy Density Plasmas

Brad Shadwick and Alexander Stamm, University of Nebraska, Lincoln, U.S.; Bedros Afeyan, Polymath Research Inc., U.S.

9:20-9:40 Multidimensional Confinement of Self-Consistent Particle Orbits in Coherent Phase Space Plasma Structures

Richard Sydora, University of Alberta, Canada; Bedros Afeyan, Polymath Research Inc., U.S.; Brad Shadwick, University of Nebraska, Lincoln, U.S.

9:45-10:05 Spectrally Accurate Methods for Kinetic Electron Plasma Wave Dynamics

Jon Wilkening and Rockford Sison, University of California, Berkeley, U.S.; Bedros Afeyan, Polymath Research Inc., U.S.

Thursday, May 23

MS169

Recent Developments in Dynamics of Localized Patterns - Part II of II

8:30 a.m.-10:10 a.m.

Room: Superior B

For Part 1 see MS158

Driving mechanisms in the formation and dynamics of spatially localized patterns, can be elucidated by studying existence, stability, bifurcations and interactions of fronts, pulses, and spots arising in multi-component reaction-diffusion systems. This minisymposium will showcase resent developments in this direction, connecting researchers working on various types of model equations to extract key features of rich dynamics of localized patterns from dynamical system view point. The goal is to identify future challenges and new directions. Multi-faceted nature of the subject will be discussed from analytic results to numerical simulations or combination to those. Some potential subtopics include spatial heterogeneity and their effect on localized patterns.

Organizer: Shin-Ichiro Ei
Hokkaido University, Japan

Organizer: Takashi Teramoto
Asahikawa Medical University, Japan

Organizer: Peter van Heijster
Queensland University of Technology, Australia

8:30-8:50 Pulse Dynamics in Reaction-Diffusion Equations with Strong Spatially Localised Impurities

Peter van Heijster, Queensland University of Technology, Australia

8:55-9:15 On Compact Traveling Waves for a Mean-Curvature Flow with Driving Force

Harunori Monobe, Okayama University, Japan

9:20-9:40 Monotone Traveling Waves for a Bistable Lattice Dynamical System

Ken-Ichi Nakamura, Kanazawa University, Japan

9:45-10:05 Dynamics of Pulses for Mass-Conserved Reaction-Diffusion Systems Related to Cell Polarity

Shin-Ichiro Ei, Hokkaido University, Japan

Thursday, May 23

MS170

Data-Driven Modeling and Prediction of Geophysical Fluid Dynamics - Part I of II

8:30 a.m.-10:10 a.m.

Room: Primrose A

For Part 2 see MS180

Improved modeling and prediction of fluid dynamics is needed to better understand transport in geophysical flows. Major recent advances in machine learning, coherent structure detection, reduced-order models, uncertainty quantification, data assimilation, optimal path planning, and adaptive sampling are providing increased understanding of transport phenomena. The purpose of this minisymposium is to expose the audience to recent progress and developments, as well as to bring together researchers developing new mathematical methods and applications for use in understanding material transport in geophysical flows.

Organizer: Eric Forgoston
Montclair State University, U.S.

Organizer: M. Ani Hsieh
University of Pennsylvania, U.S.

8:30-8:50 Using Control to Shape Stochastic Escape and Switching Dynamics

Eric Forgoston, Montclair State University, U.S.; M. Ani Hsieh, Drexel University, U.S.; Dhanushka Kularatne, University of Pennsylvania, U.S.

8:55-9:15 Quantifying Lagrangian Uncertainty and Robust Sets from Noisy Unsteady Eulerian Data

Sanjeeva Balasuriya, University of Adelaide, Australia

9:20-9:40 Exploring use of Machine Learning Towards Weather Prediction

Kayo Ide, University of Maryland, College Park, U.S.

9:45-10:05 Machine Learning and Trajectory Prediction in Geophysical Flows

Eric Forgoston, Montclair State University, U.S.; Kevin Yao and *Philip Yecko*, Cooper Union, U.S.

Thursday, May 23

MS171

Regular and Chaotic Dynamics of Oscillator Populations in the Kuramoto Model and Beyond

8:30 a.m.-10:10 a.m.

Room: Primrose B

Populations of coupled oscillators can demonstrate synchronization, and this effect is captured by the famous Kuramoto model based on the phase description of the dynamics. This model is extremely simple and a complete solution can be constructed in the limiting case of infinite populations – here the Ott-Antonsen finite-dimensional reduction has been extremely successful. Thus, a typical approach in studying real-world problems like power grid networks and spin-torque oscillator arrays is in a reduction to the Kuramoto model. However, the dynamics is much less explored in non-ideal situations, in particular, for finite ensembles, or when the phase reduction is not adequate and one has to include amplitude degrees of freedom. The scope of the minisymposium is to explore, by virtue of analytical and numerical methods, the effects which appear when one extends the Kuramoto model to more realistic setups. In some cases, one can construct perturbative approaches, starting with solutions of the ideal model. In other situations, ad-hoc finite-dimensional reduction results in high-dimensional dynamical systems with nontrivial behaviors, like chimeras, collective chaos, and interplay between second- and first-order transitions.

Organizer: Arkady Pikovsky
Universität Potsdam, Germany

8:30-8:50 Collective Dynamics of Stuart-Landau Oscillators in Between Phase and Amplitude Oscillators

Antonio Politi and Pau Clusella, University of Aberdeen, United Kingdom

8:55-9:15 Microscopic Correlations in the Kuramoto Model of Coupled Oscillators

Franziska Peter, Chen Chris Gong, and *Arkady Pikovsky*, Universität Potsdam, Germany

continued in next column

9:20-9:40 First-Order Phase Transitions in the Kuramoto Model with Compact Bimodal Frequency Distributions

Andreas Daffertshofer and Bastian Pietras, Vrije Universiteit Amsterdam, The Netherlands

9:45-10:05 Understanding Chimera States via Reduction to Kuramoto and Stuart-Landau Models

Erik A. Martens, Technical University of Denmark, Denmark; Shashi Thutupalli, Tata Institute of Fundamental Research, India; Mark J Panaggio, Hillsdale College, U.S.

Thursday, May 23

CP33

Mathematical Biology II

8:30 a.m.-9:45 a.m.

Room: Wasatch A

Chair: Matthew J. Armstrong, United States Military Academy, U.S.

8:30-8:50 Using Electrokinetic-Mixing to Improve the Kinetics of the Diagnostic and Biosensor Platforms

Emir Yasun, Travis Trusty, and Igor Mezic, University of California, Santa Barbara, U.S.

8:55-9:15 Exploration of the Role of Disinfection Timing, Duration, and Other Control Parameters on Bacterial Populations Using a Mathematical Model

Nihan Acar, University of Cincinnati, U.S.

9:20-9:40 Comparison of Global, Stochastic Optimization Algorithms Using Toy Problems and Fitting Multi-Parameter Models to Kinetic Rheological Data

Matthew J. Armstrong, Corey James, and April Miller, United States Military Academy, U.S.

Thursday, May 23

CP34

Topics in Theoretical Physics

8:30 a.m.-10:10 a.m.

Room: Maybird

Chair: Parth Mukeshbhai Shah, Birla Institute of Technology Pilani, India

8:30-8:50 Dynamics of Bubbles in a Quark-Hadron System

Ricardo F. Fariello, State University of Montes Claros, Brazil

8:55-9:15 Title Not Available

Zubair Moughal, University of Waikato, New Zealand

9:20-9:40 The Roles of Inertia and Stability in Power Systems

Samantha Molnar, University of Colorado, U.S.; Elizabeth Bradley, University of Colorado, Boulder and Santa Fe Institute, U.S.; Kenny Gruchalla, National Renewable Energy Laboratory, U.S.; Bri-Matthias Hodge, University of Colorado, U.S.

9:45-10:05 Stability Analysis Using Dynamical Systems in Modified Gravity

Parth Mukeshbhai Shah and G.C. Samanta, Birla Institute of Technology Pilani, India

Thursday, May 23

CP35

Partial Differential Equations

8:30 a.m.-10:10 a.m.

Room: White Pine

Chair: Hamidreza Mofidi, University of Kansas, U.S.

8:30-8:50 Understanding and Designing Emergent Behavior via Stability Analysis of Mean Field Games

Piyush Grover, Mitsubishi Electric Research Laboratories, U.S.; Kaivalya Bakshi and Evangelos Theodorou, Georgia Institute of Technology, U.S.

8:55-9:15 Numerical Studies, of Medication Deposition Inside the Human Lungs, using LES

Marcel Ilie, Ionut E. Iacob, and Alex Stokolos, Georgia Southern University, U.S.

9:20-9:40 Blood Flow with Nano Particles through Stenosed Arteries Under the Effect of Magnetic Field

Rajbala Malik, All India Jat Heroes Memorial College Rohtak, India; Sushila Kumari, Pt. Neki Ram Sharma Goverment College Rohtak, India; Jagdish Nandal, Maharshi Dayanand University, India

9:45-10:05 Reversal Permanent Charge and Reversal Potentials: Case Studies via Classical Poisson-Nernst-Planck Models with Diffusion.

Hamidreza Mofidi, University of Kansas, U.S.

Thursday, May 23

IP101

Workshop on Network Science: Title Not Available

9:00 a.m.-9:45 a.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

Abstract not available at time of publication.

Marta Gonzalez
University of California, Berkeley, U.S.

Thursday, May 23

CP104

Workshop on Network Science: Contributed Session 5

9:50 a.m.-10:15 a.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

9:50-10:10 Understanding the Role of Seasonal Food Trade Networks in Invasive Species Spread

Abhijin Adiga and Srinivasan Venkatramanan, University of Virginia, U.S.; Sichao Wu, Bloomberg LP, U.S.; Madhav Marathe and Stephen Eubank, University of Virginia, U.S.; L P Sah, A P Giri, and Luke Colavito, International Development Enterprises, Nepal; Rangaswamy Muniappan, Virginia Tech, U.S.

Coffee Break

10:10 a.m.-10:40 a.m.

Room: Golden Cliff

Workshop on Network Science: Coffee Break

10:15 a.m.-10:45 a.m.

Room: Cottonwood A& B - Snowbird Center

Remarks and Red Sock Award Announcement

10:40 a.m.-10:45 a.m.

Room: Ballroom

Thursday, May 23

CP105

Workshop on Network Science: Contributed Session 6

10:45 a.m.-11:35 a.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

10:45-11:05 Robust Budget Allocation

Ashley M. Hou and Po-Ling Loh, University of Wisconsin, Madison, U.S.

11:10-11:30 Structured Hierarchy in Online Dating Networks: 20,000 Leagues under the City

Daniel Larremore, University of Colorado Boulder, U.S.; Swapnil Gavade and Elizabeth Bruch, University of Michigan, U.S.

Thursday, May 23

IP8

On the Impact of Dynamics on Ensemble Data Assimilation

10:45 a.m.-11:30 a.m.

Room: Ballroom

Chair: Alberto Carrassi, Nansen Environmental and Remote Sensing Center, Norway

Data assimilation aims at optimally estimating the state, the parameters, and their associated uncertainties, of a physical system using observations and a numerical model of the system's dynamics. It is nowadays common practice in numerical weather prediction, a chaotic and extremely high-dimensional application. However, data assimilation algorithms are usually derived based on statistical and numerical optimization considerations, lacking a dynamical system perspective in their design. Elucidating the impacts of the dynamics on data assimilation schemes is the objective of this talk. Specifically, I will explain the impact of chaotic dynamics on the ensemble Kalman filter, a particle data assimilation scheme increasingly popular in the geosciences and beyond. The key role of the unstable dynamics on the ensemble will be examined, and conclusions will be drawn on how this relationship can guide the design and implementation of the ensemble Kalman filter.

Marc Bocquet

Ecole Nationale des Ponts et Chaussées, France

Lunch Break

11:30 a.m.-1:00 p.m.

Attendees on their own

Workshop on Network Science: Lunch Break

11:30 a.m.-1:00 p.m.

Attendees on their own

Thursday, May 23

MS172

Data and Dynamics: Dynamical Systems Techniques in Data Assimilation - Part I of II

1:00 p.m.-2:40 p.m.

Room: Ballroom 1

For Part 2 see MS182

Data assimilation (DA) refers to techniques used to combine model and observational data to produce an estimate of the state of the physical system, including methods from Bayesian inference, dynamical systems, numerical analysis and optimal control, among others. Owing to their history in numerical weather prediction, DA systems are designed to operate in an extremely large dimension of model variables and observations. However, DA techniques differ from other “big data” learning problems in terms of the interaction of models and data. In physical applications, models and observations play dual roles as sources of incomplete and inaccurate information in prediction and uncertainty quantification. In data rich problems, physical laws constrain the degrees of freedom of massive data sets. Respectively, in data sparse problems, models fill spatial and temporal gaps in observational networks and the techniques of DA have been developed with this latter context in mind. This interplay of models and observations at the heart of DA has shaped the theory and implementation of DA algorithms. However, the explicit design of algorithms based on or inspired by the model’s structure and dynamical characteristics has not yet been fully exploited. This minisymposium will exhibit recent advances in DA theory and techniques that utilize model dynamics at the core of the approach and to suggest new directions for research at the intersection of dynamical systems and Bayesian inference.

Organizer: Colin J. Grudzien

University of Nevada, Reno, U.S.

Organizer: Marc Bocquet

Ecole Nationale des Ponts et Chaussées, France

Organizer: Alberto Carrassi

Nansen Environmental and Remote Sensing Center, Norway

continued in next column

1:00-1:20 Data Assimilation for Chaotic Geophysical Dynamics - An Overview

Alberto Carrassi, Nansen Environmental and Remote Sensing Center, Norway; Colin J. Grudzien, University of Nevada, Reno, U.S.; Marc Bocquet, Ecole Nationale des Ponts et Chaussées, France

1:25-1:45 Projected Particle Filters

John Maclean, University of Adelaide, Australia; *Erik Van Vleck*, University of Kansas, U.S.

1:50-2:10 Data Assimilation with Stochastic Model Reduction of Chaotic Systems

Fei Lu, Johns Hopkins University, U.S.; Alexandre Chorin, University of California, Berkeley, U.S.; Kevin K. Lin, University of Arizona, U.S.; Xuemin Tu, University of Kansas, U.S.

2:15-2:35 The Dynamic Likelihood Filter

Juan M. Restrepo, Oregon State University, U.S.

Thursday, May 23

MS173

Collective Behavior of Living Things

1:00 p.m.-2:40 p.m.

Room: Ballroom 2

Large collections of living things, whether films of bacterial cells or groups of people, typically exhibit important collective behavior. This emergent behavior can provide positive benefits, such as greater metabolic efficiency, or detrimental effects, as in the case of violent rioting. In this minisymposium, these phenomena will be discussed over a wide range of viewpoints, including modeling, continuum analysis, computation, and experimentation. By doing so, we will highlight common mathematical threads and approaches to such problems, and raise awareness of open mathematical and experimental issues in solving them, in an attempt to solicit new ideas on how to better understand these important phenomena.

Organizer: Scott McCalla

Montana State University, U.S.

Organizer: Martin Short

Georgia Institute of Technology, U.S.

Organizer: James von Brecht

California State University, Long Beach, U.S.

1:00-1:20 Agent-Based and Continuous Models of Locust Hopper Bands: Insights Gained through the Lens of Dynamical Systems

Andrew J. Bernoff, Harvey Mudd College, U.S.; Michael Culshaw-Maurer, University of California, Davis, U.S.; Maria D'Orsogna, California State University, Northridge, U.S.; Sarah DeVore, Macalester College, U.S.; Leah Edelstein-Keshet, University of British Columbia, Canada; Rebecca Everett, Haverford College, U.S.; Maryann Hohn, University of California, Santa Barbara, U.S.; Ryan Jones and Stephen Schein, Harvey Mudd College, U.S.; Christopher Strickland, University of Tennessee, Knoxville, U.S.; Chad M. Topaz, Williams College, U.S.; Jasper Weinburd, University of Minnesota, Twin Cities, U.S.; Jialun Zhang, Harvey Mudd College, U.S.

continued on next page

Thursday, May 23

MS173

Collective Behavior of Living Things

continued

1:25-1:45 Dynamics of Religious Group Growth and Survival

Tongzhou Chen, Georgia Institute of Technology, U.S.; Michael McBride, University of California, Irvine, U.S.; Martin Short, Georgia Institute of Technology, U.S.

1:50-2:10 A Birth-Jump Processes in Plant Dynamics

Nancy Rodriguez, University of Colorado Boulder, U.S.

2:15-2:35 Microbial Biofilm Colony Dynamics

James N. Wilking, Montana State University, U.S.

Thursday, May 23

MS174

Sparse Learning of Dynamical Systems from Temporal Data

1:00 p.m.-2:40 p.m.

Room: Ballroom 3

Unprecedented amounts of temporal measurements are constantly generated every day from almost all the areas of society, industry and science. Examples range from macroscopic processes studied for instance in physics, finance, epidemiology, social networks and population dynamics to microscopic processes such as biochemical reactions and gene regulation in a living cell, all of which are modelled as time-varying dynamical systems of complex interactions. In this minisymposium, we explore the recent advances of structural learning of dynamical systems from temporal data in terms of theory, algorithms and applications. Theoretical and algorithmic advances in sparse learning approaches are of particular focus.

Organizer: Yannis Pantazis

Foundation for Research and Technology Hellas, Greece

Organizer: Hayden Schaeffer

Carnegie Mellon University, U.S.

Organizer: Giang Tran

University of Waterloo, Canada

1:00-1:20 (Un)-Supervised Structure Learning of Biochemical Reaction Networks

Manfred Claassen, ETH Zürich, Switzerland

1:25-1:45 Uncovering Conspiracy Theories: How to Deal with Latent Confounders in Dynamical Systems

Yannis Pantazis, Foundation for Research and Technology Hellas, Greece; Sofia Triantafillou, University of Pittsburgh, U.S.; Ioannis Tsamardinos, University of Crete, Greece

1:50-2:10 Sparse Learning with Mixing Data and Outliers

Giang Tran, University of Waterloo, Canada; Rachel Ward, University of Texas at Austin, U.S.; Hayden Schaeffer, Carnegie Mellon University, U.S.

2:15-2:35 Extracting Structured Dynamics from Very Few Samples

Hayden Schaeffer, Carnegie Mellon University, U.S.; Giang Tran, University of Waterloo, Canada; Rachel Ward, University of Texas at Austin, U.S.; *Linan Zhang*, Carnegie Mellon University, U.S.

Thursday, May 23

MS175

Spatio-Temporal Bifurcation Delay

1:00 p.m.-2:40 p.m.

Room: Magpie A

Delayed bifurcation phenomena are ubiquitous in the life sciences. They have been used to explain the spiking and myriad of bursting activity in neural systems, arrhythmogenesis in cardiac systems, and the sudden change in amplitude and period of oscillations in chemical systems. Delayed bifurcations typically come in two flavours: as delayed Hopf bifurcations (DHB) or as canard dynamics. Both phenomena have been very well studied in ODEs, but much less so in PDEs. This session gathers researchers working at the forefront of the analysis and applications of DHB and canards in spatially extended media.

Organizer: Theodore Vo

Florida State University, U.S.

Organizer: Tasso J. Kaper

Boston University, U.S.

1:00-1:20 Canards and Slow Passage Through Bifurcations in Infinite-Dimensional Dynamical Systems

Daniele Avitabile, University of Nottingham, United Kingdom; Mathieu Desroches and Romain Veltz, Inria Sophia Antipolis, France; Martin Wechselberger, University of Sydney, Australia

1:25-1:45 Delayed Hopf Bifurcations in Excitable Nerve Cables

Steven M. Baer, Arizona State University, U.S.; Lydia Bilinsky, National Center for Toxicological Research/FDA, U.S.

1:50-2:10 Delayed Loss of Stability due to Slow Passage through Hopf Bifurcations in Reaction-Diffusion Equations

Theodore Vo, Florida State University, U.S.

2:15-2:35 Multi-Mode Steady State Solutions in Excitable Spatially Extended Systems

Tasso J. Kaper, Boston University, U.S.; Richard Bertram and Theodore Vo, Florida State University, U.S.

Thursday, May 23

MS176

Biological Signaling in Cellular Collectives - Part II of II

1:00 p.m.-2:40 p.m.

Room: Magpie B

For Part 1 see MS166

Single cells are capable of performing a plethora of extraordinary tasks, from adapting to a variety of environments to replicating genetic material. Yet, cells rarely act alone. They are typically part of a larger collective in which constituent cells communicate via signaling. This is specifically true for microbial colonies. The result is a complex community where cells distribute responsibilities and coordinate activities across populations, even in spatially extended domains. The mechanisms underlying such coordinated activity, however, are still largely not understood. Even in large spatial domains whose sizes are vastly greater than the typical diffusion correlation lengths of microbial quorum sensing molecules, cells are capable of coordination. Understanding how this is achieved is crucial to the progress of experimental disciplines such as synthetic biology, wherein emergent behaviors must be controlled to optimize efficiency of synthetic biocircuit function. This minisymposium will feature talks describing models of the mechanical and chemical mechanisms cellular collectives use to coordinate the activities of their constituent cells. Emphasis will be placed both on achievements to date and the exciting challenges ahead.

Organizer: William Ott
University of Houston, U.S.

Organizer: Bhargav R. Karamched
University of Houston, U.S.

1:00-1:20 From Molecules to Development: Understanding How Biological Oscillators Function and Coordinate
Qiong Yang, Michigan State University, U.S.

1:25-1:45 Dynamical Modeling to Bridge Spatial and Temporal Scales in Multicellular Collective Behavior
Allyson Sgro, Boston University, U.S.

1:50-2:10 Integrative Modeling of Synthetic Gene Circuits
Ting Lu, University of Illinois, U.S.

continued in next column

2:15-2:35 Modeling and Parameter Estimation for Synthetic Microbial Consortia
David Zong, Rice University, U.S.; *Mehdi Sadeghpour*, University of Michigan, Ann Arbor, U.S.; William Ott, University of Houston, U.S.; Kresimir Josic, University of Houston, U.S.; Matthew Bennett, Rice University, U.S.

Thursday, May 23

MS177

Mechanisms Underlying Neurological Processes - Part I of II

1:00 p.m.-2:40 p.m.

Room: Wasatch B

For Part 2 see MS184

Nervous systems regulate and maintain functions that enable the survival of many living organisms. They are responsible for sensing inputs, transmission and processing of information, decision making and output generation. Dysfunctional neurological systems can impair these operations rendering the whole organism vulnerable and many times incapable of leading a healthy life. Therefore, understanding the mechanisms underlying neurological processes is critical in the development of novel techniques for improving learning and memory, for example, but also for prevention and treatment of neuropathologies at all levels including Parkinson's, epilepsy, pain control and drug addiction. In the first of a sequence of two minisymposia we address aspects of axonal signal propagation and reliable information transmission, neuromodulator-induced neuronal transitions, modeling of sleep-awake processes, and synchronization of neurons in cortical brain areas. In the second of the two minisymposia we address plasticity, brain connectivity and synaptic delay, multisensory information processing and motor control, spontaneous activity in networked neurons, and stochastic excitable neuronal trees.

Organizer: Epaminondas Rosa
Illinois State University, U.S.

1:00-1:20 Synchronous Neuronal Transitions Mediated by Chaos
Epaminondas Rosa, Annabelle Shaffer, Zach Mobille, George Rutherford, and Rosangela Follmann, Illinois State University, U.S.

1:25-1:45 Modulator Induced Transitions between Neuronal Activities
Josselyn Gonzalez, Rosangela Follmann, Wolfgang Stein, and Epaminondas Rosa, Illinois State University, U.S.

continued on next page

Thursday, May 23

MS177

Mechanisms Underlying Neurological Processes - Part I of II

continued

1:50-2:10 Synchronization in Models of Sleep-Wake Dynamics

Tera Glaze and Sonya Bahar, University of Missouri, St. Louis, U.S.

2:15-2:35 Bursting Synchronization in a Neuronal Network Model for Cortical Areas of the Human Brain

Ricardo L. Viana, Fabiano Ferrari, and Adriane da Silva Reis, Federal University of Paraná, Brazil; Kelly Iarosz, State University of Ponta Grossa, Brazil; Iberê Caldas, Universidade of São Paulo, Brazil; Antonio Marcos Batista, Universidade Estadual de Ponta Grossa, Brazil

Thursday, May 23

MS178

Applications of Nonlinear Dynamical Systems to Kinetic Plasmas

1:00 p.m.-2:15 p.m.

Room: Superior A

For Part 1 see MS168

We propose a two-part minisymposium focusing on the connection between particle orbit dynamics in electric, magnetic and electromagnetic fields and the coherent field structures that produce and sustain them. Self-consistent plasma response to sculpted electric and magnetic high frequency waves or imposed external fields will be elucidated vis a vis stable structures that may not be stationary but which are robust. Numerical methods needed to fine tune such searches and designs will also be given.

Organizer: Jon Wilkening
University of California, Berkeley, U.S.

Organizer: Bedros Afeyan
Polymath Research Inc., U.S.

1:00-1:20 Lagrangian Chaos and Passive Scalar Advection in Stochastic Fluid Mechanics

Jacob Bedrossian, University of Maryland, U.S.

1:25-1:45 Compressed Representation of Nonlinear Dynamics in Non-Linear Coherent Plasma Waves using Lagrangian Particles

Sean Young, Stanford University, U.S.; David Larson, Lawrence Livermore National Laboratory, U.S.; Bedros Afeyan, Polymath Research Inc., U.S.

1:50-2:10 Satisfying Temporal Resolution Criteria in Relativistic Particle-in-Cell Simulations with a High-Intensity Laser Field

Guangye Chen, Los Alamos National Laboratory, U.S.; Alexey Arefiev, University of California, San Diego, U.S.

Thursday, May 23

MS179

Existence and Stability of Imperfect Patterns - Part I of II

1:00 p.m.-2:40 p.m.

Room: Superior B

For Part 2 see MS186

Patterns, arising ubiquitously in biological, chemical and physical systems, are generically "imperfect"–deformed and accompanied with defects, due to various causes such as heterogeneity and stochastic effects. Often associated with emergent behaviors and/or arising when systems pass through instability, imperfect patterns may or may not lead to permanent dynamical changes of the system. While the study on "perfect" patterns are abundant, the understanding on "imperfect" patterns is much less satisfactory. This minisymposium brings together experts from various fields to present their work on "imperfect" patterns in continuous/discrete models, dispersive/dissipative equations, and deterministic/random dynamical systems on the real line and higher spatial dimensions, with an emphasis on their existence and stability.

Organizer: Qiliang Wu
Ohio University, U.S.

Organizer: Björn De Rijk
Universität Stuttgart, Germany

1:00-1:20 Topologically Protected Defects

Shankar C. Venkataramani and Guanying Peng, University of Arizona, U.S.

1:25-1:45 Imperfect Hexagons Deformed by Spatial Inhomogeneity

Jasper Weinburd, University of Minnesota, Twin Cities, U.S.

1:50-2:10 Stability of Growing Stripes in the Complex Ginzburg-Landau Equation

Ryan Goh, Boston University, U.S.

2:15-2:35 Nonlinear Stability of Layers in Precipitation Models

Alin Pogan, Miami University, U.S.

Thursday, May 23

MS180

Data-Driven Modeling and Prediction of Geophysical Fluid Dynamics - Part II of II

1:00 p.m.-2:40 p.m.

Room: Primrose A

For Part 1 see MS170

Improved modeling and prediction of fluid dynamics is needed to better understand transport in geophysical flows. Major recent advances in machine learning, coherent structure detection, reduced-order models, uncertainty quantification, data assimilation, optimal path planning, and adaptive sampling are providing increased understanding of transport phenomena. The purpose of this minisymposium is to expose the audience to recent progress and developments, as well as to bring together researchers developing new mathematical methods and applications for use in understanding material transport in geophysical flows.

Organizer: Eric Forgoston
Montclair State University, U.S.

Organizer: M. Ani Hsieh
University of Pennsylvania, U.S.

1:00-1:20 Improving Accuracy of Motion Tomography

Fumin Zhang and Meriam Ouerghi, Georgia Institute of Technology, U.S.

1:25-1:45 PDE-Based Bayesian Learning and Generative Modeling for Stochastic Lagrangian Transport

Chinmay S. Kulkarni and Pierre F. Lermusiaux, Massachusetts Institute of Technology, U.S.

1:50-2:10 Lagrangian Incoherence: How Submesoscale Divergence and Deformation Erode Mesoscale Coherence

Helga S. Huntley, Denny Kirwan, and Henry Chang, University of Delaware, U.S.

2:15-2:35 Distributed Sampling and Tracking of Dynamic Processes with Robot Teams

Tahiya Salam, Dhanushka Kularatne, and *M. Ani Hsieh*, University of Pennsylvania, U.S.

Thursday, May 23

MS181

Scalar Transport in Fluids: Beyond Mixing by Chaotic Advection

1:00 p.m.-2:40 p.m.

Room: Primrose B

Transport of scalar quantities (chemical species, heat) in laminar flows is key to many processes in industry and technology. Scalar transport admits active manipulation via the flow and thus many studies aim at establishing efficient fluid mixing (by chaotic advection) so as to accomplish “optimal” scalar transport. However, this presumes that (i) said optimal state is a global homogeneous scalar distribution and (ii) scalar transport is dominated by advection. This is not always the case, though. Subsurface groundwater remediation e.g. relies on containment of scalars to designated flow regions by (reactive) fronts and to this end requires a well-controlled heterogeneous state (established e.g. by hydrodynamic transport barriers) instead of mixing. Moreover, scalar transport may involve significant diffusion and/or chemical reactions, as e.g. in many systems in process intensification and microfluidics, resulting in a non-trivial connection between fluid and scalar dynamics. This may render flow-forcing strategies aiming at chaotic advection inefficient or even ineffective for optimal scalar transport. The minisymposium seeks to highlight transport problems and corresponding flow-forcing strategies that are beyond the above presumptions by aiming at essentially heterogeneous states and/or involving significant diffusive-reactive phenomena.

Organizer: Michel Speetjens
Eindhoven University of Technology, Netherlands

Organizer: Sanjeeva Balasuriya
University of Adelaide, Australia

1:00-1:20 Manifolds, Reaction Barriers, and Active Mixing in Laminar Flows

Tom Solomon, Bucknell University, U.S.

continued in next column

1:25-1:45 Lagrangian Distances as a Measure of Diffusive Transport in Advection-Diffusion Processes

Alvaro de Diego and Daniel Karrasch, Technische Universität München, Germany; Peter Koltai, Freie Universität Berlin, Germany

1:50-2:10 Atmospheric Pollution Transport Patterns Obtained via Generalized Coherent Structures for Chemical Species

Peter Nolan, Hosein Foroutan, and Shane D. Ross, Virginia Tech, U.S.

2:15-2:35 Pro-Active Engineering of Scalar Transport in Reoriented Fluid Flows

Michel Speetjens, Ruud Lensvelt, and Henk Nijmeijer, Eindhoven University of Technology, Netherlands

Thursday, May 23

CP36

Koopman Analysis

1:00 p.m.-2:40 p.m.

Room: Wasatch A

Chair: Malgorzata Turalska, U.S. Army Research Laboratory, U.S.

1:00-1:20 Koopman Theory and Linear Approximation Spaces

Andrew Kurdila, Virginia Tech, U.S.; *Parag S. Bobade*, University of Michigan, U.S.

1:25-1:45 Koopman Operator and its Approximations for Dynamical Systems with Symmetries

Anastasiya Salova, Jeffrey Emenheiser, Adam Rupe, James Crutchfield, and Anastasiya Salova, University of California, Davis, U.S.

1:50-2:10 Koopman View of Dynamics on the Tangent Space and Structure Preserving DMD

Gowtham S. Seenivasaharagavan, University of California, Santa Barbara, U.S.; Milan Korda, LAAS-CNRS, Toulouse, France; Hassan Arbabi, Massachusetts Institute of Technology, U.S.; Igor Mezic, University of California, Santa Barbara, U.S.; Themistoklis Sapsis, Massachusetts Institute of Technology, U.S.

2:15-2:35 Uncoupling Structure and Dynamics of Complex Networks using Dynamic Mode Decomposition

Malgorzata Turalska, U.S. Army Research Laboratory, U.S.

Thursday, May 23

CP37

Complex Systems

1:00 p.m.-2:40 p.m.

Room: Maybird

Chair: Max Lipton, Cornell University, U.S.

1:00-1:20 Convective Instability for Microscopic Car-Following Models and their Macroscopic Counterparts

Hannes von Allwörden and Ingenuin Gasser, Universität Hamburg, Germany

1:25-1:45 Solution Attractor of Local Search Systems: The TSP Case

Weiqi Li, University of Michigan-Flint, U.S.

1:50-2:10 A Model for Interactions Between Criminal Minded Population and s Suppressed Population

Jai P. Tripathi, Central University of Rajasthan, India

2:15-2:35 Hyperbolic Groups Acting on Trajectories of Coupled Oscillators

Max Lipton, Cornell University, U.S.

Thursday, May 23

CP38

Mathematical Biology III

Cancelled

Workshop on Network Science: Conversation on NS Identity, led by Nina Fefferman and Peter Mucha

1:00 p.m.-2:00 p.m.

Room: Cottonwood C & D - Snowbird Center

Thursday, May 23

CP106

Workshop on Network Science: Contributed Session 7

2:00 p.m.-3:15 p.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

2:00-2:20 Stochastic Defense Against Complex Grid Attacks

Mauro Escobar, Daniel Bienstock, and *Apurv Shukla*, Columbia University, U.S.

2:25-2:45 Tracking Tropical and Frontal Storms Driven Extreme Rainfalls over Japan using Complex Networks

Ugur Ozturk, Potsdam Institute for Climate Impact Research and University of Potsdam, Germany; Nishant Malik, Rochester Institute of Technology, U.S.; Kevin Cheung, Macquarie University, Sydney, Australia; Norbert Marwan, Potsdam Institute for Climate Impact Research, Germany; Jürgen Kurths, Potsdam Institute for Climate Impact Research and Free University of Berlin, Germany

2:50-3:10 Bounds on the Sampling Error of Mean Differential Entropy of Subgraphs

Alice C. Schwarze, University of Oxford, United Kingdom; Philip S. Chodrow, Massachusetts Institute of Technology, U.S.; Mason A. Porter, University of California, Los Angeles, U.S.

Coffee Break

2:40 p.m.-3:10 p.m.

Room: Golden Cliff

Thursday, May 23

MS182

Data and Dynamics: Dynamical Systems Techniques in Data Assimilation - Part II of II

3:10 p.m.-4:50 p.m.

Room: Ballroom 1

For Part 1 see MS172

Data assimilation (DA) refers to techniques used to combine model and observational data to produce an estimate of the state of the physical system, including methods from Bayesian inference, dynamical systems, numerical analysis and optimal control, among others. Owing to their history in numerical weather prediction, DA systems are designed to operate in an extremely large dimension of model variables and observations. However, DA techniques differ from other “big data” learning problems in terms of the interaction of models and data. In physical applications, models and observations play dual roles as sources of incomplete and inaccurate information in prediction and uncertainty quantification. In data rich problems, physical laws constrain the degrees of freedom of massive data sets. Respectively, in data sparse problems, models fill spatial and temporal gaps in observational networks and the techniques of DA have been developed with this latter context in mind. This interplay of models and observations at the heart of DA has shaped the theory and implementation of DA algorithms. However, the explicit design of algorithms based on or inspired by the model’s structure and dynamical characteristics has not yet been fully exploited. This minisymposium will exhibit recent advances in DA theory and techniques that utilize model dynamics at the core of the approach and to suggest new directions for research at the intersection of dynamical systems and Bayesian inference.

Organizer: Colin J. Grudzien
University of Nevada, Reno, U.S.

Organizer: Marc Bocquet
Ecole Nationale des Ponts et Chaussées, France

Organizer: Alberto Carrassi
Nansen Environmental and Remote Sensing Center, Norway

continued in next column

3:10-3:30 A Detectability Criterion for Sequential Data Assimilation

Jason Frank, Utrecht University, The Netherlands; Sergiy Zhuk, IBM Research, Ireland

3:35-3:55 Routes to Long Term Predictability in Multi-Scale Systems – Analysis of the Ocean-Atmosphere System

Stéphane Vannitsem, Royal Meteorological Institute of Belgium, Belgium

4:00-4:20 Coherent Structure Identification from Macro Data: Inverse Problem Approach

Naratip Santitissadeekorn, University of Surrey, United Kingdom

4:25-4:45 Accuracy of Some Approximate Gaussian Filters for Dissipative Dynamical Systems with Model Error and Spatially Sparse Nodal Observations

Michal Branicki, University of Edinburgh, United Kingdom

Thursday, May 23

MS183

Supermodeling an Objective Process by Synchronization of Different Models

3:10 p.m.-4:50 p.m.

Room: Magpie A

The synchronization of an objective process with a model of that process, both viewed as abstract dynamical systems, has been suggested as a general framework for data assimilation – the problem, well known in meteorology, of continually re-initializing a running model to take account of new observations that are noisy and sparse. The problem has been likened to biological perception. Alternative models can also "observe" each other, in a 3-way synchronization process among models and reality, so as to fuse expert models that make divergent predictions. Supemodeling builds upon the well-studied phenomenon of synchronization of extended systems with couplings that are limited in time, space, and/or dimensionality in phase space [Chaos Focus Issue, Dec. 2017]. Couplings must be adapted so that the attractor of the supermodel matches the true attractor. Results on synchronization of parameters as well as states can be applied, or the training can be viewed from the more general but more costly perspective of machine learning. One also seeks to limit the number of independent connections – by exploiting symmetries and coherent structures (internal synchronization) within each model. Using supermodels formed from climate models and from models of cancer tissue development, this minisymposium will address issues of training and inter-model coupling, as well as the nonlinearities that make supermodeling superior to ex post facto combination of separate model outputs.

Organizer: Gregory S. Duane
University of Bergen, Norway and University of Boulder, Colorado, U.S.

3:10-3:30 Why do Supermodels Surpass Combinations of Model Outputs?

Gregory S. Duane, University of Bergen, Norway and University of Boulder, Colorado, U.S.; Mao-Lin Shen and Noel Keenlyside, University of Bergen, Norway

continued in next column

3:35-3:55 Efficient Algorithms to Train Supermodels

Francine Schevenhoven, University of Bergen, Bergen, Norway and Bjerknes Centre for Climate Research, Bergen, Norway; Frank Selten, Royal Netherlands Meteorological Institute, Netherlands; Alberto Carrassi, Nansen Environmental and Remote Sensing Center, Norway; Noel Keenlyside, University of Bergen, Norway

4:00-4:20 Assimilation of Coherent Mesoscale Ocean Eddies

Jeffrey B. Weiss, University of Colorado, U.S.; Ian Grooms, University of Colorado Boulder, U.S.

4:25-4:45 Supermodeling as the Second Level of Abstraction in Data Assimilation for Dynamic Systems

Witold Dzwinel and Adrian Klusek, AGH University of Science and Technology, Poland; Gregory S. Duane, University of Bergen, Norway and University of Boulder, Colorado, U.S.

Thursday, May 23

MS184

Mechanisms Underlying Neurological Processes - Part II of II

3:10 p.m.-4:50 p.m.

Room: Wasatch B

For Part 1 see MS177

Nervous systems regulate and maintain functions that enable the survival of many living organisms. They are responsible for sensing inputs, transmission and processing of information, decision making and output generation. Dysfunctional neurological systems can impair these operations rendering the whole organism vulnerable and many times incapable of leading a healthy life. Therefore, understanding the mechanisms underlying neurological processes is critical in the development of novel techniques for improving learning and memory, for example, but also for prevention and treatment of neuropathologies at all levels including Parkinson's, epilepsy, pain control and drug addiction. In the first of a sequence of two minisymposia we address aspects of axonal signal propagation and reliable information transmission, neuromodulator-induced neuronal transitions, modeling of sleep-awake processes, and synchronization of neurons in cortical brain areas. In the second of the two minisymposia we address plasticity, brain connectivity and synaptic delay, multisensory information processing and motor control, spontaneous activity in networked neurons, and stochastic excitable neuronal trees.

Organizer: Epaminondas Rosa
Illinois State University, U.S.

3:10-3:30 Alterations in Brain Connectivity due to Plasticity and Synaptic Delay

Elbert E. Macau, Laboratory for Computing and Applied Mathematics and Brazilian Institute for Space Research, Brazil; Ewandson Lameu, State University of Ponta Grossa, Brazil; Iberê Caldas, Universidade of São Paulo, Brazil; Ricardo L. Viana, Federal University of Paraná, Brazil; Batista Antonio and Kelly Iarosz, State University of Ponta Grossa, Brazil

continued on next page

3:35-3:55 Processing of Multimodal Sensory Information in a Motor Control Center

Rosangela Follmann, Christopher Goldsmith, and Wolfgang Stein, Illinois State University, U.S.

4:00-4:20 Dynamics of Spontaneous Activity in Networks of Two-Dimensional Integrate-and-Fire Neurons

Antonio C. Roque, University of São Paulo, Brazil; Michael Zaks, Humboldt University at Berlin, Germany; Rodrigo F. O. Pena, University of Sao Paulo, Brazil

4:25-4:45 Collective Dynamics in Random Trees of Coupled Stochastic Excitable Elements

Alexander Neiman and Khaledi Nasab Ali, Ohio University, U.S.; Kromer Justus, Stanford University, U.S.; Lutz Schimansky-Geier, Humboldt University at Berlin, Germany

Thursday, May 23

MS185

Hamiltonian Particle Dynamics

3:10 p.m.-4:50 p.m.

Room: Superior A

The aim of this minisymposium session is to bring together researchers interested in the analysis of Hamiltonian systems. The talks will focus on recent research in the geometry and dynamics of these systems such as central configurations, existence of periodic orbits through analytical and numerical techniques, and symplectic and Poisson reduction. The scope of the mini-symposium is the application of the analysis of Hamiltonian systems to the geometry and dynamics of classical mechanical systems, including celestial mechanics.

Organizer: Lennard F. Bakker

Brigham Young University, U.S.

Organizer: Cristina Stoica

Wilfrid Laurier University, Canada

3:10-3:30 Central Configurations in the Collinear N-Body Problem

Zhifu Xie, University of Southern Mississippi, U.S.

3:35-3:55 Self-Similarity in the Kepler-Heisenberg Problem

Corey Shanbrom, California State University, Sacramento, U.S.; Victor Dods, Mathematical Sciences Research Institute, Berkeley, U.S.

4:00-4:20 Four-Body Central Configurations with One Pair of Opposite Sides Parallel

Manuele Santoprete, Wilfrid Laurier University, Canada

4:25-4:45 N-Body Dynamics on an Infinite Cylinder: The Topological Signature and the Stability of a Ring

Stefanella Boatto, Universidade Federal do Rio De Janeiro, Brazil

Thursday, May 23

MS186

Existence and Stability of Imperfect Patterns - Part II of II

3:10 p.m.-4:50 p.m.

Room: Superior B

For Part 1 see MS179

Patterns, arising ubiquitously in biological, chemical and physical systems, are generically “imperfect”–deformed and accompanied with defects, due to various causes such as heterogeneity and stochastic effects. Often associated with emergent behaviors and/or arising when systems pass through instability, imperfect patterns may or may not lead to permanent dynamical changes of the system. While the study on “perfect” patterns are abundant, the understanding on “imperfect” patterns is much less satisfactory. This minisymposium brings together experts from various fields to present their work on “imperfect” patterns in continuous/discrete models, dispersive/dissipative equations, and deterministic/random dynamical systems on the real line and higher spatial dimensions, with an emphasis on their existence and stability.

Organizer: Qiliang Wu

Ohio University, U.S.

Organizer: Björn De Rijk

Universität Stuttgart, Germany

3:10-3:30 Surface Tension and Surface Transport in Defective Networks

Keith Promislow, Anne Rea, and Federica Brandizzi, Michigan State University, U.S.

3:35-3:55 Solitary Wave Solution of the Camassa-Holm Equation with Distributed Delay

Ji Li, Huazhong University of Science & Technology, China

4:00-4:20 A Nonlocal Interfacial Approach to Stripe Patterns

Scott McCalla, Montana State University, U.S.; James von Brecht, California State University, Long Beach, U.S.

4:25-4:45 Patterns on Conics

Patrick Shipman, Colorado State University, U.S.

Thursday, May 23

CP39

Mathematical Biology IV

3:10 p.m.-4:50 p.m.

Room: Ballroom 3

Chair: Iacopo Paolo Longo, Universidad de Valladolid, Spain

3:10-3:30 Immune Normalization Dynamics: Modeling Checkpoint Blockade Combination Therapies in Breast Cancer

Jesse Milzman, University of Maryland, College Park, U.S.

3:35-3:55 Multiple Time Scale Analysis of Early Afterdepolarizations in Cardiac Action Potentials

Philipp Kuegler, University of Hohenheim, Germany

4:00-4:20 Cellular Automata Modeling of Spinal Cord Growth: Effect of Stem Cell Activity and Population Pressure

David Lehotzky, Northeastern University, U.S.; Rifat Sipahi, Northeastern University, U.S.; Günther Zupanc, Northeastern University, U.S.

4:25-4:45 Study of Attractors for Compartmental Systems Modeled with Carathéodory Differential Equations

Iacopo Paolo Longo, Sylvia Novo Martin, and Rafael Obaya Garcia, Universidad de Valladolid, Spain

Thursday, May 23

CP40

Topics in Dynamics I

3:10 p.m.-4:25 p.m.

Room: Magpie B

Chair: Ian M. Hunter, Fraden Lab, U.S.

3:10-3:30 Mode Interactions and Turbulence in a Rotating Annulus Experiment with Free Surface

Uwe Harlander, Brandenburg University of Technology, Germany; Wenchao Xu, Brandenburg University of Technology Cottbus–Senftenberg, Germany

3:35-3:55 Spot Patterns on Reaction-Diffusion Networks

Shigefumi Hata, Kagoshima University, Japan

4:00-4:20 Attractor Symmetry and Stability in Symmetric Self-Driven Oscillator Networks

Ian M. Hunter, Fraden Lab, U.S.; Michael Norton, Bolun Chen, Chris Simonetti, and James Sheehy, Brandeis University, U.S.; Youssef Fahmy, Columbia University, U.S.; Lanijah Flagg, Hampton University, U.S.; Seth Fraden, Brandeis University, U.S.

Thursday, May 23

CP41

Networks and Complex Systems

3:10 p.m.-4:50 p.m.

Room: Wasatch A

Chair: Xize Xu, Northwestern University, U.S.

3:10-3:30 Dynamic Modeling and Asymptotic Approximation of Multi-Cue Multi-Choice Tasks

Qing Hui, University of Nebraska, Lincoln, U.S.; Mehdi Firouznia, Chen Peng, and Jeffrey Stevens, University of Nebraska-Lincoln, U.S.

3:35-3:55 A Minimal Mathematical Model for Free Market Competition through Advertising

Joseph D. Johnson, Northwestern University, U.S.

4:00-4:20 How Close is the Nearest Node in a Wireless Network?

Amy L. Middleton, University of Bath, United Kingdom

4:25-4:45 Enhancing the Synchronization of Coupled Rhythms through Intrinsic Network Heterogeneity

Xize Xu and Hermann Riecke, Northwestern University, U.S.

Thursday, May 23

CP42

Topics in Dynamics II

3:10 p.m.-4:50 p.m.

Room: Maybird

Chair: Bruce B. Peckham, University of Minnesota, Duluth, U.S.

3:10-3:30 Complex Dynamics of

$$z_{n+1} = \frac{\alpha + \beta Z_n + \gamma Z_{n-1}}{A + BZ_n + CZ_{n-1}}$$

Sk Sarif Hassan, Pingla Thana Mahavidyalaya, India

3:35-3:55 Connecting Puzzles and Piecewise Isometries in 1D, 2D, and 3D

Richard M. Lueptow, Northwestern University, U.S.; Lachlan D Smith, University of Sydney, Australia; Julio M Ottino, Northwestern University, U.S.; Paul B Umbanhowar, Northwestern University, U.S.

4:00-4:20 An Application of the Delayed Tyre Model in Vehicle Shimmy

Tian Mi, Southeast University, China; Gabor Stepan, Budapest University of Technology and Economics, Hungary; Denes Takacs, MTA-BME Research Group on Dynamics of Machines and Vehicles, Hungary; Nan Chen, Southeast University, China

4:25-4:45 Dynamics of Some Rational Maps of the Real Plane

Bruce B. Peckham, University of Minnesota, Duluth, U.S.

Thursday, May 23

CP43

Topics in Dynamics III

3:10 p.m.-4:50 p.m.

Room: White Pine

Chair: Stylianos Perrakis, Aristotle University of Thessaloniki, Greece

3:10-3:30 Optimal Control of Chaotic Systems using a Preconditioned Multiple Shooting Shadowing Algorithm

Karim Shawki and George Papadakis, Imperial College London, United Kingdom

3:35-3:55 Toward a Broader Definition of Rate-Tipping

Alanna Hoyer-Leitzel, Mount Holyoke College, U.S.; Alice Nadeau, University of Minnesota, U.S.; Jeffrey Landgren, University of North Georgia, U.S.

4:00-4:20 Topological Data Analysis for Detecting Dynamic State Changes via Nodal Networks

Audun D. Myers, Elizabeth Munch, and *Firas A. Khasawneh*, Michigan State University, U.S.

4:25-4:45 An Optimization Algorithm for 3D Crater Estimation by using 2D NASA's Asteroids Open Data

Christos Liambas and *Stylianos Perrakis*, Aristotle University of Thessaloniki, Greece

Thursday, May 23

CP44

Climate Dynamics

3:10 p.m.-4:25 p.m.

Room: Primrose A

Chair: Sofya Zaytseva, College of William & Mary, U.S.

3:10-3:30 Nonlinear Time-Series Analysis of a Paleoclimate Temperature Record from Antarctica

Joshua Garland, Santa Fe Institute, U.S.; Varad Deshmukh, University of Colorado, U.S.; Elizabeth Bradley, University of Colorado, Boulder and Santa Fe Institute, U.S.

3:35-3:55 Cascading Tipping Points in Dynamical Systems and Paleoclimate

Johannes Lohmann, University of Copenhagen, Denmark; Daniele Castellana and Henk Dijkstra, Utrecht University, Netherlands; Peter Ditlevsen, University of Copenhagen, Denmark

4:00-4:20 Analysis of Oyster Reef Patterns in Remotely Sensed Data

Sofya Zaytseva and Leah Shaw, College of William & Mary, U.S.; Romuald Lipcius and Donglai Gong, Virginia Institute of Marine Science, U.S.

Thursday, May 23

CP45

Stochastics and Other Topics

3:10 p.m.-4:00 p.m.

Room: Primrose B

3:10-3:30 Complex Dynamics in a Fractional-Ordered Prey-Predator Model

Anuraj Singh, Indian Institute of Information Technology & Management Gwalior, India

3:35-3:55 Efficient Computational Approaches for Treatment of Transformed Path Integrals

Prakash Vedula, *Matthew Von Gonten*, and Gnana M. Subramaniam, University of Oklahoma, U.S.

Workshop on Network Science: Coffee Break

3:15 p.m.-3:45 p.m.

Room: Cottonwood A& B - Snowbird Center

Thursday, May 23

CP107

Workshop on Network Science: Contributed Session 8

3:45 p.m.-4:35 p.m.

Room: Cottonwood C & D - Snowbird Center

Chair: To Be Determined

3:45-4:05 Synaptic Plasticity in Correlated Balanced Networks

Alan E. Akil, University of Houston, U.S.; Robert Rosenbaum, University of Notre Dame, U.S.; Krešimiv Josić, University of Houston, U.S.

4:10-4:30 Approximating Network Reliability and Birnbaum Importance

Stephen Eubank, University of Virginia, U.S.; Madhurima Nath, Virginia Tech, U.S.; Yihui Ren, Brookhaven National Laboratory, U.S.

Intermission

4:50 p.m.-5:00 p.m.

Thursday, May 23

CP46

Mathematical Biology IV

5:00 p.m.-5:50 p.m.

Room: Magpie A

5:00-5:20 Particle Capture and Manipulation in Vibrationally Excited Viscous Flows

Rodrigo Abrajan-Guerrero, University of North Carolina, Charlotte, U.S.; Jeff D. Eldredge, University of California, Los Angeles, U.S.; Scott D. Kelly, University of North Carolina, Charlotte, U.S.

5:25-5:45 Finding Conditions to Control the Spread of Dengue Via Analysis of Invariant Manifolds

Pablo Aguirre and Dana Contreras, Universidad Técnica Federico Santa María, Chile

Thursday, May 23

CP47

Spectra and Symbolic Dynamics

5:00 p.m.-5:50 p.m.

Room: Magpie B

5:00-5:20 The Devil Is in the Spectrum: The Eigenvalue Distribution of the Discrete Preisach Memory Model

Andreas Amann, University College Cork, Ireland; Tamas Kalmar-Nagy, Budapest University of Technology and Economics, Hungary; Daniel Kim, Texas Academy of Mathematics and Science, U.S.; Dmitrii Rachinskii, University of Texas at Dallas, U.S.

5:25-5:45 Symbolic Dynamics Applied to the Periodically Driven Hill's Vortex

Joshua Arenson and Kevin A. Mitchell, University of California, Merced, U.S.

Thursday, May 23

CP48

Algorithms and Numerics

5:00 p.m.-5:50 p.m.

Room: Wasatch A

Chair: Nolan Tsuchiya, California Polytechnic State University, Pomona, U.S.

5:00-5:20 Variable Stepsize, Variable Order Methods for Partial Differential Equations

Victor P. Decaria, University of Pittsburgh, U.S.

5:25-5:45 Implementation of a Gough-Stewart Platform Controller Using the Levenberg-Marquardt Algorithm

David Gordon, California Polytechnic State University, Pomona, U.S.; Kevin R. Anderson, California State Polytechnic University, Pomona, U.S.; *Nolan Tsuchiya*, California Polytechnic State University, Pomona, U.S.

Thursday, May 23

CP49

Topics in Physics

5:00 p.m.-5:50 p.m.

Room: Wasatch B

5:00-5:20 A Differential Inclusion Approach to Mineral Precipitation-Dissolution Reactions in Geochemistry

Bastien Hamlat and Tangi Migot, INRIA, IRMAR, France; Jocelyne Erhel, Inria-Rennes, France; Anthony Michel, IFP, France

5:25-5:45 Inhomogeneous Domain Walls in Spin-Tronic Nanowires

Lars Siemer and Jens Rademacher, Universität Bremen, Germany; Ivan Ovsyannikov, University of Hamburg, Germany

Thursday, May 23

CP50

Mechanics

5:00 p.m.-5:50 p.m.

Room: Maybird

Chair: Melih C. Yesilli, Michigan State University, U.S.

5:00-5:20 On the Impact of an Elastoplastic Missile into a Robust Structure

Gyorgy Karolyi, Lili Laczak, and Andras Sipos, Budapest University of Technology and Economics, Hungary

5:25-5:45 Topological Feature Vectors for Chatter Detection in Turning Processes

Melih C. Yesilli and Firas A. Khasawneh, Michigan State University, U.S.; Andreas Otto, Chemnitz University of Technology, Germany

Thursday, May 23

CP51

Fluid Dynamics II

5:00 p.m.-5:50 p.m.

Room: Superior A

5:00-5:20 Time-Periodic Inertial Range Dynamics

Lennaert van Veen, University of Ontario Institute of Technology, Canada; Alberto Vela-Martin, Technical University of Madrid, Spain; Genta Kawahara, Osaka University, Japan

5:25-5:45 Modeling of the Trailing Vortex Pair Within an Underbody Diffuser Flow in Ground Effect

Salvador Mayoral and *Hope Weiss*, California State University, Fullerton, U.S.

Thursday, May 23

CP52

Stochastics and Numerics

5:00 p.m.-5:50 p.m.

Room: Superior B

Chair: Rahul Kumar, Indian Institute of Tecnology Madras, India

5:00-5:20 Application of a Stabilized Reduced-Order Method with Inputs and Outputs for Reservoir Simulations

Mustafa C. Kara, Sathish Sankaran, and Ajay Singh, Anadarko Petroleum Corporation, U.S.

5:25-5:45 Dynamic Analysis of Stochastically Parametered Inhomogeneous Structures using PCE Based ROM

Rahul Kumar, Indian Institute of Tecnology Madras, India; Sayan Gupta, Indian Institute of Technology Madras, India; Shaikh Faruque Ali, Indian Institute of Tecnology Madras, India

Thursday, May 23

CP53

Stochastic Dynamics

5:00 p.m.-5:50 p.m.

Room: White Pine

Chair: Kalle Timperi, Imperial College London, United Kingdom

5:00-5:20 Compressed Stochastic Digital Twins

Kyle R. Cochran, University of Illinois at Urbana-Champaign, U.S.; Sri Namachchivaya, University of Waterloo, Canada; Ryne Beeson, University of Illinois at Urbana-Champaign, U.S.; Peter Imkeller, Humboldt University Berlin, Germany

5:25-5:45 Transitions in Dynamical Systems with Bounded Uncertainty

Kalle Timperi, Jeroen Lamb, and Martin Rasmussen, Imperial College London, United Kingdom

Thursday, May 23

CP54

Time Series and Delay Embeddings

5:00 p.m.-5:50 p.m.

Room: Primrose A

Chair: Yonatan Gutman, Polish Academy of Sciences, Poland

5:00-5:20 Curvature Based Parameter Selection for Delay-Coordinate Reconstruction

Elizabeth Bradley, University of Colorado, Boulder and Santa Fe Institute, U.S.; Varad Deshmukh, University of Colorado, U.S.; Joshua Garland, Santa Fe Institute, U.S.; James D. Meiss, University of Colorado Boulder, U.S.

5:25-5:45 A Probabilistic Takens Theorem

Yonatan Gutman, Polish Academy of Sciences, Poland

Intermission

5:50 p.m.-6:05 p.m.

Closing Remarks

6:05 p.m.-6:10 p.m.

Room: Ballroom

Thursday, May 23

IP9

Networks Thinking Themselves

6:10 p.m.-6:55 p.m.

Room: Ballroom

Chair: Jeff Moehlis, University of California, Santa Barbara, U.S.

Human learners acquire not only disconnected bits of information, but complex interconnected networks of relational knowledge. The capacity for such learning naturally depends on the architecture of the knowledge network itself, and also on the architecture of the computational unit – the brain – that encodes and processes the information. Here, I will discuss emerging work assessing network constraints on the learnability of relational knowledge, and physical constraints on the development of interconnect patterns in neural systems. What do the correspondences between these domains this tell us about the nature of modeling and computation in the brain, and mechanisms for knowledge acquisition?

Danielle S. Bassett
University of Pennsylvania, U.S.

Speaker and Organizer Index

SIAM Conference on
Applications of Dynamical Systems
May 19–23, 2019
Snowbird, Utah, U.S.

Held jointly with the SIAM Workshop on Network Science (NS19)

SIAM Workshop on
Network Science
May 22–23, 2019

A

B

Italicized names indicate session organizers

C

Italicized names indicate session organizers

D

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F

G

H

Italicized names indicate session organizers

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V

W

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Italicized names indicate session organizers

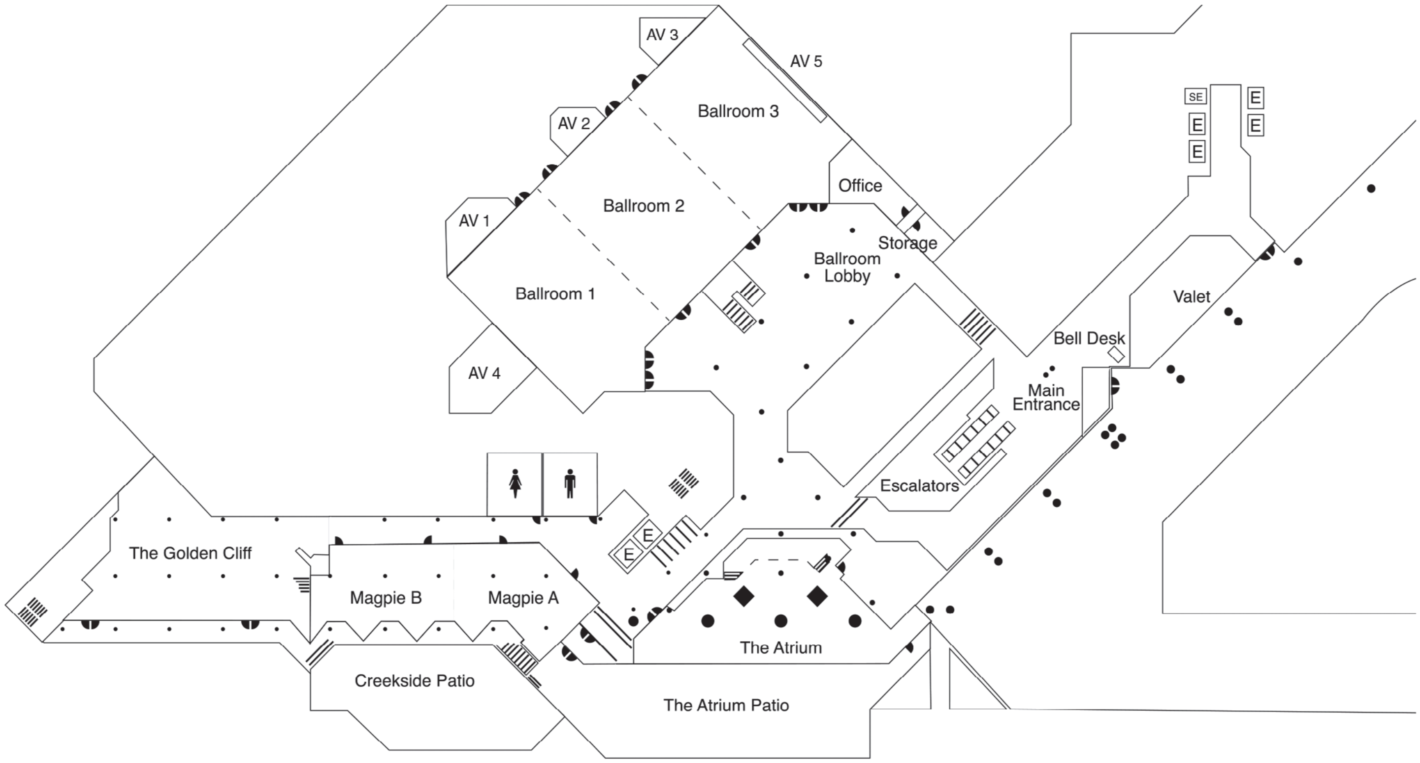
Conference Budget

Conference Budget
SIAM Conference on Dynamical Systems
SIAM Workshop on Network Science
May 19 - 23, 2019
Snowbird, UT

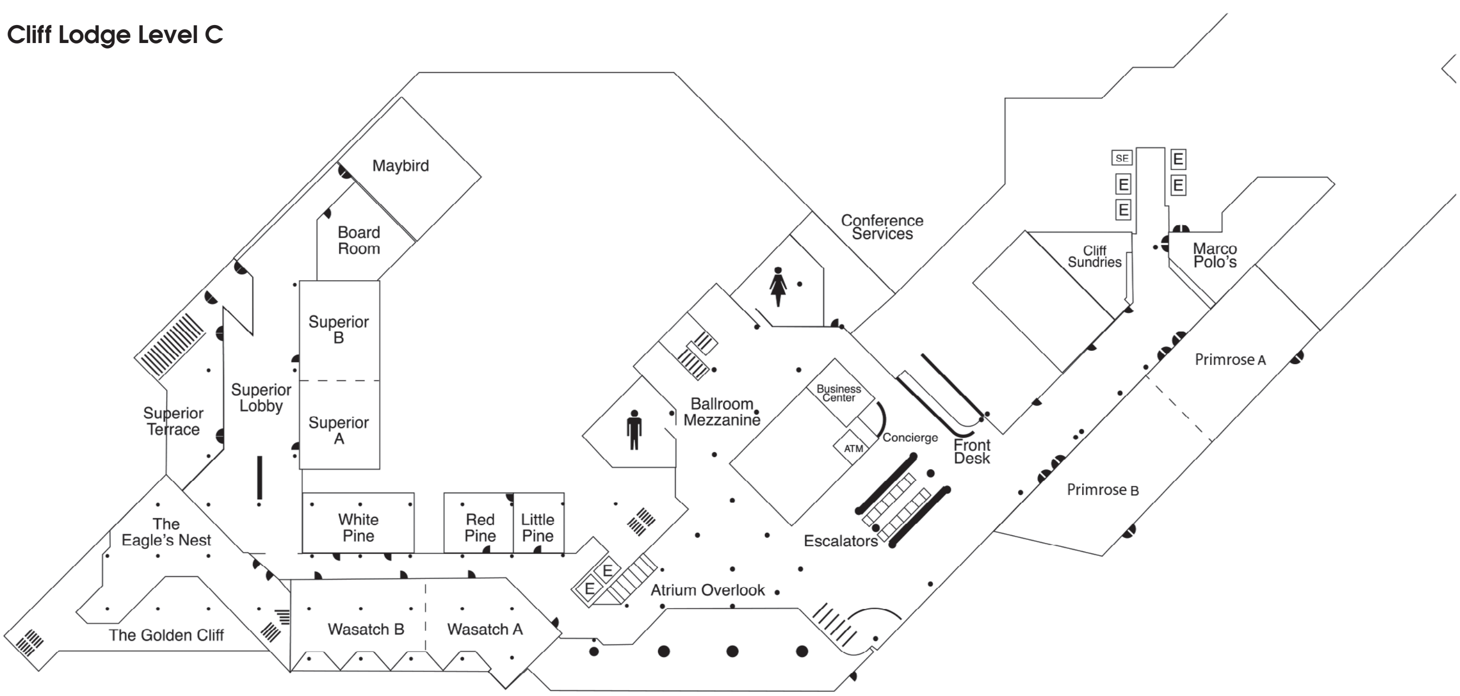
Expected Paid Attendance	870	
Revenue		
Registration Income		$270,920
	Total	$270,920
Expenses		
Printing		$8,500
Organizing Committee		$6,000
Invited Speakers		$21,800
Food and Beverage		$51,900
AV Equipment and Telecommunication		$21,100
Advertising		$9,700
Conference Labor (including benefits)		$68,383
Other (supplies, staff travel, freight, misc.)		$17,100
Administrative		$27,523
Accounting/Distribution & Shipping		$15,635
Information Systems		$26,987
Customer Service		$9,484
Marketing		$18,000
Office Space (Building)		$10,859
Other SIAM Services		$10,209
	Total	$323,180
Net Conference Expense		-$52,260
Support Provided by SIAM		$52,260
		$0

Snowbird Ski and Summer Resort Hotel Floor Plans

Cliff Lodge Level B



Cliff Lodge Level C



IP1

Chain Reactions

To every action corresponds an equal and opposite reaction. However, there turn out to exist in nature situations where the reaction seems neither equal in magnitude nor opposite in direction to the action. We will see a series of table-top demos and experimental movies, apparently in more and more violation of Newton's 3rd law, and give an analysis of what is happening, discovering in the end that the phenomenon is in a sense generic. The keys are shock, singularity in the material property, and supply of critical geometry'.

Tadashi Tokieda
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IP2

Localized Pattern Formation

Spatially localized patterns arise in many natural processes: buckled shells, spots in autocatalytic chemical reactions, crime hotspots, localized fluid structures, and vegetation spots are prominent examples that have attracted much attention. Despite appearing on vastly different scales, spatially localized structures often share similar features and properties, and mathematical techniques can help identify the origins of such patterns across different systems. In this talk, I will highlight the use of analytical and geometric dynamical-systems techniques to better understand when localized patterns may emerge, how their shape and form is determined, and what their stability properties might be. I will also discuss open problems and challenges.

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IP3

Starbursts and Flowers: When Spreading Droplets Break Bad

A droplet of pure water placed on a clean glass surface will spread axisymmetrically: there is nothing to break the symmetry. For more interesting fluids or more interesting surfaces, new patterns of spreading are possible. I will highlight two systems in which dramatic instabilities arise through the interaction of surface tension, elasticity, and the interface between them. The first example – starburst fractures – arises when droplets are placed on very soft substrates, such that elastic forces are in direct competition with capillary forces. The second example is the surprising case of a liquid metals, where fingering instabilities are unexpected due to typically large interfacial tensions. However, electrochemical oxidation can lower the interfacial tension of gallium-based liquid metal alloys, thereby inducing drastic shape changes including the formation of fractals.

Karen Daniels
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IP4

Hybrid Forecasting of Complex Systems: Combining Machine Learning with Knowledge-based Models

In recent years, machine learning methods such as "deep learning" have proven enormously successful for tasks such as image classification, voice recognition, and more. Despite their effectiveness for big-data classification problems, these methods have had limited success for time series prediction, especially for complex systems like those we see in weather, solar activity, and brain dynamics. In this talk, I will discuss how a Reservoir Computer (RC) - a special kind of machine learning system that offers a "universal" dynamical system - can draw on its own internal complex dynamics in order to forecast systems like the weather, beyond the time horizon of other methods. The RC provides a knowledge-free approach because it builds forecasts purely from past measurements without any specific knowledge of the system dynamics. By building a new hybrid approach that judiciously combines the knowledge-free prediction of the RC with a knowledge-based, mechanistic model, we demonstrate a further, dramatic, improvement in forecasting complex systems. This hybrid approach can given us new insights into the weaknesses of our knowledge-based models and also reveal limitations in our machine learning system, guiding improvements in both knowledge-free and knowledge-based prediction techniques.

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IP5

A Topological View of Collective Behavior Models

From nanoparticle assembly to synchronized neurons to locust swarms, collective behaviors abound anywhere in nature that objects or agents interact. Investigators modeling collective behavior face a variety of challenges involving data from simulation and/or experiment. These challenges include exploring large, complex data sets to understand and characterize the system, inferring the model parameters that most accurately reflect a given data set, and assessing the goodness-of-fit between experimental data sets and proposed models. Topological data analysis provides a lens through which these challenges may be addressed. This talk consists of three parts. First, I introduce the core ideas of topological data analysis for newcomers to the field. Second, I highlight how these topological techniques can be applied to models arising from the study of groups displaying collective motion, such as bird flocks, fish schools, and insect swarms. The key approach is to characterize a system's dynamics via the time-evolution of topological invariants called Betti numbers, accounting for persistence of topological features across multiple scales. Finally, moving towards a theory of reduced topological descriptions of complex behavior, I present open questions on the topology of random data, complementing research in random geometric graph theory.

Chad M. Topaz
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IP6

Biological Fluid Mechanics: Hydrodynamically-

coupled Oscillators

Respiratory cilia that transport mucus in the lungs, spermatozoa that collectively move through the female reproductive tract, paddling appendages that propel a crawfish, and fish swimming in a school are all examples of oscillators that exert force on a surrounding fluid. Do the synchronous or phase-shifted periodic motions that we observe arise due to hydrodynamic coupling? We will discuss experiments and models of the self-organized pattern of beating flagella and cilia from minimal models of colloidal particles driven by optical traps to more detailed models that include dynamics of the molecular motors driving the motion. We will also examine the role of fluid inertia on the dynamics of synchronization of such systems.

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IP7

Inference in Dynamical Systems: The Thermodynamic Formalism and Bayesian Inference

We consider inference of dynamical systems from ergodic observations using a general Bayesian framework for updating belief distributions using a loss function, called Gibbs posterior inference. Suppose that make observations of an ergodic system, and we attempt to model the system by a parametrized family of Gibbs measures on a mixing shift of finite type. For fixed loss function and prior distribution on the parameter space, we characterize the asymptotic behavior of the Gibbs posterior distribution on the parameter space as the number of observations tends to infinity In particular, we de fine a limiting variational problem over the space of joinings of the model system with the observed system, and we show that the Gibbs posterior distributions concentrate around the solution set of this variational problem. Our convergence results hold in general misspecified settings, and our examples illustrate that in the properly specified case they may be used to establish posterior consistency. This work establishes tight connections between Gibbs posterior inference and the thermodynamic formalism, which may inspire new proof techniques in the study of Bayesian posterior consistency for dependent processes. Joint work with Kevin McGoff, UNC Charlotte and Andrew Nobel, UNC Chapel Hill.

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IP8

On the Impact of Dynamics on Ensemble Data Assimilation

Data assimilation aims at optimally estimating the state, the parameters, and their associated uncertainties, of a physical system using observations and a numerical model of the systems dynamics. It is nowadays common practice in numerical weather prediction, a chaotic and extremely high-dimensional application. However, data assimilation algorithms are usually derived based on statistical and numerical optimization considerations, lacking a dynamical system perspective in their design. Elucidating the impacts of the dynamics on data assimilation schemes is the objective of this talk. Specifically, I will explain the impact of chaotic dynamics on the ensemble Kalman filter, a particle data assimilation scheme increasingly popular in the geosciences and beyond. The key role of the unstable dynamics on the ensemble will be examined, and conclusions will be drawn on how this relationship can guide the design and implementation of the ensemble Kalman filter.

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IP9

Networks Thinking Themselves

Human learners acquire not only disconnected bits of information, but complex interconnected networks of relational knowledge. The capacity for such learning naturally depends on the architecture of the knowledge network itself, and also on the architecture of the computational unit the brain that encodes and processes the information. Here, I will discuss emerging work assessing network constraints on the learnability of relational knowledge, and physical constraints on the development of interconnect patterns in neural systems. What do the correspondences between these domains this tell us about the nature of modeling and computation in the brain, and mechanisms for knowledge acquisition?

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IP100

Workshop on Network Science: From Single Networks to Networks of Networks

Network science has been focused on the properties of a single isolated network that does not interact or depends on other networks. I will present several applications of networks in physiology, traffic, climate, and epidemics. In reality, many real networks, such as the power grid, protein networks, transportation, and communication infrastructures interact and depend on each other. I will present a framework for studying the vulnerability of networks of interacting networks. In interdependent networks, when nodes in one network fail, they cause dependent nodes in other networks to also fail. This may lead to a cascade of failures and to a sudden fragmentation of the system. I will present analytical solutions for the critical threshold and the giant component of a network of N interdependent networks. I will show, that the general theory has many novel features that are not present in the classical network theory. I will also show that interdependent networks embedded in space are significantly more vulnerable compared to random networks.

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IP102

Workshop on Network Science: Title to Be Determined

Abstract to be determined

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SP1

Juergen Moser Lecture - Vocal Development in Marmoset Monkeys: Neuromechanics and Social Interactions

Vocal development requires adaptive coordination of the lungs and larynx, their controlling muscles, the nervous system, and social interactions. We build a bio-mechanical model of the marmoset monkey vocal apparatus and, using behavioral data and maximum entropy methods, show that combinations of growth in the vocal tract, muscles and nervous system can account for juvenile vocal development. Our analysis appeals to dynamical systems and bifurcation theory, and is based on a normal form reduction of the bio-mechanical model. In this talk I hope to display lively interactions among mathematical modeling and analysis, probabilistic methods, and bio-physical data. This is joint work with Yayoi Teramoto, Daniel Takahashi and Asif Ghazanfar.

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CP1

A Nonlinear Model of Opinion Network Dynamics and Its Experimental Investigation

We present a novel opinion dynamics model that describes the temporal evolution of opinions due to interactions among a network of individuals (nodes). The model is formulated in terms of coupled nonlinear differential equations for node opinions and uncertainties. Our model allows for the emergence and persistence of majority positions so that the mean opinion can shift even for a network with symmetric coupling, a dynamic missing from existing continuous opinion network models. This allows the modeling of discussion-induced shifts toward the extreme, a robust social psychological phenomenon known as group polarization, without the assumption of greater resistance to persuasion among extremists that is typically made in the opinion network modeling literature. The models predictions for discussion-induced shifts are in qualitative and quantitative agreement with the results of an experiment in which triads engaged in online discussion concerning wagering on football games. Applying the model to large networks reveals a sharp transition between unimodal and bimodal final opinion distributions, thereby offering a novel mechanism by which public opinion can split into opposing camps.

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CP1

A Dynamical Systems Approach to Threshold Models of Social Influence

With concepts like virality and polarization on social networks in the forefront of the public consciousness, it is increasingly crucial to model the spread of ideas on networks. Many studies of cascades on these networks have considered threshold models of binary decisions, such as the Watts threshold model, where each actor in the network switches from an inactive to an active state if a threshold fraction of its neighbours is active. We look at the problem of idea spreading using dynamical systems: each node on the network is governed by a differential equation driven by the state of its neighbours. Considering extremely fast dynamics, approximated by each node moving to its steady state in a single 'step', recovers the Watts threshold model. For more general time scales we can study the spatiotemporal dynamics of cascades. On Newman–Watts small-world networks, we present an expression for the proportion of active nodes against time that matches the "S-shaped' curves found widely in the literature. It is of logistic form, as in the Bass model for the adoption of innovations. We find that on Newman–Watts networks, increasing the number of connections can reduce the mean path length and in turn speed up cascades. Conversely, on networks with already short mean path lengths (e.g. Erdős–Rényi $G(n, p)$ networks with $p \gg n^{-1}$), adding more connections can slow down a cascade.

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Mason A. Porter
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CP1

Implication Avoiding Dynamics for Externally Observed Networks

French social theorist Michel Foucault suggested that human behaviors surrounding credibility shift in response to the introduction of an external observer. We envision a signed, directed network where positive edges represent endorsements or trust and negative edges represent accusations or disapproval, and question when an external observer is able to detect a set of duplicitous nodes and how those nodes might adjust their behavior to avoid suspicion. We develop criterion for when honest nodes can be detected regardless of the behavior of the duplicitous nodes, both when the honest nodes have completely reliable knowledge and when they are prone to limited amounts of error. Building on these notions, we develop a discrete time dynamical system where nodes engage in implication avoiding dynamics, where inconsistent arrangements of edges that cause a node to look 'suspicious' exert pressure for that node to change edges. We show that for some parameter values, the network evolves such that a large majority of the honest nodes can be distinguished by an external observer, but for others, which do not appropriately balance accusations with endorsements, the duplicitous nodes can turn the dynamics to their favor.

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CP1

Spectral Analysis of a Non-Equilibrium Stochastic

Dynamics on a Complex Network

Unravelling underlying complex structures from limited resolution measurements is a known problem arising in many scientific disciplines. We study a stochastic dynamical model with a multiplicative noise. It consists of a stochastic differential equation living on a graph, like approaches used in population dynamics or directed polymers in random media. We develop a new tool for approximation of correlation functions based on spectral analysis that does not require translation invariance. This enables us to go beyond lattices and analyze complex networks. We show, analytically, that this model has different phases depending on the topology of the network. One of the main parameters which describe the network topology is the spectral dimension $\widetilde{d}$. We show that the correlation functions depend on the spectral dimension and that only for $\widetilde{d} > 2$ a dynamical phase transition occurs. We show by simulation how the system behaves for different network topologies, by defining and calculating the Lyapunov exponents on the graph. We present an application of this model in the context of Magnetic Resonance Imaging (MRI) measurements of porous structure such as brain tissue. This model can also be interpreted as a KPZ equation on a graph.

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CP2

Data Driven Hamiltonian Dynamics for Hydrogen-Oxygen Combustion via Programmable Potentials

Although quantum scale simulations of hydrogen-oxygen combustion offer an accurate description of the process, a multi-atom quantum simulation of combustion is unfeasible as it would not terminate in a scientist's lifetime. Multi-atom simulations of combustion are feasible at the molecular scale, however, the potential bond energies are inaccurate and results often fail to match quantum data. Here we demonstrate how the programmable potentials methodology can be utilized to develop approximate molecular level bond energy potentials for several intermediate reactions involved in hydrogen-oxygen combustion. Limited Electronic Structure Theory (EST) simulation data is utilized to train our programmable potentials which are then inputted into the Hamiltonian of a molecular dynamics simulation package for verification. Our results demonstrate that the developed programmable potentials generalize beyond the EST training dataset and provide a feasible manner of producing molecular level simulations of hydrogen-oxygen combustion at EST quantum accuracy.

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CP2

Diffusion of Medium Earth Orbits from a Hamiltonian Perturbative Approach

The existence and interplay of multiple lunisolar secular resonances strongly affects the long term behavior of Medium Earth Orbits (MEOs). Regular and chaotic domains are known to coexist in both the prograde and retrograde MEO sectors, as revealed via the use of variational chaos indicators (Daquin et al., 2016; Gkolias et al., 2016; Celletti et al., 2017). In this work we recall a first order averaged model (expressed in closed formulas) and perform an analysis of the resonant structure and long-term dynamics at particular resonances. The model takes into account the Earths oblateness (J_2) and perturbations by external bodies (Moon and Sun). We first classify the resonances in terms of 'fundamental resonance models', and give formulas for the separatrices at each resonance. We then estimate analytically the local domains and timescales for stability and long-term diffusion. We treat both cases of drift along a simple resonance or at a resonance junction. We finally compare analytical with numerical results regarding the mediation of the drift within the hyperbolic web (Daquin et al., 2018). Practical applications refer to the sustainability in long-term space traffic.

Celletti, A., Gales, C., Pucacco, G. et al. 2017, CeMDA, 127(3). Daquin, J., Gkolias, I., and Rosengren, A. J. 2018, Front. Appl. Math. Stat., 4(35). Daquin, J., Rosengren, A., Alessi et al. 2016, CeMDA 124(4). Gkolias, I., Daquin, J., Gachet, F. et al. 2016, AJ, 152(5).

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CP2

Studying the Effect of the Solvent on the Position of the Dividing Surface with the Aid of Lagrangian Descriptors

The correct location of the Transition State dividing surface is a key point; not only for the precise calculation of the rate constant of the reaction, but for the proper prediction of its behaviour after the barrier crossing. The correct location of this surface is defined by the requirement that reactive trajectories do not recross it. When that condition is satisfied, the true transition state for the reaction has been found. In the case of reactions in solution the solvent plays an important role in the location of this dividing surface, one that is not shown in its potential energy surface and that can fully change the behavior of the reaction. We aim to show the extent of this effect in a simple 2 degree of freedom model system by computing the Periodic Orbits Dividing Surfaces (PODS) and to compare them with the results obtained by calculating the Lagrangian Descriptors in a different procedure that could be possible to apply to multiple degree of freedom models.

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CP2

On Exponential Fermi Accelerators and on Energy Equilibration

In 1949, Fermi proposed a mechanism for the heating of particles in cosmic rays. He suggested that on average, charged particles gain energy from collisions with moving magnetic mirrors since they hit the mirrors more frequently with heads on collisions. Fermi, Ulam and their followers modeled this problem by studying the energy gain of particles moving in billiards with slowly moving boundaries. Until 2010 several examples of such oscillating billiards leading to power-law growth of the particles averaged energy were studied. In 2010 we constructed an oscillating billiard which produces exponential in time growth of the particles energy. The novel mechanism which leads to such an exponential growth is robust and may be extended to arbitrary dimension. Moreover, the exponential rate of the energy gain may be predicted by utilizing adiabatic theory and probabilistic models. The extension of these results to billiards with mixed phase space leads to the development of adiabatic theory for non-ergodic systems. Finally, such accelerators lead to a faster energy gain in open systems, when particles are allowed to enter and exit them through a small hole. The implications of this mechanism on transport in extended systems and on equilibration of energy in closed systems like "springy billiards" will be discussed. The latter application provides a key principle: to achieve ergodicity in slow-fast systems in the adiabatic limit, the fast subsystems should NOT be ergodic.

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CP3

Bogdanov-Takens Resonance in Time-Delayed Systems

In this talk, we present our work on *delayed time* systems, in which we analyze the oscillatory dynamics of a time-delayed dynamical system subjected to a periodic external forcing. We show that, for certain values of the delay, the response can be greatly enhanced by a very small forcing amplitude. This phenomenon is related to the presence of a BogdanovTakens bifurcation and displays some analogies to other resonance phenomena, but also substantial differences. This is a joint work with BeiBei Zhu, Miguel A.F. Sanjuán and Jesús M. Sanz-Serna.

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CP3

Comparison and Connection Between Delay Oscillators and ODE Oscillators

Agents with internal delay in their actions, such as a reaction time or processing time, can exhibit oscillatory behavior including stable limit cycles. In previous studies, these delay limit cycle oscillators have been shown to exhibit behaviors that are similar to limit cycle oscillators defined by second-order ordinary differential equations, such as the van der Pol oscillator. Since the oscillator models exhibit such similarities, particularly in the steady-state, it is then prudent to consider the differences between them as well. By distinguishing between the models, we may be able to apply them more effectively to describe physical systems. In this talk, I will explore the differences between the delay oscillator model and its ODE counterparts, using numerical methods applied to simulated time series data, and supported by the results of perturbation methods. By characterizing the two types of model through their transient behaviors and other specific details, I hope to distinguish between the physical systems where each model is a more accurate description.

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CP3

Time Delay Models of Vehicular Traffic and their Comparison to Microscopic Traffic Data

The dynamics of traffic jams and the formation of congestion waves in vehicular traffic are investigated by analyzing microscopic and macroscopic models of traffic flow. Microscopic models trace the motion of each individual vehicle separately, typically in a Lagrangian framework. These models can be described by delay differential equations when taking into account time delays arising from various sources such as driver reaction time or engine dynamics. Macroscopic models describe the flow of traffic similarly to fluid flows, typically in an Eulerian framework. These models are usually described by partial differential equations, where the effects of time delays are often neglected. In this work, microscopic and macroscopic models are compared and linked together via descriptions in terms of traffic density and flux as well as in terms of vehicle position and velocity. The possibility of including time delays in macroscopic models is also considered. Finally, some specific microscopic and macroscopic models are compared to experimental microscopic traffic data that was obtained by measuring vehicle trajectories in traffic via GPS. Based on the experiments, the performance of these models is evaluated in terms of capturing the time, location and amplitude of velocity fluctuations in traffic jams.

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CP3

Vector-Valued Spectral Analysis of Complex Flows

We introduce a recently developed framework for spatiotemporal pattern extraction called Vector-Valued Spectral Analysis (VSA). This approach is based on the eigendecomposition of a kernel integral operator acting on vector-valued observables (spatially extended fields) of the dynamical system generating the data, constructed by combining elements of the theory of operator-valued kernels for multitask machine learning with delay-coordinate maps of dynamical systems. A key aspect of this method is that it utilizes a kernel measure of similarity that takes into account both temporal and spatial degrees of freedom (whereas classical techniques such as EOF analysis are based on aggregate measures of similarity between snapshots). As a result, VSA has high skill in extracting physically meaningful patterns with intermittency in both space and time, while factoring out any symmetries present in the data. We demonstrate the efficacy of this method with applications to various cases of complex turbulent flows.

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CP4

Structure and Physics Preserving Reductions of Power Grid Models

The large size of multiscale power grids hinder fast system-wide estimation and real-time control and optimization. We study graph reduction methods that are favorable for fast simulations and follow-up applications. While the classical Kron reduction has been successful in reduced order modeling of power grids with traditional, hierarchical design, the selection of reference nodes for the reduced model in a multiscale, distribution and transmission, network becomes ambiguous. In this work we extend the use of the Kron reduction by utilizing the electric grid's graph topology for the selection of reference nodes, consistent with the design features of multiscale networks. Additionally, we propose further reductions by aggregation of coherent subnetworks of triangular meshes, based on the graph topology and network characteristics, in order to preserve currents and build another power-flow equivalent network. Our reductions are achieved through the use of iterative aggregation of sub-graphs that include general tree structures, lines, and triangles. Our reduction algorithms are designed so that: (i) the reductions are, either, equivalent to the Kron reduction, or otherwise produce a power-flow equivalent network; (ii) due to the former mentioned power-flow equivalence, the reduced network can model the dynamic of the swing equations for a lossless, inductive, steady state network; (iii) the algorithms efficiently utilize hash-tables to store the sequential reduction steps

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CP4

Relativistic Chaotic Scattering

The phenomenon of chaotic scattering is very relevant in different fields of science and engineering. It has been mainly studied in the context of Newtonian mechanics, where the velocities of the particles are low in comparison with the speed of light. In this talk, we analyze global properties such as the escape time distribution and the decay law of the Hénon-Heiles system in the context of special relativity. Our results show that the average escape time decreases with increasing values of the relativistic factor β. As a matter of fact, we have found a crossover point for which the KAM islands in the phase space are destroyed when $\beta \simeq 0.4$. On the other hand, the study of the survival probability of particles in the scattering region shows an algebraic decay for values of $\beta \leq 0.4$, and this law becomes exponential for $\beta > 0.4$. Surprisingly, a scaling law between the exponent of the decay law and the β factor is uncovered where a quadratic fitting between them is found. The results of our numerical simulations agree faithfully with our qualitative arguments. Besides, we compute the basin entropy and the fractal dimension of the set of singularities of the scattering function in function of β. We expect this work to be useful for a better understanding of both chaotic and relativistic systems. This is joint work with Miguel A. F. Sanjuán and Juan D. Bernal (Spain).

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CP4

Stability and Bifurcation Analysis of the Period-T

Motion of a Vibroimpacting Energy Generator

Stability and bifurcation conditions for the period-T vibroimpact motion in an inclined energy harvester are determined analytically and numerically. This investigation provides a better understanding of low-velocity impacts resulting in a low energy harvesting efficiency and can be used to optimally design the device in terms of initial parameters vs converted energy. The numerical and analytical results of periodic motions are in precise agreement. The region for stability conditions are developed in non-dimensional parameter space. The range for simple 2-periodic behavior is reduced with increasing angle of incline β, since the influence of gravity increases the asymmetry of dynamics following impacts at the bottom and top. These asymmetric 2-periodic solutions loses stability to period doubling solutions for all β, which are appear through increased asymmetry. The period doubling, symmetric and asymmetric periodic motion are illustrated by phase portrait and velocity time series.

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CP4

Ac Response of Coupled Phase Oscillators with Inertia

Kuramoto oscillators have been extensively studied to understand phase synchronization in various networked systems. Recently, the modified Kuramoto system including inertia has been used to model power grid stability. Based on this, our work investigates the so-called low frequency oscillations in the modified Kuramoto system, which extends the previous studies on Kuramoto oscillators from synchronized state to ac steady state. We analyze dynamics of the Kuramoto systems (e.g. 2- and 3-nodes) under periodic disturbance. We also show the temporal evolution and spatial distribution of node oscillation amplitudes. Several interesting results are found, such as a link strength corresponding to maximum oscillation amplitude and the enhanced amplitude at nodes far from the disturbance source. Our work has implications in modern electric power systems design and control since the low frequency oscillation has been a growing concern as the grid expands rapidly and becomes more and more complex.

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CP5

Evolutionary Dynamics in a Group Population Structure with Barriers to Group Entry

The evolution of cooperation has been studied in many systems, from bacterial communities to human populations. It is well known that population structure is crucial to a system's dynamics. In human populations, group memberships are critical. Humans often meet and interact with each other due to common group memberships. There exist network-based models to study human dynamics, but they generally do not allow for multiple group affiliations or incorporate barriers to group entry. In this work, we present a framework in which individuals in a group-structured population interact, through an evolutionary game, with those who share their groups. Individuals update stochastically, with strategy and group memberships subject to evolutionary updating. We impose realistic barriers to group entry based on group size. We find that with barriers, cooperation can emerge, but that it is most favored when we allow for the existence of "loners": a changing subset of individuals who spend a temporary "time-out" period not interacting with others. This work provides an analytical framework in which behavior in realistic population structures can be studied, and adds to a growing body of literature that recognizes the existence of loners as vital parts of systems.

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CP5

Fitting In and Breaking Up: Two Versions of Coevolving Voter Models

We explore two versions of coevolving voter models, in which both node states and network structure update in a coupled stochastic dynamical process. Both of the versions we consider are "edge-based' and update asynchronously. During each time step, we randomly select a discordant edge between nodes of different states, and then we randomly select one of the nodes incident to the edge to be the primary node and the other node to be the secondary node. Much of the prior work on coevolving voter models involved versions in which with some fixed probability the primary node changes their local network structure by rewiring the discordant edge; or with complementary probability the primary node adopts the state of the secondary node. In the first version we present, we make use of the quantity p_c, which we define as the current proportion of neighbors of the primary node who are in the same state as the primary node. In the update, with probability p_c, the primary node rewires the discordant edge; or with complementary probability the primary node adopts the state of the secondary node. In the second version, with some probability the primary node deletes the discordant edge (akin to 'unfriending' on social media); or with complementary probability the primary node adopts the state of the secondary node. In this talk we will discuss how these versions of coevolving voter models behave qualitatively differently from each other and from previously studied versions.

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CP5

Voter Dynamics and Non-Equilibrium Behaviour

in a Two-Population Voter Model with Zealotry

We introduce a heterogeneous non-linear q-voter model with zealots and two types of susceptible voters, and study its non-equilibrium properties when the population is finite and well mixed. In this two-opinion model, each individual supports one of two parties and is either a zealot or a susceptible voter of type q_1 or q_2. While here zealots never change their opinion, a q_i-susceptible voter consults a group of q_i neighbors at each time step, and adopts their opinion only if all group members agree. We show that this model violates the detailed balance whenever $q_1 \neq q_2$ and has surprisingly rich properties. In particular we find that subpopulations which are more susceptible to opinion change (i.e. lower q_i) are a driving force for the system, eventually forcing the system between stationary states. This analysis may go some way to explaining how there can be societal shifts in behaviour or voting stance, such as in recent global elections, despite a significant percentage of the population being robust in their conviction. The behaviour of the model can be studied through a characterization of the non-equilibrium stationary state (NESS) in terms of the probability distribution and currents which are examined through exact numerics and analytical calculation, the latter being obtained using a linear Gaussian approximation.

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CP5

Punctuating Literature with Time-Series Analysis

Whether enjoying the lucid prose of my coauthors or slogging through my cumbersome, seemingly mindless, heavy-set prattle (full of parentheses, em-dashes, compound adjectives, and Oxford commas), readers will notice stylistic signatures not only in word choice and grammar, but also in punctuation itself. Indeed, visual sequences of punctuation from different authors produce marvelously different (and visually striking) sequences. After spending several years discussing the arguably trivial subtleties of grammar and punctuation — much to the dismay of my students, to whom I am supposed to be making substantive comments about their academic work — I encountered a blog entry by Adam Calhoun with striking visualizations of punctuation, and my collaborators and I asked if we could quantify punctuation sequences. In this talk, I'll discuss where we are with this project. Are the properties of such sequences a distinguishing feature of different authors? Is it possible to distinguish literary genres based on their punctuation sequences? Do the punctuation styles of authors evolve over time? Are my coauthors and I on to something interesting in trying to do writing analysis without words, or are we full of sound and fury (signifying nothing)?

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CP6

Stochastic Spatial Model for Yeast Biofilm Social Interactions: Investigating the Fitness Benefits of Within-Strain Cooperation

Biofilms are communities composed of one or more species of microorganisms. These communities are attached to a surface and are protected from antibiotics and other environmental hazards by an extracellular matrix; this makes them difficult to remove from industrial and medical settings, such as catheters and medical implants. Biofilms require cooperation, in which individuals produce public goods that are shared with other members. Such communities are susceptible to cheating individuals that do not produce the public goods but benefit from them. One possible way that cooperators can avoid invasion by cheaters is by interacting with their own kind and not with others (kin selection). Within biofilms, clonal growth can generate patches of cooperators; thus, spatial structure alone can lead to stable cooperation. However, another possible mechanism by which individuals could restrict their cooperative behavior to like kinds is kin recognition. This idea has received far less attention in microbial communities. The model yeast, *Saccharomyces cerevisiae*, has been used to test the effect of microbial social dynamics in lab studies. Here, we investigate the spatial growth of yeast biofilms and model social interactions between strains, including kin recognition and cheating, by using stochastic spatial simulations. We determine the conditions under which kin recognition confers a significant fitness advantage within spatially structured communities.

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CP6

Stochastic Hiv Rebound During Post Treatment-Interruption: the Role of Immune Pressure

Combination antiretroviral therapy (cART) suppresses HIV load to low levels in HIV infected individuals. After cessation of cART, most infected individuals will see an increase in their viral-load to pre-treatment levels as a result of HIV reactivation from latently infected cells. This resurgence is termed viral rebound (VR). Although VR is most likely to occur immediately after drug washout, viral

load remains low for months or years after cART cessation in a small fraction of individuals; this is termed post treatment control (PTC). Previous stochastic models considered how the time to rebound depends on the size of the HIV latent reservoir. Here we present a stochastic within-host model incorporating the immune response to viral reactivation. We use a Wentzel-Kramers-Brillouin ansatz to approximate the time to rebound. Model results suggest that, for a weak immune response to viral reactivation, VR is most strongly dependent on the mean time to activation and establishment of latently infected cells. In the case of a strong immune response, VR is dependent on both reactivation of latently infected cells and rare large-stochastic-fluctuations that allow the virus population to evade the immune pressure. Our results have implications of estimation and design of immunotherapies aiming to improve an individuals immune response to lead to longer PTC.

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CP6

The Spatiotemporal Dynamics of African Infant Infections

Neonatal sepsis continues to kill about 1 million infants worldwide each year. One of the most severe sequelae in survivors of neonatal sepsis is postinfectious hydrocephalus, which often is accompanied by substantial brain destruction and accumulating fluid. We have embarked on a detailed analysis of the microbial origins of such infections in Uganda, and find significant clustering in geographic location in contrast to control non-infected cases. In addition, there is substantial environmental effect on such infection rates, with a significant rainfall link. We have fused the location of all villages in Uganda to the satellite climate grid. We can now show the interrelationships between location, rainfall, elevation, and other satellite derived environmental variables to such infant infections, demonstrating substantial predictive power knowing only the location and timing of infection.

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CP7

The Unruly Effective Diffusion Coefficient of Phase-Locked Bursters

We investigate the noise response properties of phase-locked bursters, i.e. bursters in which the fast oscillations are phase-locked to the slower burst cycle. We find that the phase response of such bursters to noise is quite unruly: the effective "output" diffusion is non-monotonic in the input noise strength and greatly enhanced compared to a linear prediction. The dynamics of the principal neurons of the mammalian olfactory bulb serves as a motivating example. The cell's membrane potential exhibits mixed-mode oscillations with both the large amplitude spikes typical of neurons and small amplitude, sub-threshold oscillations (STOs). Noisy input from upstream neurons can strongly perturb the patterns of spikes and STOs displayed, as is reflected in an unruly diffusion coefficient for spiking times. The noise-driven perturbations can greatly affect the spike-driven interactions between cells, and we note the implications of the diffusion on coherent, population-level behavior. We show how the extreme sensitivity of the spiking to noisy inputs can be generalized. We capture the bursting mechanism of the specific 9-dimensional neuronal model in a 3-dimensional canonical burster model, which we reduce in turn to a simple stochastic circle map with a labeling of some states as "spikes" and some as "STO peaks". The dramatic qualitative features of the effective diffusion persist across this drastic simplification, and we make use of the simple model to elucidate them.

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CP7

Non-Reciprocal Dynamics and Bifurcation Analysis of Coupled Bilinear Oscillators

We investigate the nonlinear dynamics of coupled bilinear oscillators subject to external harmonic excitation. The bilinear nature of the problem is due to elements that have different elastic modulus (stiffness) in compression and extension. Our focus is on exploring scenarios in which the dynamical system is not reciprocal; i.e. when changing the location of the external excitation results in a different response in the other unit. We show that we can obtain different responses for the forward and backward configurations relying on either (i) the harmonic (frequency-preserving) operating range, or (ii) different onsets of instability. Using the coupled oscillators as the unit cell of a one-dimensional lattice, we discuss the underlying mechanism for asymmetric wave propagation in bilinear lattices. We discuss experimental realization of the unit cell based on 3D-printed macroscale structures.

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CP7

Reduced Dynamics for the Kuramoto-Sakaguchi Model Using Collective Coordinates

The Kuramoto-Sakaguchi Model is a common model that describes the interactions of ensembles of coupled oscillators, which has a wide range application in many different natural and artificial systems. It is an extension of the paradigmatic Kuramoto model including the effect of a phase offset. The model exhibits intriguing dynamical behavior such as multi-stability, chimera states, and chaos. We attempt to arrive at a reduced description of the model through collective coordinates. This method has been successfully applied to the standard Kuramoto model capturing partial synchronization, standing waves as well as the transition between different dynamic regimes. The additional complexity of the phase offset in the Kuramoto-Sakaguchi model requires a modification of the collective coordinate approach by including the non-entrained oscillators. We present analytical results and corroborate them with numerical simulations.

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CP8

Modeling and Dynamics of Planar Swimmers Coupled through Wake Vorticity

The dynamics of a system of free solid bodies interacting with a system of point vortices in a planar ideal fluid exhibit a Hamiltonian structure reflecting the overall conservation of circulation and momentum. Vortex shedding from one or more of the bodies can be modeled by imposing localized velocity constraints that respect these conservation laws. A fishlike swimmer can be realized in such a setting, for instance, by imposing a Kutta condition at the trailing point on a Joukowski foil with time-varying camber. Vorticity shed from one swimming body can influence the dynamics of another, providing a mechanism for the exchange of energy and information between the two. This talk will examine dynamic interactions of this kind from the standpoint of energy harvesting and cooperative locomotion.

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CP8

Ferrofluid Lubrication of Circular Squeeze Film Bearings Controlled by Variable Magnetic Field

Based on the Shliomis ferrofluid flow model(SFFM) and continuity equation for the film as well as porous region, modified Reynolds equation for lubrication of circular squeeze film bearings is derived by considering the effects of oblique radially variable magnetic field(VMF),slip velocity at the film-porous interface and rotations of both the discs. The squeeze film bearings are made up of circular porous upper disc of different shapes(exponential, secant, mirror image of secant and parallel) and circular impermeable flat lower disc. The validity of Darcy's Law is assumed in the porous region. The SFFM is important because it includes the effects of rotations of the carrier liquid as well as magnetic particles. The VMF is used because of its advantage of generating maximum field at the required active contact area of the bearing design system. Also, the effect of porosity is included because of its advantageous property of self-lubrication. Using Reynolds equation, general form of pressure equation is derived and expression for dimensionless load-carrying capacity is obtained. Using this expression, results for different bearing design systems(due to different shapes of the upper disc) are computed and compared for variation of different parameters like rotation, curvature of the upper discs, thickness of the porous matrix and squeeze velocity.

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CP8

Deep Reinforcement Learning for Robot Locomotion

The locomotion of underactuated and nonlinear robots is often high-dimensional and difficult to control. Recent advances in deep reinforcement learning have yielded methods that are promising for systems with a continuous formulation, including a large class of locomoting robots. In this work we seek to employ reinforcement learning to derive efficient and novel gaits for multi-link robot systems. Such systems especially benefit from a geometric analysis in the idealized case but are difficult to generalize when adding or removing to the input degrees of freedom. We present initial results in combining novel model-free learning results with established geometric theory for these systems.

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CP8

Bounds on Lyapunov Exponents for Random and Deterministic Products of Shears

Lyapunov exponents are generally difficult to calculate rigorously. A well-known exception is the system of alternating shears on the 2-torus, or Arnold Cat Map. When such shear matrices are applied in a random order, the calculation is famously challenging. We give rigorous lower and upper bounds on both the Lyapunov exponent and generalised Lyapunov exponents for the random product of positive and negative shear matrices. More difficult still is the case where the randomness is replaced by deterministic dynamics. We study Lyapunov exponents for linked twist maps (canonical examples of non-uniformly hyperbolic systems), and again give rigorous lower and upper bounds. The motivation is two-fold: first, a wide class of fluid mixing and stirring devices can be modelled by composition of shears; second, although numerical computation of Lyapunov exponents may seem a simple task, we note that for linked twist maps, convergence of Lyapunov exponents is anomalously slow.

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CP9

On the Onset of Hysteresis and Hopf-Bifurcation in Thermally Convective Spherical Couette Flow

In an annular spherical domain of separation d, cellular fluid motions may be sustained, either by rotating the sphere's boundaries (Couette flow), or by imposing a sufficiently large temperature gradient across the annulus (Rayleigh-Bénard convection). In the first instance rotation imparts momentum to the fluid driving a large scale cellular flow (mode $\ell = 2$) symmetric about the equator, while thermal convection may sustain any mode ℓ depending on d. Using a minimal mode representation of the system, we numerically study the interplay between cellular motions sustained by rotation and those by thermal convection for a wide annulus $d \gg 1$. For Prandtl number $Pr \gg 1$ the system chooses a rotating state, for $Pr \ll 1$ a thermally convecting state. While at intermediate Prandtl numbers of $Pr \sim 1$, we find that a transition between these states occurs with hysteresis as described by a cusp bifurcation, or to a periodic solution as described by a Hopf-bifurcation.

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CP9

: Is the Mid-Pleistocene Transition (mpt) a Grazing Bifurcation?

The Earth climate system has been characterized by alternating glacial and interglacial cycles which have been found to have changed from 23kilo years , 40 kilo years, and from half million years ago at the MPT to 100 kilo year. The previous change from 23kyrs to 40kyrs has been explained by the Milankovitch theory. However, the 100kyr cycle could not be explained by this theory. This has led to the construction of different models of glacial cycles such as the PP04 model which are used to study the factors and mechanisms that govern the initiation and termination of the 100kilo year ice age cycles. PP04 model is a non-smooth quasi-periodically forced dynamical system made of a number of relaxation systems with a discontinuity due to the sudden release of carbon dioxide into the atmosphere at every glacial termination. I will present an analysis of this model using methods from the theory of non-smooth dynamical systems. In particular I will show that if the system is periodically forced (by changes in the solar insolation) that there are both periodic and quasi periodic solutions with non-smooth Arnold tongues, and multiple periodic states. As the amplitude of the forcing increases these solutions break up at grazing bifurcations. Close to these bifurcations we see transitions between periodic orbits which resemble those seen at the MPT. I will present an analysis of this combined with Monte-Carlo simulations of the resulting dynamics.

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CP9

Keeping Automated Vehicles on the Road Using Bifurcation Analysis

Automated vehicles are likely to occupy our roads soon and they need to satisfy more strict safety requirements compared to their human-driven counterparts. Traditional vehicle models typically omit nonlinearities and thus, they are not able to adequately describe the motion of vehicles in safety critical situations. In this talk we utilize the tools of analytical mechanics, namely the Appellian approach, in order to develop vehicle models that can capture the geometrical nonlinearities in the lateral vehicle dynamics. Then, using numerical bifurcation analysis we explore the different steady states and determine the corresponding regions of attraction. In particular we highlight the differences between front-wheel drive and rear-wheel drive vehicles when they are pushed to their handling limits. This framework allows us to design nonlinear controllers that are tailored to the automated vehicles drive type that can ensure safety at the limits of handling. Our theoretical results are compared to experimental ones for an automated vehicle performing safety critical maneuvers.

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CP9

Bifurcation Analysis for Breast Cancer Model with Control Strategies

We propose and analyse breast cancer model with combined anticancer drugs and ketogenic diet. In the first place, the stable Tumor-Free Equilibrium (TFE) of the model coexists with a stable endemic equilibrium when the invasion reproduction number, R_i is less than unity. However, Lyapunov function was constructed to prove that TFE is globally asymptotically stable and sensitivity index was calculated. Hence, we apply optimal control theory to investigate how the combination of anticancer drugs and ketogenic-diet was implemented, for a certain period, in order to inhibit the tumor growth and eliminate cancer cells. Furthermore, we establish the existence of the optimality system and use Pontryagin's Maximum Principle (PMP) to characterize the optimal levels of the two treatment measures. However, the infection averted ratio (IAR), the decrement of tumor cells and incremental cost-effectiveness ratio (ICER) were calculated to investigate the cost-effectiveness of all possible combinations of the control strategies, while minimizing the implementation cost of the treatment strategy. In addition, the simulation results show that the combination of anticancer drugs and ketogenic diet is the most cost-effective strategy for treating breast cancer.

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CP10

Energy Models and Koopman Operator Analysis of Thermal Data

As a step towards our goals of energy efficiency, we investigate data-driven, simple-to-implement residential environmental models that can serve as the basis for energy saving algorithms in both retrofits and new designs of residential buildings. We find that currently used models of thermal behavior of buildings are lacking in a fundamental way associated with the thermal mass of buildings. Despite the nonlinearity of the underlying dynamics, in this study we show that a linear second order model embedding, that captures the physics that occur inside a single or multi zone of a space does well in comparison with data. Regardless of thermal properties of a residential structure, either being constructed of wood or brick, the model will capture the critical thermal mass physics accordingly. In order to validate our model, we used EnergyPlus to simulate indoor air temperature. The error ranges from 3.3% to 7.2% according to different thermal mass properties of the residential building. We were able to observe the direct change of each coefficient in our model and quantify their representation as thermal mass, insulation, and heat conduction. We also analyze dynamic data from thermal sensors and extract associated Koopman modes, adding to the set of tools for indoor energy and environment analysis.

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CP10

Dynamic Modes of Ignition Phenomena: Learning Chemistry from Data

There are no model-independent methods for the identification of the causal chemical mechanisms hidden within the emergent dynamics of ignition phenomena. Additionally, molecular dynamics simulations of atomistic models of hydrogen oxidation do not require prior knowledge of possible mechanisms or intermediates and can be validated against electronic structure calculations; along with the relative simplicity of hydrogen oxidation, this makes these simulations a natural starting point for the development of data-driven methods of analysis for both numerical simulations and experimental measurements. Here, we demonstrate a machine learning methodology for dynamical processes, based on Koopman mode analysis, to extract dynamic modes for the kinetic stability and instability of reacting mixtures out of chemical and thermal equilibrium and apply it to extensive atomistic simulations of hydrogen oxidation. By defining persistent dynamic modes, we have developed an automated means to extract persistent local (in time) effective reactions along with a fuel-agnostic measure of ignition-delay time.

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CP10

Local Ensemble Transform Kalman Filtering Implemented on 2D and 3D Dynamo Flows

The behavior of Earth's magnetic field and the influence of its core dynamics has been investigated in recent years through experiments and numerical models. At the University of Maryland, the geodynamo is replicated by experimental studies of the three-meter diameter spherical Couette device which is filled with liquid sodium and driven by two independently rotating concentric shells, an applied approximately dipole magnetic field, and dynamo action. These experiments incorporate high velocity flows aiming to recreate the turbulence in convection-driven flows of Earths outer core. Collaborators at ISTerre have created the numerical code XSHELLS which features finite difference methods in the radial direction and pseudospectral spherical harmonic transforms for the angular directions. Highly turbulent flows are unfeasible to resolve limiting the abilities of purely numerical models. Experiments can produce highly turbulent flows but measurement can be intrusive. Our goal is to use data assimilation to synchronize the outputs from the numerical code with the experimental magnetic boundary data which would provide us insight in predicting the dynamics of Earths magnetic field. In this project, we present preliminary validation studies implementing Local Ensemble Transform Kalman Filtering on the numerical model with synthetic observation data to test the feasibility of using sparse, yet temporally-dense observations to control the model. NSF Grant No. DGE1322106 & EAR1417148

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CP10

Nonlinear-Linear Alchemy: Koopman Operators

and Tape Recorders

We naively apply Koopman operator theory to obtain a linear, infinite-dimensional representation of a chaotic one-dimensional iterated map. At first glance, the result appears pathologically simple and of little interest: it is mathematically equivalent to a tape recorder that provides storage and playback of the chaotic time series. Further, the result does not explicitly depend on the particular iterated map, and we find the same linear system can model any iterated map, including higher dimensional systems and even random signals. However, we can make a connection to the mathematical oddity of linear chaos, with the surprising result that a tape recorder, when viewed as a dynamical system, is provably chaotic. That is, a storage-and-playback system formally satisfies the three conditions in Devaneys definition of chaos: a transitive orbit, dense periodic orbits, and sensitivity to initial conditions. We conclude by clarifying the meaning of linear chaos in a tape recorder, which is not simply a restatement of chaos in the original iterated map.

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CP11

A Numerical Method for Solving the Non-Local Problems Related to Stochastic Dynamic Systems Driven by Levy Noise

Stochastic dynamic systems (SDEs) driven by non-Gaussian noise have attracted lots of attention recently and are widely studied in physics, biology, economics, and ecosystem. We employ mean exit time,escape probability,space-fractional Fokker-Planck equation to quantify the stochastic dynamics. In this talk, I will first introduce the connections between SDEs and space-fractional PDEs and then present the finite difference scheme to solve the two-dimensional fractional PDEs, in which the space-fractional derivative operator is a generator of independent Levy noise. Also, I will apply the proposed scheme to solve the MeKS nonlinear gene regulatory system.

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CP11

Most Probable Evolution Trajectories in a Genetic Regulatory System Excited by Stable Lévy Noise

We study the most probable trajectories of the concentration evolution for the transcription factor activator in a genetic regulation system, with non-Gaussian stable Lévy noise in the synthesis reaction rate taking into account. We calculate the most probable trajectory by spatially maximizing the probability density of the system path, i.e., the solution of the associated nonlocal Fokker-Planck equation. We especially examine those most probable trajectories from low concentration state to high concentration state for certain parameters, in order to gain insights into the transcription processes and the tipping time for the transcription likely to occur. This enables us: (i) to observe whether the system enters the transcription regime within a given time period; (ii) to predict or avoid certain transcriptions via selecting specific noise parameters in particular regions in the parameter space. Moreover, we have found some peculiar or counter-intuitive phenomena in this gene model system, including (a) a smaller noise intensity may trigger the transcription process, while a larger noise intensity can not, under the same asymmetric Lévy noise. This phenomenon does not occur in the case of symmetric Lévy noise; (b) the symmetric Lévy motion always induces transition to high concentration, but certain asymmetric Lévy motions do not trigger the switch to transcription.

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CP11

Diffusive Search for Diffusing Targets with Fluctuating Diffusivity and Gating

The time that it takes a diffusing particle to find a small target has emerged as a critical quantity in many systems in molecular and cellular biology. In this paper, we extend the theory for calculating this time to account for several ubiquitous biological features which have largely been ignored in the mathematics and physics literature on this problem. In particular, we allow (i) targets to diffuse on the two-dimensional boundary of the three-dimensional domain, (ii) targets to diffuse in the interior of the domain, (iii) the diffusivities of the searcher particle and the targets to stochastically fluctuate, (iv) targets to be stochastically gated, and (v) the transition times between fluctuations in diffusivity and gating to have effectively any probability distribution. In this general framework, we analytically calculate the leading order behavior of the mean first passage time and splitting probability for the searcher to reach a target as the target size decays, which is the so-called narrow escape limit. To make these extensions, we use a generalized Itos formula to derive a system of coupled partial differential equations which are satisfied by statistics of the process, where the size of the system and its spatial dimension can be arbitrarily large. We apply matched asymptotic analysis to this system and verify our analytical results by numerical simulation. Our results reveal several new features and generic principles of diffusive search for small targets.

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CP11

A Generalized Transformed Path Integral Approach for Stochastic Dynamical Systems

We present a generalized transformed path integral approach for addressing uncertainties in nonlinear dynamical systems—namely, uncertainties in initial conditions, parameters, and forcing parameters of a white/colored noise process. The transformed path integral (TPI) approach is a novel path integral-based method for the solution of the Fokker-Planck equation. While previous implementations of TPI were restricted to cases with nonsingular diffusion matrices, here we propose a Trotter formula-based generalization that allows extensions to cases with singular diffusion matrices, thereby enabling estimation of probabilities in a broad class of stochastic dynamical systems with the aforementioned uncertainties. The generalized TPI approach allows for evolution of probability density functions (PDFs) in a transformed computational domain where a more accurate representation of the PDFs can be obtained. Our proposed approach is better able to handle challenges from dynamical systems with large drift, diffusion, and concentration of PDF. Key features of the approach include ability to estimate error bounds on PDFs via Chebyshev's inequality, preservation of short-time stochastic properties of the dynamical system, and possibility for a more accurate representation of PDF tail information. The benefits of the generalized TPI approach over conventional methods will be illustrated through canonical examples in one-dimensional and multidimensional spaces.

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CP12

Hill Four-Body Problem with Oblate Tertiary: With Application to the Sun-Jupiter-Hektor-Skamandrios System

We consider a restricted four-body problem consisting of three heavy bodies which move under mutual gravity, with one of them being oblate, and a fourth infinitesimal body, which moves under the gravitational influence of three heavy bodies but without affecting them. First, we find the triangular central configurations of three heavy bodies, with one of them being oblate. Second, assuming that the three heavy bodies are in such a central configuration, we perform a Hill approximation for the motion of the infinitesimal body in a neighborhood of the oblate body, which, through the use of Hills variables and a limiting procedure, sends the two other bodies to infinity. Third, for the Hill approximation, we find the equilibrium points and determine their stability. A motivation for this work is the dynamics of the moonlet Skamandrios of the Jupiter trojan Hektor.

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CP12

Characterizing Fractal Mixing with Ergodic Subsets

Mixing by cutting-and-shuffling can be mathematically described by the dynamics of piecewise isometries, higher dimensional representations of one-dimensional interval exchange transformations. The mixed state of a two-dimensional domain is highly dependent on the structure created by iterated cutting lines in the domain, which often create a fat fractal structure. We investigate dynamics within this fat fractal to explain subtle mixing behaviors and barriers to mixing formed by invariant ergodic subsets within the structure of cutting lines. The size and shape of the cutting line fractal, used in the past to correlate with mixing, only indicate where mixing is possible, not where it is actually occurring. A new approach, based on examining the variation in a measured 'density' of cutting lines, easily assesses mixing within the fractal since ergodic sets necessarily share the same density. Since the fractal is generated by a one dimensional set of cutting lines, every two dimensional orbit in the fractal can be projected in a one-to-one fashion to a one dimensional set where measurements on the 'connectivity,' and therefore the mixing, of the fractal can be easily evaluated.

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CP12

Finding Nhim: Identifying High Dimensional Phase Space Structures using Lagrangian Descriptors

Computing codimension-1 separatrices and their anchor, normally hyperbolic invariant manifold (NHIM), is the stepping stone in applying phase space transport methods to dynamical systems. Many of these problems give rise to phase space of 4 or more dimensions, and hence geometric approaches become expensive (in time) since a large number of sample initial conditions are required to discretize a volume in phase space. Thus, a practitioner relies on detection methods that are low dimensional probe of the high dimensional phase space structures. One such method is the Lagrangian descriptor (LD) which encodes geometric property (such as, arc length) of a trajectory at the initial condition on a two dimensional slice of an isoenergetic hypersurface. In this talk, we assess the capability of LD for revealing the high dimensional phase space structures that are relevant in chemical reactions. Recent studies have shown that LD plots are versatile, across different models, in locating invariant manifolds that are pathways for reactive trajectories. This calls for a systematic approach to verify that "specific features in LD plot identify NHIM and codimension-1 separatrices. We discuss this approach in the settings of two and three degrees of freedom Hamiltonian systems where NHIM is known exactly. Then, we present application to models of chemical reaction where analytical results are unknown.

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CP12

The Speed of Arnold Diffusion Along Single Resonances: A Predictive Semi-Analytic Approach

Several types of dynamical systems appearing in different physical contexts can be represented by simple models of chaotic diffusion along resonances, making the clarification of the diffusion mechanisms an important question. In this talk, we will focus on the use of a technique based on normal form computations, that allows to unveil the fastest diffusing chaotic orbits. In particular, we implement a normalization process that completely erases the deformation effects over the orbits evolution in action space. This, in turn, makes possible to visualize the chaotic diffusion in the separatrix domain of the resonant chaotic layers. While it is customary to consider every remainder term of the optimal normal form to estimate diffusion rates, we demonstrate that in reality only a few terms (less than 1% of the total) drive the chaotic jumps in action space. We obtain precise quantitative estimates of the diffusion rate, by implementing a Melnikov-type analysis of the dynamics induced by the above remainder terms, that show excellent agreement with numerical experiments.

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CP13

Response-Signaling Feedback with Diffusive Coupling Leads to Division Waves in a Model of *Drosophila* Embryogenesis

The 'division waves' that occur in *Drosophila* embryogenesis are known to be a result of cyclin / cell dependent kinase diffusion across the syncytium. The nuclei undergoing these divisions can be generically described as a network of Response-Signaling (RS) oscillators with diffusive coupling. Mechanistic models of the protein interactions underlying the waves suggest that the oscillators have two responsive phases of opposite feedback signs, one of which overlaps with the signaling phase. The dynamics of diffusively coupled RS oscillators with these characteristics leads to physiologically realistic division waves as a natural consequence of the geometry of the embryo, without need for *a priori* chemical gradients or forcing. The resulting waves have a characteristic speed that corresponds to realistic signaling parameters when fit to experimental data.

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CP13

Energy and Phased Based Movement Recovery

Retaining the ability to move despite body damage is a feature legged animals display - through injury, animals often compensate. Legged robots would be advantaged if they also had the ability to preserve a gait through damage, where we take a gait to be an exponentially stable limit cycle for a mechanical Lagrangian with periodic inputs. Given an prior gait, we wish to preserve that limit cycle by finding a control input that compensates for changes in the Lagrangian. We employ asymptotic phase, a cyclic coordinate, to compare the evolution of the original and new systems in a geometric way. To avoid models, we employ optimization. The complex dynamics of legged robots makes this optimization challenging. We enrich the optimization problem with necessary constraints that will improve convergence rate. For mechanical systems, the Lagrangian is determined via energy. We require that the phase evolution of mechanical power is preserved between the two systems, as well as that the new flow continues to be a semi-conjugacy with the original phase map. We see this practical, as energy is a physical quantity that can be found from data. We perform recovery on two systems. One, in simulation on a CT-SLIP, we recover a periodic motion by matching the phasing of kinetic energy. Two, we performed the optimization experimentally on a hexapod robot with springy legs. We see that the optimization produces a similar gait

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CP13

Chaotic Dynamics Enhance the Sensitivity of Inner Ear Hair Cells

Hair cells of the auditory and vestibular systems are capable of detecting sounds that induce sub-nanometer vibrations of the hair bundle, below the stochastic noise levels of the surrounding fluid. Hair cells of certain species are also known to oscillate without external stimulation. The role of these spontaneous oscillations is not yet understood, but they are believed to be a manifestation of an underlying active mechanism and may play a role in signal detection. We previously demonstrated experimentally that these spontaneous oscillations exhibit chaotic dynamics. We propose that hair cells exploit the nature of chaotic dynamics, characterized by sensitivity to small perturbations, to enhance their detection of weak sounds. We will present experimental measurements of spontaneous and driven hair bundle oscillations. By varying the Calcium concentration and the viscosity of the surrounding fluid, we were able to modulate the degree of chaos in the hair cell dynamics. We found that the hair bundle is most sensitive to weak stimuli when it is poised in a weakly chaotic regime. Further, we found that the response time to a force step decreases as the degree of chaos is increased. These results agree well with our numerical simulations of a chaotic Hopf oscillator and suggest that chaos may be responsible for the extreme sensitivity and temporal resolution of hair cells.

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CP14

Pattern Formation on Cubic Superlattices

Prior research on two-dimensional pattern formation has analyzed systems with the periodicities not only of the square and hexagonal lattices, but of higher dimensional representations thereof (superlattices). The simple, face-centered and body-centered representations of the cubic lattice have similarly been studied, along with one of the higher dimensional representations. We complete the catalog for cubic symmetry by studying the superlattices generated by the vertices of the truncated octahedron $(0, \pm m, \pm n)$ and the great rhombicuboctahedron $(\pm l, \pm m, \pm n)$. In each case we use group theoretic means to find the general equivariant system, its axial solutions and their stabilities.

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CP14

Effects of Strain Rate on Fronts in Advection-Reaction-Diffusion Systems

The growth of a reactive scalar in a fluid flow is determined by the combined effects of advection, reaction, and diffusion (ARD). Each of these effects interact in such a way that it is difficult to predict the reactive scalars behavior. In this talk we look into the motion of fronts, which bound reacted regions, and how the advective strain rate alters their measured growth rate. We compare to the base case where the flow simply displaces the reaction front, and then the front to propagates outward at a constant chemical speed given by chemical parameters. Deviations from the expected, constant chemical speed can then be analyzed. We find that strain rate has profound effects in multiple contexts. I will show how strain causes two-dimensional (2D) experiments to behave differently than true 2D ARD systems. I will also show experimental measurements of reactions in the presence of straining flows to demonstrate how front speed is altered, bulk reaction rate is changed, and stirring can actually inhibit reaction. I will identify some mathematical origins of these front growth changes. These results illustrate mechanisms by which advection changes reactions and may also create reaction barriers.

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CP14

Weakly Nonlinear Theory for Spatio-Temporal Patterns in Coupled Bulk-Surface Reaction-Diffusion Systems

We discuss a class of systems for which passive diffusion in some bulk domain is coupled to a nonlinear reaction-diffusion process on the boundary. Such a modeling paradigm has been employed to study various biological phenomena including intracellular pattern formation and cell polarization, as well as diffusion and quorum sensing within populations of diffusively coupled oscillators. We first consider the spatio-temporal patterns in a 2-D coupled bulk-membrane reaction-diffusion system with circular bulk geometry. Then, we investigate the conditions for which the dynamics of two oscillators coupled via a 1-D bulk diffusion field can lead to synchrony or asynchony. For each of these systems, a multiple-time scale asymptotic analysis is used to derive normal form amplitude equations characterizing the local branching behavior of solutions near a variety of codimension-one (Hopf or pitchfork) and codimension-two (Hopf-Hopf or pitchfork-Hopf) bifurcation points. Here, the novelty and technical challenge of performing a weakly nonlinear analysis is that the underlying spectral problem is nonstandard: both the differential operator and the boundary conditions involve the eigenvalue parameter. This requires care in formulating the spectral adjoint operator and the solvability condition, which are central to implementing the multiple time-scale expansion. This is a joint work with Michael Ward and Wayne Nagata, UBC.

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CP14

Dynamics of Exact Localized States in Plane Couette Flow

Transition to turbulence has been investigated from the viewpoint of dynamical systems theory for a long time. Much of the recent research has been focused on the numerical calculation of exact solutions and resulted in a discovery of spatially localized solutions resembling turbulent spots observed experimentally during transition to turbulence. In plane Couette flow, i.e., the viscous flow between two oppositely moving parallel walls, these states are organized in two branches of equilibria and travelling waves intertwined in a bifurcation scenario known as homoclinic snaking. In this talk, we first discuss these localized states, used as initial conditions for time-integration, and the details of their oscillatory dynamics. We will then present a map of dynamics in a parameter space constituted of two variables: the width of a localized state and Reynolds number. The map is subdivided into different relaminarization regimes the distinctive features of which (oscillatory dynamics, splitting of the initial spot and front growth) will be explained. The talk concludes with a discussion of prospective control strategies.

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CP15

Theoretical Analysis of Information Content of the Dynamics of One Dimensional Chaotic Maps

class of one dimensional ergodic maps with equidistributivity property (EDP) and constant summation property (CSP) has been considered in the generation of chaotic sequences which are transformed into an i.i.d binary random variables. The application of these random variables in communication systems and cryptography relies heavily on the information content contained in the sequences. In this paper, we determined a binary i.i.d random variables from the chaotic real-valued orbit of one dimensional chaotic maps satisfying the two properties above, and theoretically analyze and estimate their correlation functions as is required in cryptography/communication systems. The measure of the information content, which is equally computed, determines its viability to be implemented in a cryptography and/or communication systems.

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CP15

Billiards Inside, Circles Outside: Dynamics of a Charged Particle in a Piecewise Constant Magnetic Field

Consider a magnetic field orthogonal to the Euclidean plane which is zero inside a fixed convex domain while having constant strength B outside. The dynamics of a charged particle starting in the domain can be viewed as a perturbation of usual billiard dynamics, the perturbation parameter being $1/B$. If the boundary is smooth and B is greater than the maximum curvature of the boundary, we show the resulting "billiard" map is a twist map, with all the consequences regarding period orbits, etc. ensuing.

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CP15

Template Iterations of Quadratic Maps and Hybrid Mandelbrot Sets

Using random iterations of discrete functions, we build a mathematical framework that can be used to study the effect of errors in copying mechanisms (such as DNA replication). We study iterations of two quadratic maps $f_{c_0} = z^2 + c_0$ and $f_{c_1} = z^2 + c_1$, according to a prescribed binary sequence, which we call *template*. In this theoretical setup – in which one of the functions is the correct one, and the other one is the erroneous perturbation – we consider problems that a sustainable replication system may have to solve when facing the potential for errors. We study the asymptotic behavior of the critical orbits, and define the Mandelbrot set in this case as the postcritically bounded locus. Unlike in the case of single maps, this can be understood in several ways. For a fixed template, one may consider this locus as a subset of the parameter space in $(c_0, c_1) \in \mathbb{C}^2$; for fixed quadratic parameters, one may consider the set of templates which produce a bounded critical orbit. Here, we study the set topology in both situations, as well as for *hybrid* combinations. We find that it is possible to tell which specific "errors" are more likely to affect the system's dynamics, in absence of prior knowledge of their timing. Moreover, within an optimal locus for the correct function, almost no errors can affect the sustainability of the system.

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CP15

The Effect of Explosive Divergence in a 2D Coupled Map Lattice of Matrices

The extension of the 2D Coupled map lattice (CML) model by replacing scalar nodal variable by a matrix of variables is investigated. The dynamics of the extended 2D CML model where each node is coupled with four nearest neighbors and each node in the lattice is described by the logistic map of matrices of order 2 is analyzed using formal analytical and computational techniques. Necessary conditions for the occurrence of the effect of explosive divergence in the extended 2D CML are derived. It is demonstrated that the extended 2D CML model can generate complex fractal patterns representing spatiotemporal divergence. The effect of explosive divergence can be controlled by the coupling parameter between the nodes in the extended 2D CML model. The effect of tendency to diverge is exploited to reveal the image after iterating the extended CML model with a matrix of image dot-skeleton perturbated control parameters. The improper choice of coupling parameters, the matrix of control parameters, the perturbation volume of a single node control parameter, the clearance between perturbated nodes or even the number of iterations to apply the extended CML model may result in fail to generate the image the effect of explosive divergence may expand to the whole domain or, on the contrary, no tendency to diverge may occur at all (processes calms down and values goes to zero).

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CP16

Self-Similar, Blow-Up Solutions of the Generalised Korteweg-De Vries Equation Near Criticality

In this talk we will give a detailed asymptotic analysis of the near critical self-similar blow-up solutions to the Generalized Korteweg-de Vries equation (GKdV). For a nonlinearity that has a power larger than the critical value p=5, solitary waves of the GKdV can become unstable and become infinite in finite time, in other words they blow up. Numerical simulations indicate that if p ¿ 5 the solitary waves travel to the right with an increasing speed, and simultaneously, form a similarity structure as they approach the blow-up time. This structure breaks down at p = 5. Based on these observations, we rescale the GKdV equation to give an equation that will be analysed by using asymptotic methods as p approaches 5. By doing this we resolve the complete structure of these self-similar blow-up solutions and study the singular nature of the solutions in the critical limit. In both the numerics and the asymptotics, we find that the solution has sech-like behaviour near the peak. Moreover, it becomes asymmetric with slow algebraic decay to the left of the peak and much more rapid algebraic decay to the right. The asymptotic expressions agree to high accuracy with the numerical results, performed by adaptive high-order solvers based on collocation or finite difference methods. Based on these expressions we make some conjectures about the approximately self-similar form of the solutions when p = 5.

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CP16

On Boundary Layers for the Burgers Equations in a Bounded Domain

As a simplified model derived from the Navier-Stokes equations, we consider the viscous Burgers equations in a bounded domain with two-point boundary conditions,

$$\begin{aligned}
&u_t^\epsilon - \epsilon u_{xx} + \frac{(u^\epsilon)^2}{2} = f(x,t), \quad x \in (0,1), \quad t \geq 0 \\
&u^\epsilon(x,0) = u_0(x), \quad x \in (0,1), \\
&u^\epsilon(0,t) = g(t),\ u^\epsilon(1,t) = h(t), \quad \forall t \geq 0.
\end{aligned}$$

We investigate the singular behaviors of their solutions u^ϵ as the viscosity parameter ϵ gets smaller. Indeed, when ϵ gets smaller, u_x^ϵ has $1/\epsilon$ order slope. So controlling the sharp layer is one of the most important parts in this research. The idea is constructing the asymptotic expansions in the order of the ϵ and validating the convergence of the expansions to the solutions u^ϵ as $\epsilon \to 0$ in $L^2(0,T;H^1((0,1))))$ space. In this talk, we consider the case where sharp transitions occur at the boundaries, i.e. boundary layers, and we fully analyse the convergence at any order of ϵ using the so-called boundary layer. In the end, we also numerically verify the convergences.

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CP16

2D Solutions of the Hyperbolic Discrete Nonlinear Schrödinger Equation

We derive stationary solutions to the two-dimensional discrete nonlinear hyperbolic Schrödinger equation by starting from the anti-continuum limit and extending solutions to include nearest-neighbor interactions via arclength continuation in the coupling parameter. We focus on nine primary types of solutions: single site, double site in- and out-of-phase, four site in-phase, four site out-of phase in each of the vertical and horizontal directions, four site out-of-phase arranged in a line horizontally, and two additional solutions having respectively six and eight nonzero sites. The chosen configurations are found to merge into four distinct branches. We examine the stability and dynamical properties of the found solutions on all examined branches.

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CP16

The Effects of Shear Currents on Oceanic Rogue Waves

The evolution of weakly nonlinear, narrow-band wave packets for free surface flows is governed by the nonlinear Schrödinger equation, where second order dispersion and cubic nonlinearity constitute the main elements in the dynamics. Rogue waves, unexpectedly large displacements from equilibrium background can occur if the water depth is sufficiently large. In practice, shear currents nearly always occur in oceans, but modeling studies on wave dynamics are usually restricted to the case of linear current. The dynamics of rogue waves in the presence of a linear shear current has been studied in the literature. Generally rogue waves become narrower and with a short period of existence in terms of time if the background plane wave moves against the current. However, the modulation instability can be enhanced when background plane wave moves with the current. Here the investigation is extended to the case of a current with arbitrary vorticity gradient, by enhancing theoretical formulation established earlier by our group. The transient growth rate and the spatial extent of the rogue waves will be reported for two broad classes of velocity profiles, those convex to the right and those convex to the left. Rogue waves pose significant risk to marine shipping, and thus knowledge on such focusing mechanisms of free surface waves will be of importance in both nonlinear science and physical oceanography.

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CP17

Emergent Explosive Synchronization in Adaptive Complex Networks

One of the most significant challenges of present-day research is bringing to light the processes underlying the spontaneous organization of networked dynamical units. Here, we are interested in studying the cases in which the transition to a synchronized state is explosive. These studies so far have concentrated on proposing topologies for which the transition is explosive, given a specific frequency distribution on the dynamical units, or vice versa, proposing a frequency distribution on the oscillators, given a specific connectivity structure. However, no models have yet succeeded in generating dynamically the conditions for a transition to be explosive. We show here [1] that these conditions may spontaneously emerge in an adaptive network of interacting oscillators, as the result of a delicate interplay between synchronization processes and co-evolution of the connectivity structure. When the connectivity dynamics is such that links coupling the nodes with non-synchronous (synchronous) dynamics are promoted (weakened), we prove that an initially unstructured clique configuration evolves in time toward an emerging structured network whose transition is explosive. [1] V. Avalos-Gaytan, J.A. Almendral, I. Leyva, F. Battiston, V. Nicosia, V. Latora, S. Boccaletti, *Phys. Rev. E* **97**, 042301 (2018).

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CP17

Synchronization Sensitivity of a Nonlocal Network

We address the network final state sensitivity due to fractal basin boundaries of synchronized states. Investigating this relation, we find the existence of final state sensitivity between synchronized and desynchronized states of a network composed of periodically forced nonlocal coupled Duffing oscillators, arranged in a ring. We fix oscillator control parameters for which each isolated oscillator would exhibit a stable period-3 attractor and an unstable chaotic set. We observe that a small perturbation in the initial condition of a single oscillator is capable of desynchronizing the whole network. Depending on the perturbation strength, we identify two possible network long-term states: a moderate sensitivity corresponding to fractal boundaries of a continuous region of initial conditions leading to synchronization; and a very sensitive regime corresponding to the riddled like region of initial conditions leading to synchronized and desynchronized states. The reported sensitivity is due to the interplay of the coupling and the unstable chaotic sets.

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CP17

Using Critical Curves to Compute Master Stability Islands for Amplitude Death in Networks of Delay-Coupled Oscillators

Master stability islands are contoured amplitude death islands that provide regions of stable amplitude death for any network configuration of a chosen nonlinear system under linear delay-coupling. These islands are called master stability islands because they were originally computed using the master stability function approach. When a network and its nodes can be diagonalized, we find that critical curves can also be used to compute the master stability island boundaries and the master stability island contours. The critical curves depend on the eigenvalues of the Jacobian matrix of the chosen nonlinear system and the eigenvalues of the network adjacency matrix. We present a general study of the effects of these parameters on the critical curves and the resulting master stability islands. We also demonstrate the use of critical curves in computing master stability islands for several classic nonlinear systems.

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CP18

Extreme Events in Delay-Coupled Relaxation Oscillators

While rare, recurrent, irregularly spaced yet impactful events — also known as extreme events — might be manifested in different systems in different ways, previous research works have identified a few underlying mechanisms which may generate such events from as dynamical systems point of view. In the current work, we present time-delay as a new mechanism through which extreme events may be generated and study their salient features in detail. To this end, we show that in a system of two identical FitzHugh-Nagumo oscillators coupled to each other by multiple delay-diffusive couplings, extreme events can be generated in parameter regimes sandwiched between a period adding cascade and a period doubling cascade. Due to infinite dimensions of the phase space and the presence of an invariant synchronization manifold, the system studied, exhibits rich and interesting dynamical features. We also identify the role of the invariant sets on this manifold in the long transience and the observed in-out intermittency, and present our investigations regarding the basin structure of the system when multiple attractors are present simultaneously. Our results show that if one of the attractors present in such a parameter regime corresponds to extreme events, the basins are riddled. This implies that any tiny perturbation of initial conditions in the mixed region could yield the emergence of extreme events because the latter state possesses a riddled basin of attraction.

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CP18

Drive-Based Motivation Dynamics for Coordination of Limit-Cycle Behaviors

Navigation is often be considered a prototypical behavior for a robotic system. Constructing robots capable of complex behaviors requires developing a method for switching among possible behaviors, for example using a hybrid automaton. Recent work has developed an alternative approach using continuous dynamical systems that use an internal drive state to select the desired behavior. In one particular result, authors developed drive dynamics that result in trajectories where the robot repeatedly flows to one point attractor and then another, yielding a limit cycle where the robot patrols between two points. A further level of complexity arises when one seeks to create a system that switches between these basic limit cycles instead of the original point attractors. This work outlines the problem using the recently-developed drive-based dynamical framework. As a proof-of-concept we demonstrate the existence of an attracting set consisting of orbits that repeatedly flow between two canonical limit cycles (e.g., Hopf oscillators). This attracting set connecting limit cycle behaviors arises from a bifurcation depending on a family of parameters ε_v, ε_λ, and σ which is analogous to the bifurcation that produces the limit cycle connecting two point-attractor behaviors in previously-published system. Implications and next-steps in the case of arbitrary limit cycles are discussed.

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CP18

Critical Switching Behavior in Globally Attractive Chimera States

We report on a new type of chimera state in networks of identically coupled chaotic oscillators that attracts almost all initial conditions. Despite their global nature, these chimeras are extremely sensitive to noise—arbitrarily small noise triggers and sustains perpetual switching between the coherent and incoherent clusters. The average switching frequency increases as a power law with the noise intensity, which is in contrast with the exponential scaling observed in typical stochastic transitions. Rigorous numerical analysis reveals that the power-law switching behavior originates from riddled basins associated with two symmetric chimeras, which in turn are induced by chaos and symmetry in the system. Experiments on coupled optoelectronic oscillators demonstrate the genericity and robustness of the global switching chimeras reported here. The results have implications for symmetry breaking in dynamical systems and the impact of noise at singular limits.

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CP19

Modeling Gnrh Neuronal Dynamics in Response to Kisspeptin Stimulation

Pulsatile secretion of gonadotropin-releasing hormone (GnRH) from hypothalamic GnRH neurons tightly regulates the release of reproductive hormones. While key factors such as electrical activity and stimulation by kisspeptin have been extensively studied in these neurons, the underlying mechanisms regulating GnRH release remain incompletely understood. We have recently developed a mathematical model that integrates the hormonal and electrical properties of GnRH neurons to study how they interact in the presence and absence of kisspeptin. The model consists of two components: an electrical submodel comprised of a modified Izhikevich formalism, and a hormonal submodel that incorporates pulsatile kisspeptin stimulation and a GnRH autocrine feedback mechanism. Using the model, we examine the electrical activity of GnRH neurons and how kisspeptin effects GnRH pulsatility. The model reproduces the noise-driven bursting behaviour of GnRH neurons as well as the experimentally observed electrophysiological effects induced by GnRH and kisspeptin. Furthermore, the model reveals that GnRH release follows a pulsatile profile and that kisspeptin and GnRH exhibit approximately 7-1 locking in their pulsatility. These results suggest that 8-min pulsatile kisspeptin stimulation (a global signal) can induce 8-min calcium oscillations in GnRH neurons and drive the autocrine mechanism (local signal) beyond a threshold to generate pronounced GnRH pulses every hour.

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CP19

A GSPT Approach in a Breakspear & Friston Like Model

We study a three-dimensional vector field model that describes the interactions in an interconnected neuronal system. The system consists of an array of coupled small-scale neural subsystems, each of them consituted by densely interconnected excitatory and inhibitory neurons. These subsystems are then coupled together in such a way that they form a larger array. The local dynamics within and between subsystems is determined by voltage- and ligand-gated ion channels, and the feedback between the excitatory and inhibitory neurons. Preliminar numerical results show that the system presents complex oscillations and chaotic behavior associated to a Bogdanov-Takens bifurcation. Simulations also show evidence of multiple time scales in the system. In this talk we will discuss how tools from GSPT can provide new insights on understanding the organization of complex oscillations and chaos in the system.

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CP19

Computational Approaches for Multistable Rhythms in Modular Neural Networks

The emergence of, and transitions between, stable polyrhythms exhibited by half center oscillators and three cell neural motifs, along with their dynamics under the influence of external input and varying chemical (inhibitory and excitatory) and electrical synaptic connectivity, have been exhaustively demonstrated previously. Co-existence and stability of polyrhythms in more complex and modular CPGs has remained unclear thus far. We address this issue in this study by identifying the dynamical principles and mechanisms that govern the robustness of multistable modular CPGs by combining clustering and machine learning techniques with dynamical systems analysis for the study of the phase space, bifurcations and rhythm switching in larger neural networks.

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CP19

Mathematical Treatment of Action Potential Propagation in Axonal Fibre Bundles

With the advent of advanced imaging techniques it has become possible to study brain networks non-invasively and in great detail. Measuring the various parameters of long-range connections opens up the possibility to build and refine detailed models of large-scale neuronal activity. One particular challenge is to find a mathematical description of action potential propagation that is sufficiently simple, yet still biologically plausible to model signal transmission across entire axonal fibre bundles. We develop a mathematical framework that can achieve this by simplifying the Hodgkin-Huxley dynamics into a leaky integrate-and-fire framework with passive sub-threshold dynamics and explicit, threshold-activated ion currents. This allows us to study in detail the influence of the various model parameters on action potential velocity and on the entrainment of action potentials between ephaptically coupled fibres. Specifically, we recover known results regarding the influence of axon diameter, node of Ranvier length and internode length on the velocity of action potentials. We further explain the slowing down and synchronisation of action potentials in ephaptically coupled fibres through changes in their effective electrotonic length constant. Simplified expressions of the parameter dependence are then used to derive the delay distribution between brain regions given a specific distribution of axonal diameters within a fibre bundle.

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CP20

A Dynamical Systems Based Hierarchy for Shannon, Metric and Topological Entropy

Since its introduction by Clausius in 1850 there have been many different definitions of entropy. These include Clausius, Boltzmann, Gibbs, Shannon (information), topological and metric entropies where, for example, the approaches of Gibbs and Boltzmann can actually lead to contradictory results. We find that a dynamical systems approach as first proposed by Helmholtz is a common thread between these different definitions. In this talk, we focus on the connections between metric, Shannon and topological entropy. Generally speaking, increases from zero to positive metric or topological entropy correspond to the exponential statistical or topological growth rate of distinct orbits, respectively, leading to chaotic behavior. Information entropy on the other hand provides a measure for the uncertainty in interpreting communicated messages,which suggests a connection with both metric and topological entropies. In fact, we show that Shannon entropy can be considered to be a special case of metric entropy by recasting the communication process as a Bernoulli scheme. Also, we demonstrate that although the calculation for an arbitrary number of symbols relies on some deep theory, it is much simpler for a binary alphabet. Finally, it is shown that for many measurable dynamical systems,the right choice of a subbasis comprising measurable sets yields a topology for which the metric and topological entropies are equal.

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CP20

On the Automatic Parameter Selection for Permutation Entropy

Permutation Entropy (PE) is a powerful tool for quantifying the predictability of a sequence which includes measuring the regularity of a time series. Despite its successful application in many fields such as damage detection and financial volatility analysis, PE is sensitive to the choice of two required parameters: motif dimension n and delay τ. These parameters are often suggested by experts based on a heuristic approach, and they require experience in the application domain. In this paper, we present a systematic approach for automatically determining both parameters using three different methods: (1) information-theoretic-based, (2) statistical-based, and (3) topological-based. We evaluate the results from each approach by comparing the resulting parameters for a variety of examples to the optimum values listed in published literature.

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CP20

Framework for An Ensemble-Based Topological Entropy Calculation in Three Dimensions

Topological entropy measures the number of distinguishable orbits in a dynamical system, thereby quantifying the complexity of chaotic dynamics. Such knowledge aids greatly in a wide variety of natural and industrial fluid systems, including the large-scale dispersion of pollutants in the Earth's atmosphere and oceans and the rapidly developing field of microfluidics. We introduce a computational geometry framework for estimating a three dimensional flow's topological entropy from the collective motion of an ensemble of system trajectories. This work is analogous to the entropy calculation from "braiding" of system trajectories in two dimensions and is a first step towards building a triangulation-based method for computing topological entropy from an ensemble of trajectory data in three dimensions and higher. In it, we consider a two-dimensional rubber sheet stretched around a collection of points in a three-dimensional flow. A 3D triangulation may be used to track point-face or edge-edge collisions and the rubber sheet may be chosen as one of the faces in the initial triangulation. As the points evolve in time, they carry the sheet along with them, stretching and folding it so that its growth reflects the flow complexity. The topological entropy is bounded below by the exponential growth rate of this sheet.

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CP20

Entropy and Functional Redundancy in Biological Networks

Several scholars of evolutionary biology have suggested that functional redundancy (also known as biological "degeneracy) is important for robustness of biological networks. Functional redundancy indicates the existence of structurally different subsystems that can perform the same function. For networks with Ornstein–Uhlenbeck dynamics, Tononi et al. [Proc. Natl. Acad. Sci. U.S.A. 96, 3257–3262 (1999)] proposed a measure of functional redundancy that is based on mutual information between subnetworks. For a network of n vertices, an exact computation of these quantities requires $O(n!)$ time. We derive expansions for entropy, mutual information, and functional redundancy that one can compute in $O(n^3)$ time. Using these expansions, we compare the contributions of different types of motifs to a network's entropy and functional redundancy. We identify motifs with large contributions to a network's entropy and functional redundancy as entropy-inducing and redundancy-inducing motifs. Our results establish a link between a network's structure and its functional redundancy.

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CP21

On the Continuous Time Limit of the Ensemble Kalman Filter

We present recent results on the existence of a continuous time limit for Ensemble Kalman Filter algorithms. In the setting of continuous signal and observation processes, we apply the original Ensemble Kalman Filter algorithm proposed by [Burgers, G., van Leeuwen, P. J., Evensen, G. (1998). Analysis scheme in the ensemble Kalman filter. Monthly Weather Review, 126(6), 1719-1724] as well as a recent variant [de Wiljes, J., Reich, S., Stannat, W. (2018). Long-Time Stability and Accuracy of the Ensemble Kalman-Bucy Filter for Fully Observed Processes and Small Measurement Noise. SIAM Journal on Applied Dynamical Systems, 17(2), 1152-1181] to the respective discretizations and show that in the limit of decreasing stepsize the filter equations converge to an ensemble of interacting (stochastic) differential equations in the ensemble-mean-square sense. Our analysis also allows for the derivation of convergence rates with respect to the stepsize. An application of our analysis is the rigorous derivation of continuous ensemble filtering algorithms consistent with discrete approximation schemes. Conversely, the continuous time limit allows for a better qualitative and quantitative analysis of the time-discrete counterparts using the rich theory of dynamical systems in continuous time.

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CP21

Identification of Distributed Parameters in Size-Structured Aerosol Populations Using Bayesian State Estimation

According to the Intergovernmental Panel on Climate Change reports, aerosols play a key role in the global radiative balance of the earth; it is the most important source of uncertainties in climate models. The number concentration, size distribution (SD) and chemical composition of aerosols affect their ability to scatter and absorb radiations, which controls cloud properties, e.g. lifetime. To quantify these effects, we need to be able to estimate, from time series of SD, the parameters describing the microphysical processes that are driving aerosol formation and growth. Despite the plentiful of papers dealing with the estimation of distributed parameters in population balance equations (PBE), the estimation of parameters, such as the growth rate, is still performed manually or via oversimplified methods, e.g. regression methods. The reason is twofold: 1) no method is specifically designed for the general dynamic equation (GDE) for aerosols, and 2) existing methods for related PBE rarely produce an estimation of the uncertainty. We propose to use a Bayesian approach, the Fixed Interval Kalman Smoother (FIKS), that gives time-dependent parameters along with their uncertainties in a proper theoretical framework. The FIKS needs evolution models for the SD (i.e. GDE) but also for the parameters being investigated. Therefore, stochastic processes substitute the unknown evolution equations. We successfully applied this method to several relevant experimental setups.

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CP21

Efficiently Quantifying Chaotic Advection in Sparse Trajectory Data

Chaotic advection in 2-dimensional fluid flows arises from the repeated stretching and folding of material lines. The exponential rate of increase in the length of these curves provides a lower-bound estimate of the topological entropy, a fundamental measure of flow complexity. This presents an interesting challenge in the case where our knowledge of the fluid flow comes from sparse data: Given a set of trajectories and an initial curve, find the minimal length final curve that is homotopically compatible with the motion of these points. A very elegant algorithm by Moussafir, and elaborated on by Thiffeault, solves this by encoding the trajectories as braids, loops as algebraic coordinates (Dynnikov), and specifying the action of braids on loops. I will present a new algorithm which solves this same problem more efficiently. It uses ideas from computational geometry to maintain a triangulation of the points as they move, while encoding curves as edge weights that enumerate transverse intersections. Using this approach, we recover the Dynnikov coordinate update rules of the braid approach from a single simple rule for updating the triangulation. These results also pave the way toward rapid detection of coherent structures in flows and provide a foothold to higher-dimensional versions of this problem.

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CP21

Temporal Asymmetry of Lagrangian Coherent Structures

In fluid dynamics, viscosity breaks the time-reversal symmetry of the Navier-Stokes equation. However, in certain cases with a small Reynolds number (Re), time-asymmetry may be negligible, such as the famous demonstration by G. I. Taylor. Multiple recent studies of 2D and 3D turbulence have quantified the growth of time irreversibility with Re. We utilize a quasi-2D laboratory flow and a 2D direct numerical simulation (which accurately models the experiment) to quantify the growth of time-asymmetry in Lagrangian coherent structures (LCSs), which are the most important mixing barriers in the flow. We obtain attracting and repelling LCSs by computing ridges of the finite-time Lyapunov exponent fields using velocity fields evolving in backward or forward time, respectively. We find that the attracting and repelling LCSs exhibit an asymmetry that emerges with the onset of time dependence and grows with Re. The asymmetry is characterized by attracting LCSs that explore a larger fraction of the spatial domain than the repelling LCSs, which is consistent with a prior study. Our results suggest the asymmetry arises because hyperbolic stagnation points in the flow move preferentially along repelling LCSs. Our results help improve predictions of fluid mixing, as we find that repelling LCSs are more predictable than attracting LCSs.

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CP22

Theory and Computation of Nonlinear Deformation Spectra of Flows with Geophysical Applications

We present mathematical theory and an efficient computational framework for spectral information of the nonlinear (large) deformation tensor for flows on general Riemannian manifolds characterized by a generic metric tensor. The eigenvalues of the nonlinear deformation tensor have applications in fluid mechanics, such as identification of Lagrangian Coherent structures (LCS). Our method improves efficiency and accuracy of computing Finite Time Lyapunov Exponent (FTLE) fields, particularly on the spherical Earth. In order to validate this our method, we have derived an exact solution for the eigenvalues and eigenvectors of the deformation tensor for vortex flows on the sphere and demonstrate that the numerical results are in agreement with the exact solutions up to the numerical integration tolerance. Additionally, we present an online server-based gateway as a community resource that is developed for high performance computation of Lagrangian fields with our method. We demonstrate examples of FTLE calculations on large scale ocean surface domains with on web-base interactive visualization tool.

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CP22

Stability Analysis of the Maas Ocean Model

The Maas model is a generalization to traditional box-models of the large-scale thermally and wind-driven ocean circulation. It consists of a set of nonlinear equations describing the time evolution of the basin-averaged buoyancy gradient and the angular momentum of a rectangular ocean in an f-plane. Unlike an equivalent atmospheric circulation, which may be chaotic in nature, the parameter values in the ocean typically restrict the circulation to a steady state or a self-sustained oscillation. If the ocean is solely forced by heat, the steady state is unique and characterized by a fixed point in phase space. This fixed point is determined by the solution of a cubic eigenvalue equation. Depending on the coefficients of this equation, the fixed point may be a stable node or a stable or unstable spiral. An unstable spiral results in a limit cycle through self-sustained oscillations in the buoyancy space. The nature of the spiral can be transitioned from stable to unstable through a Hopf bifurcation by monotonically varying one of the coefficients. Mathematically, this implies changing the sign of the real part of the complex conjugate eigenvalues from negative to positive. Using non-linear stability analysis, we determine the surface separating the buoyancy space into regions with different stability properties. Finally, we study the effect of wind stress resulting in multiple equilibria and analyze the nature of these steady states.

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CP22

Well-Posedness and Long-Time Dynamics of the Rotating Boussinesq and Quasigeostrophic Equations: Recent Past and Proximate Future

The authors elucidate in a concrete way dynamical challenges concerning approximate inertial manifolds (AIMS), i.e., globally invariant, exponentially attracting, finite-dimensional smooth manifolds, for nonlinear dynamical systems on Hilbert spaces. The goal of this theory is to prove the basic theorem of approximation dynamics, wherein it is shown that there is a fundamental connection between the order of the approximating manifold and the well-posedness and long-time dynamics of the rotating Boussinesq and quasigeostrophic equations. In this talk we present the most recent advances concerning the questions of global regularity of solutions to the 3D Navier-Stokes and Euler equations of incompressible fluids. Furthermore, we also present recent global regularity (and finite time blow-up) results concerning certain 3D geophysical fluid flows, including the 3D quasigeostrophic and rotating Boussinesq equations describing the motion of a viscous incompressible rotating stratified fluid flow, which refers to PDE that are singular problems for which the equation has a parabolic structure (rotating Boussinesq equations) and the singular limit is hyperbolic (quasigeostrophic equations) in the asymptotic limit of small Rossby number of oceanic and atmospheric dynamics.

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CP22

Decay Profiles of a Linear System Associated with the Compressible Navier Stokes Equations

In their 1995 paper, Hoff and Zumbrun showed that the leading order asymptotic behavior of suitably small solutions to the compressible Navier Stokes equations is governed by a much simpler linear artificial viscosity system. We give an asymptotic expansion for solutions of the artificial viscosity system to any inverse power of time by combining techniques of Gallay and Wayne with those of Constantin.

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CP23

Using Machine Learning to Separate Chaotic Signals: A Chaos Version of the Cocktail Party Problem

We demonstrate the efficacy of a machine learning technique called reservoir computing for the separation of chaotic signals. Specifically, we consider the case where one has ongoing measurements of a single composite signal consisting of a linear combination of chaotic signals from different dynamical systems, and desires to extract from this composite signal only one of its components; i.e., to 'separate out' the signal that originated from a desired source (a chaos version of the 'cocktail party problem,' where a party-goer hears several conversations at once, but only wants to listen to one). Our method does not require knowledge of the governing equations of the dynamical systems that generate the signals; it only requires 'training data' consisting of limited-time samples of each of the component signals. We test the method in a variety of scenarios, and show that it compares favorably with linear methods (in particular, the Wiener filter, which is optimal amongst linear filters in a least squares sense).

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CP23

Exploring Chaotic Motion Through Dynamically-Evolving Reference Frames

We present a new method for identifying the regions on a chaotic attractor that are locally more stable and hence potentially more predictable than other regions. To do this, we construct in each neighborhood of a chaotic attractor an independent coordinate system in which one axis is carefully aligned with the local flow direction and the remaining axes are aligned with the other dynamical directions. This creates a moving reference frame that evolves along a given trajectory, but is independent in the sense that its axes are determined by the attractor's local dynamical geometry and not by parametric properties of the trajectory itself. The novelty of our technique lies in its ability to consider the local dynamics of chaotic systems, while being robust to both noise and to any nonlinearities in the governing equations. We demonstrate our method with the classic Lorenz system, the Double Scroll system, and the hyperchaotic Rossler system.

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CP23

Bounding Lyapunov Exponents Using Semidefinite Programming

This talk will present methods for computing upper bounds on maximal Lyapunov exponents in systems governed by nonlinear ODEs. Bounds can be formulated both for global Lyapunov exponents and for local Lyapunov exponents on an attractor. These bounds apply to all trajectories, regardless of stability. The methods are based on polynomial optimization, in particular using sum-of-squares constraints for matrices of polynomials. The resulting optimization problems can be solved computationally using semidefinite programming, and in some cases they can be solved analytically also. This talk will illustrate the use of these methods to obtain both computational and analytical bounds on Lyapunov exponents for chaotic systems including the Lorenz equations. In many cases the resulting bounds are sharp.

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CP23

Generalized Transitivity and Mixing

A point x is generalized recurrent if every Lyapunov function is constant along the orbit of x; this is a stronger condition than chain recurrence. We extend this notion to transitivity and mixing, and give a dichotomy result showing that every transitive system either is mixing or else factors onto a minimal equicontinuous system.

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CP24

A Deferred Correction with Penalty Projection Method for Magnetohydrodynamics

An algorithm for resolving magnetohydrodynamic (MHD) flows has been presented recently, that allows for a stable decoupling of the system and uses the penalty-projection method for extra efficiency. The algorithm relies on the choice of Scott-Vogelius finite elements to complement the grad-div stabilization.Based on this idea, we propose a new method that is efficient and second oreder accurate in time. For that, we start by introducing an extra grad-div term, that allows for the computationally cheaper Taylor-Hood finite element pair to be used. Next, we introduce the

Deferred Correction procedure to achieve second order accuracy.

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CP24

Blade-Vortex Interaction Numerical Study Using Potential Flow Theory and Neural Networks

Classical Computational Fluid Dynamics (CFD) numerical methods for studying the helicopter blade-vortex interaction (BVI) are known to be numerically expensive. At the same time, these methods compute numerical solutions only, making it difficult to produce results at interior points of the numerical grid being considered. Recently, Machine Learning techniques have been successfully used for solving various flow equations and/or as model reduction techniques for classical CFD methods. In particular, Artificial Neural Networks (ANNs) models, known to be "universal approximators", are successfully used to learn relevant information from data. Given input and output data for which we hypothesize a relationship exists, an ANN produces an analytical approximation function relating the output data to the input data. In this work we show that ANNs with one hidden layer and enhanced boundary constraints produce very good approximations for simple cases such as Laplace equations with Dirichlet boundary conditions. We then use ANNs to analyze a uniform flow with a superimposed vortex past an airfoil. We carry our analysis for a variety of flow parameters: initial vortex position (above or below blade), vertical offset, angle of attack, and the vortex circulation.

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CP24

A New Compact Difference Scheme of Second Order for Variable Order Fractional Sub-Diffusion Wave Equation

In this paper, we propose to construct a new efficient finite difference scheme for a variable order fractional subdiffusion wave equation. Fractional derivative will be considered in the sense of Caputo and approximated using $L2-1\sigma$ formula which gives second order convergence for $\alpha(t) \in (0,1)$. For spatial dimensions, we will consider compact difference operator which improves the convergence order to $O(h^4)$, where h is spatial mesh size. Next, we will prove the stability, solvability, and convergence of our constructed scheme using discrete energy method with help of L_2-norm. Our proposed scheme is new and efficient in terms of convergence orders in both time and spatial dimensions. Then, a few examples will be provided to demonstrate the accuracy and efficiency of the proposed scheme. This scheme can further be implemented easily to non-linear and time delay oriented problems.

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CP25

The Geometry of Rest-Spike Bistability

Rest-spike bistability has long been recognized as a key element in the generation of bursting. Its analyses often rely on planar systems, in particular [Franci et al, SIADS, 11(4):16981722, 2012] proposes a two-dimensional slow-fast model in which a stable fixed point coexists with a spiking attractor. In this system, through geometric singular perturbation theory, it is possible to explain how the classical bifurcation diagram associated to rest-spike bistability arises. Key to that analysis is a transcritical bifurcation of the slow manifold that allows the generation of a homoclinic trajectory. However, this geometric picture does not readily generalize to larger models, in which the slow manifold does not show this type of behavior. To understand how rest-spike bistability is generated in larger dimension we consider the classic Hodgkin-Huxley model with reverse potential of Potassium increased. While reductions of this system predict the correct qualitative behavior, we find that from a geometric viewpoint the structure of solutions is different when the full system is considered. Specifically, we find that a folded saddle plays a key role in the dynamics of the system and it is involved in the generation of the homoclinic trajectory that terminates the family of periodic solutions. These types of points can be present only when the slow manifold is at least two dimensional, thus the same geometric picture cannot be found in planar models.

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CP25

Homoclinic Saddle to Saddle-Focus Transitions in Four Dimensional Systems

We consider a saddle to saddle-focus homoclinic transition when the stable leading eigenspace is 3-dimensional (called the 3DL-bifurcation). Here a pair of complex eigenvalues and a real eigenvalue exchange their position relative to the imaginary axis, giving rise to a 3-dimensional stable leading eigenspace at the critical parameter values. This transition is different from the standard Belyakov bifurcation, where a double real eigenvalue splits either into a pair of complex-conjugate eigenvalues or two distinct real eigenvalues. There are two cases depending on the saddle quantity, the sum of the real part of the leading eigenvalues. For the case with positive saddle quantity, i.e. the wild case, we obtain sets of codimension 1 and 2 bifurca-

tion curves and points that asymptotically approach the 3DL-bifurcation point. The structure of the bifurcation set differs from that of the standard Belyakov case. This 3DL-transition was first reported in a 4D neural field for traveling waves in [Meijer & Coombes, Travelling waves in models of neural tissue: from localised structures to periodic waves, EPJ Nonlinear BioMedical Physics 2014]. In the neural field model, the saddle quantity is negative at the transition. We shortly discuss this tame case in the context of bifurcations of traveling waves. We also illustrate our results for the wild case with an example in a perturbed Lorenz-Stenflo 4D ODE model.

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CP25

On the Effect of Invisibility of Stable Periodic Orbits at Homoclinic Bifurcations

We study bifurcations of a homoclinic tangency to a saddle-focus periodic point. We show that the stability domain for single-round periodic orbits which bifurcate near the homoclinic tangency has a characteristic comb-like structure and depends strongly on the saddle value, i.e. on the area-contracting properties of the map at the saddle-focus. In particular, when the map contracts two-dimensional areas, we have a cascade of periodic sinks in any generic one-parameter family transverse to the bifurcation surface that corresponds to the homoclinic tangency. However, when the area-contraction property is broken (while three-dimensional volumes are still contracted), the cascade of single-round sinks appears with probability zero only. Thus, if three-dimensional volumes are contracted, chaos associated with a homoclinic tangency to a saddle-focus is always accompanied by stability windows; however the violation of the area-contraction property can make the stability windows invisible in one-parameter families.

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CP25

Bifurcation Analysis of Spiral Waves

Spiral waves are spatio temporal solutions to reaction-diffusion system of equations, observed in various biological, chemical and physical systems. The tip of a spiral defines the motion of spiral wave, of which there are several types. In the simplest case, a free spiral rotates rigidly while its tip describes a circular trajectory. It was observed that under certain conditions a spiral tip meanders rather than following a periodic circular orbit. Meandering is often not a random motion; rather the spiral tip traces a path resembling an epicycloid, exhibiting flower-like patterns. It is a type of quasiperiodic motion. Various authors proved that the transition from rigid rotation to meander is due to a supercritical Hopf bifurcation. However, these studies were limited to small core spirals. In this project, we study the solutions to reaction-diffusion equations in a comoving frame of reference (FOR). This leads to a system of reaction-diffusion-advection equations in which the tip of a spiral is fixed in position and orientation. In this FOR, we can afford smaller domain sizes and therefore extend the analysis to large core spirals. We performed the Hopf bifurcation analysis using the Fitz-Hugh Nagumo model, and further completed a numerical bifurcation analysis by studying the underlying limit cycles of meandering spiral waves in a comoving FOR. Results show that indeed a Hopf bifurcation is responsible for the transition from rigid rotation to meander.

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CP26

One-Dimensional Stochastic Reaction Networks: Classification and Dynamics

Stochastic reaction networks are widely used to model various biochemical phenomena. To understand their long-term stochastic dynamics, stationary distributions are often computed. One crucial dynamical property to guarantee the existence of a stationary distribution is *positive recurrence*. However, it is not easy to provide checkable criteria for stochastic reaction networks, only by topological or graphical structures. Motivated by this need, this talk contributes to stochastic dynamics of chemical reaction networks (CRNs) with one-dimensional stoichiometric subspace. I will first present a classification of the state space of the underlying continuous time Markov chain (CTMC) and mention how to use this result to discuss the diversity of long-term dynamics of stochastic CRNs. Moreover, I will present checkable necessary and sufficient network conditions for various dynamical properties: Recurrence (positive and null), transience, (non)explosivity, (non)implosivity, as well as existence of moments of passage times. As a byproduct, any one-dimensional weakly reversible CRN is positive recurrent, confirming the Positive Recurrence Conjecture proposed by Anderson and Kim in 2018 (in 1-d case). Finally, I will emphasize results on *one-species CRNs*, regarding stationary distributions and present parameter regions for consistency and inconsistency of stochastic and deterministic one-species CRNs regarding various dynamical properties aforementioned.

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CP26

Most Probable Tipping Events in a Noisy Piecewise

Linear System with Periodic Forcing

This project exploresnoise-induced tipping events in a scalarstochastic differential equation with piecewise smooth linear drift, additive noise, and external periodic forcing. The goal of this study is to determine the most probable path oftransition between two metastable states over a discontinuity in the drift. For parameter regimes in which the geometry of the flow clearly partitions the domains of attraction, these tipping events can be directly estimated using the Freidlin-Wentzell theory of large deviations. In regimes in which there are sliding regions along the discontinuity, the standard Freidlin-Wentzell theory is not sufficient. However, by studying local minimizers of theOnsager-Machlup functional applied to a smoothed out version of the drift,we provide a framework for determining the most probable transition path in these parameter regimes.By carefully considering the limit in which both the noise and the length scale of the smoothing vanish, we obtain a limiting functional that extends the Friedlin-Wentzell theory to the nonsmooth case. Our results are then compared with Monte-Carlo simulations.

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CP27

D-Chain Tomography: a New Structure Spectrum for the Study of Network Dynamics

The analysis of the dynamics on complex networks is closely connected to structural features of the networks themselves. Features like, for instance, graph-cores and node degrees have been proven to be discriminants of network dynamics and have been studied ubiquitously. Here we connect node degree and graph-core by means of the D-spectrum of a network, a novel framework that is based on a collection of nested chains of subgraphs within the network. We identify graph-cores and node degrees from two particular such chains of the D-spectrum. Each chain gives rise to a ranking of nodes and, for a fixed node, the collection of these ranks provides us with the D-spectrum of the node. We provide two ways to compute the D-spectrum of a network: first via a node deletion algorithm, and secondly we construct a specific graph dynamical system (MC system), in which the D-spectrum manifests as a fixed point. Using the D-spectrum we identify nodes of similar spreading power in the susceptible-infectious-recovered (SIR) model on a collection of real world networks. We then discuss our results and conclude that D-spectra represent a meaningful augmentation of graph-cores and node degrees.

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CP27

Optimal Control of Stochastic Temporal Networks

In the last decades, our understanding of the mechanisms allowing to control large complex networks has been significantly improved. Recently, the work of Li et al. (The fundamental advantages of temporal networks. *Science* (2017)) has spurred the attention of the community over a counterintuitive, at first sight, advantage in controlling a temporal network, that is, a network whose structure changes in time, with respect to a classical static one. Variability is of course a crucial element to faithfully describe most real-world systems that can represented in terms of networks. The human relationships, for example, continuously evolve. However, nobody can deterministically predict how the network varies and this potentially hinders our ability to control temporal networks. For this reason, we propose a novel concept of stochastic temporal networks, where we only have a probabilistic description of the future evolution of the network topology. In this novel setting, we discuss whether the advantages of temporal networks still remain.

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CP27

Exoplanetary Mass Constraints Based on Topology of Interacting Networks

The continuously increasing number of newly discovered worlds outside of our own solar system requires as precise as possible parameter estimations such as planetary masses, orbital characteristics, bulk density, etc. Comprehensive statistical methods and inverse dynamical analyses have been worked out to obtain system parameters from astronomical observations. Nevertheless, the time domain measurements as scalar time series transformed into complex networks serve a powerful tool to investigate dynamical systems via network topology. Many recent works make significant effort to explore the causality relations and coupling directions between connected dynamical systems. In this study a new estimation procedure of planetary masses is presented making use of eclipse time variation in multi-planetary systems. Due to the gravitational coupling the motion of planets differs from pure Keplerian ellipse resulting in variable orbital periods. Measuring this tiny effect for nearly co-planar planets one is able to reconstruct the trajectories sharing the same phase space. Transforming then the obtained state vectors of the entangled dynamical systems into network representation, it can be shown that the coupling directions between the interacting subnetworks are related to planetary masses relative to each other.

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CP27

Specialization Models of Network Growth

One of the characteristics often observed in real networks is that, as a network's topology evolves so does the network's ability to perform various complex tasks. To explain this, it has also been observed that as a network grows certain subnetworks begin to specialize the function(s) they perform. Here, we introduce a model of network growth based on this notion of *specialization* and show that as a network is specialized, using this model, its topology becomes increasingly modular, hierarchical, and sparser, each of which are important properties observed in real networks. This model is also highly flexible in that a network can be specialized over any subset of its elements. This flexibility allows those studying networks the ability to search for mechanisms that lead to specific types of network growth. For instance, by randomly selecting these elements we find that a network's topology acquires some of the most well-known properties of real networks including the small-world property, disassortativity, power-law like degree distributions, and clustering coefficients. We show that this growth process also maintains the basic spectral properties of a network. This allows us to show that as a network is specialized it maintains certain dynamic properties, specifically stability, which links this model of specialization to the robustness of network function.

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CP28

Periodic and Quasi-Periodic Orbit Optimization in Dynamical Systems with Delay

We perform optimization along families of periodic orbits and quasiperiodic invariant tori in dynamical systems with delay. We rely on a technique originally proposed by Kernévez and Doedel, in which successive continuation problems are used to locate stationary points of a fitness function along a submanifold of design space. Applications include design optimization in subtractive manufacturing and vibration control. The technique developed here generalizes a methodology applied previously to systems without delay by deriving the necessary adjoint conditions associated with periodic/quasiperiodic extremal solutions to delay-differential equations with a single, constant delay. For example, in the 2d quasiperiodic case, a Lagrangian formulation and the method of characteristics are used to derive coupled, piecewise-defined, partial differential equations with delay, as well as associated boundary and interval conditions representing periodicity in one dimension and rotation in the other. The overall problem is then discretized using a truncated Fourier representation along with continuous piecewise-polynomial approximations of the coefficient functions constrained by imposition of the governing equations on a set of collocation nodes. Analysis using the COCO software package validates the parameter continuation approach, as well as the simultaneous discretization of the dynamic constraints and adjoint equations for both periodic and quasiperiodic optimization.

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CP28

A Recipe for State Dependent Distributed Delay Differential Equations

Age structured population models have been used extensively in mathematical biology throughout the past 90 years. These age structured models describe the progression of individuals through an ageing and can, in certain cases, be reduced to a delay differential equation (DDE). In many populations, the speed at which an individual matures is often decoupled from chronological time and is controlled by the availability of resources. Consequently, when considering the age of an individual in a population, it is the biological age – and not chronological age– that is of interest. It is possible to allow for this dynamic accumulation of biological age by including a state dependent delay. Given the importance of individual differences in a population, it is crucial that intraspecies heterogeneity is included in mathematical models. We develop a technique to explicitly incorporate maturation age heterogeneity and external control of age accumulation by providing a framework for state dependent distributed DDEs. We show that the resulting delay differential equation preserves non-negativity of initial conditions and we characterise local stability of equilibria. By specifying the distribution of maturation age, we recover state dependent discrete, uniform and gamma distributed delay differential equations. Finally, we convert previously published transit compartment models into the equivalent distributed delay differential equations.

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CP28

Centre Manifolds for Impulsive Delay Differential Equations: Approximation and Applications

The analysis of mathematical models governed by impulsive functional differential equations is complicated by several factors. These systems notably contain discrete events called impulses that interrupt the smooth evolution of the system with a discontinuous jump in state. Coupled with time delays and other memory effects, the methods available to analyze the rich orbit structure of these systems is limited. I will present a computational framework for the approximation of centre manifolds for retarded impulsive functional differential equations. A Taylor expansion ansatz naturally leads to system of impulsive evolution equations for the Taylor coefficients. As an illustration, the method will be used to perform centre manifold reduction in an infectious disease model with pulse vaccination and finite immunity period. The reduction will be used to classify bifurcation points and to compute the bifurcation diagram.

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CP28

Bistabilities in Nonlinear Delayed Systems: Saturation Effects in Connected Automated Vehicle Design

In this contribution, heterogeneous connected vehicle systems, that include human-driven as well as connected automated vehicles, are investigated. The reaction time delay of human drivers as well as the communication and actuation delays of connected automated vehicles are incorporated in the model. Saturations due to the speed limit and limited acceleration capabilities of the vehicles are also taken into account. The arising nonlinear delayed system is studied using analytical and numerical bifurcation analysis. Stability analysis is used to identify regions in parameter space where oscillations arise due to loss of linear stability of the equilibrium. Moreover, with the help of numerical continuation, bistability between the equilibrium and oscillations are shown to exist due to the presence of an isola. It demonstrated that utilizing long-range wireless vehicle-to-vehicle communication the connected automated vehicle is able to completely eliminate the oscillations and keep the traffic flow smooth. The theoretical results are validated experimentally using full-size vehicles.

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CP29

Featurization of Persistence Diagrams for Classifying Attractors

The field of topological data analysis holds a wealth of tools for summarizing the shape of data in a quantifiable way. Recently, this has been heavily used in time series analysis, where the Takens embedding of a signal can be turned into a persistence diagram encoding information about the structure of the attractor. Clearly, the next step is to plug these persistence diagrams into a machine learning algorithm in order to automatically classify time series coming from different systems. However, there are mathematical roadblocks to immediately applying the available ML theory to persistence diagrams. In this talk, we will provide a new method of featurization of persistence diagrams using a construction called a template function, which circumvents these issues and we will show the application to numerical and experimental data.

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CP29

Chaos Detection Through Persistent Homology

Traditionally, computation of Lyapunov exponents has been the marque method for identifying chaos in a time-series. Recently, new methods have emerged for systems with both known and unknown models to produce a definitive 0/1 diagnostic. However, there still lacks a method which can reliably perform an evaluation for noisy time-series with no known model. In this paper, we present a new chaos detection method which utilizes tools from topological data analysis. Bi-variate density estimates of the randomly projected time-series in the p-q plane described in Gottwald and Melbourne's approach for 0/1 detection are used to generate a gray-scale image. We show that Wasserstein distances corresponding to the 1-D sublevel set persistence of the images can elucidate whether or not the underlying time series is chaotic. Case studies on the Lorenz and Rossler attractors are used to validate this claim. Similar to the original 0/1 test, our approach is unable to distinguish partially predicable chaotic and periodic behavior in the p-q space. However, although our method does not deliver a binary 0/1 result, we show that it is able to identify the shift points between chaotic and periodic dynamics in time-series even at high noise-levels.

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CP29

Using Persistent Homology to Quantify Periodic Circular Structures in Dynamic Image Data

This project aims to detect circular structure in dynamic image data, as well as determine the periodicity of cyclic behavior in the images. Using tools from Topological Data Analysis, specifically one-dimensional persistent homology, as well as some image processing techniques, our method is able to quantify a cyclic pattern in this type of image data. An application of this is the diurnal cycle in IR hurricane imagery. The tropical cyclone (TC) diurnal cycle is a regular, daily cycle in hurricanes that may have implications for the structure and intensity of hurricanes. This pattern can be seen in a cooling ring forming in the inner core of the storm near sunset and propagating away from the storm center overnight, followed by warmer clouds on its inside edge. The current state of the art for diurnal cycle measurement has a limited ability to analyze the behavior beyond qualitative observations. Our method creates a

more advanced mathematical method for quantifying this cycle and its periodicity. Using geostationary operational environmental satellite (GOES) IR imagery data from Hurricane Felix in 2007, our method is able to detect an approximately daily cycle in the hurricane.

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CP30

Fitness Dependence of the Fixation Time Distribution in Solvable Evolutionary Birth-Death Processes

Evolutionary dynamics involves selective competition between mutant and non-mutant individuals. Recent studies have shown that fixation times, which determine the rate of biological evolution, often have highly right-skewed distributions. Relatively little is known, however, about how these distributions and their skew depend on mutant fitness. We calculate the full fitness dependence of the fixation time distribution for the Moran Birth-death process on two extreme networks: the complete graph and the one-dimensional lattice, each of which admit an exact analytical solution in the limit of large network size. We find that the Moran process on the lattice with non-neutral fitness has normally distributed fixation times, independent of the fitness level. In contrast, on the complete graph, the fixation time distribution is a weighted convolution of two Gumbel distributions, depending on the fitness level. With neutral fitness, the Moran process has a highly skewed fixation time distribution on both the complete graph and the lattice. Even on these simple network structures, the Moran process exhibits rich fitness dependence of the fixation time distribution, with discontinuities and regions of universality. Applications of our methods to a multi-fitness Moran model, times to partial fixation, and evolution on random networks are discussed.

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CP30

Number and Stability of Relaxation Oscillations for Predator-Prey Systems with Small Death Rates

Predator-prey models that possess limit cycles have been studied extensively in the literature. In this talk, we use fast-slow dynamics to study predator-prey systems with small predator death rates, and derive new characteristic functions that determine the location and the stability of relaxation oscillations. This criterion determines the number and the global stability of limit cycles for some planar predator-prey systems. We also extend the criterion to some three-dimensional systems, including chemostat predator-prey systems and an epidemic model.

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CP30

Spatial Effects in Savanna Dynamics

Empirical evidence led ecologists to conjecture that at intermediate rainfall savanna and forest may represent alternative stable states [Staver, Archibald & Levin, “Tree cover in sub-Saharan Africa: rainfall and fire constrain forest and savanna as alternative stable states', Ecology, 2011]. This work sparked detailed analytical studies of mean-field models intended to explain the forest-savanna bistability hypothesis from a mechanistic viewpoint [Touboul, Staver & Levin, “On the complex dynamics of savanna landscapes', Proc. Natl. Acad. Sci. U.S.A., 2018]. However, the applicability of the insights gleaned from these models is limited given the highly spatially inhomogeneous cover type distributions observed in reality. I will discuss recent work on spatially extended versions of the aforementioned models which capture the nonlocal character of the cover type interactions via integral operators, resulting in a system of integrodifferential equations. Our main analytic results identify the classes of kernels for which the system exhibits pattern formation via spatially induced instabilities. We also present a comprehensive analysis of the system in the presence of a linear rainfall gradient, drawing heavily on ecological motivations and bifurcation analysis to systematically narrow the range of possible spatial phenomena; we observe front formation, travelling waves and “breathing fronts', and provide the ecological rationale for the emergence of these effects.

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CP30

Evolutionary Dynamics of a Spatiotemporal Stoichiometric Producer-Grazer Systems

An understanding of evolutionary dynamics requires a good understanding of genotypic selection. Natural selection can occur when a genotypic variation arises that corresponds to a consistent variation in fitness. Various environmental conditions, such as varying light levels and nutrient loads, may exert selection pressures giving an advantage to a particular genotype. Here we use theoretical approaches to explore the connections between genotypic selection and ecological stoichiometry in spatially heterogeneous environments. We present models of a producer and two grazing genotypes with different stoichiometric phosphorus to carbon ratios under spatially homogeneous and

heterogeneous conditions. Numerical experiments predict that selection of a single genotype, co-persistence of both genotypes, and extinction are possible outcomes depending on environmental conditions. Our results indicated that in spatially homogeneous settings, co-persistence of both genotypes can occur when population dynamics oscillate on limit cycles near a key stoichiometric threshold on food quality. Under spatially heterogeneous settings, dynamics are more complex, where co-persistence is observed on limit cycles, as well as stable equilibria.

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CP31
A Generalized Model of Flocking

In the Cucker-Smale (CS) model of flocking of N agents

$$\dot{v}_i = \sum_{j=1}^{N} \phi(|x_j - x_i|)(v_j - v_i), \quad i = 1, \ldots, N,$$

where x_i and v_i are positions and velocities. Motsch and Tadmor (MT) generalized CS model as

$$\dot{v}_i(t) = \alpha(\bar{v}_i(t) - v_i(t)), \quad i = 1, \ldots, N,$$

where α is a constant and the *target velocity* $\bar{v}_i$ of agent i is a (time and/or position dependent) convex combination of $v_j(t)$: $\bar{v}_i = \sum_j a_{ij} v_j$. While the CS model is limited to symmetric influence between agents i and j, the MT model allows for asymmetric influences. Motsch and Tadmor also set the stage for flocking analysis of the asymmetric case and for the special case of

$$a_{ij} = \phi(|x_j - x_i|)/(\sum_k \phi(|x_k - x_i|)),$$

provide sufficient conditions for flocking. In order to allow for bounds on the maximal acceleration of each agent, we generalize the MT model by allowing for the proportionality scalar α to depend on i and t. We also consider a very general form of $a_{ij} = a_{ij}(x)$ which allows for *partial masking* where two agents j and k equidistant from i may exert different influence depending on whether there is another agent in between and in the line of sight. We provide sufficient conditions on flocking for our generalized model.

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CP31
Stability Analysis for an N-Particle System in the Plane with Spring-Like Coupling

In this talk, we will discuss the dynamics of the system of n agents in the plane whose motion is determined by the second-order differential equations:$r_k' = (1-|r_k'|^2)r_k' - (r_k - R)$, where R is the center of mass of the swarm. In other words, every agent accelerates or slows down in the direction of its velocity vector and, simultaneously, experiences a force that pulls this agent towards the moving center of mass of the swarm. Previous numerical experiments have shown that for a large set of initial conditions the system converges to a rotating circular limit cycle with a fixed center of mass (the coordinates of the center of mass depend on the initial conditions), dubbed a ring state. We prove that a ring state is stable whenever the positions of the particles are not collinear, that is, they do not lie on a single straight line. Additionally, we show that every solution that starts near a stable ring state asymptotically approaches a stable ring state. The proofs are based on center manifold theory. We also provide the full description of limit cycles and the stability analysis, incl., the construction of a Lyapunov function, for the decoupled system (the center of mass = constant).

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CP31
Collective Mechanical Adaptation of Honeybee Swarms

Honeybee *Apis mellifera* swarms form large congested tree–hanging clusters made solely of bees attached to each other. How these structures are maintained under the influence of dynamic mechanical forcing is unknown. To address this, we created pendant clusters and subject them to dynamic loads of varying orientation, amplitude, frequency and duration. We find that horizontally shaken clusters adapt by spreading out to form wider, flatter cones that recover their original shape when unloaded. Measuring the response of a cluster to an impulsive pendular excitation shows that flattened cones deform less and relax faster than the elongated ones (that is, they are more stable). Particle-based simulations of a passive assemblage suggest a behavioural hypothesis: individual bees respond to local variations in strain by moving up the strain gradient, which is qualitatively consistent with our observations of individual bee movement during dynamic loading. The simulations also suggest that vertical shaking will not lead to significant differential strains and thus no shape adaptation, which we confirmed experimentally. Together, our findings highlight how a super-organismal structure responds to dynamic loading by actively changing its morphology to improve the collective stability of the cluster at the expense of increasing the average mechanical burden of an individual.

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CP31

Emergent Pattern Forming Swarms and the Physics of Mixed Reality Experiments

With the availability of ever more cheap and powerful computing, interest in the use of mixed-reality experiments has grown considerably in the engineering and physical sciences, especially in studies involving swarms of mobile robots. Broadly speaking, these experiments consist of a simulated, or virtual model coupled directly to a physical experiment. Within the physical experiment, it is typical to find a good deal of uncertainty and noise since it is connected to the real world, and thus subjected to random perturbations. In contrast, the virtual part represents a somewhat idealized version of reality in which noise can be eliminated entirely, or at least well characterized. In this talk we consider, first, the pattern formation of delaycoupled swarms theoretically and experimentally to illustrate the idea of mixed-reality. Motivated by experiments, we then analyze a model for mixed-reality systems, and show how noise in the physical part can influence the virtual dynamics through a large fluctuation, even when there is no noise in the virtual components. We quantify the effects of uncertainty by showing how characteristic time scales of noise-induced switching scale as a function of the delayed-coupling topology between the real and virtual parts of the experiment.

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CP32

On Volterra Quadratic Stochastic Operators of a Two-Sex Population on $S^1 \times S^1$

We consider a four-parametric (a, b, α, β) family of Volterra quadratic stochastic operators for a bisexual population (i.e., each organism of the population must belong either to the female sex or the male sex). We show that independently on parameters each such operator has at least two fixed points. Moreover, under some conditions on parameters the operator has infinitely many (continuum) fixed points. Choosing parameters, numerically we show that a fixed point may be any type: attracting, repelling, saddle and non-hyperbolic. We separate five subfamilies of quadratic operators and show that each operator of these subfamilies is regular, i.e. any trajectory constructed by the operator converges to a fixed point.

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CP32

The Replicator Dynamics for Multilevel Selection in Evolutionary Games

We consider a stochastic model for evolution of group-structured populations in which selection operates at two organization levels: individuals compete with individuals in their group, while groups compete with other groups. Payoff is obtained from the Prisoners Dilemma or the Hawk-Dove game. In the limit of infinite population size, we derive a non-local PDE describing the probability distribution of groups in the population. We characterize the long-time behavior of our system, with an emphasis on understanding the most frequent group compositions at steady state. When average payoff of groups is maximized by all-cooperator groups, steady state composition ranges from all-defector groups when individual-level selection dominates to all-cooperator groups when group-level selection dominates. When group payoff is maximized by a mix of cooperators and defectors, then the steady state features a fewer cooperators than required for the mix optimizing group payoff, even in the limit where group-level selection is infinitely stronger than individual-level selection. In such cases, the conflict between the two levels of selection cannot be decoupled, and cooperation cannot be sustained in when between-group competition favors perfect coexistence of cooperators and defectors.

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CP32

Mathematical Modeling of Cancer Self Remission and Tumor Instabilty as a Prey - Predator System

This paper studied a system of non linear ordinary differential equations in modeling the phenomena of a cancer self remission as a prey-predator system in homogeneous space. Prey are assumed to be tumor cells and predators are assumed to be the natural killer which are T-cells(hunting cells and resting cells). From the analysis in the homogeneous space, we came up with condition which enable the system to control the growth of cancer cells.A full stability analysis of the system is presented and numerical simulation carried out.

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CP32

Role of Additional Food on the Local and Global Dynamics of a Diffusive Predator-Prey System

In the present paper, we consider a diffusive prey-predator system with mutually interfering predator by consideration of Crowley-Martin functional response and additional food. We consider both spatially homogeneous model based on ordinary differential equations and reaction-diffusion model. The local stability analysis ensures that as the quality of additional food decreases, the predator free equilibrium stabilizes. Moreover, we have also obtained a condition providing a threshold value of quality of additional food (ξ) for the global stability of interior equilibrium. The local stability analysis of diffusive model ensures that the conditions obtained for local asymtotic stability of interior equilibrium solution of temporal model system also determines the local asymptotic stability of the associated diffusive model system. The global stability of interior equilibrium solution of diffusive model system is discussed by contructing a suitable Lyapunov functional with the use of Green's first identity. The non-existence of non-constant positive steady state solution of diffusive model system is established by using Harnack inequality and maximum modulus principle ensuring the effect of additional food on patterned solution of the diffusive model system. Furthermore, we illustrate the spatial patterns via numerical simulations, which show that the model dynamics exhibits diffusion controlled pattern formation by different interesting patterns.

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CP33

Exploration of the Role of Disinfection Timing, Duration, and Other Control Parameters on Bacterial Populations Using a Mathematical Model

Tolerant bacteria enmeshed in a biofilm causes several difficult to treat illnesses like tuberculosis, chronic pneumonia, and chronic inner ear infections. These diseases typically respond poorly to antibiotics due to high tolerance. Bacterial tolerance can be genotypic (resistance-e.g. MRSA) or phenotypic (non-heritable). Persister formation is phenotypic tolerance that is highly tolerant to disinfection. Constant dosing is typically ineffective in eliminating persister cells. This study investigates how manipulating the application of antibiotics and the addition of nutrient may enhance the disinfection of a bacterial population in batch culture. We present a mathematical model that captures the dynamics between susceptible and persister bacteria with antibiotic and nutrient as control variables. We investigate the optimal dose-withdrawal timing of antibiotic in several cases including: constant nutrient in time, dynamic nutrient in time, and piecewise constant nutrient in time. Also a global sensitivity analysis method, Partial Rank Correlation Coefficient (PRCC), is applied to determine the significance of model parameters for a quantity of interest.

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CP33

Comparison of Global, Stochastic Optimization Algorithms Using Toy Problems and Fitting Multi-Parameter Models to Kinetic Rheological Data

The evaluation of multiple parameters involved in nonlinear dynamic simulation models based on a minimization of the sum of the squares of the differences between the predictions and experimental data is often a non-trivial step. Classical least squares minimization methods are all local methods that only converge to a local minimum that is not necessarily the global one, the answer depending crucially of the initial guess. The evaluation of the sensitivity of the local minimization solution to the initial guess can be quite time-consuming, especially when the model predictions involve the solution of a set of ODEs the time-integration of which requires by itself a non-negligible computational time. In this work we present a stochastic method to evaluate that dependence effectively with an application to the evaluations of parameters in the dynamic simulation of a thixotropic concentrated suspension system using Large Amplitude Oscillatory Shear (LAOS) and other transient data, as well as kinetic data from a set of fermentation reactions. In addition, with this work we compare several other contemporary stochastic methods including Genetic Algorithm (GA), Prticle Swarm Optimization (PSO), Simultaneous Perturbation Stochastic Approximation (SPSA) and Simulated Annealing (SA) using several classic chemical engineering toy problems from literature

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CP33

Using Electrokinetic-Mixing to Improve the Kinetics of the Diagnostic and Biosensor Platforms

Rapid and accurate biosensing with especially low concentrations of the analytes is usually challenged by the diffusion limited reaction kinetics. Thus, long incubation times or excess amounts of the reagents are employed in biosensor and diagnostic platforms to ensure the reactions to go to completion. Here we propose a technology that provides electrokinetic-mixing (EKM) of the reagents in solutions placed in the wells of an electrode-embedded multiwell plate, where the incubation times, or in other words, the time required for the desired molecules to meet in stationary solutions, can be reduced substantially. This technology has been applied to an immunoassay based diagnostic kit for diabetes (glycated hemoglobin (HbA1c) test) and a FRET based quenching bioplatform consists of a molecular beacon DNA and gold nanoparticles. When electrokinetic-mixing was employed, the incubation times were reduced by approximately a factor of 5 and 4 for the diabetes diagnostic kit and FRET based quenching bioplatform, respectively. Furthermore, if the quantity of the reagents was further reduced by half, where almost no distinguishable signals could be obtained with conventional immunoassay, electrokinetic-mixing still facilitated acquisition of signals while varying the concentration of the glycated hemoglobin

(HbA1c). Thus, EKM can open new avenues in biomedical applications where especially very small volumes can be mixed efficiently to acquire signals in a much shorter time.

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CP34

Dynamics of Bubbles in a Quark-Hadron System

We study the evolution of bubbles during the quark-hadron phase transition. In the literature, we have found only one derivation of the form of the bubble equation we use here. This is a relativistic version of the Rayleigh-Plesset equation for bubble dynamics. In the non-relativistic approach, this equation becomes a Briot-Bouquet equation. Interestingly, Cauchy's problem for the non-relativistic equation of motion can be a case of the problem of spherical cavities that can always be rearranged in a standard canonical form by means of a transformation of scale known as Sundman transformation. The equation that gives the dynamics of the relativistic bubble, which is integro-differential, and which must be numerically integrated, has a pressure difference term that controls the collapse or expansion. Our calculations show that the time-scale of the transition is rather large, lasting several Fermis.

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CP34

The Roles of Inertia and Stability in Power Systems

The integration of variable renewable generation (VRG) sources, such as solar and wind, is changing the dynamics of power systems. Traditional generation sources, such as natural gas and coal, provide *inertial support*, using stored kinetic energy in the turbines to help respond to system instabilities. VRG sources do not, on their own, provide this kind of support. As these kinds of sources take over a larger portion of the generation mix, the dynamics of power systems can change in significant ways. At worst, this can make the system more vulnerable to failures; at the very least it increases the probability of large perturbations in frequency, which can cascade across the power system. This issue has been recognized across the world-most notably in Australia, where specific requirements on inertial support are being implemented. However, a thorough understanding of the interplay between total system inertia and cascade response is specifically lacking from the power-systems literature. As a first step in this direction, we analyze a large number of simulations over a wide range of inertia values and component-failure contingencies, studying the intertwined roles of inertia and power-system stability. In particular, we are interested in determining at what inertial value(s) do cascades and perturbations become severe. This information could be used to inform critical design and policy.

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CP34

Title Not Available

In general relativity, the dynamics of spacetime is describe by the EInstein field equation, which are a set of partial differential equations. The Geroch transformation is solution generating transformation and may generate spike solution. Most spiky solution generated so far form spike at early times. In this talk I present a solution that forms spike at late times.

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CP35

Understanding and Designing Emergent Behavior via Stability Analysis of Mean Field Games

Mean Field Games (MFG) have emerged as a promising tool in the analysis of large-scale self-organizing networked systems. The MFG framework provides a non-cooperative game theoretic optimal control description of emergent behavior of large population of rational dynamic agents. Each agents state is driven by optimally controlled dynamics that result in a Nash equilibrium between itself and the population. Its optimal control is computed by minimizing the sum of its control effort, and a mean-field interaction term that depends on its own state and statistical information about the population. The agent distribution in phase space evolves under the optimal feedback control policy. Mathematically, a MFG system is described by a coupled forward-backward system of nonlinear Fokker-Planck and Hamilton-Jacobi-Bellman PDEs. In this talk, we discuss a class of MFGs whose qualitative behavior mimics certain well known empirical flocking models. We provide a closed-loop stability analysis of the non-local forward-backward PDE system demonstrating that these MFGs exhibit bifurcations similar to those found in the empirical model. The present work is a step towards developing a set of tools for systematic analysis, and eventually design, of collective behavior of non-cooperative dynamic agents via an inverse modeling approach. We also briefly discuss ongoing efforts to develop low-order models of MFGs that possess rich phase space structure and undergo global bifurcations.

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CP35

Numerical Studies, of Medication Deposition Inside the Human Lungs, using LES

In the recent years, the solid lipid nanoparticles (SLNs) have emerged as a promising non-toxic nano-carrier for drugs, using the pulmonary route. From a drug delivery point of view, the human lungs present several advantages such as large absorptive area, extensive vasculature, easily permeable membrane, low extra-cellular and intracellular enzyme activity. However, the mechanism of drug delivery, through lungs, depends at a large extent on the fluid dynamics of human airways. Therefore, computational fluid dynamics (CFD) play a key role in the understanding and prediction of medication dispersion and deposition, into human airways. In the present research we propose a Lagrangian particle-tracking along with the large-eddy simulation (LES) approach, for the prediction of medication dispersion and deposition, inside the human lungs. The computational results show a good agreement with the experimental data. The research shows that the nanoscale particulate medication follows very closely the flow streamlines. High-levels of medication deposition were observed on the sides of the lungs, while lower levels of medication deposition were observed at the lower side of the lungs.

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CP35

Blood Flow with Nano Particles through Stenosed Arteries Under the Effect of Magnetic Field

The present investigation is devoted to suppositional study of blood flow with nano particles through a stenosed artery with permeable walls. The initiation of nanoparticles in blood will produce unharmonious consequences for stenosed tube. This study is carried out to reveal the effects of magnetic field on the harsh consequences of nanoparticles in case of stenosed artery. The governing equations of visualized model of blood flow are solved using the blend of laplace and Hankel transform method. The closed forms of expressions are accomplished for velocity and temperature distributions. The flow rate and shear stress are also compassed in the constricted region of tube. The results are manifested by using MATLAB and are demonstrated as plots for the distinctive parameters. It is depicted that the combined effect of time and magnetic field, is advantageous for the flow of blood in the stenosis region and with the rise in volume fraction of nanoparticles, the velocity of blood takes the edge off. Keywords: permeability, magnetic field, couple stress blood flow, stenosed artery, nanoparticles.

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CP35

Reversal Permanent Charge and Reversal Potentials: Case Studies via Classical Poisson-Nernst-Planck Models with Diffusion.

In this talk, we are interested in effects of permanent charges on ionic flows. We determine when a permanent charge produces current reversal via the classical Poisson-Nernst-Planck models of ionic flows. The starting point of our analysis is geometric singular perturbation approach for Poisson-Nernst-Planck models that is a useful method for Multiple Time Scales problems. We are able to identify a governing system of equations for the existence and the value of the permanent charge for a current reversal. The related topic on reversal potential can be viewed as a dual problem and will be briefly examined in this talk too.

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CP36

Koopman Theory and Linear Approximation Spaces

Koopman theory studies dynamical systems in terms of operator theoretic properties of the Perron-Frobenius $\mathcal{P}$ and Koopman operators $\mathcal{U}$ respectively. In this talk, we present the rates of convergence of approximations of $\mathcal{P}$ or $\mathcal{U}$ that are generated by finite dimensional bases like wavelets, multiwavelets, and eigenfunctions, as well as approaches that use samples of the input and output of the system in conjunction with these bases. We introduce a general class of priors that describe the information available for constructing such approximations and facilitate the error estimates in many applications of interest. These priors are defined in terms of the action of $\mathcal{P}$ or $\mathcal{U}$ on certain linear approximation spaces. The rates of convergence for the estimates of these operators are investigated under a variety of situations that are motivated from associated assumptions in practical applications. When the estimates of these operators are generated by samples, we also show that the error in approximation of the Perron-Frobenius or Koopman operators can be decomposed into two parts, the approximation error and the sampling error. This result emphasizes that sample-based estimates of Perron-Frobenius and Koopman operators are subject to the well-known trade-off between the bias and variance that contribute to the error, a balance that also features in nonlinear regression and statistical learning theory.

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CP36

Koopman Operator and its Approximations for Dynamical Systems with Symmetries

Taking symmetries of dynamical systems into account can help simplify analysis of these systems and gain insights into their behavior, such as the attractor basin structure and synchronization patterns. A particular challenge is that many modern systems of interest are high-dimensional and nonlinear, making them inaccessible to approaches based on traditional dynamics of states. Thus, operator based approaches to dynamical systems have gained popularity in recent years. Moreover, the approximations of these operators provide ways to apply these methods directly to data. We employ an operator based approach to systems with point symmetries. In particular, we focus on the linear infinite-dimensional Koopman operator that evolves functions on state space. Using tools from representation theory we study the structure of the eigendecomposition of this operator, which we show is especially revealing of the symmetries through an appropriate isotypic component basis. We apply the knowledge of the structure of the eigenspace gained via our symmetry considerations to produce dictionaries of observables that ensure that the matrix corresponding to the Koopman operator approximation obtained using the recently proposed extended dynamic mode decomposition method is block diagonal. That can offer computational advantages, illuminate the attractor stricture of the underlying system, and potentially lead to new methods of detecting symmetries in high dimensional nonlinear dynamical systems.

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CP36

Koopman View of Dynamics on the Tangent Space and Structure Preserving DMD

The local stability properties of trajectories in autonomous dynamical systems are often studied using the variational equation. In this work, we present a framework for such considerations based on Koopman operator theory. This Koopman operator is defined on the product of the state and tangent spaces. Drawing intuition from the evolution on the tangent space, eigenfunctions that are linear in the tangent space are considered. We show that these eigenfunctions can be constructed in an open fashion in a neighborhood of a fixed point/limit cycle, using initial values that are intrinsic to the geometric invariant. On a different note, we develop a variant of DMD that preserves a priori knowledge of the dynamics. Linearity of the Koopman operator allows for encoding known geometric invariants and eigen-pairs as linear constraints on the DMD matrix. The resulting constrained optimization can be reduced to a typical least squares problem with appropriate SVDs. In a purely data driven scenario, one can always preserve the constant eigen-function and this justifies mean subtraction in some cases. However, if there is additional information on fixed points and limit cycles, or even the spectrum of the operator, one can produce a more meaningful approximation than an agnostic regression. Prototype dynamical systems illustrate the applicability of this technique.

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CP36

Uncoupling Structure and Dynamics of Complex Networks using Dynamic Mode Decomposition

Understanding the connection between topology of a system and its dynamics is a central challenge in the field of complex networks. For example, the very same set of nodes and links that under regular conditions displays uncoordinated behavior may become synchronized as a result of a change in the dynamical interaction rules. In this work, we study complex networks of Kuramoto oscillators through the lens of the Koopman operator framework. We investigate the relationship between the spectrum of the Koopman operator (defined by the network dynamics) and the spectral properties of the underlying topology (Laplacian spectrum). We show that an abrupt transition in the distribution of Koopman modes corresponds to the phase transition in the Kuramoto dynamics. We demonstrate different signatures of the spectrum of the Koopman operator which capture unique paths towards the collective behavior in different topologies (random and scale-free). Finally, we discuss applicability of proposed approach in designing the control protocols for complex systems.

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CP37

Solution Attractor of Local Search Systems: The TSP Case

Traveling Salesman Problem (TSP) is one of the most important combinatorial optimization problems. It is an intractable problem. For such a problem there exists no efficient algorithm to solve it; and only the brute-force search algorithm can provide a solution. However, this approach is not feasible for larger problem instances. Local search is a common approximate approach to find good solutions to these hard problems. A local search trajectory is characterized by the progressive emergence of new irreducible space-time level of dynamical behavior from successive search steps. In this sense, a local search system is essentially in the domain of dynamical systems. The goal of a dynamical system analysis is to capture the distinctive properties of certain points or regions in the state space for a given dynamical system. The behavior of a local search system for the TSP is studied in our paper. It was found that all local search trajectories converge to a small region, called solution attractor. This attractor can be used to help us identify the optimal point in an efficient way. The P-vs-NP problem is about how fast we can search through all possibilities. In fact, there are a huge number of possibilities, we dont always need to explore them all. Therefore, the P-vs-NP problem actually asks us if we can find a way to explore only the region that contains the optimal solution. The solution attractor gives us hope to solve the TSP efficiently with optimality guarantee.

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CP37

Hyperbolic Groups Acting on Trajectories of Coupled Oscillators

The Kuramoto Model is a dynamical system which describes coupled oscillators such as Josephson Junctions, population sleep cycles, mechanically-linked motors, and more. The classic case of N bodies on S^1 is well-studied. In 1991, Watanabe and Strogatz derived $N-3$ conserved quantities based on the cross ratios of the bodies, which reduces the high-dimensional system in N dimensions to a more manageable three dimensional system. In 2009, Mirollo et. al. noticed these conserved quantities are preserved by Mobius transformations of the unit disc inside S^1. The Kuramoto Model can be generalized to N bodies on S^d, along with their conserved quantities which are preserved by isometries on the disc model of hyperbolic $d+1$ space inside S^d. Much like how trajectories of rigid body systems on a sphere are described by a path of Euclidean isometries, the trajectories of the Kuramoto Model are described by a path of hyperbolic isometries. I will derive Lohe's reduced Kuramoto Model equations using hyperbolic geometry, and then show how the continuum N limit resembles Ott's ansatz, which he derived by primarily algebraic methods.

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CP37

A Model for Interactions Between Criminal Minded Population and s Suppressed Population

In the present work, we use a predator-prey model to study the interactions between criminal minded population and suppressed population. Our aim is to study various possibilities of interactions between them. First we model it using predator-prey interaction with Holling type II functional response, then we modify it by incorporating enforcement law in the criminal minded population. The obtained result suggests that by incorporating enforcement law, the criminal population reduces from the very beginning, which resembles with real life situation. Our result indicates that the criminal minded population exist so long as coefficient of enforcement l_c does not cross a threshold value and after this value the criminal minded population extinct. In addition, we also discuss the occurrence of saddle-node bifurcation in case of model system with law of enforcement. Numerical examples and simulations are presented to illustrate the obtained results.

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CP37

Convective Instability for Microscopic Car-Following Models and their Macroscopic Counterparts

With increasing economical and ecological damages caused by traffic congestion worldwide, the modelling, understanding and prediction of traffic flow phenomena become ever more important. For a given model, the conditions and details of spontaneous breakdown of homogeneous flow are of particular interest. Traffic Flow modelling with differential equations can be done either from a microscopic perspective, describing individual trajectories by ODEs, or from a more holistic macroscopic point of view, where the evolution of vehicular density is described by PDEs, similar to fluid dynamical models. Macroscopic models can be derived from microscopic ones by different techniques. We consider a class of microscopic car-following models on the infinite lane. For models of this type, different concepts of stability have been proposed, including a notion of convective stability. Since the term of convective stability is also well-known from the context of PDEs, we ask in which sense these properties persist upon transition to corresponding macroscopic models. The obtained results are discussed in the application context.

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CP39

Cellular Automata Modeling of Spinal Cord Growth: Effect of Stem Cell Activity and Population Pressure

Adult neural stem cells are widely distributed in the vertebrate central nervous system (CNS). In contrast to mammals, in teleost fish such stem cells exhibit high mitotic activity and give rise in many regions of the CNS not only to glia but also to neurons. This persistent neurogenic activity, combined with limited cell death and long-term survival of the new cells, leads to continuous growth of the adult CNS, in concert with the continued growth of the fish. A PDE-type mathematical model has indicated that, in addition to proliferation of adult stem cells, cell drift due to population pressure plays a critical role in this growth process [Ilies I, Sipahi R, Zupanc GKH, J Theor Biol 437:101-114, 2018]. To study the effects of population pressure with cellular resolution, here we have built an *in vivo* cellular automata model based on an *in vitro* version [Sipahi R, Zupanc GKH, J Theor Biol 445: 151-165, 2018]. The *in vivo* model is based on a comprehensive set of quantitative cellular mapping data and on rules derived from cell biological observations [Srbulescu RF, Ilies I, Meyer A, Zupanc GKH, Dev Neurobiol 77:1269-1307, 2017]. Simulations of the model featuring population growth have yielded growth trajectories and tissue properties that are in close agreement with those identified through biological analysis. Most significantly, such simulations have led to the prediction of potentially novel cellular mechanisms mediating growth of adult CNS tissue.

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CP39

Study of Attractors for Compartmental Systems Modeled with Carathodory Differential Equations

Due to their weak assumptions on regularity, non-autonomous ordinary differential equations (ODEs) and functional differential equations (FDEs) of Carathodory type can be succesfully applied to model a wide range of real phenomena. Particularly, the talk will show how to model non-autonomous, non-linear compartmental systems and infer stability results of the associated mean age system. Additionally, we outline the abstract version of these results, giving sufficient conditions to prove the existence of a pullback attractor for any Carathodory system with suitable features. Finally, we also show how to "propagate" such pullback attractor if a continuous skew product semiflow can be defined.

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CP39

Immune Normalization Dynamics: Modeling Checkpoint Blockade Combination Therapies in Breast Cancer

Cancer researchers have spent the past several decades attempting to harness the bodys natural immune response. Most of these early attempts directly enhanced immune activity (e.g. via pro-immune cytokines such as IL-2), to no significant clinical benefit. Typically, antitumor immunity fails not due to a lack of immune activity, but rather due to local immunodeficiencies in the tumor microenvironment. Successful immunotherapies must normalize the tumor-immune environment, and not merely enhance the immune response. For instance, many tumor cells express the PD-L1 surface ligand, which targets the PD1 immune checkpoint. Anti-PD1 therapies have shown promising clinical results in the past decade, preventing PD1-induced inhibition of immune cytotoxicity. In our current work, we developed an original model of autoregulated immune-tumor dynamics. Using recent murine data, we incorporated a combinatorial checkpoint blockade therapy into the model. Specifically, we simulated the combination of an immune normalizing anti-PD1 agent with an immune enhancing LSD1 inhibitor, under a variety of treatment schedules. We evaluate these regimens, and explore key mechanisms of the potential combined effect.

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CP40

Mode Interactions and Turbulence in a Rotating Annulus Experiment with Free Surface

Rotating fluids frequently show nonlinear wave interactions and turbulence. This is true in particular for non-uniformly rotating systems. One example of such a non-uniform rotating object is the Earth. Due to its fast rotation it is not exactly spherical. As a result of the interaction with the Sun and Moon the non-spherical Earth cannot rotate uniformly but shows precession and libration. This has consequences for the fluid enclosed in the outer Earth core. Due to the forcing it might become turbulent, one of the key factors in the present theories explaining the generation of the geomagnetic field. In the present paper we show experimental results from a system that is simpler than a precession experiment but for which very similar wave interactions and a collapse to turbulence can be found. This system consists of a rotating annulus that rotates about its symmetry axis slightly tilted with respect to the gravity vector. In contrast to precession experiments, the annulus has a free upper surface. Due to the tilt with respect to gravity a spin-over mode is excited even without precession. In analogy to the more classical precession experiments we also find a geostrophic mode and free Kelvin modes that show triadic interactions. For the precession experiment a low order dynamical system exists that can describe the main features of the nonlinear interaction. We try to connect this model to our data and compare it with data from precession experiments.

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CP40

Spot Patterns on Reaction-Diffusion Networks

Reaction-diffusion system provides a rich variety of dissipative structures. Pattern formation by Turing instability in activator-inhibitor system has recently been investigated on networks, revealing significant differences from patterns in classical continuous media. The results suggest that pattern formation processes depends strikingly on the topology of medium. Here we focus on the localized spot patterns on networks. To our knowledge, typical mathematical models that provide spots in continuous media, e.g. Gray-Sccott model and Rinzel-Keller models, do not give spots on networks. Spots on networked systems may thus be provided by alternative mechanisms. We show in this presentation a new class of reaction-diffusion model, leading localized spot patterns on complex networks. Numerical results suggest that a spot stays on a single node or travels over entire network depending on the parameter values. Statistical properties of spots will be discussed.

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CP40

Attractor Symmetry and Stability in Symmetric Self-Driven Oscillator Networks

The dynamics governing networks of identical oscillators are unchanged by node interchange symmetries, or automorphisms, of the network. Equivariant dynamical system theory predicts such networks consequently must possess steady states, and flow invariant manifolds where particular nodes, exchanged by subgroups of network symmetries, are synchronized. Homogeneous microreactors containing the oscillatory Belousov Zhabotinsky (BZ) reaction, coupled by diffusion, allow the experimental study of symmetric self-driven oscillator networks. A ring of 4 inhibitory-coupled BZ reactors was studied as a model system. This system exhibits symmetric gaits found in quadrupedal animals as its attractors. Experimental invariant manifolds, steady states, and stabilities are compared to those theoretically predicted using methods generalizable to other networks.

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CP41

Dynamic Modeling and Asymptotic Approximation of Multi-Cue Multi-Choice Tasks

In this talk, we first develop a multi-cue multi-choice task model for describing human decision making behavior based on two different approaches. The first approach is to merge the existing multi-cue two-choice task model and the existing single-cue multi-choice task model together by analogy. The second approach is to use a Markov chain technique to derive this multi-cue multi-choice model. Next, we discuss asymptotic approximation of the first moment equation for this model. Specifically, we treat the first moment equation as a switched linear nonautonomous system. Then we use a contraction-mapping-based numerical analysis method to derive a sufficient condition for asymptotic convergence of the first moment equation.

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CP41

A Minimal Mathematical Model for Free Market Competition through Advertising

Firms in the U.S. spend over 150 billion dollars a year in advertising their products to consumers. Given the clear importance promotion has in market competition, it is of great interest to understand how that budget could be optimally distributed, and how market prices should be affected. Constructing a system of differential equations to model dynamics of competition, we explore firm behavior under idealized conditions and find a surprising prediction: firms should split into two groups, one with significantly less advertising (a "generic' group) and one with significantly more advertising (a "name-brand' group). We use consumer data to compare predictions from the model with real world pricing and find qualitative agreement.

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CP41

How Close is the Nearest Node in a Wireless Network?

The ability of small-cell wireless networks to self-organise is important for improving capacity and performance in such communication networks. This talk proposes heuristics that can be used by a cell to estimate the distance to its nearest neighbour, based only on observed signal. This ability would allow a cell to configure its power settings accordingly to optimise network performance in a truly distributed way. The accuracy of the several different heuristics are compared and it is found that the best offer considerable improvement, yet remain tractable and fast to compute. One of these heuristics is specifically for use with Rayleigh fading. The heuristics are a function of observed signal and pathloss.

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CP41

Enhancing the Synchronization of Coupled Rhythms through Intrinsic Network Heterogeneity

The study of collective oscillations or rhythms is an intriguing subject. In the brain the interaction of rhythms is thought to play a functional role. Here we focus on the interaction between the rhythms of two heterogeneous populations of mutually inhibiting oscillators. To gain insight into that interaction we first utilize the previously developed framework of the macroscopic phase-resetting curve (mPRC) for spiking networks [G. Dumont, G.B. Ermentrout, and B. Gutkin. Physical Review E, 96:042311, 2017.]. Surprisingly, although the PRC of each individual oscillator is strictly positive, we find that the mPRC of the population is biphasic: external inhibition can both delay and advance the network depending on the time when it is applied. This biphasic mechanism results from the competition between the external inhibition and a decrease in the self-inhibition within the network caused by a reduction in the number of neurons spiking in a given cycle. The advancing component of the mPRC allows coupled networks to synchronize if the frequencies of the oscillators in each network are sufficiently heterogeneous. This hetereogeneity plays a role similar to that of uncorrelated noise, which has been found to enhance the synchronization of ING rhythms [J.H. Meng and H. Riecke. Scientific Reports, 8:6949, 2018.].

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CP42

Complex Dynamics of $z_{n+1} = \dfrac{\alpha + \beta Z_n + \gamma Z_{n-1}}{A + BZ_n + CZ_{n-1}}$

The dynamics of the second order rational difference equation $z_{n+1} = \dfrac{\alpha + \beta z_n + \gamma z_{n-1}}{A + Bz_n + Cz_{n-1}}$ with complex parameters and arbitrary complex initial conditions is investigated. In the complex set up, the local asymptotic stability and boundedness are studied vividly for this difference equation. Several interesting characteristics of the solutions of this equation, using computations, which does not arise when we consider the same equation with positive real parameters and initial conditions are shown. The chaotic solutions of the difference equation is absolutely new feature in the complex set up which is also shown in this article. Some of the interesting observations led us to pose some open interesting problems regarding chaotic and higher order periodic solutions and global asymptotic convergence of this equation.

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CP42

Connecting Puzzles and Piecewise Isometries in 1D, 2D, and 3D

A wide range of possibilities for cutting-and-shuffling mechanisms, also known as piecewise isometries (PWIs), are based on one-dimensional systems, which leads to two-dimensional planar, two-dimensional spherical, and three-dimensional geometries. Many of the higher dimensional cutting and shuffling motions are natural extensions of interval exchange transformations (IETs), which are defined as cutting-and-shuffling on a line interval and are the only way to cut-and-shuffle in one dimension. To guarantee that PWIs can be performed on solid bodies without solids overlapping or the domain needing to be deformed or extended, it is necessary to introduce the concept of PWIs that are time-continuous. PWIs with this property are easier to implement in experiments and applications, as can be demonstrated through their connection to static mixers for fluids, mixing in spherical granular tumblers, and twisty puzzles, such as the Cohan circle puzzle and the spherical version of the Rubik's cube. Partially supported by NSF grant CMMI-1435065.

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CP42

An Application of the Delayed Tyre Model in Vehicle Shimmy

The Delayed Tyre Model is a physics-based tyre model which can be used in the study of vehicle dynamics. It does not restrict the shape of the lateral tyre deformation, and keeps the nonlinearity in space. Assuming the tyre-ground contact region is a thin line, the delay τ comes from the time needed for a tyre particle to travel from the leading contact point to an arbitrary point of the contact line. Shimmy is a self-excited vibration of wheeled mechanisms, and vehicle shimmy is used to describe the shimmy of ground vehicles, characterized by the oscillation of front wheels around their kingpins. A vehicle shimmy model considering the steering system and the suspension system is established with the Delayed Tyre Model. Both brush-type tyre and stretched string-type tyre assumptions are investigated, which take into account the lateral deformation only within the contact line, and also outside the contact region, respectively. The characteristic function of the resultant delay differential equations has infinite many eigenvalues, but only a few (if any) of them that locate on the right half of the complex plane, which leads to instability, i.e. shimmy. Linear stability analysis shows that the Delayed Tyre Model predicts some extra instability with a new vibration mode in certain parameter combinations. Conclusions of the advantages and disadvantages of this tyre model are obtained.

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CP42

Dynamics of Some Rational Maps of the Real Plane

We study the dynamics and bifurcations in families of complex analytic polynomials perturbed by a non-complex-analytic singular term. We also contrast these perturbations with complex-analytic perturbations. The general families considered are of the form

$$z^n + c + \beta(t/z^d + (1-t)/\overline{z}^d)$$

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CP43

Topological Data Analysis for Detecting Dynamic State Changes via Nodal Networks

In this talk, we explore topological measures for identifying the state of a dynamic system by examining its time series. Specifically, we investigate embedding time series into a graph via two different methods: 1) Using Takens embedding and then mapping the embedded points into a network by connecting each node to its k-nearest neighbors, and 2) constructing ordinal networks by running a window of size n over the time series. The latter converts the time-indexed time series into an integer-indexed sequence of symbols or motifs. We study the resulting network using metrics derived from their persistence diagrams, which are constructions from Topological Data Analysis (TDA). We apply our approach to several examples, show the results for both types of embeddings using novel TDA-based metrics, and compare the resulting scores to existing methods which utilize graph-based metrics.

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CP43

An Optimization Algorithm for 3D Crater Estimation by using 2D NASAs Asteroids Open Data

Planetary astronomy is a science that focuses on objects in space where the size varies from micrometeoroids to gas giants. Without a doubt, asteroids are a remarkable class of astronomical objects that mainly exist at the asteroid belt in our Solar System. There exist millions of asteroids where their surface analysis can provide useful information for deeper space exploration. In particular, asteroids surface is continuously changed where the location, number and the size of the craters reflect the space activity by the collision of meteors, comets and other objects. Hence, an optimization algorithm is developed by using digital image processing techniques in order to analyze automatically 2-D NASAs open data, without any human intervention. The algorithm extracts significant 3D morphological information by taking into consideration light characteristics and shadows that appear in the 2D images. It is well known that the way an object reflects light depends not only on its the percentage of light it reflects but also on the illumination angle. The great amount of processing data is an additional issue which increases problems complexity. In conclusion, the proposed algorithm provides estimated metrics for the depth and location of the abnormalities on the corresponding surface by using 2D digital images.

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CP43

Optimal Control of Chaotic Systems using a Preconditioned Multiple Shooting Shadowing Algo-

rithm

Standard sensitivity analysis methods (such as the well-known adjoint method) fail when the considered dynamical system exhibits chaotic behaviour. The recent Multiple Shooting Shadowing (MSS) method [Blonigan & Wang, 2018] however, can be used to compute derivatives of a time-averaged objective to system parameters for chaotic systems. Its use for the optimal control of complex chaotic flows is promising, but remains unexplored due to the method's slow convergence. We propose a block diagonal preconditioner (see [Shawki & Papadakis, https://arxiv.org/abs/1810.12222]), which is based on a partial singular value decomposition of the MSS constraint matrix. The preconditioner can be computed using matrix-vector products only, and is fully parallelised in time. Test cases are conducted for two chaotic systems; the Lorenz system and the 1D Kuramoto Sivashinsky (KS) equation. The combination of the preconditioner with a regularisation method leads to tight bracketing of the eigenvalues to a narrow range. This results in a significant reduction in the number of iterations, and renders the convergence rate almost independent of the number of degrees of freedom of the system, and the length of the trajectory that is used to compute the time-averaged objective. Preconditioned MSS is then used in the optimal control of the KS equation. Optimal control of more complex flows (such as the flow around an airfoil) using preconditioned MSS will be considered and presented in due course.

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CP44

Nonlinear Time-Series Analysis of a Paleoclimate Temperature Record from Antarctica

Until recently, the resolution of ice-core records was inadequate for nonlinear time-series analysis. Advances in laboratory techniques have greatly improved this situation. The isotopic content of the WAIS Divide core, for instance-the longest continuous and highest-resolution such record yet recovered from Antarctica-was measured at 0.5 cm intervals. This is an order of magnitude better than older cores from both poles, which lump years or even decades worth of climate information into each data point. These particular isotopic measurements-ratios of the heavy to light isotopes of hydrogen and oxygen-are considered to be proxies for Earth's temperature. Taking a nonlinear dynamics view of this, we consider these two traces as the outputs of two different measurement functions sampling the dynamics of the paleoclimate and use the method of delays to reconstruct those dynamics over the past 31,000 years. There are a number of unique challenges involved in this analysis. The measurements are spaced unevenly in time because of the progressive downcore thinning of the ice. The relationship between depth and age, and hence the timeline of the data, is uncertain. And the ice itself has undergone tens of thousands of years of unknown natural processes, which can affect both the data values and the timeline. We discuss all of these effects from the standpoint of nonlinear time-series analysis, including change-point detection, fractal dimension, and Lyapunov exponents.

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CP44

Cascading Tipping Points in Dynamical Systems and Paleoclimate

In the framework of cascading tipping points, networks of dynamical systems exhibit cascades where a critical transition in one sub-system triggers a critical transition in one or more other sub-systems. The individual transitions may arise via noise- or rate-induced switching in between attractors, or via slow passage through a bifurcation. This yields a variety of different cascading scenarios. Real-world analogues might exist in the climate, where several subsystems could undergo chains of critical transitions under future anthropogenic climate change. Recent studies indicate a role of cascading effects leading up to past climate changes. Paleoclimate data and models suggest that so-called Dansgaard-Oeschger events arise from sequential shifts in the atmospheric circulation, sea ice cover and ocean circulation. We hypothesize a tipping cascade as underlying mechanism, and construct a conceptual model with sea ice and ocean components, which both show a double fold bifurcation structure. Changing atmospheric conditions are modeled by a slow parameter drift or additive noise. The ocean component permits rate-induced tipping, yielding a rich array of tipping cascades. With this system we explore mathematical signatures of tipping cascades and implications for paleoclimate changes. We assess the statistical significance of early warning signals related to critical slowing down and changes in cross-correlation, as well as the transient behavior of the probability density.

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CP44

Analysis of Oyster Reef Patterns in Remotely Sensed Data

Despite being a resilient species, the Eastern oyster population has plummeted over the last century due to unregulated harvesting, effects of pollution and prevalence of disease. Because the Eastern oyster population serves a variety of ecological and economic functions, restoration has become of critical importance. While factors such as water temperature, salinity, bottom hardness, and food availability are important for successful oyster restoration, water flow and geophysical processes remain key aspects of successful reef development and have not been investigated

in detail. Three oyster reef configurations are thought to dominate the landscape string reefs (perpendicular to flow), fringing reefs (parallel to flow) and patch reefs (no particular orientation). Currently, the mechanism of this pattern formation and the role that the reefs orientations to flow play in their persistence are not well understood. We use a Geographic Information System (GIS) approach to investigate the spatial self-organization of historic oyster reefs in conjunction with hydrodynamics and topography by analyzing remotely sensed data of oyster reefs. Two types of reefs are investigated subtidal reefs (using sonar imagery) and intertidal reefs (using aerial imagery). The ultimate goal is to achieve a better understanding of reef morphology and inform oyster restoration efforts in determining suitable locations and configurations for artificial reef construction.

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CP45

Complex Dynamics in a Fractional-Ordered Prey-Predator Model

In this work, a fractional ordered prey-predator model is investigated. A sufficient condition for existence and uniqueness of the solution of the discretized system is determined. Jury stability test is applied for the occurrence of stability of equilibrium point of the discretized system. The system undergoes Neimark-Sacker and flip bifurcation under certain conditions. Numerical simulation suggests rich dynamical behavior including limit cycles, quasi-periodicity and chaos. The system exhibits a wide range of dynamical behaviors for key parameter fractional order α.

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CP45

Efficient Computational Approaches for Treatment of Transformed Path Integrals

We present efficient computational approaches for treatment of path integrals in the transformed path integral (TPI) method, a novel path integral-based method for the solution of the Fokker-Planck equation. TPI approaches allow us to calculate the time evolution of probability density functions (PDFs) associated with dynamical systems in a transformed computational domain where more accurate representations of PDFs may be obtained. In grid-based implementations of TPI, the short-time propagator is realized as a matrix and the PDF propagation is performed through a matrix-vector multiplication operation. Utilizing the properties of the propagator matrix, we develop two computationally efficient grid-based implementations of TPI; (1) reduction to a banded matrix and (2) separation of the source and target terms in the propagator matrix. While the former takes advantage of concentration of the transition probability density around a peak probability target state, the latter is based on a Taylor series expansion of the Gaussian kernel in the propagator matrix. In either approach, we showcase the reduction in computational complexity associated with PDF propagation for comparable accuracies or fractional reduction thereof. The features of our proposed approaches are illustrated using comparisons with the standard TPI implementation for canonical problems in one-dimensional and multidimensional spaces.

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CP46

Particle Capture and Manipulation in Vibrationally Excited Viscous Flows

An arrangement of solid bodies vibrating in a planar viscous fluid at low Reynolds number can excite a streaming flow with closed time-averaged Lagrangian streamlines defining one or more circulatory cells. An inertial particle with finite size in such a flow will follow a time-averaged trajectory that differs from that of an infinitesimal fluid particle and that depends on the distribution of such cells. The centers of the cells act as regions of attraction for inertial particles, allowing the controlled capture and transport of particles based on the controlled manipulation of cell topology and geometry. This talk will address the reduced-order modeling of inertial particle dynamics within an array of vibrating circular cylinders in a planar fluid at low Reynolds number and the development of control strategies for particle manipulation through parametric variations in cylinder vibration.

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CP47

The Devil Is in the Spectrum: The Eigenvalue Distribution of the Discrete Preisach Memory Model

The discrete Preisach memory model generically appears in the description of systems with hysteresis. The spectrum of its transition matrix is therefore of interest in understanding its dynamical properties. Here we present an explicit representation for the spectrum by first showing that the characteristic polynomial is the product of Chebyshev polynomials with certain well-defined multiplicities. The eigenvalue distribution is then explicitly calculated and is shown to be associated with a scaled Devil's staircase function,

$$f(x) = \sum_{n=1}^{\infty} \frac{\lfloor nx \rfloor}{2^n}.$$

The eigenvectors are also explicitly calculated.

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CP47

Symbolic Dynamics Applied to the Periodically Driven Hill's Vortex

Homotopic Lobe Dynamics (HLD) is a symbolic method capable of describing the topological dynamics of a fully 3D map. We apply this method to the numerically computed periodically driven Hill's vortex flow. Passive tracers are drawn into the vortex and then ejected. We observe the time these tracers remain in the vortex as a function of two impact parameters. Using this data we derive the topological dynamics of the flow. We compare the computed data to the results predicted by HLD. This method also produces an effective lower bound for the topological entropy of the system.

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CP48

Variable Stepsize, Variable Order Methods for Partial Differential Equations

Variable stepsize, variable order (VSVO) timestepping methods are commonly used to solve difficult ODEs. Existing VSVO methods are computationally complex, and do not scale well for PDE applications with many unknowns. However, these methods are essential to achieve assured accuracy over long time intervals for stiff problems. I will discuss new methods we've developed that bridge the gap between what is computable for ODEs and PDEs.

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CP48

Implementation of a Gough-Stewart Platform Controller Using the Levenberg-Marquardt Algorithm

This research presents findings of implementing a Gough-Stewart Platform using Levenberg-Marquardt Algorithm for state space based control. The Gough-Stewart platform is a system allowing for control of the six degrees of freedom of a rigid body in space, controlled by six actuators functioning in parallel. To have state-feedback the Levenberg-Marquardt algorithm, a least-squares method, was applied to estimate the system state when supplied with measured lengths. This method was successfully tested and applied for state-feedback control. Initial system modeling was done in linearized state-space but was later moved to the s-domain when the state-space equations represented each state as independent of one another. Details of the fabrication of the Gough-Stewart platform, the selection of actuators and implementation of the control law to the platform are presented herein. To both reduce the stabilization time of the system and reduce the effects of individual state change on others a controller was designed based on actuator length control. Since the nonlinear nature of the Gough-Stewart platform would consequently require nonlinear changes in length of the actuators, a path for each actuators length as the system moved from its current states to its set states would allow for the length control to take incremental steps towards the set states. Results for control of the platform x, y and z translation and roll, pitch and yaw are summarized in the presentation.

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CP50

On the Impact of an Elastoplastic Missile into a Robust Structure

Motivated by the grave consequences of an aircraft impact into robust engineering structures like nuclear power plants, we investigate the time dependent reaction force during the impact of a crushing elastoplastic missile into an elastic target. We find that a simple dimensionless number gives accurate prediction on the impact force. We find that the peak force can be higher than that predicted from previous theories due to a resonant vibration in both the missile and the target.

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CP50

Topological Feature Vectors for Chatter Detection in Turning Processes

Machining processes are most accurately described using complex dynamical systems that include nonlinearities, time delays and stochastic effects. Due to the nature of these models as well as the practical challenges which include time-varying parameters, the transition from numerical/analytical modeling of machining to the analysis of real cutting signals remains challenging. Some studies have focused on studying the time series of cutting processes using machine learning algorithms with the goal of identifying and predicting undesirable vibrations during machining referred to as chatter. These tools typically apply a sim-

ilarity measure to the time series combined with a k-NN classifier. In this study, we present an alternative approach based on featurizing the time series of the cutting process using its topological features. We utilize support vector machine classifier combined with feature vectors derived from persistence diagrams, a tool from persistent homology, to encode distinguishing characteristics based on embedding the time series as a point cloud using Takens embedding. We present the results for several choices of the topological feature vectors, and we compare our results to the state-of-the-art using experimental time series from a turning cutting test.

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CP51

Time-Periodic Inertial Range Dynamics

Over the past three decades, spectacular progress has been made in the study of fluid turbulence with tools of computational dynamical systems theory. The onset of turbulence in elementary geometries has been explained with period doubling cascades, heteroclinic and homoclinic cycles and boundary crises. The relevant invariant solutions can be computed directly from well-resolved simulations of Navier-Stokes flow. However, these results were restricted to computational domains small compared to a typical experimental setup and low-Reynold number flows. Recently, various attempts have been made to overcome these limitations. Spatially localized solutions in large domains have been shown to be relevant for transitional dynamics, e.g. in the asymptotic suction boundary layer. The extension to high-Reynolds number flows, in contrast, is an open challenge. In this work, we present the first ever evidence that developed turbulence can be studied through invariant solutions, in particular through relative unstable periodic orbits (UPOs). We computed such a UPO in large eddy simulation of a fluid subject to a constant body force and periodic boundary conditions. The energy spectrum of this orbit compares well to that of Navier-Stokes flow at the mixing transition that signals the onset of fully developed turbulence. We show that the UPO exhibits multi-scale dynamics in the inertial range and examine the Floquet spectrum and its relation to the dynamics of interacting vortices.

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CP52

Application of a Stabilized Reduced-Order Method with Inputs and Outputs for Reservoir Simulations

Reservoir simulations are essential tools for subsurface flow modeling to characterize important energy related physical processes active in the reservoir. Optimization of field performance require large number and dimension of flow simulation sets and this task is computationally very demanding. In this paper a reduced-order modeling (ROM) technique is utilized to reduce the simulation time of subsurface flow models.The ROM technique considered here is based on dynamic mode decomposition (DMD), an unsupervised data-driven method for representing high-dimensional and nonlinear dynamical systems. This paper utilizes an extension of DMD to construct an input-output reduced-order model for linear time-invariant (LTI) systems called input-output dynamic mode decomposition (ioDMD). In addition, a post-processing procedure is applied to stabilize ioDMD identified model using an optimization-based stabilization strategy. In this work, ioDMD is first benchmarked against problems which have been used to compare contemporary black-oil simulators for years. Then, the methodology is applied to results of bigger size flow simulations which are setup for a real data test case. ioDMD system identification is tested to be efficient to obtain better representation of target data in a reduced-order fashion. In addition, a highly complex optimization technique is shown to be viable for stabilizing the derived system while retaining important properties in system identification.

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CP52

Dynamic Analysis of Stochastically Parametered Inhomogeneous Structures using PCE Based ROM

This study focusses on the development of a novel reduced order model (ROM) for the dynamic analysis of stochastically parametered linear large scale dynamical systems (LSDS). The system properties and the loadings are assumed to have spatio-temporal random inhomogeneity and are modelled as non-Gaussian random fields. Finite element (FE) is employed for mathematical modelling of the stochastic LSDS. The corresponding mathematical model involves large ordered FE matrices with random coefficients. Numerical analysis of such systems therefore require extensive computer memory and prohibitive computational costs. These difficulties are bypassed by building on a recently developed polynomial chaos expansion based system equivalent reduction expansion process framework. The underlying principle lies in arbitrarily selecting a set of FE nodes and reformulating the governing equations through linear transformations. This study extends this formulation by considering a random perturbation matrix which contains spatial (noisy) measurements about system parameters, which serve as an input to the mathematical model. Applying appropriate linear transformations enable rewriting the equations in terms of the deterministic FE matrices of LSDS and random perturbations. Here only single operation of the deterministic LSDS matrices is required, which makes it computationally efficient for stochastic analysis. The efficiency of the framework is demonstrated through numerical examples.

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CP53

Compressed Stochastic Digital Twins

Inference and prediction of performance and potential hazards in complex aircraft systems is critical to flight safety. To this end, a simulated model of these systems is kept concurrently with the physical system. These 'digital twins' are often computationally very expensive to model with high fidelity, making real-time analysis intractable. In particular, a digital twin of the axial-flow compressor system in a jet engine can be modeled using a coupled PDE-ODE model. This system experiences a Hopf bifurcation based on the throttling strategy of the compressor and undergoes instabilities known as surge and rotating stall for throttle parameters below a certain threshold. These instabilities produce cyclic variations in the axial airflow through the compressor which can cause substantial negative performance effects. To account for uncertainties in modeling and boundary conditions, we consider a stochastic version of the axial-flow compressor system; hence a coupled SPDE-SDE model. We adapt theory from compressive sensing and sparse systems identification to isolate the most influential modes related to the surge and rotating stall instabilities. The aim is to produce a reduced stochastic system that can be modeled with much lower computational cost, possibly enabling real-time analysis, while still capturing the effects that are most relevant to engine performance and flight safety.

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CP53

Transitions in Dynamical Systems with Bounded Uncertainty

As an alternative to stochastic differential equations, the assumption of bounded noise can offer a flexible and transparent paradigm for modelling systems with uncertainty. We study the stability and bifurcations in dynamical systems with bounded noise, using a set-valued dynamics approach. Our aim is to model a random dynamical system represented by a mapping $f : R^d \to R^d$ with a bounded noise of size $\varepsilon > 0$,

$$x_{n+1} := f(x_n) + \xi_n,$$

where for all $n \in \mathcal{N}$ the ξ_n are random variables taking values in $\overline{B_\varepsilon(0)} := \{x \in R^d : \|x\| \le \varepsilon\}$. The collective behaviour of all future trajectories is then represented by a set-valued mapping $F : \mathcal{K}(R^d) \to \mathcal{K}(R^d)$, defined by

$$f_\varepsilon(A) := \overline{B_\varepsilon(f(A))},$$

where $\mathcal{K}(R^d)$ is the set of all compact subsets of R^d. We describe in R^2 the geometric properties of invariant sets M, defined by $f_\varepsilon(M) = M$, and provide a classification result for the singularity points on the boundary ∂M. The geometry is quite well understood in R^2, but becomes increasingly more complicated in higher dimensions. In order to illuminate the loss of stability near a set-valued bifurcation, we will discuss the boundary dynamics on ∂M, and present a numerical scheme for tracking the boundaries of minimal invariant sets in R^2.

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CP54

Curvature Based Parameter Selection for Delay-Coordinate Reconstruction

We propose a curvature-based approach for choosing good values for the time-delay parameter τ in delay-coordinate reconstructions. The idea is based on exploiting the geometry of delay reconstructions. If the delay is chosen too small, the reconstructed dynamics are flattened along the main diagonal of the embedding space; too-large delays, on the other hand, can overfold those dynamics. Calculating the curvature of a two-dimensional delay reconstruction is an effective way to identify these extremes, and to find a middle ground between them, since both the sharp reversals at the ends of an insufficiently unfolded reconstruction and the folds in an overfolded one create spurious spikes in the curvature of a 2D projection of the reconstructed dynamics. We quantify this by computing various statistics over the Menger curvature of 2D reconstructions for different time delays. We argue that this result generalizes to higher-dimensional embeddings of the dynamics, and we show that the first minimum of the variance of the Menger curvature as a function of τ is an effective heuristic for choosing the time delay. In addition, we show that this heuristic is useful, even in cases where the gold standard, average mutual information, fails (e.g., infinite-memory processes).

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CP54

A Probabilistic Takens Theorem

Let $X \subset \mathbb{R}^N$ be a Borel set, μ a Borel probability measure on X and $T : X \to X$ Lipschitz and injective. Assume that $k \in \mathbb{N}$ is strictly greater than the (lower box-counting) dimension of X. We prove that if the sets of p-periodic points for $p = 1, \ldots, k-1$ are of sufficiently small dimension, then for a typical polynomial perturbation $\tilde{h}$ of a given Lipschitz map $h : X \to \mathbb{R}$, the k-delay coordinate map $x \mapsto (\tilde{h}(x), \tilde{h}(Tx), \ldots, \tilde{h}(T^{k-1}x))$ is injective on a set of full measure μ. This is a probabilistic version of the Takens delay embedding theorem as proven by Sauer, Yorke and Casdagli. We also provide both dynamical and non-dynamical probabilistic embedding theorems involving the Hausdorff dimension. The non-dynamical version strengthens a previous result by Alberti, Bölcskei, De Lellis, Koliander and Riegler. In both cases, the key differences with the non-probabilistic counterparts are the reduction of the number of required measurements from $2\dim(X)$ to $\dim(X)$ and the fact that one can consider the Hausdorff dimension instead of the box-counting dimension. This is a joint work with Krzysztof Barański and Adam Śpiewak. https://arxiv.org/abs/1811.05959

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CP100

A Preferential Attachment Graph Model with Triangles

Preferential attachment models are a common class of graph models which have been used to explain why power-law distributions appear in the degree sequences of real network data. One of the things they lack, however, is higher-order network clustering, including non-trivial clustering coefficients. We present a specific Triangle Generalized Preferential Attachment Model (TGPA) that, by construction, has nontrivial clustering, and use it to explore power-law distributions in the spectra.

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CP100

Optimal Structure and Parameter Learning of Ising Models

Reconstruction of the structure and parameters of an Ising model from binary samples is a problem of practical importance in a variety of disciplines, ranging from statistical physics and computational biology to image processing and machine learning. The focus of the research community shifted toward developing universal reconstruction algorithms that are both computationally efficient and require the minimal amount of expensive data. We introduce a new method, interaction screening, which accurately estimates model parameters using local optimization problems. The algorithm provably achieves perfect graph structure recovery with an information-theoretically optimal number of samples, notably in the low-temperature regime, which is known to be the hardest for learning. The efficacy of interaction screening is assessed through extensive numerical tests on synthetic Ising models of various topologies with different types of interactions, as well as on real data produced by a D-Wave quantum computer. This study shows that the interaction screening method is an exact, tractable, and optimal technique that universally solves the inverse Ising problem. Finally, we discuss a recent generalization of the interaction screening method that allows for a provable reconstruction of arbitrary discrete graphical models with non-binary alphabets and multi-body interactions.

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CP101

Concurrency and Reachability in Tree-Like Temporal Networks

Network properties govern the rate and extent of various spreading processes, from simple contagions to complex cascades. Recently, the analysis of spreading processes has been extended from static networks to temporal networks, where nodes and links appear and disappear. We focus on the effects of accessibility, whether there is a temporally consistent path from one node to another, and reachability, the density of the corresponding accessibility graph representation of the temporal network. The level of reachability thus inherently limits the possible extent of any spreading process on the temporal network. We study reachability in terms of the overall levels of temporal concurrency between edges and the structural cohesion of the network agglomerating over all edges. Here, the structural cohesiveness is defined as the number of node-independent paths between two nodes, and the temporal concurrency is specifically defined as a probability that two randomly selected links overlap in time. We use simulation results and develop heterogeneous mean field model predictions for random networks to better quantify how the properties of the underlying temporal network regulate reachability. The model prediction shows good agreement with the numerical reachability in the low temporal concurrency regime.

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CP101

Node Connectivity and Centrality Drive Pathogen Spread in Human Mobility Networks

An algorithm is introduced to understand the impacts of network topology on the spread of infectious diseases in a human mobility network. A Susceptible-Infected-Recovered (SIR) model is a mathematical framework used in epidemiology to describe the dynamics of an infectious disease. Individuals from an at-risk population are classified among three states, and differential equations describe the rate of transition between states based upon transmission and recovery rates derived from empirical data. A metapopulation SIR model is an elaboration of the basic model that considers a network of population centers or nodes, each with its own nested SIR model, and rates of human migration between nodes. We investigate how network properties influence the time between arrival of the first infected individual to a node and establishment of transmission within a node. A Monte Carlo method is used to analyze several population networks exhibiting properties of small-world, scale-free, and Delaunay triangulation models to determine the effects of connectivity, clustering, and centrality on the rate of spread of the epidemic. This project examines how global network properties affect the time duration between the introduction of the disease to the entire network and the introduction to each individual node, and how local network properties affect the time between the introduction and establishment of local transmission within each node.

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CP102

Recovering Planted Hitting Sets in Hypergraphs

In various application areas, networked data is collected by measuring interactions involving some set C of core nodes. This results in a network dataset containing the core nodes along with a potentially much larger set F of fringe nodes that all have at least one interaction with a core node in C. Here, we consider the scenario where the measured data takes the form of a hypergraph; for example, the core nodes might be a set of individuals under surveillance, and we observe the attendees of meetings involving at least one of the individuals. We then study the problem of core recovery: if we observe the hypergraph but not the labels of core and fringe nodes, can we recover the core that is "planted' in the hypergraph? Such problems arise in cyber security, where a set of emails could get released through by the hacking of a few individual accounts (in this case, the hacked accounts form the core, and each email makes a hyperedge). We provide theory and numerical experiments to show that core recovery is indeed possible. The crux of our analysis and algorithm is that the core nodes are a *planted hitting set* of the hypergraph. Formally, we consider a hypergraph $G = (V, E)$ where V is a set of nodes and E is a set of subsets of V of size at least two called hyperedges. In particular, there is some unidentified subset $C \subseteq V$ that is designated as the set of "core nodes' – and our goal is then to find C, knowing that C is a hitting set of G.

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CP102

Configuration Models of Random Hypergraphs and their Applications

Many empirical "networks" – such as collaboration networks; co-occurence networks; and communication networks – are intrinsically polyadic, with multiple entities interacting simultaneously. Historically, such polyadic data has been represented dyadically via a standard projection operation, which can have uncontrolled imnpact on downstream analysis. In this work, we develop a class of random null models for polyadic data in the framework of hypergraphs, circumventing the need for projection. These nulls are uniform on the space of hypergraphs sharing common degree and edge dimension sequences, and thus provide direct generalizations of the classical configuration model of network science. We also derive Metropolis-Hastings algorithms in order to sample from these spaces. We then apply the model to study three applications in network data analysis. In each application, we emphasize the importance of randomizing over hypergraph space rather than projected graph space, showing that this choice can dramatically alter directional study conclusions and statistical findings. For example, we find that many of social networks we study are less clustered than would be expected at random, a finding in tension with much conventional wisdom within network science. Our findings underscore the importance of carefully choosing appropriate null spaces for polyadic relational data, and demonstrate the utility of random hypergraphs in many study contexts.

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CP102

From Connections to Relationships with Cellular Sheaves

Network science typically focuses on the connectivity properties of a network structure; that is, it investigates the consequences of patterns of connection between entities. In many situations, it is desirable to model more than simply the presence or absence of a connection between nodes, and explicitly describe the nature of the connection, or

the relationship between nodes that the connection implies. Cellular sheaves, a tool from algebraic topology, describe the way data varies across a combinatorial space such as a graph. They provide a principled way to model algebraic relationships between nodes, and offer tools for the global analysis of data associated with the network structure. This talk will define cellular sheaves and outline areas of application to the study of networks.

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CP103

Critical Network Cascades: Why Locally Tree-Like Approximations Work, when they Breakdown, and how to Correct Them

Cascade processes on networks, also referred to as avalanches on networks, are widely applicable to a variety of contexts, such as networks of neurons and epidemiology. Previous work on the theory for cascades has generally been restricted to networks that are locally tree-like or within a narrow class of network topologies. We discuss cascade models that allow for multiple re-excitations of each node, and discuss the reasons for deviations of predictions of network criticality from a tree-based theory, in terms of the motifs present in the network. The results we derive here apply to networks with more general topologies, by explicitly accounting for simple motifs that break the locally tree-like approximation. In particular, we focus on the bi-parallel motif, the smallest motif relevant to the failure of a tree-based theory for discrete-time processes on directed networks, and we derive the corrections due to such motifs on the conditions for criticality, as dictated by the distributions of avalanche durations. We verify our claims on computer-generated networks designed to have a large number of these motifs, and we demonstrate that the observed deviations from criticality are well predicted by the derived theory.

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CP103

Coupled Point Processes and Network Evolution Dynamics

We consider a model in which a point process and a temporal network are coupled, and we apply it to studying gang involvement. We model crime as a self-exciting point process that is coupled to a temporal affiliation network in which edges are in an active or inactive state. The dynamics of the network are driven by crime such that the rate at which edges activate or deactivate is affected by crime events. We use this model to explore the relationship between gang involvement and safety. In particular, we are interested in comparing with whom individuals choose to affiliate in response to crime: whether it is with their gang or with non-gang associates such as family or friends. To test the extent to which safety needs can drive gang involvement, we hypothesize that social interactions should more closely adhere to gang-based communities shortly after eruptions of gang violence than during gaps between gang violence. We propose a model that consists of a temporal affiliation network, which is driven by the crime point process. Edges in the network activate and deactivate, representing the affiliation in which an individual is currently participating actively. We model these activations and deactivations based on conditional intensity functions that are coupled with the history of criminal events. We model the crime rate as driven by self-excitation as well as network affiliation. We explore the dynamics of this model both analytically and numerically.

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CP104

Understanding the Role of Seasonal Food Trade Networks in Invasive Species Spread

Trade and transport of goods is widely accepted as a primary pathway for the dispersal of invasive species. A temporal network-based approach is used to model market-to-market seasonal flow of agricultural produce and examine its role in pest spread. Through dynamical analysis of the network, we apply it to study the role of trade in the spread of a major pest of tomato, *Tuta absoluta*. Network analysis reveals that the roles of nodes as sources or hubs of spread changes with season, and hence makes the network more vulnerable to attacks. We apply a novel ranking-based inference approach to show that tomato trade is a driving factor in the rapid spread of this pest.

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Robust Budget Allocation

We consider the problem of budget allocation, where we are given a bipartite graph containing source nodes, target nodes, and edge weights that represent the probability of influence transmission between source and target nodes. We are given a fixed budget to distribute amongst source nodes in a way that maximally influence target nodes. In applications, the influence process and transmission probabilities are rarely exactly known. Therefore, we consider a robust approach where we only know the influence function up to an uncertainty set and must simultaneously optimize over all functions of the set. As a result, we are able to obtain a solution that is robust against the worst possible influence function. We extend the results of previous works on the related problem of influence maximization, as the notion of budgets requires us to consider the problem on the integer lattice rather than over set functions. Our method primarily leverages the diminishing returns submodularity property of influence functions. We employ a submodular saturation algorithm that achieves a bicriterion guarantee and demonstrate the optimality of our approximation algorithm, proving that better approximations cannot be achieved. Finally, we present experimental results that demonstrate our robust solution performs favorably in comparison to non-robust and heuristic methods.

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CP105

Structured Hierarchy in Online Dating Networks: 20,000 Leagues under the City

In systems of many individuals, interactions and their outcomes are often correlated with those individuals' positions in a hierarchy. While in most cases these positions are hidden, their presence is nevertheless revealed in the asymmetric patterns of interactions we observe. Modern courtship is a system in which asymmetries and hierarchies not only exist, but are encoded in our language: When a person says that someone is "out of my league,' that person has (i) observed that leagues or hierarchies of desirability exist, (ii) evaluated their own position, and (iii) compared it to the position of another, in this case, unfavorably. Do such hierarchies actually exist? If so, are they predictive of actual behavior, and how strict or noisy are they? Furthermore, are all desirability hierarchies the same, or are the "leagues' of one city meaningfully different than the leagues of another? We answer these questions by analyzing an extensive and anonymized dataset of messaging behavior in a popular online dating service. We first map observed patterns of reciprocated and unreciprocated messaging to a directed network of comparisons and then infer real-valued desirability ranks of each individual. After validating our ability to extract desirability hierarchies by simulating messaging behavior and confirming that our approach does indeed correctly discover latent ranks, we then use our method to answer questions about structured hierarchy in online dating, across U.S. cities.

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CP106

Tracking Tropical and Frontal Storms Driven Extreme Rainfalls over Japan using Complex Networks

Predicting extreme rainfall is a challenging but a necessary task due to the concomitant natural hazards, such as flash floods or landslides. Theory of network science offers alternative tools to explore the spatiotemporal properties of extreme rainfall, which might reveal the predictive behavior of those extremes. In this case study, we use complex network metrics in conjunction with a nonlinear correlation measures of event synchronization to study extreme rainfall generated by the tropical and frontal (Baiu) storms over Japan. These two weather systems trigger extreme events in two discrete seasons; the Baiu front dominates the rainfall events from June to July, whereas tropical storms activity peak at August, and are active until November. We found that the spatial scales involved in the Baiu driven rainfall extremes are consistently more extensive than the extremes due to tropical storms. We further delineate an east-west extending horizontal region of coherent rainfall during Baiu season based on network communities, whereas nearly all Japan fall in one single coherent rainfall community during tropical storm season.

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CP106

Bounds on the Sampling Error of Mean Differential Entropy of Subgraphs

A common task in physics, information theory, and other fields is the analysis of properties of subsystems of a given system. Given the covariance matrix M of a system of n coupled variables, the covariance matrices of the subsystems are principal submatrices of M. The rapid growth with n of the set of principal submatrices makes it impractical to exhaustively study each submatrix for even

modestly-sized systems. It is therefore of great interest to derive methods for approximating the distributions of important submatrix properties for a given matrix. Motivated by the importance of differential entropy as a systemic measure of disorder, we study the distribution of log-determinants of principal $k \times k$ submatrices when the covariance matrix has bounded condition number. We derive upper bounds for the right tail and the variance of the distribution of minors, and we use these in turn to derive upper bounds on the standard error of the sample mean of subsystem entropy. Our results demonstrate that, despite the rapid growth of the set of subsystems with n, the number of samples that are needed to bound the sampling error is asymptotically independent of n. Instead, it is sufficient to increase the number of samples in linear proportion to k to achieve a desired sampling accuracy.

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CP106

Stochastic Defense Against Complex Grid Attacks

We describe strong, mathematically justified defense mechanisms to protect a power grid in the event of a cyber-physical attack under the AC power flow model. Existing literature details construction of attacks over the network wherein the adversary can modify the demand as well as the signals and remain consistent from the perspective of the network operator. We propose a complex attack scheme and show numerical results on significant attacks on networks with more than 2,300 buses. We describe two different algorithms to discover the affected zone. These algorithms rely on random changes to power injection at the grids generators to alter the voltages and thus help to unmask inconsistencies. The first algorithm causes discrepancies on sensors over branches that connect the attacked area with the rest of the grid. In the second defense, the network operator learns voltage phase angle covariance matrix which changes depending on the nature of attack and injections. Under technical conditions, we describe impossibility results for detecting changes in a covariance matrix by determining the minimum number of samples necessary for covariance estimation. The effect of the proposed defense strategies is incorporated by allowing the covariance matrix to smoothly vary within a prescribed budget of variation. From the perspective of the system operator, we characterize the rate of artificial injections to deceive the adversary, thereby providing rate-optimal defense mechanisms.

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CP107

Synaptic Plasticity in Correlated Balanced Networks

Neurons in the cortex exhibit temporally irregular, but correlated spiking during ongoing sensory experiences. It is still unclear what mechanisms drive the emergence of global activity patterns, while supporting local fluctuations. Models that exhibit an emergent balance between excitation and inhibition produce responses remarkably similar to those in the cortex, but in their original version, they lead to asynchronous states. Recently, mechanisms supporting correlated activity have been proposed. Yet no theories about how this activity is maintained and shaped by changes in synaptic weights exist. How do emergent patterns in correlated activity drive changes in synaptic architecture, and how do these changes, in turn, shape the activity of the network? Could changes in synaptic architecture self-amplify, and drive the network out of balance? To answer these questions, we develop a general theory of plasticity in correlated balanced networks. We show that balance is attained and maintained both in asynchronous and correlated states. We find that correlated activity drive significant changes in the synaptic connectivity and firing rates under an inhibitory plasticity rule. However, for excitatory-to-excitatory plasticity rules, correlations do not impact weights and firing rates. Our general framework allows us to determine under which conditions correlated activity drives changes in synaptic connectivity, which in turn, shape activity patterns in balanced networks.

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CP107

Approximating Network Reliability and Birnbaum Importance

The Moore-Shannon network reliability [E. F. Moore and C. Shannon, Reliable circuits using less reliable relays, Journal of the Franklin Institute, 1956] is a statistical physics partition function for a dynamical system defined on a network of interactions. Birnbaum importance [Z. W. Birnbaum, On the importance of different components in a multicomponent system, in P. R. Krishnaian, ed., Multivariate Analysis – II, 1969] measures the contribution of sets of interactions to the reliability. Together, they provide a rigorous formalism for analyzing the sensitivity of dynamics to network structure. Unfortunately, exact evaluation of the reliability or the importance is impractical because of the computational complexity. We demonstrate the feasibility of using approximation techniques borrowed from statistical physics – specifically, MC simulations and strong- and weak-coupling expansions – to render this formalism practical even for large, complex networks. We also explore the counter-intuitive nature of solutions to the

common question, "What are the most important elements of the network?" using results borrowed from computer science – specifically, properties of solutions to satisfiability problems.

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MS1

Early Events During Hepatitis B Virus Infection

Experimental studies in non-human primates inoculated with hepatitis B virus have shown that virus dose influences the kinetics of virus spread and the disease outcome. In particular, high and low doses lead to 100% liver infection, while intermediate doses lead to less than 0.1% liver infection. To determine the relationship between virus dynamics, percentage of liver infection, and immune priming we developed an in-host mathematical model that considers the effects of cellular immune responses in controlling the disease. We fitted the model to data and predicted correlations between dose size, the timing of the immune response, the potency of immune effects, and disease outcome. Such results can guide our understanding of the virus-host dynamics that control the virus or permit a transition to chronic disease.

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MS1

Heterogeneous HIV Viral Rebound Dynamics Following Treatment Interruption

Antiretroviral therapy (ART) effectively controls HIV infection, suppressing HIV viral loads. Typically suspension of therapy is rapidly followed by rebound of viral loads to high, pre-therapy levels. Indeed, a recent study showed that approximately 90% of treatment interruption study participants show viral rebound within at most a few months of therapy suspension, but the remaining 10%, showed viral rebound some months, years, or maybe permanently, after ART suspension. We will discuss our branching process model to gain insight into these post-treatment dynamics. Specifically we provide theory that explains both short- and long-term viral rebounds, and post-treatment control, via a branching process with time inhomogeneous rates, validated with data from Li et al. (2016). We will discuss the associated biological interpretation and implications. Armed with the model, we will also discuss epidemiological implications of treatment suspension. ART is invaluable in preventing onwards transmission by controlling infection; similarly, individuals with controlled infection post-ART will have low risk of transmission. However that risk will increase at viral rebound, at which time an individual would re-initiate ART. We will discuss model predictions that can be used to guide management of treatment suspension.

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MS1

On the Importance of Spatial Structure in Within-Host Models of Viral Dynamics and the Immune Responses

There are growing evidences that viruses often spread spatially within a host. In this talk, I will present our recent works demonstrating the importance of considering spatial structure (implicitly or explicitly) in within-host viral dynamic models, and how this consideration can qualitatively affect our understanding and model predictions about the role of biological processes. First, I will talk about our modeling efforts to understand how the innate immune response protects us from virus invasion. The innate immune response, particularly interferon signaling, represents the body's first line of defense against viral invasions. We developed a series of models using ODEs, PDEs and cellular automata and found that considering the spatial structure of host cells is crucial to the understanding of how the interferon response in stopping an infection at the site of entry. Second, I will present our models to understand the role of influenza semi-infectious particles and defective interfering particles on modulating the within-host viral load. Again, we found that correctly incorporating spatial structure of host cells is critical to correctly predict the frequency of co-infection and thus the impact of semi-infectious and defective interfering particles. We argue that incorporating spatial structure is critical to the understanding and prediction of the impact of many key viral and host processes as well as therapeutic interventions.

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MS1

Incorporating Infected Cell Phenotypes into Models of Within-Host Viral Dynamics

Existing within-host models show remarkable structural similarity: they generally consider target cells to be either uninfected or infected, with the possibility of accommodating further resolution (e.g., eclipse phase cells). Recent findings, however, indicate that cellular coinfection is the norm rather than the exception for many viral infectious diseases. Cellular coinfection dynamics are generally not accommodated in current within-host models although they may be critical for understanding within-host dynamics, particularly if multiplicity of infection impacts infected cell phenotypes such as their death rate and their viral production rates. Here, we present a new class of within-host disease models that allow for cellular coinfection in a scalable, low-dimensional manner. The models we propose adopt the general structure of epidemiological macroparasite models that allow hosts to be variably infected by parasites such as nematodes and host phenotypes to flexibly depend on parasite burden. Specifically, our within-host models consider target cells as hosts and viral particles as macroparasites, and allow viral output and infected cell lifespans, among other phenotypes, to depend on a cells multiplicity of infection. We show with an application to influenza that these models can be statistically fit to viral load data and that they can reproduce notable, and new, features of within-host viral dynamics.

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MS2

Effective Networks: Predicting Network Structure and Critical Transitions from Data

Real-world complex systems such as ecosystems and neuron networks appear in most aspects of our everyday life. These complex systems are often made up of components, called nodes, which interact through an intricate network. By observing past behavior of such complex systems, it may be possible to predict behavior for some time in the future. However, it is much harder to predict new behavior of such complex systems when parameters change to a new range. In this talk, I will address this challenge by building an effective network, that is, a faithful model of the network consisting of the underlying local dynamics at each node and an accurate statistical description of the interactions. An effective network makes it possible to predict sudden changes in behavior – also known as critical transitions – that can lead to major disruptions in the complex system. The construct of an effective network only requires observations of the states of a representative sample of nodes for a relatively short time window. To illustrate the power of this approach, we show how to reconstruct the dynamics and structure of real networks, such as neuronal interactions in the cat cerebral cortex. In such network we were even able to predict critical transitions for parameters outside the observed range. These findings raise the possibility of network control to anticipate malfunctions in advance of sudden changes in behavior.

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MS2

Effects of Structural Changes in Network Dynamics: More is Less

We investigate the effects of structural perturbations of directed networks and their ability to synchronize. We focus on adding directed links in weakly connected networks having a strongly connected component acting as driver. When the connectivity of the driver is not stronger than the connectivity of the slave component, we can always make the network strongly connected while hindering synchronization. On the other hand, we prove the existence of a perturbation which makes the network strongly connected while increasing the synchronizability. Under additional conditions, there is a node in the driving component such that adding a single link starting at an arbitrary node of the driven component and ending at this node increases the synchronizability.

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MS2

Towards a Bifurcation Theory for Network Dynamical Systems using Hidden Symmetry

The specific connection structure of a network system may have a dramatic impact on the dynamical transitions and bifurcations that may be observed in the network. This talk is motivated by the question how one can predict and calculate this impact. For example: what exactly are the restrictions on local normal forms when a bifurcation occurs in a network? Can bifurcations in networks be classified on the basis of geometric properties of the network graph? It turns out that "hidden symmetry provides a helpful geometric framework / language for answering these questions. During this talk I will give an overview of recent results obtained with the help of hidden symmetry.

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MS2

Generalized Feedforward Networks: Algebraic Structure and Steady State Bifurcations

We investigate homogeneous coupled cell systems with underlying generalized feedforward structure. We show that these can be characterized via different equivalent definitions – in algebraic, order-theoretic and combinatorial terms. These definitions can be exploited in order to fully understand the fundamental networks (compare to B. Rink & J. Sanders. *Coupled Cell Networks and Their Hidden Symmetries*. SIAM J. Math. Anal. 2014). This allows us to determine possible center subspaces in dynamics with an underlying feedforward structure. Using all these results, the generic steady state bifurcations and their asymptotics for a given network with one-dimensional internal dynamics can be computed. Furthermore, we hint at a generalization to networks with higher-dimensional internal dynamics.

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MS3

Geometric Methods for Stochastic Dynamics

Dynamical systems arising in engineering and science are often subject to random fluctuations. The noisy fluctuations may be Gaussian or non-Gaussian, which are modeled by Brownian motion or α-stable Lévy motion, respectively. Non-Gaussianity of the noise manifests as nonlocality at a macroscopic level. Stochastic dynamical systems with non-Gaussian noise (modeled by α-stable Lévy motion) have attracted a lot of attention recently. The non-Gaussianity index α is a significant indicator for various dynamical behaviors. The speaker will overview recent advances in geometrical methods for stochastic dynamical systems, including random invariant sets, random invariant manifolds, stochastic bifurcation, mean exit time, escape probability, tipping time, most probable orbits, and transition pathways between metastable states.

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MS3

Homogenization of Periodic Linear Nonlocal Partial Differential Equations

We study the “periodic homogenization” for a class of linear nonlocal partial differential equations of parabolic-type with rapidly oscillating coefficients, associated to stochastic differential equations driven by multiplicative isotropic α-stable Lévy noise for $1 < \alpha < 2$. Our homogenization method is probabilistic. It turns out that, under some weak regularity assumptions, the limit of the solutions satisfies a nonlocal partial differential equation with constant coefficients, associated to a symmetric α-stable Lévy process.

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MS3

Slow Manifolds for Stochastic Systems with Non-Gaussian Stable Lévy Noise

This work is concerned with the dynamics of a class of slow-fast stochastic dynamical systems driven by non-Gaussian stable Lévy noise with a scale parameter. Slow manifolds with exponentially tracking property are constructed, and then we eliminate the fast variables to reduce the dimensions of these stochastic dynamical systems. It is shown that as the scale parameter tends to zero, the slow manifolds converge to critical manifolds in distribution, which helps investigate long time dynamics. The approximations of slow manifolds with error estimate in distribution are also established. Furthermore, we corroborate these results by some examples from biological sciences.

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MS4

Canard-Induced Mixed Mode Oscillations in Coupled FitzHugh-Nagumo Systems with Non-Symmetric Coupling

Mixed-mode oscillations (MMOs) and bursting oscillations are exhibited by systems with multiple timescale dynamics. Using techniques from bifurcation theory and singular perturbation theory and leveraging multiple time scales in the dynamics, one can describe the generation of these oscillations. In this talk, we review some of these techniques, and in particular we focus on the existence of canard and folded singularities and a global return mechanism to explain the onset of MMOs and bursting oscillations. As an illustration, we consider a unidirectional coupled FitzHugh-Nagumo system with 2-fast and 2-slow dynamics and provide a sufficient condition for onset of canard solutions and hence the generation of MMOs. The condition depends upon two key model parameters, the external current input only to the first system and the strength of the coupling from the first to the second systems.

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MS4

Canards as a Mechanism for Early Afterdepolarizations in Cardiac Cells

Early afterdepolarizations (EADs) are voltage oscillations observed during the repolarization phase of the cardiac action potential, and are a potentially lethal source of cardiac arrhythmia. Experiments have shown that the production of EADs can depend on the complex interplay between cellular ion channel properties, the extrinsic chemical environment, and the rate of sinoatrial pacing. However, the mechanisms by which alterations in these qualities induce EADs are not well understood. In this work, we analyze a canonical model of the electrical activity in a cardiac cell using geometric singular perturbation techniques. We demonstrate that the EADs are canard-induced mixed-mode oscillations, and explain how the EADs respond to both changes in their intrinsic properties and changes in their environment (especially periodic stimulation) from the viewpoint of canard theory.

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MS4

Canard-Mediated Complex Oscillations in a Rate Model

Complex oscillatory patterns arising in Neuroscience (excitability, spiking, bursting and subthreshold oscillations) have been intensively studied via mathematical modeling at multiple spatial and temporal scales, ranging from single cell to network level. These complex dynamics occur due to strong interaction of system variables across various timescales. Multiple-timescale dynamical systems and geometric singular perturbation theory provide an efficient ground to study those patterns. In this work we study the multiple-timescale dynamics of related rate models of developing spinal cord of embryo. The complete system contains 4 variables (2 fast and 2 slow), where the fast subsystem corresponds to a recurrent excitatory network with fast activity-dependent synaptic depression, and the slow variables represent the threshold for cell firing and slow activity-dependent synaptic depression. First, we reconsider three different combinations of the 4 variables and identify the link between the excitable structure of each model and canard solutions. Then, we discuss how a canard-mediated slow passage in the 4-dimensional model gives rise to mixed-mode bursting oscillations (MMBOs) and explains the sub-threshold oscillatory behavior which cannot be reproduced by any of the 3-dimensional models. Finally, we dissect the MMBOs in the 4-dimensional model by pointing out the relation between the sub-threshold oscillations and spike-adding mechanism to the bursts.

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MS4

Bursting in the Presence of alocally Separating Manifold

The mechanism underlying multi-spike bursting of neurons is typically explained with models that exhibitdifferent time scales with a single slow variable. The bursting patterns observed in such slow-fast systemsare periodic orbits that successively track different coexisting attracting states associated with the so-calledfast subsystem, for which the slow variable is viewed as a parameter. In particular, the threshold thatdetermines when bursting occurs is identified as the basin boundary between two attractors associated withthe active and silent phases. In reality, however, the bursting threshold is a more complicated object. Wecompute an approximation of the bursting threshold as a locally separating stable manifold of the full slow-fast system. Our approach is based on the continuation of a suitable two-point boundary value problem. As arepresentative example, we use a three-dimensional Morris-Lecar model that has one slow and two fastvariables. We compute the locally separating stable manifold and investigate how the bursting periodic orbitinteracts with this manifold. We also explain how this manifold organizes the number of spikes in the burstingperiodic orbit and illustrate its role in a spike-adding transition as we vary a parameter.

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MS5

What Kind of Music do Songbirds Like? A Dynamical Systems Approach to Predicting Female Song Preferences

Female cowbirds display preferences for songs of particular males, and females raised in isolation independently rank a set of songs in an identical order. Following lesions to the female song circuit, these preferences dissolve. Traditional tools for song analysis have failed to identify a predictor for this metric governing preference. This is not surprising: most tools rely on linear spectral analysis, while vocal production is a complex nonlinear phenomenon. It is important to characterize this metric, in advance of analyzing its dissolution upon lesions to brain regions associated with audition. We employ time-delay embedding to unfold the geometric structure of the dynamics that created the acoustic signal. The time-delayed vectors define the coordinate basis of a space wherein the songs attractor lives. With a proper choice of time delay, this representation preserves phase information, and we find systematic differences among the attractors across male birds. We are devising a classification scheme for song desirability, where the attractors are used as training data to create synthesized songs, to be played to females. The goal is to ascertain what aspects of a song's structure must be retained so that the females recognize them, and to perform this experiment following lesions to the song-related neural circuit. A long-term goal is to reconstruct the dynamical system itself, to compare to existing models of neuronal connections to the syrinx.

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MS5

A Neuromechanistic Model for Keeping a Simple

Rhythmic Beat in the Context of Music

When listening to music, humans can easily identify and move to the beat. Related to beat perception is the question of how we learn to generate and keep a beat. In this talk, we present a neuronal framework for a beat generator that is capable of learning isochronous rhythms (equally spaced in time) over a range of frequencies that are relevant to music and speech. Our approach combines ideas from error-correction and entrainment models to investigate the dynamics of how a biophysically-based neuronal network model synchronizes its period and phase to match that of an external stimulus. The model makes novel use of on-going faster gamma rhythms to form a set of discrete clocks that provide estimates, but not exact information, of how well the beat generator spike times match those of a stimulus sequence. Our model makes generalizable predictions about the existence of asymmetries in the synchronization process, as well as specific predictions about resynchronization times after changes in stimulus tempo or phase. We then extend the model to show how it learns complex sound sequences that include tones of different intensities. Analysis of the model demonstrates that accurate rhythmic time keeping can be achieved over a range of frequencies relevant to music, in a manner that is robust to changes in parameters and to the presence of noise.

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MS5

Scalar Reduction of a Neural Field Model with Spike Frequency Adaptation

We study a deterministic version of a one- and two-dimensional attractor neural network model of hippocampal activity first studied by Itskov et al. (2011). We analyze the dynamics of the system on the ring and torus domains with an even periodized weight matrix, assuming weak and slow spike frequency adaptation and a weak stationary input current. On these domains, we find transitions from spatially localized stationary solutions "bumps" to (periodically modulated) solutions ("sloshers"), as well as constant and nonconstant velocity traveling bumps depending on the relative strength of external input current and adaptation. The weak and slow adaptation allows for a reduction of the system from a distributed partial integro-differential equation to a system of scalar Volterra integro-differential equations describing the movement of the centroid of the bump solution. Using this reduction, we show that on both domains, sloshing solutions arise through an Andronov–Hopf bifurcation and derive a normal form for the Hopf bifurcation on the ring. We also show existence and stability of constant velocity solutions on both domains using Evans functions. In contrast to existing studies, we assume a general weight matrix of Mexican-hat type in addition to a smooth firing rate function.

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MS5

Bayesian Parameter Estimation in the Spatial Organization of Metabolism

Some enteric bacteria utilize spatial organization of the metabolic pathway to proliferate in the hostile environment of the host intestine. Spatial organization can improve metabolic flux through portions of the metabolic pathway by generating local regions of high concentration. One type of spatial organization is microcompartments (MCPs): protein bound structures which encapsulate and segregate a subset of the metabolic pathway. MCPs may be used to engineer metabolic pathways to maximize flux into a desired chemical product. Unfortunately, characteristic properties of MCPs, such as permeability, and their internal dynamics are not directly measurable. Bacterial metabolic pathways are often assumed to exist in a steady state which is governed by a combination of environmental conditions and intrinsic chemical properties. We develop computational methods through which time series data of the transient behavior of externally measured metabolites may be used to infer unknown parameters and internal MCP dynamics. We use Bayesian methods to analyze simulated time series data to determine the regions of parameter space in which unknown parameters are recoverable. We estimate previously inaccessible model parameters and the internal dynamics of the MCP through constraints determined by the model equations. Results of these analyses are used to guide experimental design and the development of engineered metabolic pathways. This research is supported by DOE grant DE-SC0019337.

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MS6

Complex Dynamics of Unsteady Microchannel Fluid–Structure Interactions: 1D Model

A 1D model of the transient fluid–structure interaction (FSI) between a soft-walled microchannel and a Newtonian viscous fluid flow is developed. An Euler–Bernoulli beam, with transverse bending rigidity and nonlinear axial tension, is coupled to fluid model obtained under the lubrication approximation from depth-averaging 2D incompressible Navier–Stokes. The von Kármán–Pohlhausen approximation is used to close the system, arriving at a coupled set of nonlinear PDEs. We solve these PDEs numerically through a segregated approach based on fully-implicit time stepping and second-order finite-differencing in space. We explore the dynamics of the model through a set of dimensionless groups. The Reynolds number Re and a dimensionless Young's modulus Σ are varied independently. We define a critical Re_{crit} by determining when the maximum steady-state deformation H_{max} exceeds a threshold. We show that $Re_{crit} \propto \Sigma^{3/4}$ and $H_{max} \propto Re/\Sigma^{0.9}$. Complex nonlinear oscillations and marginal metastable states are observed in the transients during startup. The linear stability of the inflated microchannel steady state is addressed numerically through a modal eigenvalue analysis. Although the steady state is stable, many marginal modes exists, highlighting the inherent stiffness of the FSI problem. This work was supported, in part, by the US National Science Foundation under grant CBET-1705637.

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MS6

Marangoni-Driven Motion of Particles at Liquid-Gas Interfaces

We theoretically study the Marangoni-driven motion of chemically and thermally active particles located at a flat liquid-gas interface that sits above a liquid layer of finite depth. The particles activity creates and maintains a surface tension gradient resulting in the self-propulsion of the particle. It is intuitively perceived that Marangoni surfers propel towards the direction with a higher surface tension. Remarkably, we find that the surfers may propel in the lower surface tension direction depending on their geometry and proximity to the bottom of the liquid layer. In particular, our analytical calculations for Stokes flow and diffusion-dominated scalar (i.e. chemical concentration and temperature) fields indicate that spherical particles undergo reverse Marangoni propulsion under confinement whereas disk-shaped surfers always move in the expected direction. We extend our results by proposing an approximate formula for the propulsion speed of oblate spheroidal particles based on the speeds of spheres and disks. Overall, our findings pave the way for designing microsurfers capable of operating in bounded environments.

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MS6

Dynamical Models for Interacting Flapping Swimmers

We construct and analyze a continuum model of a 1D school of flapping swimmers. Our starting point is a delay differential equation that models the interaction between a swimmer and its upstream neighbors wakes, which is motivated by recent experiments in the Applied Math Lab at NYU. We coarse-grain the evolution equations and derive PDEs for the swimmer density and variables describing the upstream wake. We study the equations both analytically and numerically, and find that a uniform density of swimmers destabilizes into a traveling wave. Our model makes a number of predictions about the properties of such traveling waves, and sheds light on the role of hydrodynamics in mediating the structure of swimming schools.

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MS6

On Stability of Oriented Meteorites

The atmospheric erosion of meteors is a splendid example of the reshaping of a solid object due to its motion through a fluid. Meteors are self-stabilizing in the sense that they seem to reshape themselves through erosion into a flight-stable form. Motivated by meteorite samples collected on Earth that suggest fixed orientation during flightmost notably the strikingly conical shape of so called oriented meteoritehere the hypothesis that such forms result from an aerodynamic stabilization of posture that may be achieved only by specific shapes, is explored. The laboratory- scale experiment is conducted for exploring systematic static stability tests on cones of varying apex angles in fast flows, and the resulting map of the orientational equilibria and their stability. A 2D mathematical model has been developed, and is compared with the experimental results. Armed with the simplified 2D model of oriented meteorites (with a conical shape), an isosceles triangle is considered in order to calculate its flow wake structure using free streamline theory. This work is supported, in part, by RTG/DMS-1646339 and NSF CBET-1805506.

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MS7

Bifurcation of Localized Structures in Biologically Inspired Reaction-Diffusion Equations

Localized structures in a Schnakenberglike reaction diffusion models are investigated numerically and analytically. Such systems have been proposed as models for sub-cellular pattern formation and cell polarity formation through interaction between active and inactive proteins. Focussing on models in one space dimension,we use analytical techniques such as linear stability analysis, normal forms and semi-strong interaction asymptotic analysis to show the existence of two different kinds of localized structures, namely isolated spikes and localised patterns. The same state diagram is found to occur in a range of models. The results are backed up by numericalcontinuation of the localised states, and time simulation to check for stability. We end by studying a more realistic biological to investigate the emergenceof localized structures in cell polarity due to interactions of two different families of active and inactive proteins. We find yet more complex structures, which are influenced strongly by which reaction has the stronger kinetics.

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MS7

Localized Traveling Waves in Thermosolutal Convection

Thermosolutal convection occurs in fluids subject to gradients both in temperature and concentration. With low solute diffusivity and temperature increase, steady convection can occur via a pitchfork bifurcation. When the solute diffuses faster than temperature, the primary bifurcation changes to a Hopf bifurcation leading to oscillatory convection. In the past, two dimensional nonlinear thermosolutal convection with Boussinesq approximation has been considered analytically by many researchers, who use the truncation method to reduce the full PDEs to low order sets of ODEs. This work develops a PDE model which replicates the linear behaviour of thermosolutal convection and whose amplitude equations can be reduced to the Takens-Bogdanov normal form. This model is useful in two ways. Firstly, we can easily investigate the behaviour of small amplitude solutions near onset, both analytically and numerically. Secondly, we can explore the global behaviour of the system in extended domains and identify parameter ranges where spatially localized solutions are possible. Spatially localised states are normally found in regions of bistability between two different solutions. Using amplitude equations to identify bistable regions in our model system, we numerically obtain different types of spatially localized states. This talk will focus on two examples for localised travelling waves: localised travelling wave and localised travelling waves in a background of steady state.

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MS7

Convectons and Chaos in Doubly Diffusive Convection

Doubly diffusive convection in a closed vertically extended 3D container driven by horizontal temperature and concentration gradients is studied under the assumption that the buoyancy ratio N=-1 so that thermal and solutal variations within the fluid yield forces of equal strengths but opposite directions. This configuration admits a conduction state where the fluid is stationary and the temperature and concentration fields are linear in space. The primary instability from the conduction state is subcritical and generates two families of spatially localized rolls known as convectons. These steady states are organized in a pair of intertwined solution branches within a well-defined range of Rayleigh numbers in a behavior known as homoclinic snaking. Secondary instabilities along the primary branches of convectons are found to yield twisted convectons whose branches describe secondary snaking. The twist instability destabilizes the primary convectons and are responsible for the absence of stable steady states, localized or otherwise, in the subcritical regime. As a result, for Rayleigh numbers beyond the threshold for primary instability, the system exhibits an abrupt transition to large amplitude spatio-temporal chaos.

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MS7

Exploiting Topographic Heterogeneity to Probe Models of Dryland Vegetation Patterns

Bands of vegetation, alternating nearly periodically with bare soil, have been observed in many dryland environments since their discovery in the Horn of Africa in the 1950s. Mathematical modeling efforts over the past two decades have sought to account for these bands via interaction between vegetation and the limited water resources. This is typically done within a familiar reaction-advection-diffusion pattern formation framework. The focus of this talk will be on the role of topography in shaping the bands, their position on the landscape, and their dynamics. For instance, in many cases these vegetation bands are arced, with observations suggesting a link between the orientation of arcing relative to the grade and the curvature of underlying terrain. It has also long been known that the bands can migrate slowly upslope. Due to the long timescales of vegetation dynamics, we propose exploiting the known, large-scale topographic heterogeneity as a way to probe validity of models of vegetation patterns. In order to do this, we argue for improved modeling of the water transport incorporated in the models, which leads naturally to a multi-scale modeling framework.

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MS8

Adjoint Sensitivity Analysis of a Scale-Resolving Turbulent Flow Simulation

Abstract not available.

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MS8

Space-Split Statistical Sensitivity Computation in Chaotic Systems

Abstract not available.

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MS8

Adjoint Shadowing Directions in Chaotic Dynami-

cal Systems for Sensitivity Analysis

For hyperbolic diffeomorphisms, we define adjoint shadowing directions as a bounded inhomogeneous adjoint solution whose initial condition has zero component in the unstable adjoint direction. For hyperbolic flows, we define adjoint shadowing directions similarly, with the additional requirement that the average of its inner-product with the trajectory direction is zero. In both cases, we show unique existence of adjoint shadowing directions, and how they can be used for adjoint sensitivity analysis. Our work set a theoretical foundation for efficient adjoint sensitivity methods for long-time-averaged objectives such as NILSAS. We will also address the relation between shadowing methods and Ruelle's linear response formula.

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MS8

Computation of Sensitivities in Chaotic Systems: An Overview

Abstract not available.

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MS9

Spontaneous Initiation of Ventricular Fibrillation

Ventricular fibrillation (VF) is one of the major causes of sudden cardiac arrest. The mechanism of VF initiation has been extensively studied in the context of oscillatory dynamics of cardiac cells called action potential duration (APD) alternans. However, clinical studies showed that T wave alternans, an electrocardiographic (ECG) equivalent of APD alternans, does not predict lethal arrhythmia. In addition, extended ECG monitoring with implantable cardioverter-defibrillators suggests that APD alternans accounts for only a minority of VF initiation. In contrast, the transition from normal sinus rhythm to VF is caused by a single ectopic beat in most patients, but the mechanism remains poorly understood. Clinical and quantitative approaches to understanding the mechanism of VF initiation will be discussed.

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MS9

Sensitivity of Spiral Wave Core Formation and Transient Spiral Core Interactions

Atrial fibrillation may be understood as a dynamical equilibrium within spatiotemporal chaos between mechanisms which increase the number of spiral wave cores and those which decrease the number of spiral wave cores. Trajectories which feature increases and decreases in sequence correspond to short-lived spiral wave cores, and the linearized dynamics about these trajectories reveal the sensitivity of the formation of these topological structures. Systematic truncation of the linearized dynamics simplifies the finite range of configurations which develop into persistent spiral cores – from artificial constructions like cross-field stimulation to their organic development within sustained spiral chaos. We apply these techniques to a simple model of cardiac excitation and try to prevent the development of spiral chaos through the introduction of localized forcing constructed from the linearization.

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MS9

Novel Approaches for Mapping-Specific Rotor Ablation During Atrial Fibrillation

Atrial Fibrillation (AF) is most common cardiac arrhythmia and is associated with increased risk of stroke, heart failure and sudden cardiac death. Catheter ablation is one common treatment approach used to control AF, but it is associated with limited success rates in patients with persistent AF, which is mostly maintained by rotors that are located outside of the pulmonary veins (PV) region. Currently existing commercial mapping systems cannot accurately identify the rotor location outside of the PV regions in patients with persistent AF. Recently, novel techniques namely, multiscale frequency (MSF), kurtosis (Kr), and multiscale entropy (MSE), were developed for accurate identification of pivot points of rotors and validated using optical mapping experiments in ex-vivo rabbit hearts, where electrical activity can be directly visualized. However, the optical signal has a different nature from intracardiac electrograms (EGMs), which are available for clinicians during AF ablation. Here, we validated the efficacy of MSF, Kt and MSE techniques in identification of pivot point of both stationary and meandering rotors using unipolar and bipolar EGMs derived from numerical simulations of a human atrial tissue model. We also applied MSF, Kt and MSE approaches to clinical intracardiac EGMs from patients with persistent AF, and compare its prediction with the traditional dominant frequency approach, using Pearsons correlation and earth movers distance methods.

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MS10

Dynamical Instabilities in Networked Systems, it is a Matter of Time and Direction

Order from disorder is a leitmotif in Nature that has determined decades of research efforts to unravel the underlying rules. Spatio-temporal patterns, i.e. spatially nonhomogenous states, abound in real scenarios and the Turing mechanism is a paradigm of self-organisation [1, 2]. The emergence of the resulting order has been hypothesised to arise from the interaction of slow diffusing activators and fast diffusing inhibitors. In many relevant cases, interactions arise via an intricate architecture of nested couplings, which can be adequately represented as complex networks. Understanding the patterns onset for networked reaction-diffusion systems is thus a major challenge. In several realms of application, the underlying networks evolve in time and diffusion across links may have some preferred direction, the resulting network is thus directed. We will show that both directionality and the own network dynamics have a strong impact in the patterns formation process [8, 9, 10]. [1] G. Nicolis and I. Prigogine, Self-organization in nonequilibrium systems: From dissipative structures to order through fluctuations (J. Wi-

ley & Sons, 1977) [2] J. D. Murray, Mathematical biology II: Spatial models and biomedical applications (Springer-Verlag, 2001) [3] M. Asllani and T. Carletti, Phys.Rev.E, 97, (2018), pp. 042302 [4] M. Asllani, R. Lambiotte, and T. Carletti, in press Sci. Adv. (2018) [5] Petit J., Lauwens B., Fanelli D. and Carletti T., Phys.Rev.Lett., 119 (2017) 148301

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MS10

Multifaceted Dynamics of Janus Oscillator Networks

Recent research has uncovered fundamental new phenomena in network synchronization, including chimera states, explosive synchronization, and asymmetry-induced synchronization. Each of these has thus far been observed only in systems designed to exhibit that one phenomenon, which raises the questions of whether they are mutually compatible and of what the required conditions are. We introduce a class of remarkably simple oscillator networks that concurrently exhibit all of these phenomena, thus ruling out previously assumed conditions. The dynamical units consist of pairs of non-identical phase oscillators, which we refer to as Janus oscillators by analogy with Janus particles. In contrast to previous studies, these networks exhibit: i) explosive synchronization in the absence of any correlation between the network structure and the oscillator's frequencies; ii) extreme multi-stability of chimera states, including traveling, intermittent, and bouncing chimeras; and iii) asymmetry-induced synchronization in which synchronization is promoted by random oscillator heterogeneity. These networks also exhibit previously unobserved inverted synchronization transitions, in which transition to a more synchronous state is induced by a reduction rather than increase in coupling strength. These various phenomena emerge under rather parsimonious conditions, even in ring topologies, which has the potential to facilitate their use to control and manipulate synchronization in experiments.

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MS10

Synchronization, Information, and Memory in Simplex Networks: Dynamics of Coupled Oscillators with Higher-Order Interactions

Synchronization dynamics and pattern formation in complex networks have seen plenty of attention from researchers due to their roles in a wide range of applications. Much of this work has focused on networks where links represent interactions between pairs of oscillators. However, recent work suggests that higher-order interactions, between three or more units, may play an important role in the various phenomena. Such connections are known as simplices, where an n-simplex connects n+1-units. Here we study the dynamics of oscillators in simplex networks. Starting with the all-to-all case, we show that new synchronization patterns consisting of multiple clusters of synchronized oscillators appear that are not found in the typical (pair-wise connection) networks. These macroscopic dynamics can be described using a pair of generalized order parameters. Moreover, each oscillators cluster can be mapped to the value of one bit, thereby allowing the system to store information We then turn our attention to non-trivial network topologies. Focusing on the 2-simplex case of triplet interactions, we show that, unlike the all-to-all case, some cluster patterns are stable while others are unstable. Thus, the network topology judiciously chooses which pieces of information may be stored and which may not. We then investigate how the structural properties of the network, e.g., overall connectivity, heterogeneity, etc., affect the stability properties of various clustered states.

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MS10

Chaos and Multistability in Networks of Coupled Oscillators

Synchronization is ubiquitous to networks of coupled oscillators. We study the Kuramoto model with multimodal natural frequency distributions, where oscillators with similar natural frequencies form synchronized clusters. We use a collective coordinates approach to reduce the dimension of the full Kuramoto model, which elucidates the inter-cluster and intra-cluster dynamics. We show that complex dynamics and chaos can occur in the cluster-synchronized state as long as there are at least two peaks in the frequency distribution. When there are four peaks or more, the potenital for chaos is intuitive because the clusters can be thought of as meta-oscillators, and the Kuramoto model with four (or more) oscillators with evenly distributed natural frequencies exhibits phase chaos. However, the same reasoning cannot be applied when there are less than four peaks, because the Kuramoto model with two or three oscillators is not chaotic. Nevertheless, chaos can occur. Furthermore, time-scale splitting of the collective coordinate dynamics provides parametric constraints necessary for chaos to occur.

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MS11

A Probabilistic Regularization of Zeno Hybrid Systems by a Convolution Method

In this paper a new technique is proposed to extend simulations beyond the Zeno time. It consists of a probabilistic regularization by a convolution method that includes noise in the system. For example, low-amplitude Gaussian noise can be used to transform discontinuous vector fields to continuous vector fields. This convolution approach makes the value observed for the continuous evolution over time slightly different from what would be predicted without the noise, but in a way that should correspond to what happens in reality. An example of a Zeno hybrid system is employed to illustrate the result. The evolution beyond the Zeno time depends on the noise that exists in physical systems and on how the noise is included in the regularized model. However, a useful idealization is obtained in the limit of low noise amplitude.

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MS11

Sleep, Dreams, and Bifurcations: REM Sleep and Nonsmooth Maps for Sleep/Wake Dynamics

The temporal structure of human sleep changes across development as sleep consolidates from the fragmented sleep of infants to the single nighttime sleep period typical in adults. This transition is likely driven by developmentally-mediated slowing in the rates of accumulation and dissipation of the homeostatic sleep drive, the physiological drive to sleep that increases with time spent awake. Given the periodicity of regular, entrained sleep-wake behavior, one-dimensional circle maps (defined analytically in some cases and numerically in others) may be used to represent the dynamics of the full sleep-wake network models. In an analysis of the bifurcations of these circle maps, we show that rapid eye movement (REM) sleep contributes to nonsmoothness of the maps. Furthermore, REM sleep interacts with changes in the number and timing of sleep episodes to affect bifurcations in sleep behavior occurring in early childhood developmental transition periods.

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MS11

Nonsmooth Dynamics in Spatially Distributed Neural Systems

In this talk, I will examine the existence and stability of waves in a pulse coupled network of neural oscillator/excitable systems in one and (possibly two-dimensions). I will show the existence of traveling waves and get some estimates of their dispersion in both the infinite line and on the ring. In the case of pulse coupled oscillators, I will pose the stability problem and use numerical shooting to determine stability. I will first consider:

$$u_t = 1 - \cos u + (1 + \cos u)[a + bK(x) \star \delta(u - u_t)]$$

which is the normal form for a saddle-node infinite cycle. Then I will turn to a ring of PRC coupled oscillators:

$$u_t = 1 + \Delta(u)K(x) \star \delta(u)$$

This is joint work with Xinfu Chen and Yuji Ding.

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MS11

Non-Smooth Dynamics Perspectives for Designing Large Scale Optimization Algorithms in Stochastic Settings

Computations in machine learning, inverse problems, data fitting, and approximations rely heavily on optimization algorithms with stochastic and non-smooth features. Dynamical systems perspectives are increasingly important for algorithm design and performance. The theoretical requirements for convergence are not necessarily met in real world, large scale problems. For sparse, consistent systems, algorithms using thresholds together with l_1-minimization of an objective function have been shown to be very effective, particularly in the compressed sensing context. However, in the realistic setting where the problem is large scale, overdetermined and inconsistent (data with noise), the algorithm faces challenges analogous to the chattering phenomena in non-smooth control problems. Chatter is particularly detrimental if the solution is not strictly sparse, but rather compressible (decay in coefficient magnitude). Viewing iterations of the algorithm as coupled systems of equations for large and small entries, we identify an efficient modified dynamic algorithm that removes the chatter and drives faster convergence, particularly for noisy, large scale, compressible problems which require subsampling and a limited number of data passes. The dynamical systems perspective also points to value for streaming (online) applications, automatic optimization of thresholds, and connections to other dynamical systems perspectives seeking optimal search directions.

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MS12

Spatial Aspects in Vaccination

Recent outbreaks of measles highlight the importance of vaccination and the role that lower than optimal vaccine coverage in some subpopulations can have on the spread in the population as a whole. Motivated in part by an outbreak of polio in 2003, we investigate the role of varying vaccination rates on the spatio-temporal spread of infectious diseases. In particular, we focus on the consequence of the interconnection of public health entities with different vaccine coverage.

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MS12

Evolution of HIV-1 Across the Within and Between-Host Scales: The Role of Transmission Bottlenecks

HIV-1 is a rapidly replicating retrovirus that faces multi-scale fitness challenges: within host HIV-1 faces viral competition for host cells and for escape from the immune system, while between hosts HIV-1 faces a competitive transmission bottleneck through which, in the majority of cases, new infections are started by a single virus strain. As a result of these two fitness landscapes the rate of evolution of HIV-1 tends to be greater within host than between hosts. A current hypothesis for this difference in evolutionary rates is that the HIV-1 latent reservoir acts to archive virus for later transmission. We offer a related but complimentary hypothesis: while some of the viruses life history traits are under selective pressure within-host which favors increased virulence, traits that are responsible for the efficiency of transmission across the bottleneck are not under direct selection and are thus subject to drift. Linking the within- and between-host scales through a stochastic, competitive transmission bottleneck, our results suggest that bottleneck effects could cause an even greater reduction in the observed rate of between-host evolution, over the epidemic, than effects caused by the latent reservoir alone.

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MS12

Control of Mosquito-Borne Diseases: To Spray or Not to Spray?

Mosquito-borne infections, such as dengue and malaria, impose a major burden on public health. We lack effective vaccines for many of these infections and so the primary control measure has been mosquito control, e.g. by spraying insecticide aimed at adult mosquitoes. In this talk we discuss counter-intuitive behavior that can result when such control measures are employed for a transient period against an endemic infection. We demonstrate the epidemiologically-troubling result (the so-called "Divorce Effect") that there can be time windows over which the total number of disease cases can exceed the number that would have occurred if no intervention had been employed: accumulation of susceptibles during the control can lead to a large outbreak following the end of the control. This outbreak can be so severe that all the benefit accrued during control can be overcome. We discuss the public health implications of the Divorce Effect, focusing on its consequences for the effectiveness of routine spraying to control endemic mosquito-borne infections.

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MS12

Application of Probability Generating Functions to Infectious Disease Modeling

Mathematical modeling of infectious disease uses a wide range of tools. In trying to to infer disease parameters from observations of small outbreaks, researchers often turn to Probability Generating Functions (PGFs). PGFs allow us to predict the size distribution of small outbreaks and epidemic probability based on a known offspring distribution. However, they have also proven useful for modeling the dynamics of SIR disease spread, particularly through contact networks. In this talk I will present a range of applications of PGFs to disease spread, including:

- Epidemic probability
- Outbreak size distribution
- Prediction of peak prevalence and peak incidence
- Prediction of epidemic dynamics (including in contact networks)

I will also discuss some technical issues related to using PGFs to numerically calculate these values.

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MS13

Continuum Mechanics of Magic

We present a mathematical analysis of an old magician's trick involving a ring sliding along a beaded chain. We illuminate the basic physics underlying this trick: namely that the ring falling under gravity excites a wave that propagates along the chain. As the ring accelerates it catches up with and interacts with the wave that it had previously excited, producing the effect. We give a simple model that explains the effect, and some high-speed video that supports this interpretation. We will also demonstrate the trick, both by hand and using a small tabletop device.

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MS13

Dynamics of Table-Top Fire Fronts

Simple nonlinear table-top systems are great media to explore spatiotemporal properties. We are using matchstick arrays and oil-candle systems to experimentally investigate the behavior of reaction-diffusion systems. In these setups, propagating fire fronts can display complex spatial dynamics by varying the match type, arrangement, and slope of the matchstick array system or the oil viscosity and wick material of the candle system. In this talk, we will discuss one-dimensional and two-dimensional arrangements and their experimental as well as numerical results.

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MS13

The Wien Bridge Oscillator as an Archetype for Exploring Practical Applications of Nonlinear Dynamics

One of the earliest killer apps of nonlinear dynamics might be the audio oscillator that was the first product sold by Hewlett-Packard in the 1930s. The original design was a Wien-bridge oscillator using a vacuum-tube amplifier and a light bulb filament as a nonlinear stabilizing element. Now it is easily possible to make such circuits using op amps. We use this as a platform to encourage students to look for practical applications of self-sustained oscillators, first using a Jupyter notebook to develop fundamental understanding of the behavior of the system that produces a Hopf bifurcation. The full set of equations that includes the dynamics of heating of the light bulb filament is unexpectedly rich, showing a phenomenon called squegging as the oscillation grows and quenches repeatedly until a steady state is reached. Even more unexpected was an experimental setup in which a particular type of timing capacitor caused the squegging phenomenon to persist near oscillation onset. Ultimately our goal is to use the Wien bridge oscillator laboratory system and its comprehensive modeling as a basis for exploring new applications for sensing and control, including applications of coupled-oscillator networks. This is part of a larger picture that we call Nonlinear PIE: Nonlinear Physics, Innovation, and Entrepreneurship wherein we develop basic archetypes in several topical areas (e.g. mechanics, optics, and biophysics) to explore real-world applications of nonlinear dynamics.

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MS13

Using a Micro-Controller for Dynamics Visualization

The spatio-temporal dynamics of complex systems traditionally have been studied and visualized using computers. However, due to the advances in microcontrollers, it is now possible to run what once were considered large scale simulations in a very small and inexpensive single integrated circuit that can furthermore perceive in and out information of the outside world in real time. In this manuscript, we show how microcontrollers can be used to perform fast simulations of nonlinear systems of a spatially extended system and visualize their dynamics using arrays of LEDs and/or touch screens. We demonstrate this using three different models: two reaction diffusion models, one for neurons, one for cardiac cells, and a generic model for network oscillations. These models are commonly used to simulate various phenomena in biophysical systems, including bifurcations, waves, chaos and synchronization. We also demonstrate how simple is to integrate real-time user interaction with the simulations by showing touch screen and light sensors examples.

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MS14

Dynamics from a Coupled Chemical - Thermal - Microsilica Particle Formation Model

Microsilica particles arise as a byproduct of silicon furnaces, created inside high temperature flames due to the combustion reaction of silicon dioxide with oxygen. These nanoparticles grow as high saturated silicon dioxide vapour condenses on the surface of existing particles, and can also form aggregates. These particles are used in a variety of composite materials, and hence being able to control the size and quality of the particles is vital since this affects the performance of the material used for numerous applications. Motivated by this application, we present a mathematical model that relates the local thermal and chemical conditions of the furnace to the formation and growth of the particles. We consider two distinct reductions of our general model: the case of initially well-mixed chemical species (where spatial diffusion is negligible), and the case of initially spatially separated chemical species (in which diffusion will play a dominant role in providing material to a combustion front). In both cases, we provide analytical solutions for the temperature, chemical concentrations, and number density function of microsilica particles, and compare them to numerical simulations. Our results suggest that a rich variety of spatiotemporal dynamics arise from these reduced models.

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MS14

Pattern Formation in Bulk-Surface Reaction-Diffusion Systems

Motivated by problems involving quorum-sensing bacteria grown on an agar substrate, we study a two-domain reaction-diffusion system with reactions localized on a surface domain, and diffusion in a bulk domain. We investigate conditions under which a spatially homogeneous steady state can be destabilized by small spatial perturbations, as in the classical Turing instability. Due to the transverse coupling between these two regions, standard techniques for computing eigenfunctions of the Laplacian do not work, and so we propose an alternative formal method to construct the dispersion relation directly. We compare instability conditions with full numerical simulations to demonstrate general properties of the geometry and coupling parameters, and explore various experimentally-relevant asymptotic regimes. In particular, in the regime where the domain is suitably thin, we can recover exactly the standard Turing conditions with a perturbation due to diffusion into the bulk. These results are valuable not just for informing design choices regarding synthetic engineering of bacterial Turing patterns, but also for understanding the role of complex geometries in modulating these pattern-forming processes in developmental biology more generally.

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MS14

Pattern Formation in Reaction-Diffusion Systems on Time-Evolving Domains

The study of instabilities leading to spatial patterning for reaction-diffusion systems defined on growing or otherwise time-evolving domains is complicated, since there is a strong dependence of spatially homogeneous base states on time and the resulting structure of the linearized perturbations used to determine the onset of stability is inherently non-autonomous. We obtain fairly general conditions for the onset and persistence of diffusion driven instabilities in reaction-diffusion systems on manifolds which evolve in time, in terms of the time-evolution of the Laplace-Beltrami spectrum for the domain and the growth rate functions, which result in sufficient conditions for diffusive instabilities phrased in terms of differential inequalities. These conditions generalize a variety of results known in the literature, such as the algebraic inequalities commonly used as sufficient criteria for the Turing instability on static domains, and approximate or asymptotic results valid for specific types of growth, or specific domains.

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MS15

Stability of Network Dynamical Systems

We will present a series of results on the question of whether stability is implied by network structure, and if so, under what conditions.

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MS15

Synchrony-Breaking Bifurcating Branches from Non-Zero Lattice Indices

We consider networks of interacting individual systems, where the individual systems are all identical with one type of interaction between them. Such networks can be formulated as regular networks in the theory of coupled cell networks. When a fully synchronised network loses coherence, we expect it to break up into multiple clusters of synchronised sub-networks. All possible partial synchronies of a given regular network form a complete lattice. The structure of a lattice is associated with the Jordan normal form of the adjacency matrix of the regular network, which represents the network structure. When the adjacency matrix has simple eigenvalues, integer indices, called lattice indices, are assigned in a simple way and non-zero indices indicate the existence of synchrony-breaking bifurcating branches. We extend this idea to the non-simple eigenvalue case, with the goal of bifurcation analysis. We show how equivalent synchrony subspaces can be identified, which leads to a reduced structure of lattice of synchrony subspaces. Construction of a reduced lattice structure for non-simple eigenvalue case is joint work with Dr. Haibo Ruan (University of Hamburg).

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MS15

Stability for Heteroclinic Dynamics of Localized Frequency Synchrony

Coupled populations of identical phase oscillators may give rise to heteroclinic cycles between invariant sets where populations show distinct frequencies. We consider an example of four coupled phase oscillator populations consisting of two oscillators each, such that there are two heteroclinic cycles forming a heteroclinic network. While such networks cannot be asymptotically stable, their local attraction properties can be quantified by stability indices. We illustrate how the indices of both cycles in the network can be calculated in terms of the coupling parameters between oscillator populations and are able to give some conclusions about the non-asymptotic stability of the network as a whole. Hence, our results elucidate how oscillator coupling influences sequential transitions along a heteroclinic network where individual oscillator populations switch between regimes of high and low frequency.

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MS15

Synchrony-Breaking Bifurcation in Feed-Forward Networks

Feed-forward networks are networks where the set of cells can be divided into layers, such that every edge targeting a layer, excluding the first one, starts in the prior layer. And a feed-forward system is a dynamical system that respects the structure of a feed-forward network. Bifurcations on feed-forward systems at a full-synchronized equilibrium generate equilibria with less synchrony. In this talk, we give a complete description of the bifurcation branches using their square-root orders and slopes. Furthermore, we study which patterns of synchrony support a bifurcation branch. We compare the bifurcation branches of a feed-forward system and those of the feed-forward system restricted to a pattern of synchrony. In most cases, it is sufficient to compare the dimension of the respective center subspaces. However, there are cases that depend generically on the chosen feed-forward system. We give results that cover some of those cases and present an example not covered by our results.

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MS16

Characterization of the Most Probable Transition Paths of Stochastic Dynamical Systems with Stable Lévy Noise

This work is devoted to the investigation of the most probable transition path for stochastic dynamical systems driven by either symmetric α-stable Lévy motion $(0 < \alpha < 1)$ or Brownian motion. For stochastic dynamical systems with Brownian motion, minimizing an action functional is a general method to determine the most probable transition path. We have developed a method based on path integrals to obtain the most probable transition path of stochastic dynamical systems with symmetric α-stable Lévy motion or Brownian motion, and the most probable path can be characterized by a deterministic dynamical system.

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MS16

Dynamics and an Averaging Principle for Completely Integrable Stochastic Hamiltonian System with Lévy Noise

A stochastic Hamiltonian system driven by Lévy noise possess the property of preserving symplectic structure. From the point of construing the stochastic Hamiltonian system as nonconservative system, for which the Lévy noise as the nonconservative 'force', we propose the stochastic action integral, Lagrange formalism, as well as the stochastic Hamilton's principle. Based on these, we investigate the effective behaviour of a small transversal perturbation of order ε to a completely integrable stochastic Hamiltonian system whose diffusion vector fields are formed from a completely integrable family of Hamiltonian functions. Rescaled in time by $1/\varepsilon$, an averaging principle is shown to hold and the action component of the solution converges to the solution of a deterministic system of differential equations, as ε goes to 0. An estimate for the rate of the convergence is given.

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MS16

Lévy Noise-Induced Transition in a Two-Dimensional Gene Regulatory System

There are often extremely unpredictable jumps and heavy tail distribution with non-Gaussian characteristics in nonlinear dynamical systems. And Gene expression is a typical nonlinear system of high interest. We here analyze the influence of non-Gaussian noise (Lévy motion) as well as Gaussian noise (Brownian motion) on the transition between the vegetative and the competence states in a two-dimensional nonlinear gene regulatory system, which contains a negative as well as a positive feedback loop.

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MS16

Asymptotic Behaviors of Several Kinds of Slow-Fast Systems Driven by Lévy Processes

Stochastic time-delay systems and switching systems, called hybrid systems, have received a great deal of attention due to their wide applications. Therefore, we mainly analyze asymptotic behaviors of two kinds of slow-fast systems driven by Lévy processes. And there exist several difficulties in our problems, such as state-dependence of the noises, choice of the perturbed test functions and the dispose of the infinitesimal operator. To overcome these difficulties, truncation technique, Ascoli-Arzela theorem, Itô formula, and so on will be taken. For the first part, we focus on the two-time-scale delay systems driven by Lévy processes considering the memory terms being included into the slow component as well as fast component respectively. The existence and uniqueness of the solution is proved. Then under dissipative conditions, we exhibit exponential ergodicity of the fast component. Further, together with tightness which can be obtained via Ascoli-Arzela theorem, the weak convergence is studied by using martingale methods, truncation technique and so on. For the second part, we mainly consider slow-fast systems driven by Lévy processes modulated by Markovian switching regimes with single and multiple weakly irreducible class separately. And we obtain the existence and uniqueness of the solution, tightness and weak convergence which is similar to the first part but more details are different.

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MS17

Existence and Stability of Periodic Traveling Waves: Who Will Prevail in a Rock-Paper-Scissors Game?

We study a Rock-Paper-Scissors model that describes the spatiotemporal evolution of three competing populations, or strategies, in evolutionary game theory and biology. The dynamics of the model is determined by a set of partial differential equations (PDEs) and features travelling waves (TWs) in one spatial dimension and spiral waves in two spatial dimensions. We focus on periodic TWs and the closely-related spiral wave patterns in this model. A characteristic feature of this model is the presence of a robust

heteroclinic cycle that plays a key role in the organization of periodic TWs. The existence of periodic TWs and associated heteroclinic cycles can be established via the transformation of the PDE model into a system of ordinary differential equations (ODEs) under the assumption that the wave speed is constant. We explore the bifurcation diagram of the ODE system and investigate the existence of TWs as different parameters are varied. Determining the stability of periodic TWs is more challenging and requires a study of the essential spectrum of the linear operator of the periodic TWs. We compute this spectrum and the curve of instability with the continuation scheme developed in [Rademacher et al., Physica D, 2007]. We also build on this scheme and develop a method for computing what we call belts of instability, which are indicators of the temporal expansion rates of unstable TWs. We finally show how these results compare with direct simulations of the PDE model.

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MS17

Mathematical Modeling of Cyclic Population Dynamics

We discuss deterministic models for three-species ecological systems exhibiting cyclic (rock-paper-scissors) dynamics, which account for delay or/and spatial nonlocality in interspecies competition. The biological origin of the temporal and spatial nonlocalities is the secretion of a toxin lethal to another species in the environment. The dynamics of spatially homogeneous states is described by ODE models, which allow for three classes of stable limit solution: (i) steady coexistence solutions; (ii) limit cycles; (iii) stable heteroclinic cycles. PDE models allow to describe the nontrivial spatial structure and dynamics of fronts between domains occupied by homogeneous states, as well as regular and irregular spatio-temporal dynamical regimes.

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MS17

Spirals, Heteroclinic Cycles and Heteroclinic Bifurcations in a Spatially Extended Rock-Paper-Scissors Model of Cyclic Dominance

TheRock-Paper-Scissors game, in which Rock blunts Scissors, Scissors cut Paper,and Paper wraps Rock,provides an appealing simple model of cyclic competitionbetween different strategies or species inevolutionary game theory andbiology. When spatial distribution and mobility of individuals is taken intoaccount, waves of Rock can invade regions of Scissors, only to be invaded byPaper in turn.The dynamics is describedby a set of partial differential equations that has travelling wave solutionsin one (spatial) dimension andspiral wave solutions in two (spatial)dimensions. In this talk, I will describe how we can understand what governsthe wavespeed andwavelength of the travelling waves, by considering thedynamics near a robust heteroclinic cycle that arises when the PDEs areconsidered in a travelling frame. We find three new types of heteroclinicbifurcations, none of which have been seen in the literaturebefore. I willfinish by proposing some ideas on how to extend our work to understand whatgoverns similar properties of the spiral wavesolutions.

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MS17

Spatially Extended Stochastic Rock-Paper-Scissors and May-Leonard Models

Spatial stochastic variants of cyclically competing three-species systems display intriguingly different structures: In the cyclic Lotka-Volterra or rock-papers-scissors (RPS) model with conserved total particle number, the individuals of each species merely cluster together, whereas the May-Leonard (ML) model (where no such conservation law holds) exhibits spiral defects. In the deterministic limit, these structures were explained through a mapping onto the complex Ginzburg-Landau equation (CGLE). Extending this earlier work to the fully stochastic dynamics, we show precisely under which conditions the ML model can be represented through a coarse-grained CGLE with additive noise. The internal reaction noise is accounted for through the Doi-Peliti Hamiltonian and equivalent coherent-state path integral formalism, and subsequent mapping to three coupled non-linear Langevin equations in the continuum limit. In the vicinity of the system's Hopf bifurcation, the ensuing separation of time scales allows a reduction to just two slow degrees of freedom. The GCLE then emerges for small fluctuations in the three-species coexistence regime. More recently, we have been investigating competing spatially separated RPS and ML patches whose diffusive coupling induces interesting boundary effects such as emanating plane wave fronts. Research was sponsored by the Army Research Office and was accomplished under Grant Number W911NF-17-1-0156.

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MS18

On the Edge: Extinction Thresholds and the Periphery of Pollination Networks

Unravelling the interrelationship between structure and stability of ecological networks is an important issue in theoretical biology. We contribute to this subject by analyzing minimal extinction thresholds in plant-pollinator systems. To this end, we assume a pollination network to be a multistable system in which one desired dynamical regime, enabling the largest number of coexisting species, competes with several 'undesired' regimes of partial extinction. Accordingly, an extinction threshold corresponds to an initial condition just outside the basin of attraction of the desired regime. We use our approach of minimal thresholds to locate weak points in various pollination networks and examine how the core-periphery structure of a network affects its stability. In this context, we are particularly interested in the relationship between the network position of a species and its risk of extinction.

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MS18

Assessing Resilience - An Overview of Concepts and Methodologies

Resilience and stability of dynamical systems are closely related concepts and a central topic with applications in various fields. Despite a number of novel approaches to assess stability/resilience in complex dynamical systems, including multistable complex networked dynamical systems, measuring stability/resilience from empirical data continues to represent a challenging issue. This talk provides an overview of concepts and methodologies to assess stability/resilience, discusses their pros and cons, and points to possible improvements.

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MS18

Dynamical Robustness and Resilience in Coupled Oscillator Networks

Network robustness is a central topic in network science. Several mathematical frameworks have been proposed to analyze robustness and resilience of networked systems against local failures. When dynamical phenomena on networks are important for network functions, the dynamical robustness framework that we have developed is appropriate for analyzing the network robustness. In the former half of our presentation, we introduce an overview of the studies on dynamical robustness and resilience of coupled oscillator networks. When the fraction of damaged components increases, the coupled oscillator network undergoes a phase transition from oscillatory to quiescent states. The critical fraction for this phase transition is used as a measure for the network robustness. Based on this approach, we have analyzed the dynamical robustness of coupled oscillators with various network structures such as multilayer networks, scale-free networks, and degree-degree correlated networks. In the latter half of our presentation, we introduce our recent study [K. Morino et al., PRE 2018] that is useful for deeper understanding of the dynamical robustness. In this study, we consider how coupled excitable oscillators, which cannot oscillate when isolated, can produce spontaneous oscillations due to interactions among them. We elucidate the mechanism of the emergence of the spontaneous oscillations using bifurcation theory. We will discuss this recent result in terms of the dynamical robustness.

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MS18

Estimating Resilience from Time Series - A Non-Perturbative Approach

We present a data-driven approach to estimate resilience of natural dynamical systems such as the brain. We map the similarity between snapshots of the system's evolving coupling structure onto a finite number of states in an abstract state-space and take recurring coupling structures as system states. The "distance" between these states is a natural proxy for resilience at a given time: the larger this distance, the more resilient is the system. We demonstrate the suitability of our approach by investigating changes in resilience of epileptic brains related to daily rhythms and to transitions into the extreme events seizures. Our approach also allows one to identify a critical transitional pre-seizure phase with high sensitivity and specificity.

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MS19

Multi-Scale Flows on the 2-Sphere: Applications to the Ocean

Coarse-graining is a powerful and versatile framework for disentangling and modeling complex multi-scale flows. It has a rigorous mathematical foundation and allows for the diagnosis of the coupling physics at various pre-determined length-scales at any spatial location and at any instant in time. However, its straightforward application to global geophysical flows suffers from commutation errors due to the spherical domain. In this talk, I will present a generalization of the convolution operator on the 2-Sphere which ensures that our coarse-graining operators and spatial derivatives on the 2-sphere commute, thereby allowing us to derive the PDEs governing any sets of scales. I will demonstrate the application of this framework to oceanic flows from satellite altimetry data and high-resolution simulations using General Circulation Models.

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MS19

A Novel Reactive Forcing Scheme for Incompressible Scalar Turbulence

We present a novel reaction analogy (RA) based forcing method for generating statistically stationary scalar fields in incompressible turbulence. The new method can produce more general scalar probability density functions (PDFs), for example, quasi-double-δ PDF, than current methods, while ensuring that scalar fields remain bounded, unlike existent forcing methodologies that can potentially violate naturally existing bounds. Such features are useful for generating initial fields in nonpremixed combustion, inlet conditions for spatially developing flows, or for studying non-Gaussian scalar turbulence. The RA method mathematically models hypothetical chemical reactions that convert reactants in a mixed state back into its pure unmixed components. Various types of chemical reactions are formulated and the corresponding mathematical expressions derived such that the reaction term is smooth in scalar space and is consistent with mass conservation. For large values of the scalar forcing rate, the method produces statistically stationary quasi-double-δ scalar PDFs. Quasiuniform, Gaussian, and stretched exponential scalar statistics are recovered for smaller values of the scalar forcing rate. The shape of the scalar PDF can be further controlled by changing the stoichiometric coefficients of the reaction. The ability of the new method to produce fully developed passive scalar fields with quasi-Gaussian PDFs is also investigated.

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MS19

Energy Dynamics of Nonlinear Acoustic Wave Turbulence

Gupta, Lodato, and Scalo (J. Fluid Mech. (2017)) have demonstrated the existence of an equilibrium spectral energy cascade in shock waves formed as a result of continued thermoacoustic amplification, consistent with Kolmogorovs theory for high-Reynolds-number hydrodynamic turbulence. Recently, Gupta and Scalo (Phys. Rev. E, 2018) have developed a rigorous theory of spectral energy cascade in an ensemble of nonlinear acoustic waves, which fully develop into randomly distributed shock waves resulting in acoustic wave turbulence (AWT). The dynamics are shown to be very similar to the homogeneous isotropic turbulence in a box. In this work, the energy dynamics of AWT will be discussed, utilizing the mathematically exact energy corollary for second order nonlinear acoustics, thus identifying the second-order energy norm for acoustics and the corresponding Lyapunov function. For randomly initialized nonlinear waves, the mean energy in the domain decays with a -2/3 law in time due to coalescence of shock waves. In the spectral space, the energy corollary yields analytical expressions of energy, energy flux, and energy dissipation in spectral space. Dimensionless scaling laws for energy spectra of acoustic wave turbulence will also be discussed.

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MS19

New Asymptotic Models for Ocean Waves

This talk will discuss the application of multi-time-scale asymptotic methods for the derivation of amplitude equations for ocean waves. Three types of waves will be considered: internal gravity waves, surface gravity waves, and acoustic waves. The amplitude equations faithfully capture complex and intricate features of the wavefield, while being much faster to numerically integrate. Numerical simulations will be presented to argue that in suitable parameter regimes, the amplitude equations can replace the full set of nonlinear governing equations.

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MS20

Fronts in Inhomogeneous Wave Equations

We first study the existence of stationary fronts in a system of two coupled inhomogeneous sine-Gordon equations. The inhomogeneity corresponds to a spatially dependent scaling of the sine-Gordon potential term. Numerically we show that, dependent on the type of inhomogeneity, the fronts undergo a pitchfork bifurcation. Then using Lyapunov-Schmidt reduction we show this analytically. Finally we consider the interaction of traveling fronts with spatial inhomogeneities.

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MS20

The Effect of Different Velocities on Global Existence and Stability in Nonlinear Reaction-Diffusion Systems

It is well-known that quadratic or cubic nonlinearities in reaction-diffusion systems can lead to growth of small, localized initial data and even finite time blow-up. In this talk I will explain that, if components propagate with different velocities in nonlinearly coupled reaction-diffusion systems, then quadratic or cubic mix-terms are harmless. In order to exploit the difference in velocities we have developed nonlinear iteration schemes that track spatio-temporal dynamics in different co-moving frames. Our theory can be applied to the stability analysis of wave trains in the Ginzburg-Landau equation at the so-called Eckhaus boundary, where one finds that the critical modes exhibit different group velocities.

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MS20

Stability of Planar Fronts in a Reaction-Diffusion System

On the stability of planar fronts with marginally unstable essential spectra. We study a planar front solution for a class of reaction-diffusion equations in the case when the essential spectrum of the linearization about the front touches the imaginary axis. The spectrum of the wave is stabilized by an exponential weight. For perturbations that belong to the intersection of the exponentially weighted space with the original space without a weight, we use a bootstrapping argument to show that initially small perturbations to the front remain bounded in the original norm and decay algebraically in time in the exponentially weighted norm.

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MS20

Asymptotic Stability of Pulled Fronts using Pointwise Estimates

We propose a simple alternative proof of a famous result of Gallay regarding the nonlinear asymptotic stability of the critical front of the Fisher-KPP equation which shows that perturbations of the critical front decay algebraically with rate $t^{-3/2}$ in a weighted L^∞ space. Our proof is based on pointwise semigroup methods and the key remark that the faster algebraic decay rate $t^{-3/2}$ is a consequence of the lack of an embedded zero of the Evans function at the origin for the linearized problem around the critical front.

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MS21

Equation-Free Approaches on Excitable Tissue Dynamics

Sudden cardiac death accounts for 50% of all cardiovascular deaths, resulting in more than 300,000 deaths annually in the United States. The majority of sudden death results from ventricular arrhythmias, including ventricular tachycardia (VT) and ventricular fibrillation (VF). Development of VT and degeneration of VT to VF can be considered as a phase transition in cardiac dynamics. There is limited investigation in methods that can be used to model and predict the onset of phase transitions. Extended dynamic mode decomposition of the Koopman operator (EDMD) and dynamic mode decomposition (DMD), that is the simplest implementation of EDMD, are emerging techniques to study dynamical systems. EDMD, DMD and other data driven approaches have been successfully used for model reduction, state estimation, prediction, and control of complex systems. In this work we will examine the applicability of DMD and EDMD of the Koopman operator as a method to describe the dynamics underlying phase transition from normal rhythm to fibrillation on 2D simulations of cardiac dynamics. Our hypothesis is that DMD and EDMD of the Koopman operator can be used to describe the spatiotemporal dynamics of a cardiac system and capture dynamical features associated with critical phase transitions. In this study we compare the results of DMD and EDMD in different dynamical states of a cardiac system, and assess for characteristic properties present prior to critical phase transitions.

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MS21

Cardiac Re-Entry Dynamics in MRI and Micro-CT Based Models of the Heart

Abnormal re-entrant regimes of self-organised synchronisation and transition to chaos underlie dangerous arrhythmias and fatal fibrillation. Recent advances in the theory of dissipative vortices elucidated the role and importance of cardiac re-entry anatomy induced drift and interaction with fine anatomical features of the heart. High resolution DT-MRI and micro-CT based anatomy realistic computer simulations of cardiac arrhythmias provide fascinating in-silico test bed at greater spatial and temporal resolutions than in experiment, in order to test the effects of anatomy on cardiac re-entry dynamics. We demonstrate effects of heart geometry and anisotropy on cardiac re-entrys either self-termination or pinning to sharp fluctuations of thickness in the tissue layer. In rat PV wall, with close to 90 degree transmural fiber rotation, the joint effect of the PV wall geometry and anisotropy turns a plane excitation wave into a re-entry pinned to fluctuation of thickness in the wall.

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MS21

Gap Junctions Induced Bistability Conductance in Cardiac Tissue

Connexins are specialized ionic channels that control the action potential propagation between cardiac myocytes. In this work we study the connexin dynamics in a one-dimensional model of cardiac tissue. We show that the connexin dynamics may lead to a spatial organization for the connexin conductance. In the numerical simulations we have found two different regimes for the spatial organization of the connexin's conductances: a) a spatially uniform conductance; b) a spatially complex pattern of local values of high and low conductances. In addition, we have observed that, locally, the two final states are limit cycles with a period equals to the period associated with the external excitation of the tissue strand. The conductance dispersion usually takes place on a very large time scale, i.e., thousands of heartbeats, and on a very short spatial scale. Due to its simplicity, the one-dimensional setting allows a detailed study of the emerging structure and in particular very long simulations. We have studied the transition between the two aforementioned states as a function of the connexin's conductance characteristics. Furthermore, we have studied the effect of initial added noises on the outcome of the system. Finally, using spatial autocorrelation functions we have characterized the spatial dispersion in conductance values.

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MS21

Electromechanical Vortex Filaments and Vortex-Substrate Interactions During Cardiac Fibrillation

The visualization of the highly dynamic electrical wave phenomena evolving within the heart muscle during cardiac fibrillation is a major scientific challenge. In recent work, we demonstrated that simultaneous imaging of both electrical and mechanical dynamics of the heart can provide novel insights into the spatio-temporal organization of cardiac fibrillation within the heart muscle. Using high-resolution 4D ultrasound, we showed that it is possible to identify mechanical filament-like phase singularities within the contracting, fibrillating heart wall. The mechanical filaments appear to evolve like fingerprints of electrical vortex filaments through the ventricular muscle, indicating the core regions of three-dimensional electrical scroll waves. On the deforming ventricular surface, it can be observed that electrical spiral vortices create vortex-like mechanical deformation patterns, which similarly rotate and whose core regions co-exist and co-localize with the core regions or phase singularities of the electrical vortices. Furthermore, it is possible to observe interactions of electrical and mechanical vortices with heterogeneities such as scar tissue, as both electrical and mechanical phase singularities equally attach to or co-localize with the heterogeneities. Lastly, the integration of the data into computer models could be used to infer in 3D the electrical wave patterns that had caused the deformations, but can not be measured yet directly.

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MS22

Model-Free Inference of Direct Network Interactions from Nonlinear Collective Dynamics

The topology of interactions in network dynamical systems fundamentally underlies their function. Accelerating technological progress creates massively available data about collective nonlinear dynamics in physical, biological, and technological systems. Detecting direct interaction patterns from those dynamics still constitutes a major open problem. In particular, current nonlinear dynamics approaches mostly require to know a priori a model of the (often high dimensional) system dynamics. Here we develop a model-independent framework for inferring direct interactions solely from recording the nonlinear collective dynamics generated. Introducing an explicit dependency matrix in combination with a block-orthogonal regression algorithm, the approach works reliably across many dynamical regimes, including transient dynamics toward steady states, periodic and non-periodic dynamics, and chaos. Together with its capabilities to reveal network (two point) as well as hypernetwork (e.g., three point) interactions, this framework may thus open up nonlinear dynamics options of inferring direct interaction patterns across systems where no model is known.

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MS22

Long-Lasting Desynchronization by Decoupling Stimulation

Abnormally strong synchronization of neuronal activity is a hallmark of several brain disorders. In Parkinsons patients, permanent delivery of high frequency deep brain stimulation suppresses symptoms. A qualitatively different, theory-based approach uses dedicated stimulus patterns to cause a desynchronization-induced decoupling of oscillatory neurons. Corresponding long-lasting desynchronizing effects were demonstrated in animal and clinical studies. However, stimulation parameters, e.g. the stimulation frequency, have to be adapted to the dominant neuronal rhythm. This is an issue as different abnormal brain rhythms may coexist. We present a novel approach which causes long-term desynchronization by decoupling stimulation - Random Step (RS) stimulation. RS stimulation successively reduces synaptic weights and ultimately leads to full-blown desynchronization by shifting neuronal networks from attractors with synchronized to attractors with desynchronized neuronal activity. Compared to desynchronizing stimulation techniques, RS stimulation causes weaker acute desynchronization, but long-lasting effects are more robust and do not require fine-tuning of stimulation parameters to the dominant neuronal rhythms. This may enable novel clinical applications. Tass, PA, Kromer, JA (2018) US Patent Application No. 62/688,962102354-0443 (S18-084)

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MS22

Stable Chimeras and Independently Synchronizable Clusters in Coupled Oscillator Networks

Cluster synchronization in a network of coupled oscillators is a phenomenon in which the network self-organizes into a pattern of synchronized sets. It has been shown that diverse patterns of stable cluster synchronization can be captured by symmetries of the network. Here, we establish a theoretical basis to divide an arbitrary pattern of symmetry clusters into independently synchronizable cluster sets, in which the synchronization stability of the individual clusters in each set is decoupled from that in all the other sets. Using this framework, we suggest a new approach to find permanently stable chimera states by capturing two or more symmetry clusters—at least one stable and one unstable—that compose the entire fully symmetric network.

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MS22

Coarse-Graining for Coupled Oscillators: A Case Study in Discovering Low-Dimensional Dynamics

Numerical simulations form a backbone of modern science. We investigate the following question: given a simulation of some dynamical process, does there exist a good lower-dimensional representation? If so, finding such a representation may offer both computational speedup and fundamental insight into the dynamics of interest. To approach this question in the abstract, we infer coarse-grained equations of motion that describe a heterogeneous population of oscillators with a modular coupling structure. We choose this system because it is known to exhibit a transition from high- to low-dimensional behavior, and that low-dimensional behavior is well-described by equations of a known form. We conclude by exploring ways to move forward by systematically discarding several of the simplifying assumptions at play.

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MS23

Symmetry and Synthesis of Agreement and Disagreement Dynamics

We derive novel nonlinear dynamic models of distributed decision-making and task allocation in multi-agent systems, leveraging singularity theory of bifurcations. The dynamics are intended for model-based investigation of stable and flexible behavior in natural systems, such as animal groups or cognitive control processes in the brain, and for design of stable and flexible behavior in technological systems, such as robotic teams. Symmetries arise naturally in these systems and serve as a flexible starting point: for example, permutation symmetry of agents in a homogeneous group and permutation symmetry of equally valuable options or tasks. Realistic systems that operate in complex environments can be modeled as deviations from the symmetric case. Here we present a new symmetric model for flexible allocation dynamics for two agents and two options, drawing inspiration from a Hopfield neural network. With the model, we show how to synthesize a wide variety of stable group behaviors, including agreement by the agents, disagreement by the agents, and outcomes in between. We prove that modulating a small number of parameters allows for smooth, flexible transitions among these stable group behaviors.

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MS23

Cellular Decision-Making Models in Yeast

We present a theoretical study of cellular decision making models which aims to describe the mechanisms enabling selection between two different extracellular carbon sources in yeast. These decision making mechanisms give rise to different consumption strategies as a function of the cell's preference for each nutrient (i.e. yeast's preference hierarchies of carbon sources). Thus the cell can be observed simultaneously consuming both sugars of similar preference, or making a preferential choice and sequentially depleting one source over the other. In the present work, the cellular decision-making processes, described as a system of coupled differential equations, are studied by means of bifurcation analysis in order to explore the different consumption regimes available to the yeast cell. We fit our model to experimental data and demonstrate its predictive potential. In a cellular decision making context, customary observations in decision-making systems, such as decision-deadlock and deadlock-breaking, can be interpreted as simultaneous sugar consumption and sequential sugar consumption regimes, respectively. We show how the transition between these regimes depends on the strength of key parameters within our model. By comparing different models we find the structural motifs required to replicate the consumption profiles observed in experimental data.

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MS23

Decision Making in Presence of Frustration on Multiagent Antagonistic Networks

In this presentation we consider a nonlinear interconnected system describing a decision-making process in a community of agents characterized by the coexistence of collaborative and antagonistic interactions. The resulting signed graph is in general not structurally balanced. We show that the decision-making process is affected by the frustration of the signed graph, in the sense that a nontrivial decision can be reached only if the social commitment of the agents is high enough to win the disorder introduced by the frustration in the network. The higher the frustration of the graph, the higher the commitment strength required from the agents.

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MS23

Motivation Dynamics for Autonomous Systems

A common design methodology to develop autonomous robotic systems consists of constructing a set of controllers, each of which permits the system to perform a particular behavior, and then constructing a decision mechanism which causes the system to select the appropriate behavior at each time. Each controller defines a closed-loop vector field for the system state and the decision mechanism selects among available vector fields. The standard decision mechanism studied in the literature is the hybrid automaton, which maintains a discrete mode state variable encoding the currently-selected controller and switches between modes according to a finite-state automaton when certain guard conditions are satisfied. In this work we seek an alternative decision mechanism based on continuous nonlinear dynamics. In contrast to the hybrid automaton mechanism which discretely selects among vector fields, our system takes a convex combination of vector fields and smoothly adjusts the weighting coefficients, which we term the *motivation state* of the system, according to an internal valuation of the importance of each behavior (i.e., vector field). We specialize to the case of two behaviors encoded as point attractors and derive sufficient conditions under which our system exhibits a limit cycle where the system repeatedly performs one behavior and then the other. We conclude by discussing extensions to the case of arbitrary numbers of behaviors and to integrate external stimuli.

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MS24

Sparse Model Selection for Structurally Challenging, Dynamic, Biological Systems

Inferring the structure and dynamical interactions of complex biological systems is critical to understanding and controlling their behavior. Often these systems have nonlinear structure, such as rational functions, which makes model selection using sparse-optimization challenging. Hybrid systems are also difficult to identify because the parameters and equation structure may vary across multiple dynamical regimes. I will discuss methods for reframing these problems so that sparse model selection is possible: implicit formulation and clustering data local to distinct dynamical regimes. I demonstrate the success of these methods on biologically motivated systems including metabolic and regulatory networks, a spring-mass model for locomotion, and a simple infectious disease model with time-dependent transmission rates.

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MS24

Dynamically Relevant Motifs in Inhibition-Dominated Neural Networks

Networks of neurons in the brain often exhibit complex patterns of activity that are shaped by the intrinsic structure of the network. For example, spontaneous sequences of neural activity have been observed in cortex and hippocampus, and patterned motor activity arises in central pattern generators (CPGs) for locomotion. To isolate the role of network connectivity in shaping this activity, we consider the *Combinatorial Threshold-Linear Network* (CTLN) model, a simple inhibition-dominated neural network model whose dynamics are controlled solely by the structure of an underlying directed graph. By varying only the underlying graph, we observe the full variety of nonlinear dynamics: multistability, limit cycles, chaos, and even quasiperiodic behavior. In this talk, we present graph rules that enable us to predict features of the dynamics from properties of the graph, with a focus on identifying graph motifs that yield emergent sequences. These motifs provide a direct link between the structure and function of these networks, and provides new insights into how connectivity may shape dynamics in real neural circuits.

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MS24

Measuring the Impact of Edge Controls on the Dynamics of Stochastic Discrete Networks

The advent of high-throughput technologies has allowed for the implementation of several comprehensive models of gene regulatory networks. However, gene expression profiles exhibit variability due to stochasticity in cellular processes such as transcription and translation. This fact results in probabilistic, noisy dynamics, where the same conditions across profiles may result in different responses. A comprehensive analysis of these processes remains an important challenge because biological networks are large and complex. In this talk, we study the stochasticity in gene regulation using the discrete modeling approach, where an important goal is to understand the impact of large perturbations such as the application of edge and node controls on the system. We will present a formula for measuring the impact of edge controls on the dynamics of stochastic Boolean networks. The formula takes into account the maximum number of changes upon an edge control along with their corresponding probabilities. We will use this formula to assess the side effects of edge controls for the identification of optimal intervention strategies.

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MS24

Algebraic Design of Experiments for Discrete Models of Gene Regulatory Networks

Network inference in systems biology is plagued by too few input data and too many candidate models which fit the data. When the data are discrete, models can be written as a linear combination of finitely many monomials. The problem of selecting a model can be reduced to selecting an appropriate monomial basis. Recently affine transformations were used to partition input data into equivalence classes with the same basis. We wrote a Python package to build the equivalence classes for small networks. We propose a "standard position' for data sets and developed a metric to measure how far a set is from being in standard position. We used this metric to define the representative of an equivalence class. The implication of this work is guidance for systems biologists in designing experiments to collect data that result in a unique model (set of predictions), thereby reducing ambiguity in modeling and improving predictions.

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MS25

Categorizing Spatiotemporal Patterns Near a Codimension-Two Point

A very large variety of spatiotemporal patterns have been observed in recent years in many fields governed by coupled NLPDE systems, both in simulations as well as experiments in Nonlinear Optics and chemical reactor systems. A diversity of mechanisms have also been introduced in modeling them, with Hopf, Turing, and Turing-Hopf bifurcations, as well as various mechanisms based on geometric singular perturbation theory all having been extensively employed. In this work, we re-examine the onset of Turing-Hopf instabilities in a representative reaction-diffusion system in an effort to separate out phenomena exhibiting small oscillations superposed on a dominant steady spatial pattern from unstable modes intermittently switching between coexisting stable patterns. It turns out that additional, sometimes overlapping classifications are required, including considering mixed modes resulting from subharmonic instabilities of the pure steady and Hopf modes, as well as domains of hysteresis involving both the homogeneous and inhomogeneous states. This talk will consider all of these phenomena with the objective of classifying those resulting from Hopf, Turing, and Turing-Hopf modes. Subsequent work will focus on additional observed patterns not explainable by these instabilities.

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MS25

Various Dynamical Regimes, and Transitions from Homogeneous to Inhomogeneous Steady States in Oscillators with Delays and Diverse Couplings

This talk will involve coupled oscillators with multiple delays, and dynamic phenomena including synchronization at large coupling, and a variety of behaviors in other parameter ranges including transitions between Amplitude Death and Oscillation Death. Both analytic multiple scale and energy methods, as well as numerical results will be presented. Behaviors in both limit cycle and chaotic oscillators will be compared for various couplings. Finally, the effects of distributed delays will be considered for systems already treated using discrete delays, including bifurcation theory results not available in the latter case.

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MS25

Dynamics of the Kudryashov generalized KdV Equation

In this talk we present the results of a numerical study addressing energy transport in the Kudryashov generalized Korteweg-de Vries (KG KdV) equation. Using a refined perturbation expansion of the Fermi-Pasta-Ulam (FPU) equations of motion, the KG KdV equation, which arises at sixth order, and the general form of higher order KdV equations are derived. A pseudospectral integrator, which accurately handles stiff equations without filtering the high modes, is developed for the KG KdV equation, allowing one to more carefully examine the dynamics and address questions such as transport of energy. Varying the strength of the perturbation and time scale of the experiments as well as the energy content of the wavefield, the spectral entropy and near-integrable diagnostics suggest that transition to equipartition is achieved on a long time scale for the KG KdV equation and some of its variants.

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MS26

Controllability-Based Network Measures and their Applications in Biological Networks

This talk focuses on the definitions, computing methods, and applications of node centrality and similarity measures we proposed in recent years for directed networks that model linear time-invariant dynamic systems. These measures quantify the "importance" of a network node in terms of the subspaces controllable and/or observable by the node, and have been shown to be highly effective in detecting functional modules, disease genes and drug targets in biological networks. As an example of applications, our approaches can be used in the study of combination therapy of complex diseases to help identify candidate targets for control multiple deregulated pathways of disease states.

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MS26

Sensor Selection and State Estimation for Nonlinear Network Dynamics

The state observation problem for systems with nonlinear network dynamics appears in a large variety of engineering and scientific disciplines. For example, to efficiently control biochemical or combustion reaction networks, it is crucial to first estimate the initial network states under the practical constraint that only a small number of state variables can be directly measured. More specifically, the problem of estimating the network state consists of two subproblems. The first subproblem is to select a small subset of state variables that need to be measured. The measurements should provide enough information to reconstruct the complete network state. The second subproblem is to develop an estimation algorithm capable of accurately reconstructing the network state. Both subproblems become challenging for large-scale networks with inherently nonlinear dynamics. In this talk, we present an optimization-based approach for solving these two subproblems. The proposed approach reveals several fundamental limitations and trade-offs in network observability. Furthermore, we show that purely graph-theoretic observability approaches cannot provide conclusions about the practical ability to estimate the states. This is because these approaches do not explicitly take into account the system dynamics. We demonstrate the effectiveness of the proposed approach on biological and combustion reaction networks with nonlinear and stiff dynamics.

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MS26

Assessing Observability of Complex Networks using a Nonlinear Theory

The observability of complex system refers to the ability to infer its whole state by measuring a limited set of its variables. Since in practice, monitoring all the variables defining the system's state is experimentally infeasible or inefficient, it is of utmost importance to develop a methodological framework for targeting those variables yielding full observability. Most of the approaches proposed neglect the nonlinear nature of complex systems and/or do not provide the space reconstructed from the measured variables. On the one hand, since nonlinearities are often related to a lack of observability, linear approaches cannot properly address this problem. On the other hand, finding the appropriate combination of sensors (and their time derivatives) spanning the reconstructed space is a very time demanding for large dimensional systems. Here, we adopt a symbolic approach taking into account the nonlinear nature of the interactions among variables. The minimal set of variables candidate to be measured for completing the reconstructed space is identified from a pruned fluence graph. Combined with the appropriate derivatives, our reduced set of measured variables indeed provides a full observability of the original state space as confirmed by the analytical determinant of the corresponding observability matrix. We thus determine the set of key sensors to observe and model (numerically and experimentally) a network of 28 nodes reproducing Rssler-like dynamics.

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MS26

Observability Condition Number for Dynamical Networks

We define an observability condition number for systems modeled by network dynamics. Assuming the dynamical equations of the network are known and a noisy trajectory is observed at a subset of the nodes, we calculate the expected distance to the nearest correct trajectory as a function of the observation noise level, and discuss how it varies over the unobserved nodes of the network. When the condition number is sufficiently large, reconstructing the trajectory from observations from the subset will be infeasible. This knowledge can be used to choose an optimal subset from which to observe a network.

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MS27

Polar Ecosystems in a Changing Climate

Ecosystems in the polar marine environment from microbial communities to sea ice fauna are being impacted by significant changes in the climate. In this talk we will discuss mathematical models of biological systems where the dynamics is coupled to climate change. In particular, we consider a model of multispecies populations where the resources depend on the climate. Under strong enough coupling the model displays the possibility for mass extinctions. We also discuss recent work on coupling algal growth in sea ice to the physics of the changing environment, and the emergence of under-ice algae blooms in the Arctic Ocean and their coupling to the geometry of melt ponds on the surface of the sea ice cover.

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MS27

Two-Dimensional Heteroclinic Attractors in the Generalized Lotka-Volterra System

We study a generalized Lotka-Volterra model exhibiting sequential dynamics. We show that in this model there exist sets of parameter values for which a cyclic chain of saddle equilibria, O_k, $k = 1, \ldots, p$, have two dimensional unstable manifolds that contain orbits connecting each O_k to the next two equilibrium points O_{k+1} and O_{k+2} in the chain ($O_{p+1} = O_1$). We show that the union of these equilibria and their unstable manifold form a 2-dimensional surface with boundary that is homeomorphic to a cylinder if p is even and a Möbius strip if p is odd. If, further each equilibrium in the chain satisfies a condition called “dissipativity,” then this surface is asymptotically stable.

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MS27

Non-Smooth Heteroclinic Tori in Models of Coordination Between the Human Minds

Recently, direct measurements have disclosed that in human social groups the neural patterns, associated to specific events directly experienced by single members, are encoded, recalled and shared by all participants. We construct and study the dynamical model for the formation and maintaining of episodic memory in small ensembles of interacting minds. The attractor of this process is the unconventional dynamical object: the non-smooth heteroclinic torus that is structurally stable within the Lotka-Volterra-like sets of kinetic equations. Dynamics on this attractor combines absence of chaos with asymptotic instability of every separate trajectory; its adequate quantitative characteristics are positive length-related Lyapunov exponents. When the coupling strength between the partners is varied, the patterns of sequential switching between metastable states can exhibit transitions; we interpret these patterns as different stages in formation and modification of the episodic memory.

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MS28

Applying Lagrangian Data Assimilation to Nextsim

Numerical models solved on adaptive moving meshes have become increas- ingly prevalent in recent years. In particular, neXtSIM is a 2D model of sea-ice that is numerically solved on a Lagrangian mesh. The mesh adaptation in this model includes remeshing, a procedure that adds or removes mesh nodes according to specific rules reflecting constraints of the model. The number of mesh points will change during the integration and, as a result, the dimension of the models state vector will not be conserved. In this talk, we present a novel approach to the formulation of ensemble data assimilation for models with this underlying computational structure. Specifically, we map ensemble members onto a common reference mesh, where the Ensemble Kalman Filter (EnKF) can be performed. Numerical experiments are carried out using 1D prototypical models: Burgers and Kuramoto-Sivashinsky equations, with both Eulerian and Lagrangian synthetic observations assimilate

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MS28

Bayesian Nonparametric Analysis of Transcriptional Processes

Optical tweezers are routinely used to extract dynamics of nucleic acid associated motors, such as RNA polymerase (RNAP). Their ability to provide data with base-pair spatial resolution is the key. It gives us access to information encoded on the sequence-dependent mechanism underlying molecular motor processivity. Of particular interest is the statistics of RNA Polymerases pause and dwell dependencies on DNA sequence during both the initiation and elongation stages of transcription. Inspired by results suggesting RNA Pols DNA composition-specific tran- scriptional mechanism, we combine the highly temporally resolved data from optical traps with the novel statistical analysis methods of Bayesian nonparametrics (BNPs) to draw base-pair level insight on RNA Pols activity during transcription elongation stage. On account of BNPs flexibility in recruiting models of RNA Pol dynamics warranted by the data, and RNA Pols intrinsically complex dynamics, we rigorously constrain the models allowed by BNPs by proposing new modeling strategies inspired by BNP tools scarcely half a decade old.

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MS28

Monitoring Life, Just a Few Photons at a Time

Monitoring life in action, as it occurs in real time within the cellular cytoplasm at the relevant single molecule scale remains an important challenge. In order to see life occur, and monitor specific biomolecules as they diffuse and assemble in the cytoplasm, we create contrast with the cellular background by fluorescently labeling such biomolecules. Yet, the diffraction limit of light keeps us from peering into length scales comparable to those of single molecules. Typical diffraction limited PSFs of light-emitting biomolecules can be two orders of magnitude greater than the biomolecules. For this reason, it has so far been impossible to clearly distinguish biomolecules within a few tens of nanometers of each other if they are simultaneously emitting light. The 2014 Chemistry Nobel Prize was awarded for separating signals from particles in time that cannot otherwise be separated in space to localize biomolecular structures to a precision beyond the diffraction limit. However, this process is slow and thus we compromise temporal resolution by separating signal in time. Here, we present new Mathematics that make it possible to consider complex dynami- cal signals from which we can build a story of life in action starting from the single photon. The methods we present, motivated by the tools of Bayesian nonparametrics that we previously adapted to single molecule, teach us how to achieve diffraction-limited tracking from signal previously considered in- sufficient

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MS28

Biologically Relevant Features on Surfaces Representing Teeth and Bones

Evolutionary anthropologists study and relate both animals that are extant (i.e.presently living) or extinct (and known only through fossil record) to understand the evolutionary processes creating the diversity of life. Some of the most fundamental questions in the filed involve detailed characterizations of anatomical surfaces like teeth and bones, which provide interesting mathematical and algorithmic challenges. This talk focuses on computing biologically relevant features on surfaces. Dirichlet Normal Energy (DNE) has become an essential metric for studies of dental morphology because it is effective at differentiating species according to dietary preferences. DNE measures how much a surface deviates from being a plane, and unlike other shape metrics, it is landmark-free and independent of the surfaces initial position, orientation and scale. However, recent studies found that the current implementation of DNE is sensitive to various surface preparation procedures, and raised concerns regarding comparability and objectivity of utilizing DNE in biological research. Here we provide a robustly implemented algorithm for DNE (ariaDNE) that can be demonstrated to be insensitive to a greater range of surface preparation protocols (e.g., when resolution, triangulation geometry and noise are varied).

Therefore, ariaDNE can be a useful tool to uniformly compare surface meshes collected with different instruments or prepared by varying procedures.

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MS29

Buckling of Small Inextensible Fibers in Turbulence

Elongated, deformable, non-diffusive particles passively transported by a turbulent flow are of relevance to describe cellulose fibers in papermaking industry, or diatom phytoplankton colonies that significantly participate to the CO2 oceanic pump. Two aspects need to be quantified: the extent to which their dynamics can be approximated as that of rigid rods and the statistics of buckling. For that purpose, we focus on the simplest model, the local slenderbody theory, which describes the motion of an inextensible EulerBernoulli beam immersed in a viscous fluid. It is found that such fibers are almost always stretched but might experience quick buckling events. Theoretical arguments, substantiated by state-of-the-art numerical simulations, are used to unveil and characterize the mechanisms which originate this phenomenon. It is demonstrated that buckling events are triggered by violent velocity fluctuations, which are strong enough to compress the fiber along the direction of its extension. In a turbulent flow, velocity gradients are very intermittent: They display non-Gaussian distributions and intricate time correlations. We quantify the impact of this intermittency on the rate at which fibers buckle and on the time distribution of such events.

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MS29

Orientation Patterns of Non-Spherical Particles in Turbulence

When non-spherical particles in a turbulent flow spend a long time near each other, they might reasonably be expected to converge toward the same orientation because turbulent strains tend to align the particles. We show here that this intuition fails in general: relative orientations of nearby particles are anomalously large because the distribution of relative orientations of nearby particles has heavy power-law tails. We measure the moments of this distribution in experiments and numerical simulations, and explain their anomalous scaling as a function of particle distance. Our analysis builds on a description of the relative motion in a phase space that includes not only the usual spatial coordinates, but also the angular degrees of freedom. In this phase space the dynamics evolves to a fractal attractor. Its fractal geometry depends on particle shape and determines the anomalous scaling exponents. This talk is based on joint work with L. Zhao, K. Gustavsson, R. Ni, S. Kramel, G. Voth and H. I. Andersson.

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MS29

Inertial Range Scaling of the Rotation of Fibres in Turbulence

We measure the rotational dynamics and statistics of fibers, neutrally buoyant slender rods, with lengths between 3 and 70 η, Kolmogorov length scale, in turbulent flow. The mean square rotation of rods has a power law dependence on the length of the rods in the inertial range of the flow. This power law scaling, -4/3, is directly derived from the time scale of flow at the length of the rods, assuming that rods only rotate with the eddies of their own size. Interestingly, the correlation time of the Lagrangian autocorrelation of rod rotation rate scales as the turn over time of eddies of the size of the rod. Experimental tracking of long rods in turbulence allows access to the dynamics of turbulent scales at the length of the particle from single particle measurements, and has potential to provide valuable information about Lagrangian dynamics as a function of scale in complex turbulent flows.

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MS29

Fiber Orientation Fields and Vortex Stretching in Turbulence

In a turbulent flow, fibers are usually aligned with their neighbors by fluid stretching. However, careful study of the orientation field of fibers in turbulence shows the existence of thin walls across which the fiber orientation changes by π which we call alignment inversion walls. Using experiments in a turbulent flow between oscillating grids and numerical simulations of homogeneous isotropic turbulence we explain the mechanism that produces alignment inversion walls in a fractal pattern. The orientation field of fibers provides not only fascinating mathematical structure but also a new way to study the dynamics of the turbulence. Fluid stretching, which drives fiber alignment is also responsible for amplifying vorticity in turbulence and as a result, fibers are strongly aligned with the vorticity vector in the flow. This suggests the field of fluid stretching orientation which matches the preferred orientation of fibers at every point provides a valuable new reference frame in which to analyze turbulent flows.

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MS30

Stability of Front Solutions in a Model for a Surfactant Driven Flow on an Inclined Plane

We consider a model for the flow of a thin liquid film down an inclined plane in the presence of a surfactant. The model is known to possess various families of traveling wave solutions. We use a combination of analytical and numerical methods to study the stability of the traveling waves.

We show that for at least some of these waves the spectra of the linearization of the system about them are within the closed left-half complex plane.

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MS30

Traveling Waves and Discontinuous Shock Solutions of the Whitham Modulation Equations

Whitham modulation theory is a powerful mathematical tool to describe the slow evolution of a nonlinear, periodic wave which yields a system of hyperbolic partial differential equations describing the evolution of the waves parameters. The typical solution of interest is a weak, self-similar solution to the hyperbolic system. In this talk we will discuss the fifth order Korteweg-de Vries (KdV) equation where discontinuous shock solutions of the modulation system can be computed. These shock correspond to a rapid transition in the periodic wave parameters which then propagates at a fixed velocity. In the context of the original partial differential equation this corresponds to disparate periodic waves in the far-field co-propagating at a fixed velocity. These traveling waves necessarily satisfy classical jump conditions for the far-field wave parameters and shock velocity. We will conclude this talk by presenting computations of these new traveling waves and discuss their relevance in other nonlinear dispersive systems.

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MS30

Grassmannian Flows and Applications to Smoluchowski's Coagulation Equation

Starting with a system of linear equations, we construct a solution to an evolutionary partial differential equation with nonlocal nonlinearities. In principle, this is achieved by considering a certain coordinate patch of the Fredholm Grassmannian associated to the linearised flow. We present how this works in practice in the case of a nonlocal Fisher-Kolmogorov type equation and the more general case of Smoluchowski's coagulation equation. In particular, regarding the latter, we show how our approach can be applied to the range of kernels for which it is known to be explicitly solvable, and investigate how it might be extended beyond these.

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MS30

Observation of Domain Walls in Stokes Waves on Deep Water

Experiments on nonlinear phase domain walls in weakly nonlinear deep water surface gravity waves will be presented. The domain walls connect homogeneous zones of weakly nonlinear plane Stokes waves of identical amplitude and wave vector but with different phases. Upon exploiting symmetry transformations within the framework of the nonlinear Schrödinger equation, we demonstrate the existence of exact analytical solutions representing such domain walls in the weakly nonlinear limit. It will be shown that the walls are in general oblique to the direction of the wave vector and stationary in moving reference frames. Experimental and numerical studies will confirm the validity of our findings.

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MS31

Mathematical Modeling of Chikungunya Dynamics with Seasonality

Chikungunya, a re-emerging disease, was first identified in 1952 in Tanzania. We develop and analyze a model for the transmission of the Chikungunya virus (CHIKV) to the human population. The disease dynamics of dengue, zika, and chikungunya are similar since those all are transmitted by Aedes mosquitoes. Vector-borne diseases, such as these, are likely to covary with environmental conditions. The abundance of the larvae and mosquitoes, the rate of pathogen transmission, parasite development within vectors, and many more things are directly related to seasonal variation. We incorporate seasonal larvae carrying capacity of the breeding sites and mosquito biting rate into our model and compare the results with real data.

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MS31

Effects of Multiple Transmission Pathways on Zika Dynamics

Although the Zika virus is transmitted to humans primarily through the bite of infected female *Aedes aegypti* mosquitoes, it can also be sexually and vertically transmitted within both populations. In this study, we develop a new mathematical model of the Zika virus which incorporates sexual transmission in humans and mosquitos, vertical transmission in mosquitos, and mosquito to human transmission through bites. Analysis of this deterministic model shows that the secondary transmission routes of Zika increase the basic reproductive number (R_0) of the virus by 5%, shift the peak time of an outbreak to occur 10% sooner, increase the initial growth of an epidemic, and have important consequences for control strategies and estimates of R_0. Furthermore, sensitivity analysis show that the basic reproductive number is most sensitive to the mosquito biting rate and transmission probability parameters and reveal that the dynamics of juvenile mosquito stages greatly impact the peak time of an outbreak. These discoveries deepen our understanding of the complex transmission routes of ZIKV and the consequences that they may hold for public health officials.

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MS31

Modeling a Nosocomial Epidemic of Middle-East Respiratory Syndrome

Abstract not available.

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MS31

Decoys and Dilution: the Impact of Incompetent Hosts on Prevalence of Chagas Disease

Biodiversity is commonly believed to reduce risk of vector-borne zoonoses. This study focuses on the effect of biodiversity, specifically on the effect of the decoy process (additional hosts distracting vectors from their focal host), on reducing infections of vector-borne diseases in humans. Here, we consider the specific case of Chagas disease and try to observe the impact of the proximity of chickens, which are incompetent hosts for the parasite but serve as a preferred food source for vectors. We consider three cases as the distance between the two host populations varies: short (when farmers bring chickens inside the home to protect them from predators), intermediate (close enough for vectors with one host to detect the presence of the other host type), and far (separate enclosed buildings such as a home and hen-house). Our analysis shows that the presence of chickens reduces parasite prevalence in humans only at an intermediate distance and under the condition that the vector birth rate associated with chickens falls below a threshold value, which is relative to the vector birth rate associated with humans and inversely proportional to the infection rate among humans.

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MS32

Dynamics, Data, and Data Assimilation: Using Physiologic Models with Data to Understand Physiology and Impact Clinical Settings

This talk will begin with an introduction to the two-part mini-symposia by addressing the interface between dynamical systems, data assimilation, and how they can be used in conjunction with clinical data in real world settings; the talk will also address how this framework plugs in to study basic science, mathematics, and inference problems. The talk will introduce the setting — clinical data and the clinical environment — in a dynamical systems context. This will include a discussion of the data, how the data are generated, and constraints and advantages of working within an applied context where data are collected. Then, anchored to real applications and constrained by data, several mathematical physiology models will be introduced, including models of the glucose-insulin system and lung (pulmonary) systems. The models will be followed by a discussion of data assimilation methods used to synchronize the models with data. This discussion will include a demonstration of data assimilation succeeding and failing to synchronize the models using real data. Though this discussion a framework for using clinical data to study basic physiology will be introduced. The talk will finish with a set of challenges from all the above perspectives, including dynamics, data assimilation, and applications; many of these challenges will be discussed in subsequent mini-symposia talk.

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MS32

Designing Metrics to Evaluate a Clinical Forecasting System

In clinical forecasting, assessing the value of a forecast is not simple. The average or maximum deviation of a forecast from the true value over time does not necessarily capture the benefits and risks of a forecast. For example, a poor forecast can provoke an inappropriate medical response that harms the patient. Furthermore, the value of a forecast depends not just on its accuracy but also on the extent to which it adds useful information, rather than simply predicting what is known. This talk discusses several metrics in the setting of glucose and insulin management in the intensive care unit, using existing insulin therapy protocols to gauge the impact of forecasts on patient care.

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MS32

Shear-Induced Reliability Failure in Physiological Systems with Delay

Medical intervention requires robust, stable, reliable prediction: Patient response to an intervention can be predicted when the state of the patient at the time of intervention is only approximately known and even if there exists some uncertainty associated with the intervention itself. We will show that prediction reliability can fail for the glucose-insulin system in particular and for physiological systems in general. Importantly, delay causes the reliability failure. Leveraging ideas from the theory of rank one dynamics, we explain what is happening using a theory we call shear-induced uncertainty. We will finish by commenting on implications for data assimilation.

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MS32

Modeling and Estimation of Glucose-Insulin Dynamics by using the Ornstein-Uhlenbeck Process

We model glucose-insulin regulation in humans by using the Ornstein-Uhlenbeck process. Through this model, we

aim to keep the blood glucose levels of patients in intensive care units (ICU) under control. Towards this goal, we first estimate the model parameters based on data collected from patients by using various approaches such as optimization and MCMC techniques. Then, we validate the model we use and the accuracy of the estimated parameters. Besides providing additional information about the glucose-insulin system of patients, these estimated parameters are used to develop a personalized model for each patient, which are used to forecast the blood glucose levels of patients and eventually to develop automated control to keep blood glucose levels of patients in a healthy range.

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MS33

Data-Driven Model Reduction in the Mori-Zwanzig Framework

In many computational dynamics problems, fully-resolved models based on first principles are either unavailable or prohibitively expensive to use. Data-driven modeling methods can be used to construct reduced models of the observable degrees of freedom. In this talk, I will provide a brief introduction to elements of data-driven modeling and model reduction, touching on some of the many dynamical and implementation issues that arise. I will then introduce the Mori-Zwanzig projection operator formalism, a general framework for model reduction from nonequilibrium statistical mechanics, and explain how a data-driven modeling method based on the NARMAX representation of stochastic processes can be studied from this point of view.

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MS33

Space-Time Numerical Approximations of a Nudging Algorithm

We consider a feedback-control (nudging) approach for data assimilation that works for a general class of dissipative dynamical systems and observables. As a model example, we consider the 2D incompressible Navier-Stokes equations (NSE). Our purpose is to present an estimate of the error between a numerical approximation of the solution to the nudging equation and a reference solution of the 2D NSE, representing the truth. We consider a spatial discretization given by the Postprocessing Galerkin method and two types of implicit Euler schemes for the time discretization: fully implicit and semi-implicit. Our results show that the time-discrete schemes are unconditionally stable and the error estimates are uniform in time. This is based on joint works with H. Ibdah and E. S. Titi.

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MS33

Changing Collective Behavior of Oscillators by Controlling the Destiny of their Phase Density

The collective behavior of biological oscillators has been recognized as an important problem for several decades, but its control has come into the limelight only recently. Much of the focus for control has been on desynchronization of an oscillator population, motivated by the pathological neural synchrony present in essential and parkinsonian tremor. Other applications, such as the beating of the heart and insulin secretion, require synchronization, and recently there has been interest in forming clusters within an oscillator population as well. In this talk, we will present a unified control framework to achieve all of these distinct collective behaviors observed in biological oscillators. The control algorithm is based on the partial differential equation governing the evolution of the phase distribution of a population of identical, uncoupled oscillators. Motivated by pathological neural synchrony, we apply our control to desynchronize an initially synchronized neural population. To enhance spike time dependent plasticity to stabilize neural clusters and counteract pathological neural synchronization, we apply our control to transform the neural phase distribution to form clusters. Finally, motivated by eliminating cardiac alternans, we apply our control to phase shift a synchronous cardiac pacemaker cell population. For the systems considered in this paper, the control algorithms can be applied to achieve any desired non-degenerate traveling-wave phase distribution.

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MS33

Reduced Models for Uncertainty Quantification

In many time-dependent problems of practical interest the parameters and/or initial conditions entering the equations describing the evolution of the various quantities exhibit uncertainty. One way to address the problem of how this uncertainty impacts the solution is to expand the solution using polynomial chaos expansions and obtain a system of differential equations for the evolution of the expansion coefficients. We present an application of the Mori-Zwanzig (MZ) formalism to the problem of constructing reduced models of such systems of differential equations. In particular, we construct reduced models for a subset of the polynomial chaos expansion coefficients that are needed for a full description of the uncertainty caused by uncertain parameters or initial conditions. Even though the MZ formalism is exact, its straightforward application to the problem of constructing reduced models for estimating uncertainty involves the computation of memory terms whose cost can become prohibitively expensive. For those cases, we present a Markovian reformulation of the MZ formalism which is better suited for reduced models with long memory. The reformulation can be used as a starting point for approximations that can alleviate some of the computational expense while retaining an accuracy advantage over reduced models that discard the memory altogether. Our results support the conclusion that successful reduced models need to include memory effects.

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MS34

Quasi-Stationarity for Reaction Networks

Stochastic reaction networks compose a broad class of applicable continuous-time Markov processes with a particularly rich structure defined through a corresponding graph. As such, they pose a general and natural framework for representing non-linear stochastic dynamical systems where the interactions among species are themselves of transformational form. Many such systems, in particular when they model real world phenomena, are certain to go extinct eventually, yet appear to be stationary over any reasonable time scale. This phenomenon is termed quasi-stationarity. A stationary measure for the stochastic process conditioned on non-extinction, called a quasi-stationary distribution, assigns mass to states in a way that mirrors this observed quasi-stationarity. We provide sufficient conditions for the existence and uniqueness of such quasi-stationary distributions and examine the relationship with the deterministic dynamics in the fluid limit, through the use of random perturbations and Morse decompositions. Finally, we illustrate the applicability of the results though various examples of stochastic population processes, including 3-dimensional competitive systems.

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MS34

The Competitive Exclusion Principle in Stochastic Environments

The competitive exclusion principle states that a number of species competing for a smaller number of resources cannot coexist. Even though this is a fundamental principle in ecology, it has been observed empirically that in some settings it will fail. One example is Hutchinson's 'paradox of the plankton'. This is an instance where a large number of phytoplankton species coexist while competing for a very limited number of resources. Both experimental and theoretical studies have shown that in some instances (deterministic) temporal fluctuations of the environment can facilitate coexistence for competing species. Hutchinson conjectured that one can get coexistence because nonequilibrium conditions would make it possible for different species to be favored by the environment at different times. In this talk I will look at how environmental noise interacts with competitive exclusion. I will give conditions for when the competitive exclusion principle holds as well as an example where, contrary to Hutchinson's explanation, one can switch between two environments in which the same species is favored and still get coexistence.

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MS34

Coexistence and Extinction for Stochastic Kolmogorov Systems

In recent years there has been a growing interest in the study of the dynamics of stochastic populations. A key question in population biology is to understand the conditions under which populations coexist or go extinct. Theoretical and empirical studies have shown that coexistence can be facilitated or negated by both biotic interactions and environmental fluctuations. We study the dynamics of n populations that live in a stochastic environment and which can interact nonlinearly (through competition for resources, predatorprey behavior, etc.). Our models are described by n-dimensional Kolmogorov systems with white noise (SDE). We give sharp conditions under which the populations converge exponentially fast to their unique stationary distribution as well as conditions under which some populations go extinct exponentially fast. The analysis is done by a careful study of the properties of the invariant measures of the process that are supported on the boundary of the domain. We are able to fully describe the properties of many of the SDE that appear in the literature. In particular, we extend results on two dimensional Lotka-Volterra models, two dimensional predatorprey models, n dimensional simple food chains, and two predator and one prey models. We also show how one can use our methods to classify the dynamics of any two-dimensional stochastic Kolmogorov system satisfying some mild assumptions.

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MS34

How Environmental Randomness Can Reverse the Trend

In this talk, we will be interested in the evolution of population in an environment that fluctuates randomly between several states. Through examples, we will show how this environmental randomness can reverse the trend, that is, how the behavior of the population can drastically change when comparing to its behavior in each state of the environment. We will also give intuition of criteria that enable to predict this random behavior. This is part of a joint work with my thesis advisor, Michel Benaïm.

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MS35

A Nondestructive Damage Detection in Bridge Structures using Information-Theoretic Methods

Damage detection of bridge structures is an important research problem in civil engineering. In this work, we study noninvasive damage detection using information-theoretic methods. We present several findings based on spatially distributed sensor time series data collected from a recent experiment on a local bridge in Northern New York. The time series data, which represent accelerations measured at the sensors, more closely follow Laplace distribution than normal distribution. Thus follows parametric estimators for associated entropic measures, allowing our proposed optimal mutual information interaction (oMII) method that is a greedy algorithm to distinguish direct versus indirect interactions. In our experimental data, we found the onset of damage corresponded to weakening and then disappearing links for energy transmission.

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MS35

On the Synchronizarion Myth for Lateral Pedestrian-Instability of Suspension Bridges

The pedestrian-induced lateral oscillation of London's Millennium bridge on the day it opened in 2000 has become a much cited paradigm of an instability caused by phase synchronization of coupled oscillators. However, a closer examination of subsequent theoretical studies and experimental observations have brought this interpretation into question. To elucidate the true cause of instability, we study a model in which each pedestrian is represented by a simplified biomechanically-inspired two-legged inverted pendulum. The key finding is that synchronization between individual pedestrians is not a necessary ingredient of instability onset. Instead, the side-to-side pedestrian motion should on average lag that of the bridge oscillation by a fraction of a cycle. Using a multi-scale asymptotic analysis, we derive a mathematically rigorous general criterion for bridge instability based on the notion of effective negative damping. This criterion suggests that the initiation of wobbling is not accompanied by crowd synchrony and crowd synchrony is a consequence but not the cause of bridge instability.

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MS35

Wind-Induced Instability of a Suspension Bridge: A Tale of Two Frequencies

The most famous example of wind-induced vibrations is that of the Tacoma Narrows Bridge, which collapsed in 1940 when mild winds at about 40 miles per hour led to large-amplitude torsion. Remarkably, the frequency of destructive aeroelastic flutter was different from all natural modes of the structure. The exact cause of the bridge's failure still remains unclear. The experts disagree, at least on some aspects of the explanation. A definitive description that meets unanimous agreement has not been reached. This work puts forward rigorous mathematical insight into the cause of dangerous bridge vibrations as a result of wind-induced oscillations at a frequency different from the natural frequencies of a bridge. Our work suggests that wind-induced phase-locking of suspension/load-bearing elements can explain the shift of the resonant frequency that can only be predicted via a rigorous mathematical analysis of the complex nonlinear system.

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MS35

Homoclinic Orbits in the Suspension Bridge Equation

In a simple model for the surface of a suspension bridge, travelling waves with speed c satisfy the fourth order ODE $u'' + c^2u' + e^u - 1 = 0$. Homoclinic orbits for this equation correspond to propagating disturbances with fixed profile. In this talk we discuss computer-assisted techniques for proving the existence of homoclinic solutions for all $0.5 \leq c^2 \leq 1.9$. To find these solutions, the stable manifold is described via the parametrization method, and the (symmetric) homoclinic orbits are obtained by solving a projected boundary value problem using Chebyshev series. To perform rigorous (parameter) continuation we use the uniform contraction theorem, which provides an efficient means of determining a set, centered at a numer-

ical approximation of a solution, on which a Newton-like operator is a contraction. This mathematically rigorous computer-assisted approach is applicable to a large class of continuation problems for heteroclinic and homoclinic orbits in systems of ODEs. This is joint work with Maxime Breden, Jean-Philippe Lessard and Maxime Murray.

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MS36

Explosive Synchronization in Adaptive and Multilayer Networks

Explosive synchronization (ES) is nowadays a hot topic of interest in nonlinear science and complex networks. Initially, it was conjectured that the root for ES was the setting of specific microscopic correlation features between the natural frequencies of the networked oscillators and their effective coupling strengths. In this talk, I will show that ES is, in fact, a much more general phenomenon, and can occur in adaptive and multilayer networks also in the absence of such correlation properties. Precisely, I will first discuss different ways of producing ES in complex networks, and then will give evidence of ES in the absence of correlation for networks where a fraction f of the nodes have links adaptively controlled by a local order parameter. Finally, I will discuss the extension of the study to a variety of two-layer networks with a fraction f of their nodes coupled each other by means of dependency links. In this latter case, ES sets in regardless of the differences in the frequency distribution and/or in the topology of connections between the two layers.

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MS36

Interdependent and Competitive Dynamics of Multilayer Networks

Abstract not available.

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MS36

Inhibition Induced Explosive Synchronization in Multiplex Networks

A multiplex network is a framework of interconnected layers, each with different connectivity explicating different dynamical processes, however, represented by a common set of nodes. It provides a more accurate representation of many real-world networks. Further, to date, explosive synchronization (ES) is shown to be originated from either degree-frequency correlation or inertia of phase oscillators on networks. Of late, it has been shown that ES can be induced in a network by adaptively controlled phase oscillators. We show that ES is a generic phenomenon and can occur in any network by appropriately multiplexing it with another layer. We devise an approach which leads to the occurrence of ES with hysteresis loop in a network upon its multiplexing with a negatively coupled (or inhibitory) layer. We discuss the impact of various structural properties of positively coupled (or excitatory) and inhibitory layer along with the strength of multiplexing in gaining control over the induced ES transition. This investigation is a step forward in highlighting the importance of multiplex framework not only in bringing novel phenomena which are not possible in an isolated network but also in providing more structural control over the induced phenomena.

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MS36

Percolation in Real Multilayer Networks

In this talk, I will review some of my recent papers about percolation on multi-layer networks. I will first illustrate a theoretical approach consisting in a system of heuristic equations able to approximate the phase diagram of the ordinary percolation model for arbitrary multi-layer networks. Second, I will introduce and characterize the redundant percolation model, a genuine model for multilayer networks where the addition of new layers boosts system robustness by creating redundant interdependencies among layers. Third, I will generalize the problem of optimal percolation from single-layer to multi-layer networks, and present several algorithms for finding approximate solutions to the problem. Finally, I will present a large-deviation approach to ordinary percolation able to shed light on the importance of fluctuations in the study of percolation on real-world multi-layer networks.

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MS37

The Role of NHIMs in Barred Galaxies

The effective potential for barred galaxies has index-1 saddle points near the places where the outer spirals connect to the inner bar. In the phase space, we find NHIMs of codimension 2 over these saddles. The development scenario as a function of the energy for the dynamics over these saddles is displayed as 2.dimensional graphics by a restriction of the Poincar map to the NHIMs. The projection of the outer branches of the unstable manifolds of the NHIMs into the position space traces out the spirals with a very good precision. This opens up the possibility to interpret the outer spirals as caused by perturbations propagated along the unstable manifolds of the NHIMs. In this sense, barred galaxies are a very nice example where we can relate properties of NHIMs rather directly to observable structures in position space.

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MS37

Topological Dynamics in Three-Dimensional

Volume-Preserving Maps

From the nonlinear dynamics perspective, understanding atomic and molecular systems involve developing a deep understanding of the phase space structures that regulate transport in Hamiltonian phase space. Though a rich theory has been developed for one- and two-degree-of-freedom systems, many challenges remain for higher-dimensional systems. We present a new topological approach to higher-dimensional chaotic scattering. The input to this approach is the delay time as a function of impact parameters. The output is a rigorous symbolic representation of the dynamics within the scattering region. The method itself develops and utilizes an efficient topological representation of the codimension-one stable and unstable manifolds attached to normally hyperbolic invariant manifolds. We apply this technique to numerical data from a spherical fluid vortex, whose dynamics reduce to a volume-preserving three-dimensional map. This system is a stepping stone to full three-degree-of-freedom Hamiltonian systems, whose feasibility we assess.

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MS37

Geometry of Escaping Dynamics in the Presence of Dissipative, Gyroscopic and Stochastic Forces

Prediction of escape from a potential well, or transition from one to another, has broad application in two or more degree-of-freedom systems, even in engineering, such as how a ship capsizes, how a mechanical structure buckles, how large space structures navigate around libration point orbits, etc. In such systems, however, one needs to consider realistic damping, stochastic forcing, and forces due to rotation. In this talk, we study the linearized dynamics in a broad range of systems, extending the framework of tube dynamics to the case of dissipation and gyroscopic forces, proving the existence of ellipsoid-like structures bounding the initial conditions of trajectories that escape from one side of a rank-1 saddle point to another. Furthermore, we discuss experimental validation of our approach, where we confirm the underlying phase space conduits that mediate transitions and the predicted phase space flux as a function of excess energy. Experimental regions of transition are found to agree with theory to within 1 percent, suggesting the robustness of phase space conduits of transition in a broad array of two or more degree-of-freedom experimental systems, despite the presence of small dissipation. In fact, phase space conduits of transition might be among the most robust phase space features found in experiments of multiple degree-of-freedom mechanical systems, given the fragility of other structures to dissipation.

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MS37

The Computation and Application of Quasi-Periodic Orbits in Space Trajectory Design

The application of dynamical systems methods to the design of spacecraft trajectories has resulted in the use of invariant orbits and their stable and unstable manifolds to effect transfers that can move across large distances in space. Most specific applications in this realm have focused on using simple invariant orbits such as periodic orbits and their manifolds to find candidate heteroclinic connections. However, the existence of higher-dimensional invariant orbits such as quasi-periodic orbits and their related manifolds has not been studied as closely, due to the difficulty in precisely computing these objects in general situations. Recent research at the University of Colorado (CU) has developed a robust computational algorithm for precisely finding and continuing quasi-periodic orbits of dimension 2 and higher, along with their manifolds (Z. Olikara, PhD. Thesis, 2016). The use of these higher-dimensional orbits can have significant impact on the design of heteroclinic transfers, along with many other applications. This arises due to the relatively high phase space co-dimensions of the stable and unstable manifolds of these orbits, making it is easier to find connections between different quasi-periodic tori of the same energy. Similarly, the ability to compute these higher-dimensional tori also enables the robust continuation of periodic orbits and tori in periodically perturbed problems.

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MS38

Dynamics of Neurons on a Random Graph

Gamma oscillation of the local field potential is a collective dynamics of numerous neurons. To investigate the dynamics of interacting inhibitory neurons, we propose the modified theta model defined on a random graph. For the continuous limit (Fokker-Planck equation), we study a bifurcation from de-synchronization to macroscopic gamma oscillation with the aid of the generalized spectrum theory.

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MS38

Modified Theta Model Provides Analytical Insights into Network of Neuronal Networks

Local field potentials in the brain are organized by interacting numerous neurons and have functional roles in cognition and/or attention. We have developed a framework of multiscale analysis of neuronal population using modified theta model, which possesses voltage-dependent dynamics with appropriate synaptic interactions. We show that the bifurcation analysis of the corresponding Fokker-Planck equation helps to consider the origin of gamma oscillation. We also show that Ott-Antonsen ansatz is appropriately introduced to our model in order to analyze the collective dynamics on network of neuronal networks.

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MS38

The Kuramoto Model on Random Graphs: Take it to the Limit

The continuum limit is one of the very few analytical tools available to us for studying dynamics of large coupled systems. Using the Kuramoto model of coupled phase oscillators as a prototypical example, we discuss a unified approach for the derivation and analysis of the continuum limit of interacting dynamical systems on graphs. Our approach covers systems on undirected and directed, dense and sparse, deterministic and random graphs. We review the main ingredients of our method and describe the main results. The former include the W-random graph model from the theory of graph limits, the averaging principle for the coupled systems on random graphs, and certain elements of the theory of evolution equations. The latter concern the analysis of convergence to the continuum limit, rate of convergence estimates, mean field approximation, as well as related results about the dynamics of the Kuramoto model on graphs. In addition, we present a randomized numerical method for nonlocal partial differential equations, motivated by the analysis of coupled systems on random graphs.

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MS38

Power Network Dynamics on Graphons

In this talk we consider the following system of coupled second order oscillators $\ddot{\phi}_k = -\alpha\dot{\phi}_k + \sum_{\ell:\,(k,\ell)\in E(G_N)} K_{k,\ell}\sin(\phi_\ell - \phi_k) + P_k$ on a weighted graph G_N. This arises as a model for power grids. A fundamental question for such systems is whether they achieve synchronisation to a common frequency on maybe even very large network structures. To study this problem, we will present a theory of continuum limit for this power grid model, both for deterministic and random networks, exploiting the theory of graph limits (graphons). In this large network limit, we will then also analyse the linear stability of synchronised states for specific graph structures. In particular, we demonstrate that the stability of the system depends on the topological properties of the underlying network and that varying certain parameters of the latter leads to potential destabilisation.

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MS39

Extreme Events: Origins, Prediction and Mitigation

A wide range of natural and engineering systems exhibit extreme events, i.e., spontaneous intermittent behavior manifested through sporadic bursts in the time series of their observables. Examples include unusually large ocean waves (commonly referred to as rogue waves), intermittency in turbulence and extreme weather patterns. Because of their undesirable impact on the system or the surrounding environment, the real-time prediction and mitigation of extreme events is of great interest. In this talk, I discuss some recent advances in the quantification and prediction of extreme events. In particular, I introduce a variational method that disentangles the mechanisms underpinning the formation of extreme events. This in turn enables the data-driven, real-time prediction of the extreme events. I demonstrate the application of this method with several examples including the prediction of ocean rogue waves and the intermittent energy dissipation bursts in turbulent fluid flows.

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MS39

Tensor Decomposition Based Splitting Methods for Rare Event Simulation

Splitting methods are a popular alternative to dynamic importance sampling for rare event estimation in complex dynamical systems. The method relies on favoring migration towards the rare event region by cloning or splitting trajectories that move in the desired direction. The performance of the method relies on the placement of thresholds at which trajectories are split. It is well known that the solution (called the importance function) of the Hamilton-Jacobi-Bellman equation defined by a dynamical system, can be used to place these thresholds. In this work, we explore computational approaches for constructing efficient splitting schemes for dynamical systems. In particular, we use the subsolutions of the HJB to construct importance functions for splitting rules that give rise to efficient rare event estimators. In the absence of these subsolutions, we use tensor decomposition based methods that exploit low rank structure in the importance function to compute approximate solutions of the HJB. We show that these solutions can then be used to construct efficient splitting schemes in real world examples.

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MS39

Rare Event Simulation via Importance Sampling for Linear SPDE's

We develop provably efficient importance sampling Monte Carlo methods for the estimation of rare events within the class of linear stochastic partial differential equations (SPDEs). We find that if a spectral gap of appropriate size exists, then one can identify a lower dimensional manifold where the rare event takes place. This allows one to build importance sampling changes of measures that perform provably well even pre-asymptotically (i.e. for small but non-zero size of the noise) without degrading in performance due to infinite dimensionality or due to long simulation time horizons. Simulation studies supplement and illustrate the theoretical results. Joint work with Michael Salins.

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MS39

Towards a Generalized Theory of Rare Event Simulation for Linear Stochastic Differential Equations

We focus on improving state-of-the-art rare event simulation methods for stochastic dynamical systems. Current methods focus on using dynamic importance sampling and particle splitting algorithms. Both approaches have been found to be improved by considering large deviations theory, in which finding biasing functions or choosing importance sets is based on finding solutions and subsolutions of a Hamilton-Jacobi equation. This task becomes increasingly difficult in high dimensional settings or when the attractors in the dynamical system are strongly stable. In this talk we present a general theory for constructing efficient importance sampling estimators for high dimensional stochastic linear dynamical systems. To do so, we study how rare events occur in linear systems which will aid in constructing provably efficient biasing functions. Along the way we will explore connections with importance sampling estimators constructed via large deviations theory. We also explore connections with gentlest ascent dynamics, nonnormal transient growth, and optimal time dependent modes. This will provide insight for constructing importance sampling estimators for nonlinear dynamical systems.

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MS40

Machine Learning vs Dynamical System Based Analysis of Neurophysiological Data: An Overview

This presentation is focused on an overview of data analysis and modeling for neurophysiological applications. The main part of the talk is on methods from different scientific areas; on one hand dynamical systems provide a bunch of understanding system dynamics, on the other hand machine learning methods have been very successful across many fields. Both approaches use statistical description, though. We will work out differences and similarities in the underlying algorithms and try to give a fair comparison of how useful the different methods are on a particular field.

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MS40

Inferring the Connectivity of Pulse-Coupled Oscillatory Networks using Phase Modelling

We present an approach for inferring the connectivity of pulse-coupled oscillatory networks from observations of spike trains. It is assumed that units are self-sustained oscillators and the coupling is weak enough that they are well modeled with phase dynamics. The approach consists of a straight forward minimization scheme applied iteratively until the solution converges. We are minimizing the difference between the observed time series and those generated with phase dynamics. Thereby we also have a natural measure of the quality of the inference regardless of whether the true system is known. The procedure yields the natural frequency and the infinitesimal phase response curve of each oscillator as well as the strength and directionality of all interactions. The algorithm has time complexity of $\mathcal{O}(N^{3-4})$ for computing all pairwise interaction, but reduces to $\mathcal{O}(N)$ if for every oscillator only a fixed number of interactions are considered (N being the number of oscillators). The method is thoroughly tested on synthetic data of several dozens continuously coupled neuronal oscillators and the inference quality evaluated as a function of the length of time series. The data requirement is modest - as a rule of thumb, the time series of each oscillator should contain at least twice as many periods as oscillators.

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MS40

Dynamical Disentanglement in Analysis of Oscillatory Data

A typical problem in data analysis is to eliminate a particular component of a given time series, e.g. to remove noise, trend, oscillation in a certain frequency band, etc. This goal can be achieved by means of filtering in the frequency domain, smoothing in a running window, subtracting a fitted polynomial, etc. Furthermore, a number of modern methods decompose a signal in a sum of modes so that dominating ones are assumed to represent certain dynamical processes. These modes can be analyzed separately or, if they are considered as irrelevant, they can be subtracted from the original data, yielding a cleansed signal. Here we elaborate on a technique, designed for analysis of signals, generated by coupled oscillatory systems. The technique is based on reconstruction of phase dynamics of the analyzed unit. The obtained equation is then used for generation of new, cleansed, data by excluding one, or, generally, several inputs to the system. For example, if only the deterministic part of the model is used, i.e. the noise term is omitted, then the simulated data represents the dynamics of noise-free system. This disentanglement procedure is neither the standard filtering (because the preserved and eliminated components can overlap in frequency domain) nor the mode decomposition (because the sum of preserved and eliminated components does not yield the original signal). Here we consider an application of this approach to analysis of cardio-respiratory interaction in humans.

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MS40

Sleep Staging with General Deep Neural Models of the Eeg

Abstract not available.

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MS41

Influence of Receptor Recharge on the Statistics of Captured Particles

We consider a setup where particles are released into a domain and diffuse freely. Part of the boundary is absorbing, where the particles can escape the domain, another part is reflecting. The rest of boundary consists of capture regions that switch between being reflecting and absorbing. After capturing a particle, the capture region becomes reflecting for an exponentially distributed amount of time. This non-zero recharge time correlates the particles paths, complicating the mathematical analysis of this system.We are interested in the distribution of the number of particles that are captured before they escape. Our results are derived from considering our system in several ways: as a full spatial diffusion process with recharging traps on the boundary; as a continuous-time Markov process approximating the original system; and lastly as a system of ODEs in a mean-field approximation. We apply these approximations to investigate time courses for the expected number and higher ordered statistics of captured particles.We find that the number of expected cumulativecaptures increases linearly before saturating, and find an analytical expression for the duration of the linear growth. We also find that the amount of variation observed in the total number of captured particles varies non-monotonically with the mean recharge time. Lastly, we combine these results together to predict stochastic properties of intracellular signals resulting from receptor activation.

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MS41

Connecting Risk Factor Prevalence to Cancer Incidence through Stochastic Carcinogenesis Models

Risk factors for cancer can be difficult to assess because of the long lag time between exposures to etiologic agents and the onset of cancer. Modeling the connection between population-level prevalence of etiologic agents and population-level incidence of cancer is particularly challenging because of the multiple spatial and temporal scales involved (e.g., from cell to population levels and exposure to carcinogenesis timescales). Multistage clonal expansion (MSCE) models are a family of inhomogeneous, continuous-time Markov models that provide a framework to integrate time-varying exposures into the analysis of cancer epidemiologic data. The initiation–promotion–malignant conversion hypothesis posits that tumors are seeded through an accumulation of rare events, nominally mutations (initiation), that tumors expand clonally (promotion), and that a final mutation transforms a tumor cell to malignancy (malignant conversion). MSCE models seek to explain cancer incidence patterns in terms of this underlying biological mechanism. Using Markov branching process theory, we derive a system of probability generating functions that we use to describe cancer incidence. We explore the connection between H. pylori and gastric cancer, smoking and lung cancer, and the HPV and oral cancer. We find both that risk factor prevalence can closely and parsimoniously predict cancer incidence and that cancer incidence may give us information about historical trends in risk factor prevalence.

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MS41

Network Stabilization of Stochastic Systems using Absolutely Robust Modules

The focus of this talk is to control the concentration of a species of interest by adding reactions into the original chemical reaction network. In particular, we develop conditions based on deficiency theory guaranteeing that the distribution of the target species approximates a Poisson distribution with a desired mean in a particular scaling limit.

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MS41

Complexity Reduction for Stochastic Network Models in Biology

Markov processes are widely used to model the dynamics of biological processes evolving on networks. Complexity reduction for such models aims to capture the essential dynamics of the process via a simpler representation, with minimal loss of accuracy. The stochastic shielding approximation is a novel dimension reduction method that has been used to simplify stochastic network models arising in neuroscience, such as randomly gated ion channel models, but applies broadly to many biological systems. In this talk, I will describe the stochastic shielding approximation and our related edge importance measure which allows us to rank each noise source according to its contribution to the observed variability. I will also explore the robustness of the method under conditions of timescale separation and population sparsity, and use the method in several biological examples.

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MS42

Interpretable Nonlinear Models of Unsteady Flow Physics

Accurate and efficient reduced-order models are essential to understand, predict, estimate, and control complex, multiscale, and nonlinear dynamical systems. These models should ideally be generalizable, interpretable, and based on limited training data. This work develops a general framework to discover the governing equations underlying a dynamical system simply from data measurements, leveraging advances in sparsity-promoting techniques and machine learning. The resulting models are parsimonious, balancing model complexity with descriptive ability while avoiding overfitting. This perspective, combining dynamical systems with machine learning and sparse sensing, is explored with the overarching goal of real-time closed-loop feedback control of unsteady fluid systems. First, we will discuss how it is possible to enforce known constraints, such as energy conserving quadratic nonlinearities in incompressible fluids, to bake in known physics. Next, we will demonstrate that higher-order nonlinearities can approximate the effect of truncated modes, resulting in more accurate models of lower order than Galerkin projection. Finally, we will discuss the use of intrinsic measurement coordinates to build nonlinear models, circumventing the well-known issue of continuous mode deformation associated with methods based on the proper orthogonal decomposition. This approach is demonstrated on several relevant systems in fluid dynamics with low-dimensional dynamics.

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MS42

Data-Driven Modeling of Unsteady Aerodynamic Systems

This talk will discuss methods for obtaining low-dimensional models for the prediction of time-varying lift and drag forces on airfoils across a wide range of angles of attack. Focusing in particular on a two-dimensional airfoil at low Reynolds number, we seek models capable of capturing phenomena at conditions ranging from fully attached flow over the suction surface through to the massively separated regime, where the airfoil resembles a bluff body. Models are identified by applying sparsity-promoting regression techniques upon training data spanning specified regimes of interest. We find that three-dimensional parametrized models are often sufficient to accurately capture features such as the bifurcation point leading to the onset of vortex shedding, the amplitude and frequency of the resulting limit cycle, and transients due to start-up or rapid maneuvering. Further to this, we demonstrate that such models may be identified using force measurements alone, making them particularly applicable for data-sparse environments. We will discuss tradeoffs between model complexity, accuracy, and regions of validity, and will further discuss possible applications of these models for estimation and control.

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MS42

Sequential DMD Mode Selection for Reduced-Order Modeling

Dynamic mode decomposition (DMD) yields a linear, approximate model of a system's dynamics that is built from data. We seek to reduce the order of this model by excluding the modes with the smallest contribution to the system's dynamics. A sequential selection method is proposed by which modes are added to an active set based on their correlation with the residual of the reconstruction error. After each selection step, the weighting coefficients of the active set are found using least squares, and we calculate the performance loss of the data reconstruction problem using the reduced-order model. Sparsity-promoting dynamic mode decomposition (DMDSP) is used as the benchmark for the performance of the sequential selection method. Preliminary results indicate that the proposed selection method yields reduced-order models that have comparable performance to DMDSP. The proposed method has the benefit that specification of a regularization weighting parameter is not required at the start of the reduced-order model construction.

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MS42

Blending Network Science and Fluid Mechanics for Modeling and Control of Vortical Flows

We consider the network-based formulation to describe the collection of interactions present in fluid flows. These interactions that occur amongst vortices or spatial modes are responsible for the emergence of the complex dynamics. One of the canonical example of such complex behavior is turbulence. In this talk, we present vortex-based and mode-based approaches to model and control unsteady vortical flows. For the former formulation, vortices and the induced vortical velocities are taken to be the network nodes and edges, respectively. For the latter formulation, spatial modes (e.g., POD modes) and the kinetic energy transfers are used to construct the network. With these formulations, we consider the use of network-based reduction techniques such as sparsification and community detection to derive sparse and low-dimensional models. We also discuss some extensions of the network based framework to model continuum mechanics in general.

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MS43

Existence and Stability of Spike Solutions in the SIRS Model with Diffusion

We investigate an SIRS epidemic PDE system with nonlinear incident rates. In the limit of small diffusion rate of infected class D_I, and on a finite interval, an equilibrium spike solution to the epidemic model is constructed asymptotically and the motion of the spike is studied. For sufficiently large diffusion rate of recovered class D_R, the interior spike is shown to be stable, however it becomes unstable and moves to the boundary when D_R is sufficiently small. We also studied two types of bifurcation behavior of multi-spike solutions: self-replication and spike competition, and their stability thresholds are precisely computed by asymptotic analysis and verified by numerical experiments. Finally, we show that the spike-type solutions can transition into an interface-type solutions when the diffusion rates of recovered and susceptible class are sufficiently small, and the transition regime is obtained precisely.

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MS43

The Dynamics of a Brusselator System with Bulk-Membrane Coupling

We consider a Brusselator model on the surface of a unit sphere that is coupled to an activator bulk-bound source term represented by a Dirac delta. For such a model, the surface activator "fuel" term is directly related to the bulk-bound source term's strength and location. By focusing on the singularly perturbed limit of a small activator to inhibitor diffusivity ratio, we use asymptotic and numerical methods to study the effect of bulk-membrane coupling on "peanut" splitting instabilities and slow spot dynamics. In particular, we explore the effect of the source strength and location on N-spot equilibrium configurations.

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MS43

Modelling Honey Bees in Winter using a Keller-Segel Model with a Chemotactic Coefficient Changing Sign

Thermoregulation in honey bee colonies is thought to be self-organised. Without mortality, this can be modelled by a special type of Keller-Segel model. In contrast to the often studied Keller-Segel models, our model includes a chemotactic coefficient which changes its sign since honey bees have a preferred temperature: when the local temperature is too low, they move towards higher temperatures, whereas the opposite is true for high temperatures. We added mortality of individual bees to this existing model. The aim of analysis is to obtain a better fundamental understanding of the consequences of honey bee mortality during winter. We analyse the model with and without mortality. Our study shows that we can distinguish two states of the colony: one in which the colony size is above a certain critical number of bees in which thebees can keep the core temperature of the colony above the threshold temperature, and one in which the core temperature drops below the critical threshold and the mortality of the bees increases dramatically, leading to a sudden death of the colony. This behaviour may explain the globally observed honey bee colony losses during winter.

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MS43

Localized Solutions on Curved Surfaces in Reaction-Diffusion Systems

We consider the motion of localized spot solutions on two-dimensional curved surface in reaction-diffusion systems. Assume the existence of a stable spot solution on the flat plane, we show that the single spot solutions move very slowly depending on the gradient flow of the Gaussian curvature. Next we discuss about the problem of multi-spot solutions on the curved surface. In the regime of weak pulse interaction, the two spots on the ellipsoid surface keep a distance each other across the maximum point of the curvature. This is a joint with Shin-Ichiro Ei and Ayuki Sekisaka.

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MS44

Rigorous Verification of Wave Stability

We discuss recent work regarding rigorous verification of stability properties of traveling waves. In particular, we describe our work developing computer assisted proof techniques to evaluate the Evans function in order to prove spectral stability of waves in the one-dimensional non-isentropic Navier-Stokes equations with an ideal, polytropic gas equation of state. For this system, spectral stability implies nonlinear stability. Proving spectral stability is the last piece of a program begun over 20 years ago for establishing the stability of traveling waves in this model.

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MS44

Computer Assisted Proofs of Wright's and Jones' Conjectures: Counting and Discounting Slowly Oscillating Periodic Solutions to a Delay Differential Equation

A classical example of a nonlinear delay differential equations is Wright's equation: $y'(t) = -\alpha y(t-1)[1 + y(t)]$, considering $\alpha > 0$ and $y(t) > -1$. This talk discusses two conjectures associated with this equation: Wright's conjecture, which states that the origin is the global attractor for all $\alpha \in (0, \frac{\pi}{2}]$; and Jones' conjecture, which states that there is a unique slowly oscillating periodic solution for $\alpha > \frac{\pi}{2}$. To prove Wright's conjecture our approach relies on a careful investigation of the neighborhood of the Hopf bifurcation occurring at $\alpha = \frac{\pi}{2}$. Using a rigorous numerical integrator we characterize slowly oscillating periodic solutions and calculate their stability, proving Jones' conjecture for $\alpha \in [1.9, 6.0]$ and thereby all $\alpha \geq 1.9$. We complete the proof of Jones conjecture using global optimization methods, extended to treat infinite dimensional problems.

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MS44

Recent Developments for Infinite Dimensional Dynamical Systems

In the study of infinite dimensional dynamical systems exploring the dynamics in the entire phase space is impossible. One strategy to tackle this problem is to focus on a set of special solutions that act as organizing centers. To single out these solutions computer-assisted proofs are being developed to find, for example, fixed points, periodic orbits and connecting orbits between those. Computer-assisted proofs in dynamics combines the strength of scientific computing, nonlinear analysis, numerical analysis, applied topology, functional analysis and approximation theory. While in the past decade, these techniques have primarily been applied to ODEs, we are starting to witness their applicability for infinite dimensional nonlinear dynamics generated by partial differential equations (PDEs), integral equations, delay differential equations (DDEs), and infinite dimensional maps. In this talk I will present recent advances in this direction, with a special emphasize on the rigorous integration of DDEs and PDEs.

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MS44

Computer Assisted Proofs in Dynamical Systems Theory: The 1980's to the Present

I'll discuss the role of the digital computer in mathematically rigorous arguments from the early 1980's to the present, emphasizing results in dynamical systems theory. The talk gives a rapid overview of both the history and some methodology in the area, and sets the stage for more detailed talks in the remainder of the sessions.

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MS45

Using MCMC to Quantify Insulin Resistance in Adolescent Girls

Insulin sensitivity decreases in puberty, and, in combination with other risk factors, can result in clinically significant insulin resistance (IR). IR is prevalent in obese adolescent girls, and reliable quantification of IR is necessary to design and assess optimal therapeutic interventions. We aimed to quantify IR in obese adolescent girls by analyzing glucose-insulin dynamics during an oral glucose tolerance test (OGTT). We described OGTT data using differential equations-based models of glucose-insulin dynamics that have been designed to estimate an individuals insulin sensitivity. Model parameters were estimated using Markov chain Monte Carlo (MCMC) techniques. The estimated parameter distributions reveal the uncertainty in the parameter estimates and enable reliable estimates of insulin sensitivity to characterize IR in individual patients and disease conditions.

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MS45

Improving Forecasts by Walking Backward

Model-based prediction-correction data assimilation schemes, such as sigma-point Kalman Filters, have the advantage of iteratively fitting model state to observed measurements - where the 'advantage' is an apparent ability to reconstruct more state variables than observation variables. This stems from the combination of constraints imposed by the model and the effect of iteration, which provides a time series of observations associated with the fitting process. In many cases, the effect of a particular variable on the observed variable appears delayed in time. In these cases, causality requires that optimal reconstruction of that variable from system state can only be optimally done with comparable delay. Reconstruction walking back through the times series - smoothing - accommodates this. I'll discuss the application of Kalman smoothers for reconstructing state in blood glucose modeling project, especially for reconstructing feeding functions and for setting initial state and parameters for ICU glucose control.

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MS45

Discovering Reproductive Phenotypes using a New Endocrine Model

A normally functioning menstrual cycle requires significant crosstalk between hormones originating in ovarian and brain tissues. Reproductive hormone dysregulation may cause abnormal function and sometimes infertility. The inherent complexity in this endocrine system poses a challenge to identifying mechanisms of cycle disruption, particularly given the large number of unknown parameters in existing mathematical models. We develop a new endocrine model to limit model complexity and use simulated distributions of unknown parameters for model analysis. By employing Monte Carlo and statistical methods, we identify a collection of mechanisms that differentiate normal and abnormal phenotypes. We also discover an intermediate phenotype–displaying relatively normal hormone levels and cycle dynamics–that is grouped statistically with the irregular phenotype. Results provide insight into how clinical symptoms associated with ovulatory disruption may not be detected through hormone measurements alone.

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MS45

A New Criterion for Prediabetes with a Mathematical Model

Prediabetes is an intermediate state between normal glucose tolerance and diabetes. 70 percentage of individuals with prediabetes (PDM) will develop diabetes during their lifetime. Identifying early signs of prediabetes is essential to initiate therapy to prevent or slow disease progression. Our mathematical model (Ha et al. Endo, 2016) predicts that the threshold of one-hour glucose during an oral glucose test, which is not a current prediabetes criterion, is crossed before the threshold of two-hour glucose, the current standard criterion. To test our predictions, a linear mixed effect model (LME) was applied to analyze a longitudinal data set from a cohort Pima Indians. The LME analysis confirmed that one-hour glucose passes its threshold about two years before two-hour glucose, a clinically significant difference. The results indicate that one-hour glucose should be considered as a new criterion for prediabetes. Moreover, the mathematical model predicts that weak early-phase insulin secretion, which is common among East Asians and cystic fibrosis patients, contributes to earlier abnormality of one-hour glucose. As the disease progresses, the abnormality in one-hour glucose disappears, which is mathematically characterized by a dynamical river, (Letson and Rubin, SIADS 17:2414 2018).

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MS46

Nonparametric Modeling of Reduced-Order Dynamical Systems

In this talk, I will discuss a computational framework to model reduced-order model from the observable time series of the resolved components and knowing only the resolved dynamical components. Such scenario often arises in applications where one may only have partial knowledge of the underlying dynamics based on analyzing real observations or laboratory experimental data. I will present a nonparametric technique, involving tools from manifold learning and reproducing kernel Hilbert space representation of densities, to reconstruct the net effect of unresolved scales to the reduced-order dynamics in the context where the classical theory of averaging and/or homogenization for stochastic differential equations is applicable.

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MS46

Learning Interaction Laws in Interacting Agent-Based Systems

We consider the following statistical learning problem for system of interacting agents: given only observations of trajectories of the system, we are interested in estimating the interaction laws between the agents. While we considered both the mean-field limit (i.e. the number of agents going to infinity) and the case of a finite number of agents, with an increasing number of observations, we will discuss only the latter. We show that at least in particular cases, where the interaction is governed by an (unknown) function of distances, the high-dimensionality of the state space of the system does not affect the learning rates. We prove that in these case in fact we can achieve an optimal learning rate for the interaction kernel, equal to that of a one-dimensional regression problem. We exhibit efficient algorithms for constructing our estimator for the interaction kernels, with statistical guarantees, and demonstrate them on various examples.

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MS46

Representing Model Inadequacy in Interacting Systems

In many applications of interacting systems, we are only interested in the dynamic behavior of a subset of all possible active species. For example, this is true in combustion models (many transient chemical species are not of interest in a given reaction) and in epidemiological models (only certain critical populations are truly consequential). Thus it is common to use greatly reduced models, in which only the interactions among the species of interest are retained. However, reduction introduces a model error, or inadequacy, which typically is not well characterized. In this work, we explore the use of an embedded and statistically calibrated inadequacy operator to represent model error. The operator is constrained by available physical information and embedded within the differential equations of the model. This design of an augmented, yet physically realistic, model is intended to allow for reliable predictions under extrapolative conditions—in, for example, time or scenario parameters.

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MS46

Theoretical And Numerical Approach to Stochastic Reduction without Scale Separation

Mathematical modeling for complex systems and processes requires concepts and techniques from stochastic dynamics.For stochastic systems with high dimensions, constructing an accurate stochastic reduced model is difficult and expensive. The main difficulty is the resolved variable in the reduced model do not process scale separation from the unresolved ones. It is still not tractable even the resolved variable is one-dimensional. Inspired by Mori-Zwanzig formalism, we will present the results on constructing the generalized Langevin equations for the stochastic reduced model. Methods to learn the Markovian terms and memory terms are discussed. Numerical examples, including the linear case will be shown.

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MS47

Applications of Erosion to Debris and Mudflows

The Birnir, Bretherton and Smith (BBS) model for fluvial landsurfaces consists of a pair of partial differential equations: one governing water flow and one governing sediment flow, and an abrasive term assisting in the channelization of rivers. Numerical solutions of these equations [D. Cattan, B. Birnir, Numerical Analysis of Fluvial Landscapes, *Math Geosci* (2017) 49:913-942] have been shown to provide realistic models of the evolution of fluvial landscapes. Further analysis of these equations shows that they possess scaling laws (Hack's Law) that are known to exist in nature. We apply the BBS equations to debris and mud flows that occurred in Montecito CA in January 2018. Numerical methods to capture these flows are presented and simulations of the initial debris flow and the subsequent mud flow. Surprisingly the BBS equations and associated numerical methods capture these flow as well as erosion. The method is general and can be applied to all hazardous areas where digital elevation models exist or can be developed.

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MS47

Water Transport in Models of Dryland Vegetation Patterns

Reaction-advection-diffusion models that capture the interactions between plants, surface water and soil moisture can qualitatively reproduce community-scale vegetation patterns that are observed in dryland ecosystems. On gently sloped terrain, these patterns often appear as bands of vegetation growth alternating with bare soil. The vegetation bands can be tens of meters thick with spacing on the order of a hundred meters, and form a regular striped pattern that often occupy tens of square kilometers on the landscape. I will focus on aspects of the surface/subsurface water dynamics within these models. Capturing these hydrological processes on appropriate timescales may allow us to better utilize observational data as we work to identify the dominant mechanisms underlying the formation of dryland vegetation patterns and understand how environmental factors influence pattern characteristics.

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MS47

Ecohydrological Drivers of Vegetation Patterns and Landscape Evolution

Precipitation drives soil moisture dynamics, which in turn determine both vegetation growth and soil erosion. Since vegetation also protects the land surface from erosion, this dual role has the potential to induce bi-stable behaviors in the soil-biomass dynamics over the landscapes with dramatic consequences for landscape stability and soil loss. We review the mechanisms linking stochastic soil moisture dynamics to plant-water stress and plant mortality. We then compare branching properties of landscape evolution patterns obtained using static vegetation with those obtained from random alternations of vegetation growth due to tree mortality by droughts. We also highlight how landscape evolution and its branching instability represent an interesting example of nonlinear and nonlocal dynamics with properties that are typical to those of hydrodynamic turbulence and of other nonequilibrium systems.

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MS47

Groundwater, Climate, and the Growth of River Networks

Shallow groundwater flow is common in humid climates. When groundwater returns to the surface at springs, channels may be incised and ramified networks can form. This talk identifies geometric consequences of their growth. First, by relating the groundwater flow to a 2D Poisson field, we remark that the direction taken by moving channel tips may be equivalently understood from the maintenance of local symmetry in the groundwater field, the maximization of flux to tips, or motion along the groundwater streamline into tips. Next, we use these ideas to show that a bifurcated tip results in a branching angle of $2\pi/5 = 72^\circ$. Branching angles in a groundwater-fed stream network on the Florida Panhandle accord well with this prediction. We also investigate the geometry of river networks throughout the contiguous United States. Results show that branching angles appear to asymptotically approach 72° as climates become more humid. The shape of river networks also appears to depend on climate. Humid basins become relatively wider as they become smaller, whereas arid basins retain their shape. We relate the absence of self-similarity in humid basins to the increasing influence of shallow groundwater flow at smaller length scales. Collectively, these results suggest that subsurface processes play a significant role in shaping humid landscapes.

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MS48

Approximations of the Fractal Spectrum of the Koopman Operator

Spectral measure of the Koopman operator decomposes into the atomic part (eigenvalues), absolutely continuous part (spectral density), and the singular-continuous (fractal) part. The vast majority of techniques for spectral analysis of the Koopman operator focus either on approximation of eigenvalues (approximation of coherent structures and modes), or on approximation of the absolutely continuous part (models of turbulence, stochastic processes). Neither of the two approaches are appropriate for approximation of the fractal part of spectral measure. The fractal component is associated with weak anomalous transport in dynamical systems, which is indicated by on-average independent, yet correlated, time traces. This talk charts a path toward approximation of fractal spectral measures using Affine Iterated Function System (AIFS) as parametric models for the measure. We demonstrate that algorithms that resolve moment problems for fractals by inference of AIFS parameters can be productively employed for approximation of the Koopman spectral measure. Then, we make connections with recent developments in computational harmonic analysis and demonstrate how fractal FFT algorithms apply to approximation of fractal Koopman spectral measures.

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MS48

Spectral Theory of the Koopman Operator and Fundamentals of Physics

Composition operators were introduced to classical physics by Bernard Koopman, following on contemporary developments in quantum physics. I will describe some modern consequences of this approach, that enable resolution of some interesting questions in classical physics (for example, why is the Hamiltonian of such importance among all, typically uncountably many invariants of Hamiltonian systems), but also bring to light some interesting connections to quantum physics.

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MS48

Koopman Operator Theory in Artificial Intelligence

Operator-theoretic methods, such as the Koopman (composition) operator and Perron-Frobenius (transport) operator, have proven extremely powerful in the analysis, especially the data-driven analysis, of dynamical systems. On the other hand, artificial intelligence technologies such as deep neural nets and manifold learning have proven to be extremely powerful tools in representing complicated relationships within a data set. In this talk, we explore the relationships between the Koopman operator and AI architectures. In one direction, we use concepts from the spectral theory of the Koopman operator to inform AI architectures, with an eye toward discovering physical laws from data. In the other direction, we use Koopman methods to analyze existing deep neural net architectures.

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MS48

Learning Koopman Eigenfunctions for Prediction and Control: The Transient Case

This work presents a data-driven framework for learning eigenfunctions of the Koopman operator geared toward prediction and control. The method relies on the richness of the spectrum of the Koopman operator in the transient, off-attractor, regime to construct a large number of eigenfunctions such that the state (or any other observable quantity of interest) is in the span of these eigenfunctions and hence predictable in a linear fashion. Once a predictor for the uncontrolled part of the system is obtained in this way, the incorporation of control is done through a *multi-step* prediction error minimization, carried out by a simple linear least-squares regression. The predictor so obtained is in the form of a linear controlled dynamical system and can be readily applied within the Koopman model predictive control framework to control *nonlinear* dynamical systems using *linear* model predictive control tools. The method is entirely data-driven and based purely on convex optimization, with no reliance on neural networks or other non-convex machine learning tools. The novel eigenfunction construction method is also analyzed theoretically, proving rigorously that the family of eigenfunctions obtained is rich enough to span the space of all continuous functions. In addition, the method is extended to construct *generalized eigenfunctions* that also give rise Koopman invariant subspaces and hence can be used for linear prediction.

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MS49

On Multiplex Networks, Hashimoto Non-Backtracking Matrix and Edges' PageRank

Multiplex and multilayer networks have received much attention from network scientists due to the multiplexed nature of real-world systems and the high applicability of multilayer structures. Hashimoto's non-backtracking matrix is a representation of the link structure of a network that is an alternative to the adjacency matrix. A non-backtracking walk in a network is a walk that does not come from a node i to a node j node only to immediately return to the node i. In this talk, we will present some relationships, properties, and applications of several extensions of the non-backtracking random walks to the context of multiplex networks and line-graphs. Moreover, some relationships, properties, and applications of various extensions of the non-backtracking random walks to the context of multilayer networks and line-graphs will be analyzed. These properties and relationships will be also used to analyze several real-life examples and also some extensions of this kind of random walkers to the context of multilayer networks and line-graphs will be presented.

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MS49

Explosive Synchronization in Multiplex Networks

The synchronization of oscillator ensembles with multimodal frequencies distributions has attracted increasing interest very recently since it is important for the description of biological collectives where interaction between different frequencies of dynamical processes. It has become particularly important in neuroscience, where the description of brain networks in term of multilayer structures has very recently development of frequency-based functonal brain networks. In this work, we study the synchronization process in a multiplex system where each layer has a different frequency distribution. He show that this mismatch can generate explosive synchronization in a system where each layer separately would undergo a second order transition. The multiplex structure generates a mutual frustration in the completion of the synchronization processes of the layers, generating an hybrid transition without imposing any specific structure-dynamics correlation. The process is sensible to the frequencies distribution and the structure of both layers, and it is robust to demultiplexing.

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MS49

Tweezer Control for Chimera States in Multilayer Networks

Chimera states are complex spatio-temporal patterns of coexisting coherent and incoherent domains, which can often be observed in networks with nonlocal coupling topology. In small-size nonlocally coupled networks, chimera states usually exhibit short lifetimes and erratic drifting of the spatial position of the incoherent domain. This problem can be solved with a tweezer feedback control which can stabilize and fix the position of chimera states [PRL 116, 114101 (2016); PRE 97, 012216 (2018)]. We analyse the action of the tweezer control in two-layer networks, where each layer is a small nonlocally coupled ring of Van der Pol oscillators. We demonstrate that tweezer control, applied to only one layer, successfully stabilizes chimera patterns in the other, uncontrolled layer, even in the case of nonidentical layers. These results might be useful for applications in multilayer networks, where one of the layers cannot be directly accessed, thus it can be effectively controlled via a neighbouring layer.

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MS49

Control of Neural Networks by Weak Multiplexing

We investigate a multilayer network of coupled FitzHugh-Nagumo neurons and focus on the case of weak multiplexing, i.e., when the coupling between the layers is smaller than that inside the layers. It turns out that weak multiplexing has an essential impact on the dynamical patterns observed in the system and can be used for controlling in both oscillatory and excitable regimes. In the oscillatory regime, we show that different types of chimera states can be induced and suppressed. Moreover, we report the occurrence of solitary states for small intra-layer coupling strength mismatch between the layers [M. Mikhaylenko, L. Ramlow, S. Jalan, and A. Zakharova, Weak multiplexing in neural networks: Switching between chimera and solitary states, arXiv 1809.07148, 2018]. For the excitable regime with noise, we find that weak multiplexing induces coherence resonance in networks that do not demonstrate this phenomenon in isolation [N. Semenova, A. Zakharova, Weak multiplexing induces coherence resonance, Chaos 28, 051104, 2018]. Examples are provided by deterministic networks and networks where the strength of interaction between the elements is not optimal for coherence resonance. In both cases, we show that the control strategy based on multiplexing can be successfully applied. The advantage of multiplexing control we discuss here is that it allows to achieve the desired state in a certain layer without manipulating its parameters, and it works for weak inter-layer coupling.

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MS50

Use of Direct Dynamics Simulations and Classical Power Spectra to Study the Intramolecular and Unimolecular Dynamics of Vibrationally Excited Molecules

With direct dynamics simulations one can investigate the atomistic dynamics of molecules and chemical reactions without the need to develop an analytic potential energy surface (PES). In particular, this provides an opportunity to study the intramolecular and unimolecular dynamics of a broad range of molecules. An example of such a study is the recent investigation of the unimolecular dissociation of dioxetane. A fraction of the trajectories were much longer lived than predicted by RRKM theory and their intramolecular dynamics were studied by calculating their classical power spectra which should that they had regular dynamics in their classical phase space. For thermally excited unimolecular reactions, the rate constants are too small to investigate the actual unimolecular decomposition by classical dynamics. To probe for possible intrinsic non-RRKM dynamics for these reactions, quasiclassical states may be randomly selected from a microcanonical ensemble corresponding to the average energy of the reacting molecules and the intramolecular dynamics of these states probed by calculating their classical power spectra. Such an analysis has been completed for CH3NC $\rightarrow$ CH3CN isomerization and the results will be discussed.

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MS50

The Phase Space Geometry of a 3D Chemical Hamiltonian Model

We study phase space geometry in a 2D caldera potential energy surface (PES) using techniques from nonlinear dynamics. The caldera PES is characterized by a flat region or shallow minimum at its center surrounded by potential walls and multiple symmetry related index one saddle points that allow entrance and exit from this intermediate region. We have found that there are three distinct mechanisms determined by the invariant manifold structure of the unstable periodic orbits govern the phase space transport. The first mechanism explains the nature of the entrance of the trajectories from the region of the low energy saddles into the caldera and how they may become trapped in the central region of the potential. The second mechanism describes the trapping of the trajectories that begin from the central region of the caldera, their transport to the regions of the saddles, and the nature of their exit from the caldera. The third mechanism describes the phase space geometry responsible for the dynamical matching of trajectories originally proposed by Carpenter and described in Collins et al 2014 for the two dimensional caldera PES that we consider.

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MS50

Machine-Learning Transition State Theory and the Descent of Organic Reactions into Chaos

Transition state theory is chemistrys most important quantitative method for the calculation of rates and qualitative framework for their understanding. Some flaws and limitations of transition state theory were apparent at its beginning, while others have become apparent in recent years from a growing number of reactions found to exhibit dynamic effects, that is, experimental observations that cannot be predicted or understood from transition state theory. Trajectory methods can often account for dynamic effects but they intrinsically provide little insight, and each new prediction requires a new set of trajectories. We describe a modification of transition state theory that uses machine learning to divide transition states in phase space into regions that lead to specific products or transition state recrossing, defining transmission coefficients for each. This requires an initial set of trajectories, but further predictions can be made without additional trajectories. This process has been applied to a series of complex organic reactions where experimental data is available and where ordinary transition state theory fails. The results make detailed predictions of temperature effects on product ratios and rates, and provide insight into the origin of trajectory selectivity in reactions. On a larger scale, the results define the limits of predictability of trajectory outcomes from initial conditions.

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MS50

Time Series Analysis of Dynamical Systems

In order to analyze trajectories of dynamical systems, we develop a method for time series analysis combining wavelet transformation and local principal component analysis (PCA). We apply our method to coupled standard maps as examples of multiple degrees of freedom Hamiltonian systems. We show that our method enables us to find those times when the trajectory changes its property such as a shift of frequencies of some degrees of freedom. Thus, we expect that it will be applicable to large degrees of freedom systems to understand how vibrational energies are distributed within the system.

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MS51

On the Landscape of Synchronization Networks: A Perspective from Nonconvex Optimization

Studying the landscape of nonconvex cost function is key towards a better understanding of optimization algorithms in signal processing, statistics, and machine learning. Meanwhile, the famous Kuramoto model has been an important mathematical model to study the synchronization phenomena of coupled oscillators over network topologies. We bring together these two seemingly unrelated objects by investigating the optimization landscape of a nonlinear function $E(\boldsymbol{\theta}) = \frac{1}{2}\sum_{1\leq i,j\leq n} a_{ij}(1-\cos(\theta_i - \theta_j))$ associated to an underlying network and exploring the relationship between the existence of local minima and network topology. This function arises in Burer-Monteiro method applied to Z_2 synchronization as well as matrix completion on the torus. Moreover, it corresponds to the energy function of the homogeneous Kuramoto model on complex networks for coupled oscillators. We prove the minimizer of the energy function is unique up to a global translation under deterministic dense graphs and Erdős-Rényi random graphs. Consequently, the stable equilibrium of the corresponding homogeneous Kuramoto model is unique and the basin of attraction for the synchronous state of these coupled oscillators is the whole phase space minus a set of measure zero. In addition, our results address when the

Burer-Monteiro method recovers the ground truth exactly from highly incomplete observations in Z_2 synchronization.

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MS51

Pattern Formation in the Kuramoto Model on Random Graphs

We study the long-time dynamics of the Kuramoto model on graphs. Similar to the classical Kuramoto model, we observe phase synchronization as coupling strength between oscillators increases. For wide range of random and deterministic graphs, synchronization emerges at the same critical coupling strength, showing that global properties such as edge density may be sufficient to determine the onset of synchronization. On the other hand, we show that, in power-law graphs, the critical parameter value leading to synchronization can be arbitrarily small. For the Kuramoto model on small-world graphs, in addition to the transition to synchronization, we identify a new bifurcation leading to stable random twisted states.

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MS51

Fixed Points and Information Flow in Boolean Networks

Boolean network model approximately describes dynamics in social and biological networks. Because of its simplicity, it is helpful for understanding the relationship between dynamical characteristics and topological properties of network systems. In the first half of this talk, we present a theorem of expected number of fixed points in Boolean networks with arbitrary topology [F. Mori and A. Mochizuki, PRL 2017]. The existence and number of fixed points is important for both social and biological systems because fixed points can be considered to correspond to solutions without frustration in opinion formation, and cell types in differentiation. We assume that while network topology is fixed, Boolean functions are drawn from probability distributions that are not required to be uniform or identical. Under the assumption, we prove that the expected number of fixed points is one, and is independent of network topology if only a feedback arc set satisfies a stochastic neutrality condition. Therefore, the expected number cannot be increased by controlling network topology. It is increased by the predominance of positive feedback in a cycle. In the second half, we discuss information flow in Boolean networks. This is based on joint research with Dr. Takashi Okada (RIKEN). We employ transfer entropy to quantify the information flow from an input vertex receiving stochastic signal to an output vertex. We report how the transfer entropy is dependent on structure of Boolean networks.

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MS51

Quasiperiodic Chimera States

In this talk we will describe recent work on quasiperiodic chimera states in a ring of nonlocally coupled phase oscillators. In the continuum limit such chimera states appear as quasiperiodic solutions (more precisely, as relative periodic orbits) of the corresponding Ott-Antonsen equation. We will show how to perform numerical continuation of these solutions and analyze their stability. Thereby we will focus on mathematical problems concerned with the solution non-smoothness and the presence of neutral continuous spectrum in the corresponding linearized problem.

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MS52

Data-Driven Spatio-Temporal Prediction of High-Dimensional Geophysical Turbulence

Dynamic Mode Decomposition (DMD) with Takens delay-embedding (Hankel-DMD) is used to forecast the spatio-temporal evolution of the fully turbulent flow in a high-dimensional 3D Rayleigh-Benard convection system at the Rayleigh number of one million. A long dataset is produced using direct numerical simulation. (DNS), which is then employed to build a reduced-order model for the horizontally averaged temperature anomaly (which is a function of height z and time t) using Hankel-DMD. Compared with the DNS data, the reduced model can accurately predict the spatio-temporal evolution of the temperature anomaly or a few hundred advective timescales before the prediction diverges from DNS and decays to zero. We show that such prediction skills with DMD hinge on using the delay-embedding and a rich-enough vector-valued observable. The impact of the length of the dataset, size of the vector-valued observables, and other parameters on the prediction skills and prediction horizon are investigated in detail to understand the capabilities and limitations of this approach. Similar high prediction skills are obtained when the method is applied to the Kuramoto-Sivashinsky equation at various levels of chaoticity.

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MS52

A Gaussian Process Regression Method for Sampling Tail Events in Dynamical Systems

We develop a method for the evaluation of extreme event statistics associated with nonlinear dynamical systems from a small number of samples. From an initial dataset of design points, we formulate a sequential strategy that provides the next-best data point (set of parameters) that when evaluated results in improved estimates of the probability density function (pdf) for a scalar quantity of interest. The approach utilizes Gaussian process regression to perform Bayesian inference on the parameter-to-observation map describing the quantity of interest. We then approximate the desired pdf along with uncertainty bounds utilizing the posterior distribution of the inferred map. The next-best design point is sequentially determined through an optimization procedure that selects the point in parameter space that maximally reduces uncertainty between the estimated bounds of the pdf prediction. The special form of the metric emphasizes the tails of the pdf. The method is practical for systems where the dimensionality of the parameter space is of moderate size and for problems where each sample is very expensive to obtain.

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MS52

Reduced-Order Statistical Models for Predicting Mean Responses and Extreme Events in Barotropic Turbulence

The capability of using imperfect statistical and stochastic reduced-order models to capture crucial statistics in turbulent flow and passive tracers is investigated. Much simpler and more tractable block-diagonal models are proposed to approximate the complex and high-dimensional turbulent flow equations. The imperfect model prediction skill is improved through a judicious calibration of the model errors using leading order statistics. A systematic framework of correcting model errors with empirical information theory is introduced, and optimal model parameters under this unbiased information measure can be achieved in a training phase before the prediction. It is demonstrated that crucial principal statistical quantities in the most important large scales can be captured efficiently with accuracy using the reduced-order model in various dynamical regimes of the flow field with distinct statistical structures.

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MS52

Simultaneous Learning of Dynamics and Signal-Noise Decomposition

A critical challenge in the data-driven modeling of dynamical systems is producing methods robust to measurement error, particularly when data is limited. Many leading methods either rely on denoising prior to learning or on access to large volumes of data to average over the effect of noise. We propose a novel paradigm for data-driven modeling that simultaneously learns the dynamics and estimates the measurement noise at each observation. Our method explicitly accounts for measurement error in the map between observations, treating both the measurement error and the dynamics as unknowns to be identified, rather than assuming idealized noiseless trajectories. We demonstrate the ability of this framework to form predictive models on a variety of canonical test problems of increasing complexity and show that it is robust to substantial amounts of measurement error.

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MS53

Homoclinic Structure in Fold/hom Bursting Models

Fold/hom bursting phenomena is found in numerous fast-slow models, and specially in neuron models. The existence of an homoclinic bifurcation curve in the fast subsystem is a requirement to its appearance, but the real structure of the homoclinic bifurcations in the global parametric space of fold/hom neuron models is not known. Here we provide a global analysis of the organization of the homoclinic bifurcation manifolds in the parametric phase space and how topologically different 2D manifolds are present. All these bifurcations are connected with the spike-adding process and canards in fast-slow models as each spike-adding bifurcation is related with the existence of one homoclinic bifurcation manifold that is exponentially close to the rest of homoclinic bifurcation manifolds, giving rise to a new global homoclinic structure that we call *homoclinic mille-feuille*.

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MS53

Domino-Like Transient Dynamics at Seizure onset in Epilepsy

The onset of an epileptiform activity is an example of a 'domino'-like transition between alternating rest and excited (seizure-like) states in a network; as each node transitions into a seizure-like state other nodes in the network are sequentially recruited. We consider a directed network model in which each node has two stable states active (oscillatory) and quiescent, the addition of noise mediates transitions between the two states. The 'excitability' of each node is the height of potential barrier from quiesent to active when uncoupled. Each node starts in the marginally quiescent state and transitions to the active state, we say it 'escapes'. When node excitability is homogeneous, escape times are affected by changes in topology, noise amplitude and coupling strength. Here, we study the effect of heterogeneous excitability and coupling weights on the emergent network dynamics. We apply our theoretical framework to the onset of epileptic seizures recorded using electroencephalogram. We find that the interplay between excitability and coupling may be a potential mechanism for observing different spatio-temporal patterns at onset. To tease apart the heterogeneous effects, we apply the model a simpler experimental system; ictal-like activity recorded in the mouse medial entorhinal cortex. We explore how gradients in excitability and coupling, individually and to-

gether, modulate the domino effect.

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MS53

Excitability of Cerebellar Stellate Cells, a New Perespective

Cerebellar stellate cells (CSCs) are inhibitory interneurons that receive excitatory and inhibitory pre-synaptic inputs from parallel fibers and other CSCs, respectively. We have previously studied the electrical properties of these cells using Hodgkin-Huxley type model that includes five ionic currents: I_{Na}, I_K, I_L, I_A and I_T. Using the model, we determined how two ionic currents (I_A and I_T) produce biphasic first spike latency in CSCs and how temporal changes in the kinetics of I_{Na} and I_A induce temporal increase in excitability in whole-cell configuration (termed runup). Using slow-fast analysis, we demonstrated that the CSC model exhibits type 1 excitability with a saddle-node on an invariant cycle bifurcation responsible for generating slow dynamics, and that it produces switching in responsiveness when stimulated by a pair of inhibitory and excitatory synaptic inputs. The latter was shown to depend on the magnitude of inhibition and excitation (while keeping the other fixed) prior to runup. Recent experimental evidence suggests that M-type K+ current (I_M) is also playing a role in runup and that blocking I_A can induce bursting. In this talk, I will present our recent findings about the underlying dynamics of biphasic first spike latency and runup, and will give an overview of what role I_M and the I_A could be playing.

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MS53

Spontaneous Excitability in the Morris-Lecar Model with Ion Channel Noise

Noise induced excitability is studied in types I and II Morris-Lecar neurons subject to constant subthreshold input, where fluctuations arise from sodium and potassium ion channels. Ion channels open and close randomly, creating current fluctuations that can induce spontaneous firing of action potentials. Both noise sources are assumed to be weak so that spontaneous action potentials occur on a longer timescale than ion channel fluctuations. Asymptotic approximations of the stationary density function and most probable paths are developed to understand the role of channel noise in spontaneous excitability. Even though the deterministic dynamical behavior of types I and II action potentials differ, results show that a single mechanism explains how ion channel noise generates spontaneous action potentials.

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MS54

Generalizations of the 'Linear Chain Trick': Incorporating More Flexible Dwell Time Distributions into Mean Field ODE Models

The Linear Chain Trick (LCT) is a technique for deriving mean field ODEs from continuous-time stochastic state transition models where the time individuals spend in a given state are Erlang distributed (i.e., gamma distributed with integer shape parameter). This work was motivated by a lack of general theory to facilitate the use of the LCT in applications, especially for complex models, where modelers must often choose between using heuristics which oversimply dwell time assumptions, using time consuming derivations from first principles, or using non-ODE models (e.g., integro-differential equations) which can be cumbersome to derive and analyze. I will present analytical results that address these issues through 1) novel extensions of the LCT to scenarios seen often in applications; 2) extensions that bypass the need to derive ODEs from integral or stochastic model equations; and 3) a novel Generalized Linear Chain Trick (GLCT) framework that extends the LCT to a broad family of distributions, including the flexible phase-type distributions which can be used to approximate many positive-valued continuous distributions and can be fit to data. These results give modelers more flexibility to incorporate appropriate dwell time assumptions into mean field ODEs, including conditional dwell time distributions, and these results help clarify connections between individual-level stochastic model assumptions and the structure of corresponding mean field ODEs.

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MS54

Modeling Particle Tracking Experiments that Reveal Intracellular Transport Mechanisms

Many of the mechanisms that underlie intracellular transport by molecular motors are well-studied by both experiments and mathematical modeling. This is especially true of cargos that are being transported by individual motors and that are perturbed by certain kinds of external forces. However, our understanding of single-motor dynamics does not yet yield robust predictions for what has been observed at a whole cell scale when multiple opposite-directed motors interact with each other. In this talk, we will explore recent mathematical modeling and Bayesian inferential efforts that are directed at new experiments that are aimed at revealing multi-motor interactions in vitro.

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MS54

Estimating Kinetic Rates of Prion Replication from a Structured Population Model

Prion proteins cause a variety of fatal neurodegenerative diseases in mammals but are harmless to yeast, making it an ideal model organism for these diseases. Determining kinetic parameters of prion replication in yeast are complicated because experiments reflect both the disease and yeast population dynamics. We present a structured population model describing the distribution and replication of yeast prions in a population of cells. I then develop a likelihood based approach for estimating kinetic rates on simulated data and four different yeast prion strains.

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MS55

DMD-Based Estimation of the Unsteady Flow Field Around an Actuated Airfoil

We describe an estimation method that generates full flow field estimates using data obtained from a limited number of sensors, based on Dynamic Mode Decomposition (DMD). DMD is a data-driven algorithm that approximates a time series of data as a sum of modes that evolve linearly. DMD modes are used to create a linear system that approximates the flow dynamics and pressure sensor output of experimental measurements of the flow field around an actuated airfoil. Sparsity Promoting DMD (SPDMD) selects a reduced number of modes in order to simplify the system while providing a sufficiently accurate approximation of the flow field. A Kalman Filter (KF) uses pressure measurements to estimate the evolution of this linear system, and thus produce an approximation of the flow field. The DMD Kalman Filter (DMD-KF) is implemented for experimental data from two different setups: a pitching cambered ellipse airfoil and a surging NACA 0012 airfoil. The effect of the number of DMD modes chosen for the filter is explored. The performance of the estimator is evaluated using the original flow field and a reconstruction using traditional DMD methods. We identify distinct sources of error: the projection into a low dimensional subspace, and the assumption of linear time evolution and measurement function. The former is related to the truncation error and is independent from the filtering process, whereas the latter is related to the process and measurement noise covariances of the Kalman Filter.

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MS55

Data-Driven Refinements of Physics-Based Models with Application to Turbulence Modeling

This talk describes how to account for second-order statistics of turbulent flows using low-complexity stochastic dynamical models based on the linearized Navier-Stokes (NS) equations. The complexity is quantified by the number of degrees of freedom in the linearized evolution model that are directly influenced by stochastic excitation sources. For the case where only a subset of correlations are known, we develop a framework to complete unavailable second-order statistics in a way that is consistent with linearization around turbulent mean velocity. In general, white-in-time stochastic forcing is not sufficient to explain turbulent flow statistics. We develop models for colored-in-time forcing using a maximum entropy formulation together with a regularization that serves as a proxy for rank minimization. We show that colored-in-time excitation of the NS equations can also be interpreted as a low-rank modification to the generator of the linearized dynamics. Our method provides a data-driven refinement of models that originate from first principles and it captures complex dynamics of turbulent flows in a way that is tractable for analysis, optimization, and control design.

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MS55

A Discrete Empirical Interpolation Method for

Nonlinear Manifolds

Manifold learning techniques seek to discover structure-preserving mappings of high-dimensional data into low-dimensional spaces. While the new sets of coordinates specified by these mappings can closely parameterize the data, they are generally complicated nonlinear functions of the original variables. This makes them difficult to interpret physically. Furthermore, in data-driven model reduction applications the governing equations may have structure. Nonlinear mapping can destroy this structure. Instead, we propose to identify a small collection of the original variables which are capable of uniquely determining all others. When the data lies on a low-dimensional subspace the existing Discrete Empirical Interpolation Method (DEIM) accomplishes this. Recent variants of DEIM employ greedy algorithms based on the Rank-Revealing QR factorization. Our proposed approach extends DEIM to data lying near nonlinear manifolds by applying a similar procedure simultaneously on patches making up a locally linear approximation of the data. Coordinates are shared across all the patches and are selected greedily to improve an objective that balances the trade-off between number of coordinates and robustness. The algorithm successfully uncovers underlying coordinates in toy problems and real-world examples.

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MS55

Multi-Rate and Multi-Fidelity Sensor Fusion for Turbulent Flow Reconstruction

Wall-bounded turbulence can be challenging to measure with full spatiotemporal resolution within experiments. Instrumentation capable of obtaining time-resolved data (e.g., hot-wire anemometers) tend to be restricted to spatially-localized point measurements; likewise, instrumentation capable of achieving spatially resolved field measurements (e.g., particle image velocimetry) tend to lack the sampling rates needed to attain time-resolution in such flows. In this study, we propose a multi-rate and multi-fidelity framework to fuse "slow-in-time" field measurements with "fast-in-time" point measurements. A "fast" filter is formulated to assimilate high-rate point measurements with estimates from a physics-based model—derived using rapid distortion theory. A "slow" filter is then used to update the reconstruction every time a new field measurement becomes available. The method is demonstrated using direct numerical simulation data from the Johns Hopkins Turbulence Database. Challenges and outlooks will also be discussed.

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MS56

The Bramson Delay in Non-Local KPP Type Problems

Abstract not available.

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MS56

White Noise and Spike Dynamics

The Gierer-Meinhardt equations are used to model pattern formation in developing organisms. The formation of localized structures is represented by highly localize spike-type solutions. Such systems are subject to random fluctuations. We will consider the effects of white noise. Specifically the effects on spike stability and dynamics.

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MS56

Blowup from Randomly Switching Between Stable Boundary Conditions for the Diffusion Equation

A number of recent biological models involve diffusion in stochastic environments. In this talk, we explore the rich dynamical behavior that this class of models can display. In particular, we give a pair of boundary conditions for the diffusion equation such that the solution goes to zero for either boundary condition, but if the boundary condition randomly switches, then the solution becomes unbounded in time. To our knowledge, this is the first PDE example showing that randomly switching between two globally asymptotically stable systems can produce a blowup. In addition, we discuss other interesting features of this system, including a region of parameter space in which the mean of the random PDE oscillates with ever increasing amplitude for slow switching rates, grows exponentially for fast switching rates, but decays to zero for intermediate switching rates. We also highlight cases in which the second moment is necessary to understand the system's qualitative behavior, rather than just the mean. Finally, we give a PDE example in which randomly switching between two unstable systems produces a stable system.

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MS56

The Role of Receptor Clustering in Chemoreception and Directional Sensing

Cells interact with their environment and communicate with other agents through contact with diffusing signaling molecules at receptor sites distributed on the cellular surface. For this process of chemoreception to be effective in such a noisy environment, surface receptors must be numerous and widely distributed. The spatial organization or 'clustering' of these receptors has long been known to play a key biophysical role, however, mathematical analysis of this role is a challenging problem that, despite much attention, is not yet resolved. In this talk I will describe new theoretical results, which give precise information of the role of clustering in scenarios where receptors occupy spherical surfaces or are periodically arranged on infinite planes. With these new results, optimizing configurations of receptors can be identified. In the case of a plane with a periodic arrangement of receptors, we find that a hexagonal configuration maximizes the sensing rate of the receptors. We will also discuss how the clustering of receptors can play a role in identifying the source of diffusing signals. In addition, we will discuss a new suite of Kinetic Monte Carlo methods for diffusive signaling problems. These methods are able to verify theoretical results and in addition allow for efficient exploration of the space of receptor clustering configurations.

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MS57

Bifurcations of Homoclinic Orbits in the Circular Restricted Four Body Problem

In the Circular Restricted Four Body Problem, we have 3 bodies in an equilateral configuration and are interested in the movement of a fourth massless body. Depending on the masses of the first three objects, there are 8, 9 or 10 Lagrangian points for the fourth body. The bifurcation diagram exists of a one-dimensional curve of saddle-node bifurcations and single point where there is a pitchfork bifurcation. If there are 10 Lagrangian points, there exist homoclinic orbits to some of the stationary points of the fourth body. In this talk, we will prove that the homoclinic orbit persists at the saddle-node bifurcations. We compute the homoclinic orbit in two steps. The first step is finding a local parameterization of the two-dimensional center manifold at the bifurcation point together with its dynamics. Using the conjugate dynamics on the center manifold, we show the existence of one-dimensional stable and unstable submanifolds inside this center manifold. The second step is computing the global stable and unstable manifolds and finding an intersection of the two global manifolds. This is joint work with Jason Mireles James.

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MS57

A Method of Reducing Validation Errors when Integrating Smooth Vector Fields

When rigorously solving initial value problems via high order series expansions, the truncation error serves as the best case lower bound on the error. However, the error bounds produced by a validation procedure are larger due to numerical effects such as rounding or the wrapping effect. While these errors often seem trivial for a single integration step, their forward propagation to later steps has a significant contribution to the overall error. In this talk we show how these numerical errors can be reduced when integrating smooth vector fields using a preprocessing technique called an "a-priori bootstrap'. The method leverages regularity of the original vector field to produce a smoother vector field which shares solutions of the original. We will show that using the bootstrapped vector field for validation estimates dampens the effects of numerical errors which occur during the validation step. This is based on joint work with Jean-Phillipe Lessard (McGill University).

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MS57

Smale Tangles in the Circular Restricted Four Body Problems

In this talk I will discuss our approach to compute stable and unstable manifold associated to periodic orbit of the circular restricted four body problem. The problem is solved numerically and the validation is completed using a fixed point argument. I will discuss the implementation of the proof as well as some further applications. This is joint work with Jason Mireles James.

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MS57

Computer Assisted Analysis of Hopf Bifurcations

Detecting Hopf bifurcations analytically usually requires, even in ODEs, a case-specific approach. But computer assisted proofs can be used to prove the existence of a Hopf bifurcation through verified numerical computations in a way that can be easily generalised to a broad class of problems. In this talk, I will present a method of validation Hopf bifurcations based on the radii polynomial approach. The applications of this technique include, at the moment, Hopf bifurcations in polynomial ODEs and in the Kuramoto-Sivashinki PDE with periodic boundary conditions.

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MS58

Asymptotic Reduction of Large Order Dynamical Systems

One of the fundamental techniques of the applied mathematician is the process of asymptotic simplification. In dynamical systems, typically consisting of (large) sets of ordinary differential equations, the basic idea is that the variables will successively collapse to quasi-equilibria, based on the size of the natural relaxation time scale for the corresponding equations. Such simplifications lead to analyses such as those involved in the solution of the relaxation Van der Pol oscillator, the Hodgkin-Huxley equations, the Belousov-Zhabotinskii equations, the Ludwig-Jones-Holling model of spruce budworm infections, and the Lorenz equations. It is less common to find such techniques applied to large sets of equations, which are commonly solved computationally. This talk will illustrate how this analytic approach can be applied in a number of examples, such as the reduction of the Grodins model of respiration to a form of the Mackey-Glass equation, the reduction of the

Jones site model for spruce budworm infestations, a simple climate model based on the carbon cycle, and a model to explain oceanic anoxia events.

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MS58

Model Reduction in Complex Networks of Kuramoto Oscillators with Collective Coordinates

We present a collective coordinate approach for coupled Kuramoto oscillators on networks with complex topologies. The approach is able to describe global and partial synchronisation, as well as the interaction between partially synchronised clusters. One of the advantages of this approach is that it is not restricted to the thermodynamic limit but can describe finite-size networks. As an illustration we show that the collective coordinate approach is capable of capturing quantitatively the finite-size induced drift of the mean phase in stochastically forced Kuramoto models.

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MS58

Macroscopic Models for the Mammalian Circadian System

Synchrony in coupled oscillator systems provides a beautiful example of emergent low dimensional dynamics in complex systems. Synchrony is fundamental to many biological systems including the production of daily cycles in behavior and physiology known as circadian rhythms. Circadian rhythms are produced through the aggregation of the genetic oscillations found in thousands of coupled clock neurons within the Suprachiasmatic Nucleus (SCN) brain region. Daily light information is crucial to keeping the mammalian circadian clock entrained to the external environment. In this work we apply a recently developed mathematical reduction, inspired by experimental results, to derive a low-dimensional system describing the circadian clock of mammals. Using our reduced model we are able to examine how light information is processed and stored within the SCN through the direct comparison of the model's predictions with experimental results. We find that several previously unrelated experimental results are neatly explained within our model.

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MS58

Purposeful Modeling of Physical Systems: A Grand Challenge for Systems Engineering

Much of Engineering education focuses on modeling the physics as accurately as possible. This is counterproductive in system design, where multiple disciplines have to be merged. We lack theoretical guidance how to do get appropriate models for integrating disciplines. For example the aero dynamicist and the fluid dynamicist and the structural expert feel the responsibility to give the computer analyst or the control theorist a high complexity detailed model of each of the component disciplines for the purpose of computer simulations, or for control design. This leads to inaccurate simulations, or inadequate control design. Why? This paper will give models that are best for computer simulations, and models that are best for control design, and they are different models because good modeling is not just physics, It involves limited computational resources, and specific performance requirements for the purpose at hand. Some examples include the control design of the Hubble space telescope, and more accurate simulations of multi-body structural dynamics. It will be shown that signal processing is the catalyst that allows the integration of structure and control design

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MS59

Stability of Traveling Wave Solutions of Nonlinear Schrödinger - Type Equations

We perturb traveling wave solutions and study the eigenvalues of the linearization around this perturbation (instability will occur if these eigenvalues have a nonzero real part). When the boundary conditions are periodic, the linearization has eigenvalues that equal zero. However, when the periodicity of the boundary conditions is perturbed, these zero eigenvalues will become nonzero, potentially indicating instability. Using matrix perturbations, we compute these eigenvalues near the origin in the complex plane and find them to be in agreement with results based on the integrability of the cubic NLS. This is particularly useful, because our method can be used for NLS-type equations that are not integrable, such as the 1D quintic NLS. This is joint work with Jared Bronski at University of Illinois. bronski@illinois.edu

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MS59

Statistical Network Representations of Energy Landscapes in Soft-Sphere Models

Many intriguing dynamical properties of complex systems, such as metastability or resistance to applied forces, emerge from the underlying energy landscape. Representative (bio)physical examples include the stochastically changing spatial organization of DNA in the nucleus, protein folding, and the response of granular materials to probing, impact or dragging, all open areas of investigation. These seemingly unrelated systems all belong to a common class of mathematical models: large stochastic systems of spheres connected through interaction potentials.

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MS59

Modeling Movement, Invasion, and Persistence of Small Organisms in Flow

Biological invasions of small organisms often have outsized consequences for the invaded ecosystem and represent both a complex and interesting system to model mathematically. Heterogeneous flow fields and biological protective layers are two major factors influencing organismal behavior with macroscale implications. In this talk, I will describe a data-driven approach to better understanding this system in a couple of settings, including the use of a newly developed agent-based modeling framework, Planktos, which provides an object-oriented code base for examining the effects of organismal behavior in flow.

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MS59

Stochastic Subgrid-Scale Parameterization for One-Dimensional Shallow Water Dynamics using Stochastic Mode Reduction

We address the question of parameterizing the subgrid scales in simulations of geophysical flows by applying stochastic mode reduction to the one-dimensional stochastically forced shallow water equations. The problem is formulated in physical space by defining resolved variables as local spatial averages over finite-volume cells and unresolved variables as corresponding residuals. Based on the assumption of a time-scale separation between the slow spatial averages and the fast residuals, the stochastic mode reduction procedure is used to obtain a low-resolution model for the spatial averages alone with local stochastic subgrid-scale parameterization coupling each resolved variable only to a few neighboring cells. The closure improves the results of the low-resolution model and outperforms two purely empirical stochastic parameterizations. It is shown that the largest benefit is in the representation of the energy spectrum. By adjusting only a single coefficient (the strength of the noise) we observe that there is a potential for improving the performance of the parameterization, if additional tuning of the coefficients is performed. In addition, the scale-awareness of the parameterizations is studied.

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MS60

Some Bifurcations and Wave Patterns Arising in Excitable and Oscillatory Models of Neuroscience Context

The aim of this talk is first to give a survey of research led these past years on bifurcation and pattern formation phenomena arising in some Neuroscience models. After highlighting some connexions with Complex Systems, Networks, Oscillatory and Excitable systems, I will focus on a particularly non-homogeneous oscillatory excitable system of PDE and I will provide some recent theoretical results obtained related to its asymptotic behavior.

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MS60

St. Petersburg Paradox for Quasiperiodically Hypermeandering Spiral Waves

It is known that quasiperiodic hypermeander of spiral waves almost certainly produces a bounded trajectory for the spiral tip. We analyse the size of this trajectory. We argue that this deterministic question does not have a physically sensible deterministic answer and requires probabilistic treatment. In probabilistic terms, the size of the hypermeander trajectory proves to have an infinite expectation, despite being finite with probability one. This can be viewed as a physical manifestation of the classical "St Petersburg paradox' from probability theory and economics.

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MS60

Role of Specta in Period-Doubling Instabilities of Spiral Waves

Spiral waves patterns seen in cardiac arrhythmias and chemical oscillations develop alternans and line defects. These instabilities that can be thought of as period-doubling bifurcations. We seek to understand how and why alternans and line defects develop. To investigate these questions, we analyze spectral properties of spirals formed in reaction-diffusion systems on bounded disks. We find that the mechanisms driving the instabilities are quite different alternans are driven from the spiral core, whereas line defects appear from boundary effects. Moreover, the shape of the alternans eigenfunction is due to the interaction of a point eigenvalue with curves of continuous spectra.

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MS60

Geometry of Wave Propagation on Active Deformable Surfaces

Chemical surface waves signal and coordinate active force generation in a wide range of biological media, ranging from cardiac tissue to newly fertilized oocytes. The complex interplay between surface geometry and contraction wave dynamics can be highly nonlinear and mechanistically unclear, and as a result the general principles of the coupled chemo-mechanical systems remain poorly understood. Here, we couple a 2D reaction-diffusion model to non-Euclidean shell mechanics to identify and characterize generic features of contractile spiral waves. The propagation of active waves on closed shells is found to exhibit emergent dynamics when local chemistry is allowed to induce isotropic contraction or expansion. Further, for an open surface, we demonstrate how bound pairs of active spiral waves can generate peristalsis-like motion. Finally, comparing simulation with recent experimental results, we examine how large-scale deformation, due to either external perturbation or wave-induced buckling, influences the localization and velocity of spirals. In particular, our results identify mechanisms by which changing Gaussian curvature alters spiral wave drift on an active surface.

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MS61

Numerical Methods for Data Driven Koopman Spectral Analysis

We present our recent work on development of new computational tools for data driven Koopman spectral analysis, based on the Dynamic Mode Decomposition (DMD). In particular, we enhance the DMD with data driven formula for the residuals, thus allowing selection of accurate Ritz pairs that provide more precise spectral information of the underlying Koopman operator. Further, we show that a numerically robust DMD type algorithm can be constructed also by following the natural formulation via the Krylov decomposition with the Frobenius companion matrix, and by using its eigenvectors explicitly - these are defined as the inverse of the notoriously ill-conditioned Vandermonde matrix. The key step to curb ill-conditioning is the discrete Fourier transform of the snapshots; in the new representation, the Vandermonde matrix is transformed into a generalized Cauchy matrix, which then allows accurate computation. We also present a new computational method for solving structured least squares problem that arises in the process of identification of coherent structures e.g. in fluid flows. It is deployed in combination with the dynamic mode decomposition (DMD) which provides a non-orthogonal set of modes corresponding to particular temporal frequencies - a selection of these is used to represent time snapshots of the underlying dynamics. Our new algorithms exploit the structure and numerical analysis identifies relevant condition numbers that govern the accuracy.

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MS61

Data-Driven Analysis of Koopman Spectra with Reproducing Kernels

Spectral analysis of Koopman operators has been attracting attention as a powerful tool to understand the global behaviors of nonlinear dynamical systems. Here, we overview a bunch of studies on data-driven methods for analyzing spectra of Koopman operators using reproducing kernels. In particular, we discuss a variant of dynamic mode decomposition (DMD) with kernels and its statistical properties. Moreover, we describe an extension of the approach with vector-valued kernels for analyzing dynamical structures in interactions among observables. We further discuss the application of the approaches to discriminant analysis of time-series data, and show some analysis of dynamics in collective motions.

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MS61

Eigendecompositions of Transfer Operators in Reproducing Kernel Hilbert Spaces

Over the last years, numerical methods for the analysis of large data sets have gained a lot of attention. Recently, different purely data-driven methods have been proposed which enable the user to extract relevant information about the global behavior of the underlying dynamical system, to identify low-order dynamics, and to compute finite-dimensional approximations of transfer operators associated with the system. However, due to the curse of dimensionality, analyzing high-dimensional systems is often infeasible using conventional methods since the amount of memory required to compute and store the results grows exponentially with the size of the system. We extend transfer operator theory to reproducing kernel Hilbert spaces and show that these operators are related to Hilbert space representations of conditional distributions, known as conditional mean embeddings in the machine learning community. One main benefit of the presented kernel-based approaches is that these methods can be applied to any domain where a similarity measure given by a kernel is available. We illustrate the results with the aid of guiding examples and highlight potential applications in molecular and fluid dynamics as well as video and text data analysis.

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MS61

Sample Complexity of Optimal Nonlinear Regulation using Koopman Operator

A data-driven approach is developed for optimal regulation of nonlinear system using the linear operator theoretic framework. Linear operator theoretic framework is used for the identification of nonlinear control system using time-series data generated by control dynamical system and for discovering sample complexity results. The nonlinear control system is approximated as a bilinear system in the Koopman eigenfunction coordinates. We use sample complexity results to determine the minimum data required to achieve the desired degree of accuracy for the approximation and derive exact error bounds as the function of data length. We use these error bounds explicitly in the design of optimal control for the bilinear representation of the nonlinear system. In particular, we develop robust-optimization based iterative algorithm for the optimal control of nonlinear system in Koopman coordinates. Simulation results are presented to demonstrate the application of the developed framework.

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MS62

Dissecting the Contributions of Neuronal and Non-Neuronal Processes to Cerebral Vascular Dynamics

The neural activity in the brain is metabolically demanding, and must be constantly supported by blood flow. Blood flow is delivered through the multiscale vascular network of arteries, capillaries and veins. During periods of elevated neural activity, blood is dynamically routed to areas of larger neural activity on a second-by-second timescale. Given its structure and transport role, efficient network theory provides an theoretical framework in which to interpret and guide experiments on the cerebral vascular network of the brain. Here, I will present recent work from my lab dissecting the control mechanisms of the vascular network, and attempts to understand the rules governing its assembly. Using two-photon microscopy to image the cerebral vasculature in awake mice, we are able to quantitatively measure the flow and control dynamics in single cerebral blood vessels. We have combined these measurements with controlled perturbations of different neural subpopulations. We have found that rather than being controlled by the overall activity of the neural population, the blood vessels are controlled by a small oligarchy of neurons. In addition to these neural control mechanisms, the arterioles have intrinsic oscillatory dynamics independent of any neuronal control. Finally, I will touch the impact of the role of these neuronally-controlled and non-neuronally controlled vessel dynamics on the assembly of the vascular network

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MS62

Mapping Brain-Wide Vascular Networks with Capillary Resolution: Topological Features and Functional Correlates

The vascular network in the brain is a complex and intricate network that supplies neurons with sufficient energy to perform neuronal computations. What are the structural features of this network that enable dynamic energy distribution towards regions of elevated electrical activity and metabolic load, as well as providing robustness against smaller blockages ? How do network features vary with brain region and function, and how do genes, pathologies, sensory deprivation, or even learning influence the networks structure? Here we present a high-throughput method for the automatic detection of vasculature networks of entire mouse brains down to capillary resolution. After tissue clearing and immunology-staining based on the iDISCO+ method [1], intact brain samples are imaged via light sheet-microscopy. Vasculature networks are then reconstructed via custom 3D image-processing software, resulting in networks of 3 million branch points and 5 million branches. By registering the data to reference brains we generate brain wide atlases of the statistics of structural features of the vasculature network. We describe diverse functional correlates between network topology and brain function, including elevated vasculature branch density in auditory pathways. [1] Renier*, Adams*, Kirst*, Wu*, et al. Cell 2016

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MS62

Modeling Hemodynamic Fluctuations: The Brain Vasculature as an Excitable Network

Multiple studies have examinedblood oxygen level dependent(BOLD) signals of functional magnetic resonance imaging(fMRI) showing spontaneous fluctuations when the brain is at rest, sleeping or even anesthetized. These fluctuations are found at lower frequencies (around 0.1 Hz) than respiratory or cardiac functions. In addition, recent experimental works suggest a non-neuronal origin for spontaneous cerebral blood volume fluctuations. We propose a minimal model for microcirculation that only assumes a nonlinear relation between the current supported by each vessel and the pressure drop between its starting and final nodes, and a dispersive relation for volume accumulation. This simple approach qualitative reproduces the main characteristics of the observed behavior. The fluctuations emerge spontaneously under constant boundary conditions as self-sustained oscillations, forming different patterns depending on the topology of the network. We expect that this model can shed light on the nature of spontaneous fluctuations on brain vasculature and its interplay with the properties of the network. Finally, the simplicity of the model makes it suitable for its use with different nonlinear flow networks exhibiting complex dynamical behavior.

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MS62

Making Microvascular Networks Work: Angiogenesis, Remodeling and Pruning

Vascular networks are dynamic structures, being generated and modified in a number of physiological and pathological conditions (development, growth, exercise, estrus cycle, wound healing, tumor growth). Network structures must provide short diffusion distances from any given point in tissue to the nearest capillary, while also having hierarchical branching arrangements to give efficient flow distribution and convective transport over long distances to the sites of diffusive exchange. These somewhat conflicting patterning requirements are met through stochastic generation of new vessels (angiogenesis) together with structural adaptation of vessel diameters (remodeling) and pruning, to generate functionally adequate network structures. A theoretical model has been developed for angiogenesis, remodeling and pruning, in which all segments in a microvascular network react to metabolic and mechanical stimuli according to a single set of biologically based rules. The model includes simulations of network hemodynamics and diffusion of oxygen and growth factors. The results are compared with experimental data derived from intravital microscopy of microvascular networks. It is shown that realistic network structures can be generated by the assumed mechanisms, and that such networks can reorganize dynamically with changing demands.

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MS63

Detailed Dynamics Study of the Linc/licn Isomerization Reaction in a Bath

The calculation of reaction rates plays a central role in Chemistry. In gas phase reactions, the interaction with the environment is usually so small that it can be simply neglected. However in condensed phase this interaction must be considered and then one must integrate not only the equations of motions for the system under study but also for the huge number of particles that form the surrounding environment. Transition State Theory (TST) provides a simple alternative to avoid the need of any time-consuming simulation. TST is able to (i) identify reactive trajectories, and (ii) compute reaction rates. This theory is based on the study of the so called "transition state" or "activated complex" that is formed when the reaction takes places, evolving from the reactants to the products. The fundamental assumption of TST to be exact is the existence of a dividing surface that is free of recrossing. The identification of such a recrossing-free is a very challenging problem, specially, when the systems is driven by colored noise or has many degrees of freedom. We will see some alternative ways to overcome this. In this talk, we will present all-atom molecular dynamics simulations to determine the reaction rate of the LiNC/LiCN molecular system in a bath environment. Then, we will discuss the effect of bath properties in the reaction rates and analyze the conditions in which the phase space structure of the system plays an important role.

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MS63

The Transition Manifold Approach to Molecular Coarse Graining

The transition processes in complex, high-dimensional molecular systems are often governed by just a small number of essential degrees of freedom. However, the analytic description of these so-called reaction coordinates is in general unknown. The computation of reaction coordinates from numerical simulation data in order to gain chemical insight or build reduced models is thus of high interest in computational chemistry and related fields. We have identified precise defining characteristics of optimal reaction coordinates and linked them to the existence of a so-called transition manifold, a manifold in an infinite-dimensional function space that can be considered the backbone of the slow transition dynamics. The new theory is compatible with established concepts from Transition Path Theory, while being applicable to a larger class of slow-fast systems. Conceptually, the transition manifold is a geometrical representation of dynamical information about the long-time transition processes. This information, in practice given by time-series or parallel simulation data, can then be extracted from the transition manifold by a wide variety of high-performance machine learning methods. In this talk, both the theoretical concepts of the transition manifold, as well as the data-driven algorithms will be presented and demonstrated on a small protein system.

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MS63

Non-adiabatic Dynamics from Classical Equations of Motion

The accurate and efficient simulation of non-adiabatic processes provides a significant challenge for simulation methodologies due to the difficulty of treating the coupled motion of electrons and nuclei in realistic systems. Towards this goal, I will present the kinetically-constrained ring polymer molecular dynamics (KC-RPMD) method for the direct simulation of non-adiabatic dynamics in complex systems. KC-RPMD is an imaginary-time path integral method that enables the use of classical molecular dynamics trajectories to model the real time quantum dynamics of a system of coupled electrons and nuclei. I will conclude the talk by discussing work utilizing KC-RPMD to investigate the mechanism of long-range electron transfer in the Azurin blue-copper protein.

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MS63

Hill Regions of Charged Three-Body Systems

For charged 3-body systems, we discuss the configurations and orientations that are admissible for given values of the conserved total energy and angular momentum. The admissible configurations and orientations are discussed on a configuration space that is reduced by the translational, rotational and dilation symmetries of charged 3-body systems. We consider the examples of the charged 3-body systems given by the compound of two electrons and one positron and the helium atom (two electrons and a nucleus). For comparison, the well known example of the Newtonian 3-body system is discussed following the same scheme. The study is relevant for transition state theory as the bifurcations of the Hill regions can result from saddle-type equilibrium points in which case transition state theory could be used to study the transport from region to another. This is joint work with Igor Hoveijn and Mohammad Zaman

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MS64

Singularities and Homeostasis in Gene Regulatory Networks

Homeostasis occurs in a biological or chemical system when some output variable remains approximately constant as input parameters vary over some range. The notion of homeostasis is often associated with regulating global physiological parameters like temperature in multi-cellular complex organisms, such as mammals. For unicellular organisms, homeostasis is related to how some internal cell state of interest (the copy number, or concentration, of an mRNA transcript or of a protein) responds to changes in the intra-cellular or extra-cellular environment. Recently, Golubitsky and Stewart ["Homeostasis, Singularities and Networks", J. Mathematical Biology 74 (2017) 387-407] introduced the notion of "infinitesimal homeostasis" allowing the use of implicit differentiation and singularity theory to find regions of homeostasis in systems of differential equations. In this talk we explain how to use these methods to explicitly find regions of homeostasis in differential equation models corresponding to certain "motifs" (small subnetwork patterns that appear with high frequency in large complex networks) in a Gene Regulatory Network (GRN) of a single-cell organism.

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MS64

Coincidence of Homeostasis and Bifurcation Points in Feedforward Networks

Homeostasis can be studied by restricting ones attention to homeostasis pointspoints at which a component of the dynamical system has a vanishing derivative with respect to an input parameter. Such homeostasis points play an important role in physiology and medicine. In a feedforward network with a dynamical system at each node, if a node has a homeostasis point, downstream nodes will inherit it. This is the case except when the downstream node has a bifurcation point coinciding with the homeostasis point. This talk will discuss this phenomena of homeostasis-bifurcation points. Near these points, the downstream node often exhibits complex behavior as the input parameter is varied. In the case of steady state bifurcation this includes switch-like behavior and multiple homeostatic plateaus. In the case of Hopf bifurcations the downstream node may have limit cycles with a wide range of near-constant amplitudes and periods.

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MS64

Network Admissible Systems: Symmetries and Bifurcations

This review will discuss how annotated graphs lead to classes of coupled systems of differential equations called *admissible systems*. We address two questions. (1) What are the patterns of synchrony and phase-shift synchrony associated with typical states in admissible systems, specifically those associated with synchrony-breaking bifurcations? (2) How do these states relate to network structure?

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MS64

Bifurcations on Fully Inhomogeneous Networks

Networks arise naturally in many areas of biology such as gene regulation, ecology and biochemistry. In these fields, networks are often fully inhomogeneous in the sense that all nodes and couplings can be different. Therefore we consider dynamics on fully inhomogeneous networks. For this class of networks there are general circumstances in which the center manifold reduced equations inherit a network structure of their own, whereas in general the reduction bears no obvious relation to the network structure of a dynamical system. The structure arises by decomposing the network into path components, which connect to each other in a feedforward manner. Critical eigenvalues can then be associated with specific components, and the network structure on the center manifold depends on how these critical components connect within the network. This observation is used to analyze codimension one and two local bifurcations. For codimension one, only one critical component is involved and generic local bifurcations are saddle-node and standard Hopf. For codimension two, we focus on the case when one component is downstream from the other in the feedforward structure. Here the generic bifurcations, within the realm of network-admissible equations, differ significantly from generic codimension two bifurcations in a general dynamical system.

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MS65

Extinction Risk of a Metapopulation under the Allee Effect

We study the extinction risk of a fragmented population residing on a network of patches, where the patches are coupled by diffusive migration and the local patch dynamics includes the Allee effect. Here we show that mixing between patches can have both a positive and negative effect on the population's viability, depending on the migration rate and flux between patches. In particular, weak migration is shown to always increase the population's extinction risk, and thus, the population is better off being isolated rather than weakly mixed. This surprising result is in stark contrast to the case where the local dynamics is logistic, where any nonzero migration rate decreases the population's extinction risk. In the regime of intermediate migration, we find in some cases a critical migration rate for which the extinction risk is maximized and the population's lifetime in minimized. Notably, as the migration rate further increases, we demonstrate the existence of an optimal migration rate for which the lifetime is maximized. However, this highly non-monotonic dependence of the extinction risk on the migration rate is parameter-dependent. In other cases, we reveal a markedly different behavior, where the extinction risk monotonically increases with the migration rate, indicating that even an arbitrarily-strong migration is insufficient to rescue the population. Our theoretical results are verified via highly-efficient numerical simulations based on the weighted ensemble method.

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MS65

Extinction and Survival in Two-Species Annihilation

We study diffusion-controlled two-species annihilation with a finite number of particles. In this stochastic process, particles move diffusively, and when two particles of opposite type come into contact, the two annihilate. We focus on the behavior in three spatial dimensions and for initial conditions where particles are confined to a compact domain. Generally, one species outnumbers the other, and we find that the difference between the number of majority and minority species, which is a conserved quantity, controls the behavior. When the number difference exceeds a critical value, the minority becomes extinct and a finite number of majority particles survive, while below this critical difference, a finite number of particles of both species survive. The critical difference Δ_c grows algebraically with the total initial number of particles N, and when $N \gg 1$, the critical difference scales as $\Delta_c \sim N^{1/3}$. Furthermore, when the initial *concentrations* of the two species are equal, the average number of surviving majority and minority particles, M_+ and M_-, exhibit two distinct scaling behaviors, $M_+ \sim N^{1/2}$ and $M_- \sim N^{1/6}$. In contrast, when the initial *populations* are equal, these two quantities are comparable $M_+ \sim M_- \sim N^{1/3}$.

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MS65

Fluctuation Pathways to Desynchronization in Coupled Oscillator Networks

There is great interest in understanding how topology, dynamics, and uncertainty conspire to produce rare and extreme events in networks. This is particularly the case for coupled oscillator networks since they appear at the core of many biological and physical systems where noise and uncertainty play a significant role. A primary example is desynchronization in power grids from input-power fluctuations. In this talk, we develop theory for the most-likely, or optimal, pathway of noise-induced desynchronization in phase-oscillator networks (with and without inertia) and in Stuart-Landau oscillator networks. We quantitatively characterize the scalings and patterns for the optimal path and the probability of desynchronization as a function of network topology and local dynamics, and compare the behavior for the various models. Lastly, we discuss the effects of non-Gaussian, pulse noise, and controls on the input power, on desynchronization. Such effects are especially relevant for power grids with renewable energy sources.

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MS65

Narrow Escape of Interacting Diffusing Particles

The narrow escape problem deals with the calculation of the mean escape time of a Brownian particle from a bounded domain through a small hole on the domains boundary. We [T. Agranov and B. Meerson, Phys. Rev. Lett. **120**, 120601 (2018)] developed a formalism which allows one to evaluate the nonescape probability of a gas of diffusing particles that may interact with each other. In some limits we can also evaluate the mean escape time of the first particle. The formalism is based on the fluctuating hydrodynamics and macroscopic fluctuation theory. We also uncover a direct mathematical connection between the narrow escape of interacting particles and thermal runaway in chemical reactors.

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MS66

The Role of Phase Shifts of Sensory Inputs in Walking Revealed by Means of Phase Reduction

Detailed neural network models of animal locomotion are important means to understand the underlying mechanisms that control the coordinated movement of individual limbs. Daun-Gruhn and Toth (2011) constructed an intersegmental network model of insect locomotion consisting of three interconnected central pattern generators (CPGs) that are associated with the protraction-retraction movements of the front, middle and hind leg. This model could reproduce the basic locomotion coordination patterns, such as tri- and tetrapod, and the transitions between them. However, the analysis of such a system is a formidable task because of its large number of variables and parameters. Here, we employed phase reduction and averaging theory to this large network model in order to reduce it to a system of coupled phase oscillators. The reduced model was able to reproduce the results of the original model. By analyzing the interaction of just two coupled phase oscillators, we found that the neighboring CPGs could operate within distinct regimes, depending on the phase shift between the sensory inputs from the extremities and the phases of the individual CPGs. We demonstrate that this dependence is essential to produce different coordination patterns and the transition between them. Additionally, applying averaging theory to the system of all three phase oscillators, we calculate the stable fixed points, corresponding tripod or tetrapod and identify two ways of transition between them.

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MS66

Metachronal Propulsion at Low to Intermediate Reynolds Numbers

Inspired by the forward swimming of long-tailed crustaceans, we propose a novel underwater propulsion mechanism for a swimming body with multiple swimming pedals attached underneath. Using a computational fluid dynamics model based on the immersed boundary method with prescribed motion, we find that metachronal propulsion with an approximate quarter-period phase difference between neighboring paddles in a back-to-front wave is the most efficient coordination pattern among all possible phase-differences. We also show that this frequency-invariant stroke pattern is the most effective and mechanically efficient paddling rhythm for Reynolds numbers ranging from 0.1 to 100 regardless of the number of paddles.

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MS66

Perturbing Muscle: Exploring Muscle Force Production as a Dynamical System

Nearly all animal move using muscles that produce force in a periodic pattern. Muscle only produces force in a shortening direction, so each muscle is opposed by at least one antagonist. The movement therefore depends on a muscles interaction with other muscles and with the environment. We are developing techniques to characterize how muscle activation produces a stable limit cycle, and also to quantify how these systems respond to perturbations. In one experiment, a sinusoidal length change was imposed on the muscle and both active and passive force were measured. Then, small sinusoidal perturbations at different frequencies are added. We find that the effective stiffness and damping of muscle varies during the swimming cycle, and that activation alters the magnitude and timing of both properties. In a second experiment, a real time simulation of a spring-mass-damper system is used so that muscle length can evolve based on its force production. From this, we quantify how stable limit cycle movements are produced based the pattern of activation. In both cases, the results are analyzed using a new system identification technique based on harmonic transfer functions, which allow us to use these data to predict the muscle function under other conditions. In particular, we are investigating how muscle behaves as part of a feedback loop, when coupled to other muscles and to the body and fluid.

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MS67

Stochastic Hybrid Biological Oscillators

Many systems in biology can be modeled through ordinary differential equations, which are piecewise smooth, but switch between different states according to a Markov jump process. In the fast switching limit, the dynamics converges to a deterministic ODE, which we assume supports a stable limit cycle. We demonstrate that a set of such oscillators can synchronize when they are uncoupled but share the same switching Markov jump process. The latter is taken to represent the effect of a common randomly switching environment. We determine the leading order of the Lyapunov coefficient governing the rate of decay of the phase difference in the fast switching limit, and show that it differs significantly from the one obtained from a diffusion approximation of the stochastic hybrid system.

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Positional Information Effects on the Schellings Model of Segregation: Applications to Neurodevelopment

Boundary formation in the developing neuroepithelium decides on the position and size of compartments in the adult nervous system. Some models propose that boundaries are formed through the combination of morphogen diffusion and of thresholds in cell responses. In contemporary terms, a response is characterized by the expression of cell-autonomous transcription factors, very often of the homeoprotein family. However, theoretical studies suggest that this sole mechanism results in the formation of boundaries of imprecise shapes and positions. Based on the Schellings socio-economic model of segregation we propose an IBM for describing the effects of positional information on the formation and clustering of cells. We replace the economic concept of utility by the condition of been placed on the *correct side of a boundary*, condition that itself has theoretically been related to the presence of a precise combination of homeoproteins. Our model extends some previous results of the authors, and will hopefully provide a useful framework for studying many spatial biological phenomena that involve cells making location choices as a function of the characteristics of their neighbors.

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MS67

Noisy Competition for Percept Dominance Amidst Ambiguity

When experiencing a complex sensory stimulus, especially an ambiguous one (e.g., the faces-vase image), subjects may report random switching (time scale, seconds) between the possible interpretations, as if undergoing perceptual exploration. I will describe dynamical models for neuronal populations that compete for dominance through mutual inhibition, influenced by slow adaptation and noise. Our modeling and psychophysical experiments involve perception of ambiguous auditory stimuli (try the link http://audition.ens.fr/sup/). Our model accounts for the statistics of switching over a range of stimulus conditions. It also addresses the effects of selective attention, distractors and deviants as well as the transient build-up phase of sound source segregation as when entering a cocktail party.

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MS67

Emergence and Persistence of Microbial Consortia at Steady State

Abstract not available.

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MS68

Power and Limitations of Sum of Squares Programming for Stability Analysis of Dynamical Systems

We study the power and limitations of sum of squares optimization and semialgebraic Lyapunov functions for proving asymptotic stability of polynomial dynamical systems. We give the first example of a globally asymptotically stable polynomial vector field with rational coefficients that does not admit a polynomial (or even analytic) Lyapunov function in any neighborhood of the origin. We show, however, that if the polynomial vector field is homogeneous, then its asymptotic stability is equivalent to existence of a rational Lyapunov function whose inequalities have sum of squares proofs. This statement generalizes the classical result in control on the equivalence between asymptotic stability of linear systems and existence of a quadratic Lyapunov function satisfying a certain linear matrix inequality.

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MS68

Convex Analysis of Maximal Transient Growth Phenomena

Quantifying the maximal amplification of scalar-valued observables along trajectories of ODE or PDE systems is a fundamental problem in nonlinear dynamics. For instance, bounds on the maximum growth of enstrophy or palinstrophy in fluid flows have far-reaching implications regarding the regularity of solutions of the incompressible Navier–Stokes equations. This talk will describe a general convex variational framework, applicable to both systems of ODEs and PDEs, to derive rigorous bounds on the extremal value of observables along trajectories that start from a prescribed set of initial conditions. The framework is closely related to relaxation methods for optimal control problems based on occupation measures, encompasses the classical "energy methods" used in fluid mechanics and, after discretization in space for PDEs, can be implemented numerically using tools for sum-of-squares (SOS) programming. In particular, for systems of ODEs that satisfy mild assumptions, arbitrarily sharp bounds can be computed numerically by solving a hierarchy of SOS programs. Examples that demonstrate both the potential and the generality of the proposed approach will be presented and discussed.

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MS68

Studying Dynamics using Polynomial Optimization

Various global properties of nonlinear ODEs and PDEs can be inferred by constructing functions that satisfying suitable inequalities. Although the most familiar example is proving stability by constructing Lyapunov functions, similar approaches can produce many other types of mathematical statements, including for systems with chaotic or otherwise complicated behavior. Such statements include bounds on attractor properties or transient behavior, estimates of basins of attraction, and design of optimal controls. Analytical results of these types often trade precision for tractability. Much greater precision can be achieved by using computational methods of polynomial optimization to construct functions that satisfy the suitable inequalities. This talk will provide an overview of the different ways in which polynomial optimization can be used to study dynamics, many of which will be illustrated by subsequent talks in the double minisymposium. Several examples will be shown in which polynomial optimization produces arbitrarily sharp results while other methods do not. These examples include the estimation of average and extreme quantities on the attractors of the Lorenz equations and the Kuramoto-Sivashinsky equation.

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MS68

Moments and Convex Optimization for Analysis and Control of Nonlinear Partial Differential Equations

This work presents a convex-optimization-based framework for analysis and control of nonlinear partial differential equations. The approach uses a particular weak embedding of the nonlinear PDE, resulting in a *linear* equation in the space of Borel measures. This equation is then used as a constraint of an infinite-dimensional linear programming problem (LP). This LP is then approximated by a hierarchy of convex, finite-dimensional, semidefinite programming problems (SDPs). In the case of analysis of uncontrolled PDEs, the solutions to these SDPs provide bounds on a specified, possibly nonlinear, functional of the solutions to the PDE; in the case of PDE control, the solutions to these SDPs provide bounds on the optimal value of a given optimal control problem as well as suboptimal feedback controllers. The entire approach is based purely on convex optimization and does not rely on spatio-temporal gridding, even though the PDE addressed can be fully nonlinear. The approach is applicable to a very broad class of nonlinear PDEs with polynomial data.

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MS69

One-Dimensional Periodic Solutions in a Three-Component Reaction-Diffusion System

Periodic patterns occur ubiquitously in nature, but the mechanism behind the formation of periodic patterns away from onset is not well understood. In this talk we consider the mechanism behind the generation of periodic stationary solutions in a singularly perturbed reaction-diffusion system. The system has one fast nonlinear component, interacting with two slow components. We investigate the existence and bifurcations of families of one-dimensional periodic solutions in this system. It will be shown how changes in the slow manifold and changes in the fast dynamics lead to an intriguing sequence of self-replicating patterns of large amplitude periodic waves. We will conclude this talk with a discussion about extensions to two-dimensional patterns and travelling waves.

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MS69

Pulse Solutions for an Extended Klausmeier Model with Spatially Varying Coefficients

Motivated by its application in ecology, we consider in this talk an extended Klausmeier model – a singularly perturbed reaction-advection-diffusion equation with spatially varying coefficients. We establish the existence of stationary pulse solutions by blending techniques from geometric singular perturbation theory with bounds derived from the theory of exponential dichotomies. Moreover, the spectral stability of these solutions is determined, using similar methods. It is found that, due to the break-down of translation invariance, the presence of spatially varying terms can stabilize or destabilize a pulse solution. In particular, we show that this leads to the discovery of a pitchfork bifurcation and the existence of stationary multi-pulse solutions.

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MS69

Grassmannian/Riccati Flows and Applications to Nonlinear Systems

We present a programme for generating the solutions of large classes of nonlinear partial differential equations, by pulling the equations back to a linear system of equations. The idea underlying this programme is to lift the standard relation between Riccati equations and linear systems to the infinite dimensional setting. This generalisation is well-known in optimal control theory where the off-line Riccati solution mediates the optimal current state feedback. The solution procedure can be presented at an elementary level and many examples will be included. Such example applications are partial differential equations with nonlocal nonlinearities, for example Smoluchowski's coagulation equation and, by association, the inviscid and viscous Burgers equations with local advective nonlinearities.

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MS69

Growing Stripes, with and Without Wrinkles

We study how the growth of a domain influences the formation of striped patterns. We focus on the planar Swift-Hohenberg equation, where stripes are "grown' in the wake of a moving parameter step. We find stripes perpendicular or oblique relative to the parameter step, and a plethora of defects nucleating at the step. Using amplitude equations, asymptotic methods, algebraic spreading speed calculations, and numerical farfield-core decompositions, we construct a surprisingly complex bifurcation diagram for coherent stripe formation. Solutions form a singular surface, the "moduli space', in the three-dimensional parameter space of wavevector of stripes and speed of quenching line. Typical scenarios of stripe formation, observed when increasing the rate of growth, go from oblique stripes to zigzag patterns and perpendicular stripes, then back to zigzag patterns, stripes with amplitude defects, and parallel stripes, before stripe formation detaches.

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MS70

Boundaries of Synchronization in Ecological Networks

In ecology, species ability of colonizing new patches in search for better conditions of resources is known to increase the structural stability of population dynamics in ecosystems. By contrast, such spatial dispersal constitutes interconnections among patches that facilitates synchrony of their oscillations. This synchronizing aspect may elevate the risk of local extinctions to become global, causing the collapse of the whole ecosystem. In this context, we offer a mechanism to avoid this downside in which unstable, and transient, dynamics, at the level of single patches emerge as stable, and perpetual, in the connected system. Specifically, unstable chaotic sets in the local population dynamics of each patch behave as stable in the spatially distributed system and generate alternative desynchronized states. Sets of initial conditions leading to undesired synchronized solutions and the ones leading to desynchronization are shown and analysed. Despite of the generality of the reported phenomenon, we demonstrate our findings, and explain the mechanism, in a food web containing three trophic levels and a diffusive coupling to represent the connections due to dispersal.

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MS70

Nonlinear Dynamics of Desertification

Desertification is defined as loss of biological productivity induced by climatic changes and human intervention. From a dynamical-system point of view, desertification is often viewed as an abrupt transition occurring across a saddle-node bifurcation. This simple tipping-point view overlooks two generic aspects of dryland ecosystems: (i) their spatial extent and the often localized form of desertification transitions, (ii) resonant response to seasonal weather variations. In this talk I will address these two aspects using mathematical models of dryland vegetation. I will discuss gradual desertification that proceeds by front propagation, focusing on the possible roles of front pinning in slowing down desertification, and of longitudinal and transverse front instabilities in reversing it. I will further discuss the existence of damped oscillatory modes in dryland vegetation, their resonant response to seasonal rainfall periodicity, and the possibility of early ecosystem collapse following a period-doubling route to chaos.

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MS70

On the Influence of Inter-Individual Differences on Herding Behavior

I will introduce a self-propelled particle model describing coordinated group behavior in multi-agent systems. The model accounts for the role of differences among interacting individuals in determining their group-level dynamics. I will subsequently reflect on the implications of the model for the collective behavior of natural and nature-inspired herding systems.

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MS70

Rapid Evolution Prevents Rate-Induced Critical Transition in a Predator-Prey System

Recent studies show that critical transitions can also be triggered by dangerous rates of environmental change instead of dangerous thresholds. These rate-induced critical transitions can occur even if the environment changes much slower than the slowest process in the system and without exceeding any dangerous threshold of environmental change. We demonstrate such a rate-induced critical transition for the well-known Rosenzweig-MacArthur predator-prey model by reducing the resources in the habitat at a given rate. This leads to a temporary collapse of the prey population due to overconsumption by the predators. We assume further that the predator population is able to adapt its handling time of the prey on a comparable ecological timescale. When the resource concentration is fixed, this rapid evolution destabilizes the stationary coexistence of both populations leading to a coexistence in oscillations. Rather surprisingly, when the resources decline at a given rate and simultaneously, the predators handling time evolves fast, rate-induced critical transitions and oscillations due to rapid evolution of the predators trait are prevented. Our results demonstrate the importance of considering destabilizing processes as rates of environmental change and rapid evolution in ecological systems because their interactions can stabilize the ecosystem or even prevent population collapses.

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MS71

Coherent Patterns using Space-Time Koopman Analysis

Coherent patterns are an important object of study in chaotic dynamics, here we will talk about structures called coherent spatiotemporal patterns. These are defined in terms of the Koopman and Perron-Frobenius groups of operators associated to any nonlinear flow. We will show how this operators-theoretic formulation of dynamical systems are useful for detecting and predicting the evolution of such coherent patterns. We will start from a general setting and then focus on incompressible time-dependent fluid flows driven by ergodic dynamical systems. Examples of such flows are periodic Gaussian vortex flows and aperiodic flows generated by Lorenz 96 systems.

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MS71

Material Barriers to Diffusive and Stochastic Transport

Observations of tracer transport in fluids typically reveal highly convoluted patterns shaped by a complex network of transport barriers and enhancers. The elements of this network appear to be universal for small diffusivities, independent of the tracer, its initial distribution and its boundary conditions. In this talk, I discuss a mathematical theory of unconstrained diffusion barriers to predict observed transport barriers and enhancers solely from the flow velocity, without reliance on expensive diffusive or stochastic simulations. As an alternative, I also discuss solutions to the same problem under a specific, fixed initial condition, i.e., solving a constrained transport barrier problem. Both theories yield a simplified computational scheme for diffusive transport problems, such as the estimation of salinity redistribution for climate studies and the forecasting of oil spill spreads on the ocean surface. I will illustrate the results on turbulence simulations and observational ocean velocity data.

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MS71

Computational Aspects of the Detection of Material Barriers to Diffusive Transport

Lagrangian coherent structures are of major importance in the description and prediction of fluid transport processes. Different existing mathematical methods for their detection have been recently put into a Lagrangian advection-diffusion framework, and new ones have been developed based on this ground. For their application to real-world problems, a flexible, efficient implementation is of utmost importance. We discuss computational challenges of the different methods and their implementation in `CoherentStructures.jl`, a computational toolbox written in the modern, dynamic high-performance programming language Julia.

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MS71

Finite-Time Averaging of Advection-Diffusion in Lagrangian Coordinates

The advection-diffusion equation in Lagrangian coordinates underlies a range of methods used for the detection of Lagrangian coherent sets. These methods often avoid the difficulties of modelling the time-dependent diffusion directly by averaging the time-dependent diffusion operators over a finite time interval. We prove that in many settings, the autonomous averaged equation is a good approximation to nonautonomous non-averaged one, and then look at geometric aspects related to the averaged diffusion equation.

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MS72

Nonautonomous Network Attractors: A New Paradigm to Model the Behaviour of Recurrent Neural Networks

Artificial recurrent neural networks (RNNs) are dynamical systems (DS) driven by inputs that allow one to perform predictions of temporal data. Notwithstanding their success in various applications, understanding their behaviour at a mechanistic level on tasks of interest remains elusive, due to the nonlinear and high-dimensional dynamics driven by inputs. In a recent contribution, we showed how particular DS models called excitable network attractors can be useful to describe the behaviour of RNNs on tasks involving learning memory states, as stable fixed points with related switching patterns driven by impulsive control inputs. However, such tasks cover only a very limited range of application scenarios and can be easily understood using the theory of autonomous DS. More realistic application scenarios for RNNs involve non-impulsive inputs, and highlights a need to develop modelling frameworks that exploit properties of nonautonomous DS. We give a mathematical description of RNN dynamics while solving tasks, by defining a notion of nonautonomous network attractor. We prove this is positively invariant under the action of the process induced by input-driven RNNs.

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MS72

A Bounded-Time Approach to Dynamics Analysis

Traditional analysis of dynamics is in terms of coordinate-invariant long-time-asymptotic properties of indefinite-time dynamical systems, and especially time-independent systems. However, we will illustrate how, for the task of reliably gaining understanding of the behaviour of real-world open systems, all approaches to dynamics that rely on models being defined over infinite time are fundamentally insufficient. We show this by identifying a simple finite-time nonautonomous dynamical phenomenon, that is both observed in inherently time-constrained models and also prone to obscuration by asymptotic-time analysis for indefinite-time models. The phenomenon is stabilisation of one-dimensional phase dynamics under slow parameter drift of a general form. One can formalise it within a rigorous mathematical framework of bounded-time dynamics, and we provide clear numerical illustration of the phenomenon. We conclude the potentially crucial importance across the sciences of a finite-time approach to investigating dynamics of open systems.

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MS72

Understanding Transients Associated with Periodic Dynamics using the LOR Coordinate Transformation

Determining that a dynamical system has an attractor is useful, but this information characterizes the long-term state of the system. For many applications, the transient dynamics that occur in the process of convergence to the attractor may be at least as important as the nature of the attractor; as the famous quote goes, "It's not the destination, it's the journey." This talk will discuss transient dynamics arising in the basin of an attracting periodic orbit, in arbitrary dimensions. To characterize such dynamics, we have introduced a new tool, *local orthogonal rectification*, or *LOR*. The idea of LOR is that a new coordinate system, the *LOR frame*, can be derived relative to an arbitrary base curve or manifold. With a suitable choice of base structure, the LOR frame can provide the information about transient dynamics that we are after. In the case of attracting periodic orbits, we can locate the manifolds that are attracting or repelling for trajectories in the basin and hence organize the transient dynamics arising in the process of convergence.

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MS72

Predicting Deterministic Transient Responses via Expectation Values

Predicting the transient patterns of perturbations spreading across network dynamical systems is essential for containing the systems dynamics and for preventing secondary failures caused by initial perturbations. However, even for simple linear systems, calculating common measures for the responses of individual units, such as the positions and height of maxima or threshold crossing times, requires solving transcendental equations and is thus impossible. Here, we propose a complementary approach and quantify deterministic transient dynamics via effective expectation values exactly as in probability theory [Wolter et al., Chaos, 2018]. Interpreting the rescaled response trajectory of a unit as a probability density over time enables us to quantify the magnitude and timing of the responses via expectation values computed analytically. We provide these analytical expressions in terms of the inverse Jacobian matrix characterizing the linearized dynamics near a stable operating point. By comparing the results to exact analytical calculations of maxima positions for different functions approximating the transient dynamics we moreover adjust the expectation values to obtain estimators for the peak response time and peak magnitude. These approximations become asymptotically exact for weak coupling strengths and large distances to the original perturbation.

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MS73

Drift of Cardiac Scroll Waves Due to Anisotropy Gradients in the Cardiac Wall

The electrical wave patterns in the heart determine the efficiency of cardiac contraction and therefore pumping of blood. Rotating spiral-shaped patterns called spiral waves (in 2D), scroll waves (in 3D) or rotors (by medical people) have been observed and are thought to be the building blocks or drivers of several types of cardiac arrhythmia. An important feature of both the atrial and ventricular cardiac wall is anisotropy of wave propagation, which emerges from the fibrous and laminar microstructure of the heart muscle. Previously, it was shown that this effect can be captured by rescaling length units such that one is effectively working in a curved space or Riemannian manifold [see e.g. Wellner et al. PNAS 99 (12) 8015-8018, 2002; Verschelde et al. Phys Rev Lett 99, 168104, 2007]. However, those approaches supposed that the spiral wave core radius is much smaller than the wall thickness, whereas in real situations both are of comparable order. Here we show that an expansion around zero thickness enables to describe and predict the drift direction and magnitude of cardiac scroll waves, depending on the local wall thickness, mid-wall fibre orientation and total fiber rotation angle. For thin walls, the zeroth order approximation (2D) is sufficient, but for e.g. ventricular wall, the first Fourier modes need to be taken into account. We validate our results against numerical simulations of simplified and detailed ionic models.

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MS73

Reconstructing Rotor Dynamics from Sparse Noisy Data

The motion of, and interaction between, phase singularities that anchor spiral waves capture a lot of qualitative and, in some cases quantitative, features of complex dynamics in excitable systems. Being able to accurately reconstruct their position is therefore quite important, even if the data is noisy and sparse, as is the case, for instance, in electrophysiology studies of cardiac arrhythmias. A recently proposed global topological approach [Marcotte & Grigoriev, Chaos 27, 093936 (2017)] promises to dramatically improve the quality of the reconstruction compared with the traditional, local approaches. Indeed, we found that this approach is capable of handling noise levels exceeding the range of the signal. Moreover, it also works successfully with data sampled on sparse grids with spacing comparable to the mean separation between the phase singularities for complex patterns featuring multiple interacting spiral waves.

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MS73

The Role of Higher Order Scroll Wave Filament Dynamics in Terminating Fibrillation

The ability to terminate multiple scroll waves in an excitable system using weak electric field pulses (1 V/cm) is important in the development of new, low-energy cardiac defibrillation methods. Previously, we showed this was possible using electric fields that were configured to depolarize one entire surface of the system. However, the method does not always work, because scroll wave filaments detached from this surface by depolarization induced by the field sometimes reattach following the pulse. In this talk, I describe how higher order filament dynamics influenced by the field strength, surface curvature and phase of the rotating waves combine to determine whether filament reattachment occurs. I then discuss implications these mechanisms have for the success of low-energy defibrillation.

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MS73

A Simple Parameter can Switch Between Different Weak-Noise-Induced Phenomena in a Simple Neu-

ron Model

In this talk, we will show that the distinct noise-induced phenomena of self-induced stochastic resonance (SISR) and inverse stochastic resonance (ISR), can be related by a simple parameter switch in the FitzHugh-Nagumo neuron model [Yamakou ME and Jost J. A simple parameter can switch between different weak-noise-induced phenomena in a simple neuron model. EPL 120, 18002 (2017)]. Depending on the stability of the fixed point and on its relative position with respect to the fold point of the critical manifold, either SISR or ISR may emerge in the same weak noise limit. We then show that SISR is more robust to parametric perturbations than ISR, and the coherent oscillation generated by SISR is more robust than that generated deterministically. Furthermore, ISR is shown to depend on the location of initial conditions and on the singular parameter of the model equation. Our results could maybe explain the experimental observation where real biological neurons having similar physiological features and synaptic inputs encode very different information.

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MS74

Periodic Approximation for the Spectral Analysis of the Koopman Operator

In this talk, we are going to look into the problem of computing the spectral decomposition of the Koopman for the measure-preserving case. A challenging aspect of this particular problem is that the Koopman operator is here generally not compact, and hence, its spectra cannot be described by eigenvalues alone: the possibility of continuous spectra has to be taken into regard in the discretization. A breakthrough on this problem can be achieved by more closely examining the structure of the operator. The Koopman operator is simultaneously unitary and Markov. In the finite dimensional case, such an operator has to necessarily be a permutation, and it seems natural to enforce this structure also in the discretization. This observation gives rise to the concept of periodic approximation. We will show that through a discretization of the operator using periodic approximations, the spectra of the operator can be approximated in a weak-sense. Herein, it is demonstrated that, even though the individual rank-one spectral projectors are all spurious, smooth weighted sums of these projectors applied to a fixed observable carry meaning, and converge to their infinite-dimensional counterparts.

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MS74

Extracting Robust Constituents in Fluid and Combustion Flow

TAnalytical and computational studies of hydrodynamic and reacting flows are extremely challenging, due in part to nonlinearities of the underlying system of equations and long-range coupling. Moreover, accurate models of many of these systems in realistic settings are not available. Recent developments in high-resolution, high frequency experimental data capture offer an alternative approach to extracting key features of the underlying systems. However, this approach elicits new issues, including how noise and other external effects can be delineated from dynamics. We adapt Koopman mode analysis and dynamic mode decomposition to extract robust constituents of a flow from experimental data. The first step involves identifying robust dynamic modes which persist in multiple, nominally identical realizations of the flow. Following the evolution of their coefficients permits the selection of dynamic modes that form individual robust flow constituents. The delineation of noise and dynamics is recast as a differentiation of the flow into robust constituents and non-robust features. The methodology is used to identify robust flow constituents in (1) cellular patterns on flame fronts, (2) reacting flows behind a bluff body, (3) injector flows, and (4) swirling combustion.

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MS74

Data-Driven Discovery of Koopman Embeddings for Spatio-Temporal Systems

Identifying coordinate transformations that make strongly nonlinear dynamics approximately linear is a central challenge in modern dynamical systems. These transformations have the potential to enable prediction, estimation, and control of nonlinear systems using standard linear theory. The Koopman operator has emerged as a leading data-driven embedding, as eigenfunctions of this operator provide intrinsic coordinates that globally linearize the dynamics. However, identifying and representing these eigenfunctions has proven to be mathematically and computationally challenging. This work leverages the power of deep learning to discover representations of Koopman eigenfunctions from trajectory data of dynamical systems. Our network is parsimonious and interpretable by construction, embedding the dynamics on a low-dimensional manifold parameterized by these eigenfunctions. In particular, we identify nonlinear coordinates on which the dynamics are globally linear using a modified auto-encoder. We also generalize Koopman representations to include a ubiquitous class of systems that exhibit continuous spectra, ranging from the simple pendulum to nonlinear optics and broadband turbulence. Our framework parametrizes the continuous frequency using an auxiliary network, enabling a compact and efficient embedding. In this way, we benefit from the power and generality of deep learning, while retaining the physical interpretability of Koopman embeddings.

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MS74

Analysis and Model Reduction of Stochastic Dynamics using Koopman Operators

Dominant spectral components of Koopman operators have played a crucial role in the analysis of numerous real-world systems, as they can often be used to distinguish large scale changes from small scale fluctuations in the system (for a review, see [Klus, Nske, et al, J. Nonlinear Sci. (2018)]). In this talk, I will present recent progress on the approximation of dominant Koopman eigenfunctions from large tensor-structured basis sets. In particular, I will discuss the use of black box algorithms, such as cross-approximation [Oseledets and Tyrtyshnikov, Linear Algebra Appl. (2009)], in order to obtain a suitable low-rank representation of the discretized Koopman operator. If time allows, I will also discuss how knowledge of dominant Koopman eigenfunctions can guide the search for simplified models which preserve the systems essential features [Nske, Koltai, Boninsegna, and Clementi (submitted to J. Nonlinear Sci.)]. Molecular Dynamics will be used as a guiding example.

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MS75

An Adaptation Model for Slime MoldPhysarum Polycephalum

A Physarum Polycephalum is a single-celled animal that appears to be able to form intelligent network structures. Such a network is used for transportation of mass and energy in its body. There have been a few models discussing the formation dynamics of the networks structure. Nevertheless, very few has been discussed about the biological stimuli that drive such adaptation models. In this talk, we present a mathematical model to show that by an adaptation dynamics in response to local shear stress on the cell wall, the Physarum Polycephalum is able to minimize the total energy cost in fluid delivery. Furthermore, using an asymptotic analysis, we reduce the three-dimensional fluid flow to a two-dimensional flow and obtain an adaptation model of the thickness of Physarum Polycephalum. This model appears to be very similar to our previous model on the initiation of biological transport networks, thus can lead to the formation of networks structure with optimized energy cost.

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MS75

Mutual Couplings and Constraints in Space-Sharing Complex Networks

Multi-point optimization of spatially extended, complex processes in biology frequently requires a correspondingly complex, spatial network architecture. The theoretical modelling and classification of such networks remains a major open problem, with little still linking known architectural families or motifs to functional outcomes or optimal states. Furthermore, until now there has been little progress in our understanding of how such a complex network couples to its environment. We here model a biologically important pair of these networks – the sinusoids and bile canaliculi of the liver – that act both as spatial constraints on one another and also maintain an important flow coupling that is crucial to their function and find a novel modality for control of the networks' architecture arising from the manner in which they couple to one another in space.

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MS75

Blood Flow and Solute Transfer in Feto-Placental Capillary Networks

Throughout the mammalian species, solute exchange takes place in complex microvascular networks. In recent years, multi-scale models have proved successful in investigating the structure-function relationship of such networks in specific contexts. However, general methods for incorporating experimental data on complex, heterogeneous capillary networks into whole-organ multi-scale models remain under-developed. Here we introduce a theoretical framework, tested against image-based computations, for quantifying the transport capacity of feto-placental capillary networks using experimental data. We find that solute transfer can be described using a near-universal physical scaling based on two non-dimensional parameters (the diffusive capacity and a Damkohler number), which can be extracted from microscopy images via standard computational and image-analysis tools.

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MS75

Dduq: An Uncertainty Quantification/Model Reduction Technique for the Vascular Network

One of the most critical and exciting challenges in computational hemodynamics is the uncertainty quantification that propagates from the data to the numerical solution. In fact, data used as boundary conditions in clinical practice are always affected by noise or errors. The impact of these errors on the numerical results is critical for the reliability of the numerical simulations. UQ, however, may be computationally demanding. In this talk, we present an efficient method for UQ in a network of pipes, based on the combination of two techniques: domain decomposition of the network in branches and an efficient solver for the incompressible Navier-Stokes equations called Hi-Mod/TEPEM. The latter is a smart combination of different methods for the axial and the transverse directions - demonstrated to reduce the computational costs significantly. We will present the core of the methodology as well as preliminary results where the Polynomial Chaos Expansion is used to introduce stochasticity of the boundary conditions in a nontrivial network of pipes including three branching generations. Results on the efficiency and the scalability of the method will be discussed.

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MS76

Unveiling the Chaotic Structure in Phase Space of Molecular Systems using Lagrangian Descriptors

We explore the feasibility of using the recently introduced Lagrangian descriptors [*Comm. Nonlinear Sci. Numerical Sim.* **18**, 3530 (2013)] to unveil the usually rich dynamics taking place in the vibrations of molecular systems, especially if they are floppy. The principal novelty of our work is the inclusion of $p-$norms in the definition of the descriptors in this kind of systems, which greatly enhance their power to discern among the different structures existing in the phase space. As an illustration we use the LiCN molecule, which exhibits isomerization between the two wells corresponding to the linear isomer configurations at moderate values of the excitation energy, described by realistic potentials in two and three dimensions.

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MS76

What is Roaming in Chemical Reaction Dynamics and Why is it so Challenging to Model Theoretically?

Roaming is a term that describes a large amplitude pathway from reactant to products that in many cases appears to be correlated with a different set of products (called radicals). Examples of roaming, starting with the centrally important photodissociation of formaldehyde, will be given. This example will be used to introduce conventional Transition State Theory, which is a relatively simple and ubiquitous approach to obtain the rate coefficient of chemical reactions. This theory centers on locating a relevant critical point (a first order saddle point) and dividing surface separating reactants and products. This simple theory does not apply to roaming for which no simple dividing surface can be constructed.

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MS76

Phase Space Structures in Time-Dependent Three-Dimensional Vector Fields

In this talk we explore the capability of Lagrangian descriptors (LDs) [A. M. Mancho, S. Wiggins, J. Curbelo, and C. Mendoza. Comm. Nonlinear Sci. Num. Sim., 18(12):3530-3557, (2013)], a tool that has been successfully applied to time-dependent 2D vector fields, to reveal phase space geometrical structures in 3D vector fields. In particular, we show how LDs can be used to reveal phase space structures that govern and mediate phase space transport. We especially highlight the identification of normally hyperbolic invariant manifolds (NHIMs) and tori. We will show that LDs successfully identify and recover the template of invariant manifolds that define the dynamics in phase space for several examples. These results are described in [V.J. Garca-Garrido, J. Curbelo, A.M. Mancho, S. Wiggins, C. Mechoso. Regul. Chaot. Dyn. (2018) 23: 551].

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MS76

Roaming Radicals in Unimolecular and Bimolecular Reactions

The roaming radical reaction mechanism in chemical dynamics emerged fifteen years ago and has come to be recognized as a fundamental aspect of chemical reactivity. In these reactions, an excited molecule spends time in regions of high potential energy prior to decomposition, often to surprising products or with unanticipated product state distributions. We will present an overview of such reactions with an emphasis on the experimental perspective. We will also show some recent examples of roaming behavior in bimolecular reactions and discuss key criteria that define a system undergoing roaming.

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MS77

Heteroclinic Cycles and Networks of Localized Frequency Synchrony in Coupled Oscillator Popula-

tions

Abstract not available.

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MS77

Dynamically Relevant Motifs in Inhibition-Dominated Networks

Many networks in the nervous system possess an abundance of inhibition, which serves to shape and stabilize neural dynamics. The neurons in such networks exhibit intricate patterns of connectivity whose structure controls the allowed patterns of neural activity. In this work, we examine inhibitory threshold-linear networks whose dynamics are constrained by an underlying directed graph. We develop a set of parameter-independent graph rules that enable us to predict features of the dynamics, such as emergent sequences and dynamic attractors, from properties of the graph. These rules provide a direct link between the structure and function of these networks, and may provide new insights into how connectivity shapes dynamics in real neural circuits.

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MS77

The Role of Symmetries in Making Collective Decisions

In many real-world situations, a group of agents (e.g., bees, bacteria, neurons, people) have to make decisions about a set of options (choosing between nest sites, deciding whether to differentiate or not, agreeing on which percept is being perceived, choosing between political candidates or between different style restaurants). Often the agents are nearly equal, their opinion counts (almost) the same, and options are objectively (almost) equally valued. What are the dynamics governing these decision making processes? By exploiting the symmetries induced by agent and option value equality, we derive a general class of dynamic decision making equations. We then leverage equivariant bifurcation theory to detail the qualitative bifurcation structure of the derived dynamics. The interpretation of this bifurcation structure provides novel insights about generic decision making; for instance, the emergence of extremist and moderate decision makers. The model symmetries further predict under which conditions decision making is likely to exhibit either smooth or jump transition from indecision to decision. The predictive value of our approach is discussed in a novel perceptual decision-making experiment and on phenotypic differentiation. Finally, we discuss its relevance for nonlinear control theory.

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MS77

(Linear) Consequences of the Fundamental Network

Network dynamical systems have a host of unusual properties. These include anomalous bifurcations, highly degenerate spectra and large numbers of invariant spaces. A construction that is used to explain many of these phenomena is the so-called fundamental network. This network, which may be seen as a lift of the original one, reveals that there are hidden symmetries present in large classes of networks. In many cases, these hidden symmetries even form an equivalent way of describing the network structure of the original system. As a result, network structures on ODEs may be analysed through techniques from equivariant dynamics and representation theory. An interesting caveat here is that often these symmetries do not form a group, but rather a more general algebraic structure such as a semigroup. I will focus my talk on yet another unusual property of network systems, namely the tendency of eigenvalues to come in easy, often linear expressions of the coefficients. I will show that this is a natural consequence of hidden symmetry, and that this yields rich machinery for analysing and controlling the spectrum of a network map.

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MS78

Dynamics Driven by Noise in Condensed Matter and Active Matter Systems

Noise can drive dynamical systems far from equilibrium to produce orderly behavior in time or space that can often be used in artificial devices or serve important purposes in living systems. We describe a number of examples of these behaviors and study them by a combination of direct numerical simulation, kinetic theory descriptions, theory of dynamical systems and bifurcation calculations. In condensed matter systems, we will describe coherence resonance and stochastic resonance in semiconductor superlattice devices and how to harvest energy from thermal fluctuations in suspended graphene sheets. Examples of biological systems include the formation and growth of blood vessels (angiogenesis) in organ growth and repair, and flocking phenomena in active matter.

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MS78

Folding and Unfolding of Proteins

Single-molecule atomic force spectroscopy probes elastic properties of proteins such as titin and ubiquitin. We analyze bioprotein folding dynamics under both force and length-clamp conditions by modeling polyprotein modules as particles in a bistable potential, connected by harmonic springs. The study of multistable equilibria in these models explains recorded sawtooth force-extension curves. We show that bifurcations and transitions through quasi-stationary domain configurations modified by thermal noise are involved in observed stepwise and abrupt refolding and unfolding phenomena under force-clamp conditions. These predictions agree with experimental observations.

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MS78

Chaos in Semiconductor Superlattices: Coherence and Stochastic Resonances and Random Number Generation

A weakly coupled semiconductor superlattice (SSL) represents an almost ideal one-dimensional nonlinear dynamical system with a large number of degrees of freedom. The nonlinearity is due to sequential resonant tunneling between adjacent quantum wells. A great variety of nonlinear transport behavior has been observed in weakly coupled SSLs, including the formation of stationary electric-field domains, periodic as well as quasi-periodic current self-oscillations, and even driven as well as undriven chaos. Recently, a coherence resonance, which appears as regular current self-oscillations with a frequency of about 82 MHz, has been induced at room temperature in a weakly coupled GaAs/(Al,Ga)As SL by driving it with external noise exceeding a certain amplitude for an applied voltage, for which no current self-oscillations are otherwise observed. In addition, a novel kind of a stochastic resonance triggered by the coherence resonance appears when the device is driven by an external ac signal with a frequency, which is relatively close to that of the regular current self-oscillations at the coherence resonance. Furthermore, spontaneous chaotic current self-oscillations with large amplitudes in a weakly coupled GaAs/(Al,Ga)As SL can be used at room temperature for all-electronic true random number generation. These oscillations are characterized by a bandwidth of several hundred MHz and do not require external feedback or conversion to an electronic signal prior to digitization.

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MS78

Fluctuations and Heat Transfer Induced by Degenerate Noise

We examine mechanical or electrical networks with many degrees of freedom, some of which are coupled to heat baths of various temperatures. These couplings are modeled by random and damping forces consistent with Onsager's reciprocity relations. If N degrees of freedom are coupled to N independent random noises, we anticipate that the stochastic trajectories in state space "fill all N dimensions." There is a rigorous theorem to that effect. If we have "degenerate" forcing with fewer than N independent noises, the straightforward intuition is that the support of trajectories collapses to some subspace with fewer than N dimensions. There are examples just like that. Nevertheless, in the space of all possible stochastic dynamical systems, these special cases comprise a set of measure zero. Generically, trajectories induced by "degenerate noise" explore all N dimensions of state space, and heat transfer between heat baths of different temperatures is precisely quantified.

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MS79

Signatures of Central and Peripheral Control in Nematode Locomotion: When Neurons Meet Biomechanics

Among the most important roles of nervous systems is to control movement as animals negotiate complex environments. The undulatory locomotion of the microswimmer *C. elegans* offers an excellent model system for linking neural dynamics with behaviour. Using a simple but biologically grounded neuromechanical model of *C. elegans* locomotion, we study the respective roles of centrally generated patterns and proprioceptive control in this system. First, we use a dimensionless formulation to estimate material properties of the body that give rise to observed ranges of kinematic parameters. In a minimal model of proprioceptive control of undulations, we show that modulation of the mechanics of locomotion (e.g., changing the external fluid viscosity or the material properties of the body) results in a positive frequency-wavelength relationship in body undulations, whereas internal modulations of the neural control manifest in a negative frequency-wavelength relationship. We further show that such forms of gait adaptation are restricted to a certain range in the ratio of external mechanical load to Young's modulus of the body and discuss the merits of proprioceptive control in optimising motion across a range of physical environments. We conclude by contrasting signatures of proprioceptive control with those of central-pattern generated control.

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MS79

The Nematode C Elegans as a Control System

How does an animal take in sensory input and process it to produce robust behaviors? Of particular mathematical interest, what types of nonlinearities are needed to achieve this? We model *C. elegans* real-time calcium imaging data, which corresponds to the the activity levels of all the neurons in the animal, using the regression technique of Dynamic Mode Decomposition with Control (DMDc). We show that almost all of the activity of the neural network can be very well described via interpretable control signals. Together, our global, linear model can stably reconstruct entire time series trajectories, constraining the need for unknown nonlinearities.

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MS79

Evolution and Analysis of Integrated Neuromechanical Models of *C. elegans* Locomotion

With 302 neurons and a near-complete reconstruction of the neural and muscle anatomy at the cellular level, *C. elegans* is an ideal candidate organism to study the neuromechanical basis of behavior. Yet, despite the breadth of knowledge available, there are still a number of unanswered questions about one of its most fundamental behaviors: forward locomotion. How the rhythmic pattern is generated and propagated along the body is not yet well understood. We report on the development and analysis of a model of forward locomotion that integrates the neuroanatomy, neurophysiology and body mechanics of the worm. We use an evolutionary algorithm to determine the unknown physiological parameters of each neuron and connection so that the complete system reproduces the locomotive behavior of the worm under different conditions. Analysis of evolved solutions demonstrate that: (1) SMD and RMD are sufficient to drive dorsoventral undulations in the head with and without proprioceptive feedback; (2) short-range posteriorly-directed proprioceptive feedback is sufficient to propagate the wave along the rest of the body; (3) the AS-DA-DB subcircuit can generate oscillations in multiple locations along the ventral nerve cord; (4) the AS-VD chemical synapse can coordinate dorsoventral out-of-phase oscillations; and (5) gap junctions AS-VA, DA-AS, and VB-DB are capable of coordinating oscillations between adjacent neural units. These insights can be used to inform experiments.

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MS79

Analysis of the Relative Roles of Neural and Mechanical Coupling in C. Elegans Gait Modulation

C. elegans is an ideal organism for studying nervous system-body-environment interactions, due to its well-described connectome, its amenability to optogenetic and mechanical manipulations, and its limited behavioral repertoire. Its simplest behavior is forward locomotion. While the anatomy of the motor circuit underlying forward locomotion is well-characterized, the exact mechanisms producing coordinated locomotion are poorly understood. For instance, *C. elegans* adapt their undulatory gait to environments of different fluid viscosities, but there is no mechanistic explanation for this phenomena that is consistent with recent experiments by Fouad et al. (2018). These experiments suggest that the motor circuit operates as a chain of local neuromechanical oscillator modules in which each module exhibits intrinsic oscillations and activity of the modules is coordinated by both proprioceptive coupling and mechanical coupling through the body and environment. We develop a neuromechanical model to explore the relative roles of mechanical and proprioceptive coupling in coordinating locomotion and uncover a mechanism that explains gait adaptation in environments of different fluid viscosities.

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MS80

Influences of Nonlinear Feedbacks on the Evolution of Self-Organized Landscapes

Ecosystems are complex adaptive systems by nature, which means that macroscopic patterns and properties emerge from, and feed back to affect, the interactions among adaptive ecological agents. In this talk, I will describe the self-organization of Big Cypress National Preserve in South Florida, a regularly patterned biogeomorphic landscape and the multiple nonlinear ecohydrologic feedbacks that shape the landscape at three spatial scales over the Holocene. I will show that local and distal feedbacks decouple landscape-scale self-organization from self-organization of its constituent agents. Further, I investigate the geobiological feedback between landscape evolution and the evolution of organisms that contribute to the landscape formation. The fundamental question I will address is: does free order generated at the landscape scale carry evolutionary function or is it merely epiphenomenal? I argue that reinforcing eco-evolutionary feedbacks do not occur at the landscape scale (the spatial scale where the order occurs) and spatial self-organization does not contribute to ecosystems status as complex adaptive systems.

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MS80

Transients in Ecological Systems

Analyses of both models and data in ecology are still focused on equilibrium or long-term dynamics, with some notable exceptions. Although recent work on tipping points does include approaches based both on underlying changing environments and dynamics on different time scales, the possible situations where dynamics on different time scales are important are much more general. Using new mathematical ideas one can address questions of dynamics on ecological time scales, rather than longer times, and include other kinds of underlying environmental change. The importance of this way of analyzing ecological systems is clear in consideration of changing environments due to anthropogenic influences. The analyses demonstrate that there are wide ranges of ecological situations where standard analyses based on assuming asymptotic behavior are misleading. Additional cases where explicit time dependence is included in dynamics show further complications. Different kinds of situations where long transient behavior is expected can be identified. In particular, adding space, which essentially makes systems very high dimensional, is often likely to lead to long transient dynamics.

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MS80

Nonlinear and Stochastic Models to Link the Dynamics of Preindustrial Human Populations with their Environment

Due to tight coupling between human population dynamics and their local environments, preindustrial societiesparticularly ones on islands–are useful for studying population-environment interaction. In Hawaii, rapid human population growth and social stratification took place before European contact, in the context of sophisticated agriculture and sometimes extreme spatiotemporal environmental variability. Coupling two nonlinear and stochastic models, one for agroecosystem dynamics and one for food-dependent human demography, enables description of the environment-population dynamics of a dryland field system as well as investigation of the consequences and possible causes of social complexity in that landscape. Results suggest that dynamic incorporation of social change could be an important component of studying population-environment interactions.

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MS80

Vegetation Distributions in Tropical Ecosystems: Correspondence Between Models and Reality

Abstract not available.

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MS81

Verification of Partially Observable Markov Decision Processes via Lyapunov Functions and Barrier Certificates

Partially observable Markov decision processes (POMDPs) provide a framework for representing autonomous agents making sequential decisions under uncertainty. Since the states of a POMDP are not directly observable, through interactions with the environment and receiving observations, the agent updates its probabilistic belief in the true state. Despite this unique modeling paradigm, POMDPs are undecidable in general, giving rise to many approximate (point-based) methods for studying POMDPs. However, these methods rely on discretization of the belief space and are prone to errors, which has made the application of POMDPs in safety-critical scenarios limited. In this talk, I discuss how one can use well-known tools from control theory, such as Lyapunov functions and barrier certificates, and polynomial optimization to address challenges in POMDPs without the need to solve them explicitly. I illustrate the theoretical results with applications in robotics and cyber-physical systems.

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MS81

Accelerating Time Averaging of the Parameters of Dynamical Systems

Frequently, the practical goal of numerical modeling of a dynamical system is to obtain the long-time average of a certain parameter, such as, for example, the lift force. Large nonlinear systems often exhibit a chaotic behaviour. When the fluctuations of the quantity of interest are large, obtaining time-averaged quantities with sufficient accuracy requires expensive numerical calculations. We propose to replace the quantity being averaged with another quantity having the same average but fluctuating less. This is achieved using some of the ideas of the recently proposed method of bounding time averages (Chernyshenko *et al.*, 2014, Phyl. Trans. Roy. Soc. A, **372**). One of the key ideas of this method is that for any differentiable function $V(x)$, where x is the state of the dynamical system, the infinite time average of $dV(x(t))/dt$ is zero provided that $x(t)$ is bounded, which is always the case when infinite time averaging is meaningful. Hence, rather than numerically averaging the quantity of interest, which we will denote F, one can average $F + dV/dt$, for any V. The function $V(x)$ can be optimized so as to accelerate the averaging. So far, this approach was tested on the Lorenz attractor and a two-dimensional flow past a square cylinder. The results revealed both a promise and certain complications. This is a work in progress.

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MS81

Bounding Periodically Driven Non-Autonomous Dynamical Systems via Convex Optimization

The auxiliary function method for deriving bounds on time averages of functions of dynamical variables in autonomous nonlinear dynamical systems may be extended to periodically driven non-autonomous systems. This is simply accomplished by adding two new dynamical variables to the unforced system and coupling them appropriately. In this talk we report on the application of semidefinite program formulations, solvable by various software packages, to study some basic periodically driven nonlinear models.

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MS81

Rigorous and Numerical Bounds on the Heat Transport for Rotating Rayleigh-Bnard Convection

Rotating Rayleigh-Bnard convection is a fundamental process that appears in a plethora of geophysical and astrophysical settings. In the limit of infinitely fast rotation, the Taylor-Proudmann theorem dictates that the flow is dormant and heat is transported via conduction alone. In the opposite regime where the temperature forcing dominates the rotation entirely, the system resembles the non-rotating convective system and the effects of rotation are negligible. In the intermediate regime where rotation and the forcing are of equal effect, the effects of varying rotation on the heat transport are still unsettled scientifically. Using a variety of asymptotic models, and the auxiliary functional method via sum of squares, we find both numerical and rigorous bounds on the heat transport in this setting providing bounds where previous classical approaches failed.

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MS82

A Maslov Index for Non-Hamiltonian Systems

The Maslov index is a powerful and well known tool in the study of Hamiltonian systems, providing a generalization of Sturm–Liouville theory to systems of equations. For non-Hamiltonian systems, one no longer has the symplectic structure needed to define the Maslov index. In this talk I will describe a recent construction of a "generalized Maslov index" for a very broad class of differential equations. The key observation is that the manifold of Lagrangian planes can be enlarged considerably without altering its topological structure, and in particular its fundamental group. This is joint work with Tom Baird, Paul Cornwell, Chris Jones and Robert Marangell.

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MS82

Long-Range Interactions of Kinks

In this work, we address the general long-range interaction between kinks and antikinks, as well as kinks and kinks, in φ^{2n+4} field theories for $n > 1$. The kink-antikink interaction is generically attractive, while the kink-kink interaction is generically repulsive. We find that the force of interaction decays with the $(\frac{2n}{n-1})$th power of separation, and we identify the general prefactor for *arbitrary* n. Importantly, we test the resulting mathematical prediction with detailed numerical simulations of the dynamic field equation, and obtain excellent agreement between theory and numerics for the cases of $n = 2$ (ϕ^8 model), $n = 3$ (ϕ^{10} model) and $n = 4$ (ϕ^{12} model).

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MS82

Normalized Ground States of Second Order PDEs with Mixed Power Non-Linearities

For each $\lambda > 0$ and under necessary conditions on the parameters, we construct normalized waves for second order PDE's with mixed power non-linearities, with $\|u\|^2_{L^2(R^n)} = \lambda$. We show that these are bell-shaped smooth and localized functions, and we compute their precise asymptotics. We study the question for the smoothness of the Lagrange multiplier with respect to the L^2 norm of the waves, namely the map $\lambda \to \omega_\lambda$, a classical problem related to its stability. We show that this is intimately related to the question for the non-degeneracy of the said solitons. We provide a wide class of non-linearities, for which the waves are non-degenerate. Under some minimal extra assumptions, we show that a.e. in λ, the map $\lambda \to f_{\omega_\lambda}$ is differentiable and the waves $e^{i\omega_\lambda t} f_{\omega_\lambda}$ are spectrally (and in the cases of non-degeneracy orbitally) stable as solutions to the NLS equation. Similar results are obtained for the same waves, as traveling waves of the Zakharov-Kuznetsov system.

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MS82

Spectral Stability of Hydraulic Shock Profiles

By reduction to a generalized Sturm Liouville problem, we establish spectral stability of hydraulic shock profiles of the Saint-Venant equations for inclined shallow-water flow, over the full parameter range of their existence, for both smooth-type profiles and discontinuous-type profiles containing subshocks. Together with work of Mascia-Zumbrun and Yang-Zumbrun, this yields linear and nonlinear $H^2 \cap L^1 \to H^2$ stability with sharp rates of decay in L^p, $p \geq 2$, the first complete stability results for large-amplitude shock profiles of a hyperbolic relaxation system.

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MS83

Analytical Calculation of the Forced Response and Backbone Curves via Spectral Submanifolds

To understand the behavior of realistic nonlinear structures, it is desirable to reduce the dimensionality of the system, as well as simplify the equation of motion. Reduction to Spectral submanifolds (SSMs) has recently been shown to provide such a dimension reduction, yielding exact and unique reduced-order models for nonlinear unforced mechanical vibrations. Here we extend these results to periodically weakly forced mechanical systems, obtaining analytic expressions for forced responses and backbone curves on modal (i.e. two-dimensional) time dependent SSMs. We demonstrate our analytical formulae on numerical examples and compare them to results obtained from available normal form methods.

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MS83

Exact Model Reduction of Nonlinear Thermo-Mechanical Systems from a Slow-Fast Analysis

In thermo-mechanical systems, a quasistatic response of the structural equations to thermal dynamics is often found to deliver a good approximation of the full system response. We propose a rigorous method to reduce multi-dimensional, nonlinear thermo-mechanical systems to a lower-dimensional model, where the structural dynamics is enslaved to the thermal dynamics. In doing so, we derive explicit conditions under which a quasistatic reduction would be mathematically justifiable and provide examples where it may fail.

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MS83

Spectral Submanifolds and their Conservative Limit

This talk introduces spectral submanifolds (SSM) for the purpose of deriving reduced order models of mechanical systems. Spectral submanifolds are the smoothest invariant manifolds tangent to an invariant linear subspace about an equilibrium (or periodic orbit). For conservative systems the equivalent notion is the Lyapunov sub-centre manifold, which is unique for differentiable vector fields. In this talk we investigate the limit of SSMs as the underlying system becomes conservative. It turns out that the defining equations of SSMs become unusually singular when the underlying system reaches a conservative limit, hence the conservative limit of an SSM is not obvious. We develop a singular perturbation technique that resolves this singularity and show that SSMs become Lyapunov sub-center manifolds in the conservative limit.

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MS83

Control-Based Continuation Applied to Wind-Tunnel Experiments with an Aerofoil

Control-based continuation is a means for extracting nonlinear features, such as unstable limit cycles and bifurcations, directly from physical experiments in a non-parametric way. Conceptually it can be thought of as relying on the existence of a controllable, reduced-order model, though in practice the results (e.g., bifurcation diagrams) are generated without ever constructing the reduced-order model. This presentation shows the results from applying control-based continuation to a self-excited aerofoil mounted in a wind tunnel; the aerofoil undergoes a subcritical Hopf bifurcation and the resulting unstable limit cycles are tracked up to a fold point whereby the limit cycle stabilises.

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MS84

Understanding Ocean Dynamics through Lagrangian Ocean Drifters and Deep Neural Networks

Transport barriers in the ocean influence the mixing of heat, salinity, debris, and the movement of complex mobile ecosystems. While their non-stationary boundaries can now be identified in a mathematically rigorous fashion, this identification relies on the availability of surface velocity fields at suitable temporal and spatial resolutions. At the same time, a wealth of independent information from ocean drifters is available but has remained largely unexploited in detecting transport barriers. The main difficulty in such a detection is the sparsity and intermittency of drifter data, which prevent the inference of a sufficiently detailed drifter velocity field for the construction of a flow map. Here we discuss how recent developments with deep neural networks enable the construction of such a drifter velocity field from observed drifter trajectories. This approach shows clear potential for uncovering the location of material transport barriers, such as fronts, eddies, and jets, from available drifter data, as well as for improving Lagrangian drifter models.

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MS84

Application of Lagrangian Clustering to Submesoscale Ensemble Forecasts

Partitioning ocean flows can be helpful in identifying materially coherent vortices and assist in search and rescue planning. One method for this type of partitioning is Lagrangian clustering, which identifies compact sets of trajectories that do not mix with trajectories from other partitions. These types of coherent structures can be useful when analyzing ocean forecasts; however, because of the necessary parameterization for ocean models, it is necessary to incorporate uncertainty quantification in the Lagrangian clustering analysis. We present an investigation of the sensitivity of the Lagrangian clustering method to noise and an approach for applying this method to an ensemble of forecasts. These studies are applied to a submesoscale simulations to identify potential conduits for vertical subduction at the edges of materially coherent vortices and a coastal ocean model to assist in partitioning the flow near Marthas Vineyard.

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MS84

Transport Properties of the Slope Sea with Appli-

cation to Atlantic Bluefin Tuna Spawning

Transport and mixing by oceanic currents can help or prevent slow-swimming biological organisms, such as fish larvae, from reaching or remaining within their suitable nursery areas. Motivated by the recent evidence of spawning by Atlantic bluefin tuna in the Slope Sea, we investigated advection patterns and water temperatures that are conducive to successful spawning by bluefin tuna in this region. The favorable temperatures are more frequently observed in the warmer southern and southwestern parts of the Slope Sea, whereas the retentive advection patterns favor more northern areas that are remote from the influence of the Gulf Stream. Statistical probability map of successful spawning locations, which results from these two competing effects, shows a maximum near the northwestern bight of the Slope Sea. The influence of Gulf Stream rings, which are both warm and retentive, on the success rates of larvae, as well as the underlying mechanism by which Gulf Stream rings transport larvae on-shore, are studied using both realistic and idealized numerical models.

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MS84

Dynamic Morphoskeleton

During embryonic development, cells undergo large-scale motion generating tissues rearrangement, which ultimately defines the final shape of the embryo. While developmental biology has identified several genes driving local cellular processes, the interplay between cell-intrinsic and external stresses is fairly less understood because several local mechanisms are still unknown or hard to measure. By contrast, with the significant advances in live imaging techniques, it is now possible to fully track cell trajectories. Using ideas from nonlinear dynamics, we propose a rigorous objective kinematic framework for analyzing cell motion, which uncovers the underlying dynamic morphoskeleton, i.e. the centerpieces of cell trajectory patterns in space and time. The dynamic morhposkeleton provides a quantitative tool for comparing different morphogenetic phenotypes, quantifying the impact of genetic and physical manipulations, studying cell fate, and overall bridging the gap between bottom-up and top-down modeling approaches. We illustrate our results on a Drosophila gastrulation dataset obtained by in toto light-sheet microscopy.

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MS85

Analyzing Chaos in Walking Droplet Models

Some rather new and spectacular bifurcations and transitions to chaos are identified and analyzed for discrete dynamical systems models of walking droplet phenomena comprising iterates of smooth self-maps of a region in 3-space. The region is typically the Cartesian product of a planar elliptical set in the plane, representing the position of the droplet, with an interval associated to its amplitude of oscillation. Behavior analogous, but involving far greater complexity, to that found for walking droplet models represented by iterates of smooth self-maps of a rectangle corresponding to 1-dimensional position and amplitude coordinates is described, analyzed and illustrated via simulations. The enhanced complexity is not really surprising given the more elaborate mechanism for generating the bifurcations and evolution to various chaotic strange attractors. More precisely, it has been shown that for the 2-dimensional models, the complexity is mainly produced by the interaction of invariant simple Jordan closed planar curves (arising from Neimark-Sacker bifurcations) and certain stable manifolds of saddles. One the other hand, it shall be shown that for the 3-dimensional model, the complexity of the dynamics is a result of interactions of invariant tori (produced by Neimark-Sacker analogs corresponding to changes in stability of invariant closed curves forming the center-lines of the tori) and stable manifolds of saddle points.

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MS85

Extreme Dynamical Complexity in Recurrent Neural Networks

Recurrent neural networks (RNNs) are used as a means of capturing temporal structure in time series. With many real-life processes exhibiting nonlinear behavior in high dimensions, this type of artificial neural network (ANN) has gained popularity in recent years. However, RNNs are notoriously known for being difficult to train. As a means of mitigating this issue, various RNN cell architectures have been invented which incorporate gating mechanisms to control what information is stored in the artificial neurons (i.e. the hidden state) and what information is sent to output at each time step. Of these gated RNN architectures, one of the most popular is the gated recurrent unit (GRU). Despite their incredible success in various tasks, very little is understood about the specific dynamic features representable in a GRU network. As a result, it is difficult to know a priori how successful a GRU-RNN will perform on a given data set. In this talk, we analyze the underlying autonomous continuous time dynamical system in one and two dimensions, which the GRU hidden state attempts to approximate. We observe an unusually large array of expressible stability structures, and various bifurcations; a result of the systems high dimensional parameter space and nested nonlinearities. In addition, the notable limitations of the low dimensional GRU network are discussed, and these theoretical findings are verified experimentally by means of time series prediction.

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MS85

Simple Proofs of Chaos for Logical Circuit and Walking Droplet Models

Both chaotic logical circuits and walking droplets have been modeled as differential equations. While many of these models are very good in reproducing the behavior observed in experiments, the equations are often too complex to analyze in detail and sometimes even too complex for tractable numerical solutions. These problems can be simplified if the models are reduced to discrete dynamical systems. Fortunately, both systems are very naturally time-discrete. For the circuits, the states change very rapidly and therefore the information during the process of change is not of importance. And for the walkers, the position when a wave is produced is important, but the dynamics of the droplets in the air are not. Another advantage with time-discrete models is the simplicity in proving interesting dynamical results. In this talk I present discrete dynamical models of chaotic logical circuits and walking droplets and show simple proofs of chaos for both phenomena.

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MS85

Complexity and Chaos in Higher Dimensional LotkaVolterra Dynamics

The focus is an investigation of several of the more complex features of an m-dimensional discrete Lotka-Volterra type model for population dynamics of m competing species, with a particular interest in the phenomena that are truly m-dimensional. Most of our results are for the case m = 3, but several extensions to higher dimensions are outlined. Complexity in the iterate dynamics of a Lotka-Volterra self-map of the plane has already been extensively investigated, revealing such things as flip bifurcations, Neimark-Sacker bifurcations and chaotic horseshoes. So, it follows from the fact that the coordinate planes in Euclidean 3-space are invariants of the 3-dimensional Lotka-Volterra maps that the dynamics are full of 2-dimensional complexities. We show that there are more complicated 3-dimensional analogs of these dynamics, with a particularly interesting and not especially well-known analog of the Neimark-Sacker bifurcation that is fully 3-dimensional. Extensions of this analog will also be briefly discussed.

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MS86

Data-Driven Modeling of Spatio-Temporal Systems with Continuous Spectrum

In recent years, data-driven methods have become immensely popular in reduced modeling of complex and high-dimensional systems. In particular, the methodology based on approximation of the Koopman operator has been successfully applied to analysis and control of high-dimensional systems with discrete spectrum (i.e. systems that possess simple attractors such as limit cycles and tori). In this talk, we present an approach for extension of this viewpoint to spatio-temporal systems with continuous spectrum. First, we describe the connection between the Koopman spectral expansion for these systems and the modal decomposition technique known as spectral proper orthogonal decomposition (SPOD).The SPOD provides a set of coordinates for a low-dimensional representation of the post-transient dynamics. Then we sketch various methods that can be used to construct stochastic models for capturing the evolution of those coordinates and reproducing the statistics of the spatio-temporal system. We demonstrate this approach in the case of high-Reynolds fluid flow in a cavity.

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MS86

Koopman Operator Theory for Turbulence Transition in Plane Couette Flow

We determine algorithmically a low-order description of the transition to turbulence in plane Couette flow from a 'minimal seed' (i.e. the lowest energy state perturbation from laminar flow which can trigger turbulence) determined using the variational direct-adjoint-looping (DAL) method. The minimal seed trajectory, after undergoing an initial period of rapid growth due to the action of the so-called 'Orr mechanism', propagates close to the 'edge manifold' (separating the basins of attraction of the turbulent and laminar state) in state space, and approaches close to the (for this flow geometry and Reynolds number) steady 'edge state' (i.e. an exact solution on the edge manifold which exhibits saddle-like dynamics) before being 'flung off' towards turbulence. We use an extension of the operator-theoretic approach to turbulence describing the evolution of observables (such as the flow velocity) in terms of 'Koopman modes' to identify low-dimensional structures associated with the stable and unstable manifolds of the edge state, as well as the initial period of the rapid growth, which well-describe the observed dynamics, embedded in a very high-dimensional state space. Our results demonstrate the utility of using an operator-theoretic approach to probe the dynamical signature of transition.

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MS86

Dynamic Mode Decomposition in Functional Magnetic Resonance Imaging

Functional Magnetic Resonance Imaging (fMRI) time series reflect the level of neuronal activity in different cerebral regions as a function of time. It has been shown that this functional activity is highly organized in space and in time, even in resting-state conditions. Component analysis is a powerful tool to explore this functional organization, and methods such as principal or independent component analysis have been applied on fMRI time series to identify the main networks shaping brain function. However, these approaches are *static* and recent findings suggest that functional *dynamics* encode richer information about brain functional organization. We use dynamic mode decomposition (DMD) to identify the dominant dynamic modes (DMs) of brain activity at rest and during a motor-task using fMRI data from 730 healthy participants. In resting-state, the dominant DMs have strong resemblance with classical resting-state networks, with an additional temporal characterization in terms of oscillatory periods and damping times. In motor-task conditions, dominant DMs reveal interactions between several brain areas, including but not limited to the posterior parietal cortex and primary motor areas, that are not found with classical static approaches. Overall, these findings illustrate the potential benefits of DMD to characterize the spatio-temporal organization of brain activity.

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MS86

Koopman Analysis of Oscillating Cylinder Flow

We study the flow around a cylinder oscillating (surging) in the streamwise direction with a frequency, f_f, much lower than the shedding frequency, f_s. While this regime has been relatively less studied than the case when these frequencies have the same order of magnitude, Glaz et al, “Quasi-Periodic Intermittency in Oscillating Cylinder Flow’ (2017), observed quasi-periodic intermittency in this regime using a Koopman mode decomposition technique. Here we apply this approach to time-resolved particle image velocimetry data to investigate the cylinder wake for nominal experimental parameters $f_f/f_s \sim 0.02 - 0.2$ and mean Reynolds number, $Re = 800$. The amplitude of oscillation in this case is such that the instantaneous Reynolds number is far from the critical value. Characterization of the wake reveals a range of phenomena associated with nonlinear interaction of the two frequencies. This work is supported under ARO grant W911NF-17-1-0306.

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MS87

Curves in Diagram Space

Computing persistent homology over a dynamical process produces a curve in persistence diagram space, which is often called a time-varying persistence diagram or a vineyard. We explore two directions related to the structure of curves in diagram space. Following the work of Turner et al. in showing that diagram space equipped with bottleneck distance does not admit curvature bounds, we further construct: (1) an infinite family of branching geodesics, and (2) an infinite family of geodesics between two diagrams that cannot be written as simple convex combinations. Additionally, following the work of Munch on integrated bottleneck/Hausdorff metrics, we define a collection of invariants that can be used as proxies for computing the dissimilarity between two vineyards.

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MS87

Investigating Sleep-Wake Signals: A Persistent Homology Approach

Biological signals reveal fundamental and vital information about our wellness. In this work, our main focus will be to investigate patterns of sleeping stages from instantaneous heart rate signals. Sleep is fundamental to our health. Understanding sleep is critical for the whole healthcare system. However, a systematic and robust way to study sleep remains a challenging problem. In this talk, we propose a persistent homology approach to identify characteristics of waking and sleeping signals. Persistence diagrams play essential roles in TDA because they contain fruitful information. To extract useful features from persistence diagrams, we use Chung's recent developments, which have been applied to human red blood cells, and skin lesions. Our classification rate is comparable to the state-of-art one.

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MS87

Topological Data Analysis for Ring Channels in Intracellular Transport

Contractile rings are cellular structures made of actin filaments that are important in development, wound healing, and cell division. In the reproductive system of the worm C. elegans, ring channels allow nutrient exchange between developing egg cells and the worm and are regulated by forces exerted by myosin motor proteins. In this talk, I will present an agent-based modeling and data analysis framework for the interactions between actin filaments and motor proteins inside cells. This approach provides key insights for the mechanistic differences between two motors that are believed to maintain the rings at a constant diameter. We also use tools from topological data analysis to analyze time-series data for ring channel formation and maintenance. Our proposed visualization methods clearly reveal the impact of certain simulation parameters on significant topological circle formation.

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MS87

Topological Data Analysis for Investigation of Dynamics and Biological Networks

Persistent homology (PH) is a technique in topological data analysis that allows one to examine features in data across multiple scales in a robust and mathematically principled manner, and it is being applied to an increasingly diverse set of applications. We investigate applications of PH to dynamic biological networks.

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MS88

Connecting the Kuramoto Model and the Chimera State

Since its discovery in 2002, the chimera state has frequently been described as a counterintuitive, puzzling phenomenon. The Kuramoto model, in contrast, has become a celebrated paradigm useful for understanding a range of phenomena related to phase transitions, synchronization, and network effects. Here we show that the chimera state can be understood as emerging naturally through a symmetry-breaking bifurcation from the Kuramoto models partially synchronized state. Our analysis sheds light on recent observations of chimera states in laser arrays, chemical oscillators, and mechanical pendula.

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MS88

The Generalized Kuramoto Model: Odd Dimensions are Different; Even Dimensions are Deceptively Similar

Since the Kuramoto model (KM) is used to describe the alignment of phases, in several contexts it has been applied to orientation of vectors in 2-dimensions, such as herds of land animals (where the animal orientation is their direction of motion), or interaction between classical 2-dimensional spins, such as in the XY model. However, the KM cannot capture the analogous dynamics of swarms in 3 dimensions, or of classical 3-dimensional spins. Motivated by such situations, we construct a Generalized Kuramoto Model (GKM) in arbitrary dimensions, resulting in interesting unexpected behavior. While the GKM in even dimensions continues to demonstrate a transition to coherence at a positive critical coupling strength, in odd dimensions the transition to coherence occurs discontinuously as the coupling strength is increased through 0. However, in contrast to the unique stable incoherent equilibrium for the KM, we find that for even dimensions larger than 2 the GKM displays a continuum of different possible pre-transition incoherent equilibria, each with distinct stability properties, leading to a novel phenomenon, which we call 'Instability-Mediated Resetting.' To aid the analysis of such systems, we construct an appropriate generalization of the Ott-Antonsen ansatz with applicability to not only the KM, but also other similar systems with high-dimensional agents beyond the KM.

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MS88

Volcano Transition in a Solvable Model of Frustrated Oscillators

In 1992 a puzzling transition was discovered in simulations of randomly coupled limit-cycle oscillators. This so-called volcano transition has resisted analysis ever since. It was originally conjectured to mark the emergence of an oscillator glass, but here we show it need not. We introduce and solve a simpler model with a qualitatively identical volcano transition and find that its supercritical state is not glassy. We discuss the implications for the original model and suggest experimental systems in which a volcano transition and oscillator glass may appear.

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MS88

Phase Approximation Beyond the First Order: The

Kuramoto Model with Non-Pairwise Interactions

We study extensions of the Kuramoto model arising when the averaging approximation is considered beyond the first order. Key multi-body (non-pairwise) interactions already appear for second-order approximations. They allow non-trivial states absent in the first-order analysis, such as clustering or quasiperiodic partial synchrony.

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MS89

Experiments with Symmetric Networks of Heterogeneous Electronic Oscillators

Interactions between fundamentally dissimilar oscillators are of interest because of the presence of such interactions in biological systems. This work is the first to study fundamentally dissimilar kinds of coupling within an experimental multilayer network. We investigate cluster synchronization in experiments with multilayer networks of electronic oscillators. We observe and analytically characterize the appearance of several cluster states as we change coupling in layers. We utilize both bifurcation analysis and the computation of transverse Lyapunov exponents.

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MS89

Exploring Synchronization in Networks of Coupled Oscillators

Exploring Synchronization in Networks of Coupled Oscillators When several similar or dissimilar oscillators interact, a sort of "ordered" global behavior normally arises. In the limiting case, all oscillators behave in unison, giving a system that is globally synchronized (in other words, the oscillators reach "the consensus"). A more interesting case is obtained when oscillators synchronize in groups, especially when the groups are not defined from the nature of the oscillators (i.e., when only similar oscillators synchronize), but only by the topology of the interactions between them. This case is called cluster synchronization, and has attracted the attention of scientists from many fields, from biology and chemistry (for example, to explain patterns in animal coats or neurons interactions in the brain), to social sciences (where clustered opinions form), to electronics and engineering (to coordinate robots assigned to different tasks). In this talk, we introduce the basic theoretical concepts that ground the study of total and clustered synchronization, and we review the experimental studies in the literature. Consequentially, we identify good practices when investigating this kind of phenomena.

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MS89

Experiments on Networks of Coupled Chemical Oscillators

At the coarsest level of description, neurons are non-linear oscillators that when coupled together in tissue through excitatory and inhibitory connections give rise to complex spatio-temporal patterns. When organized, these patterns are capable of processing and storing sensory information, and actuating musculature. Extrapolating from this general definition of a neuronal network, we posit these dynamics can be captured on an abiologic reaction–diffusion platform. Here, we report advances in soft lithography that allow the engineering of synthetic reaction-diffusion networks. We employ the well-known oscillatory Belousov-Zhabotinsky reaction and develop methods to create diffusively coupled networks involving hundreds of nodes over which we design (i) the topology of the network, the (ii) boundary and (iii) initial conditions, (iv) the volume of each reactor, (v) the coupling strength, and (vi) whether the coupling is of an inhibitory or excitatory nature. Additionally, using a light sensitive catalyst and a digital projector, we can dynamically change the topology of the network by reversibly pruning nodes from the network. See http://fradenlab.com and T. Litschel, M. M. Norton, V. Tserunyan and S. Fraden, "Engineering reaction–diffusion networks with properties of neural tissue," Lab on a Chip **18**, 714 - 722, (2018).

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MS89

Weak Chimera States in Modular Electrochemical Oscillator Networks

When electrochemical reactions take place on electrode arrays, a network can form through the potential drop among the elements. In the presentation, experimental results are shown that confirm the existence of weak chimera states in modular networks of the nickel electrodissolution system with two approaches. In the first approach, we consider oscillatory dynamics close to a Hopf bifurcation. We employ synchronization engineering to design nonlinear delayed feedback to induce pattern, where one group of two oscillators are in-phase, and another group of oscillators are anti-phase; the elements in the same groups have the same, but the elements in the different groups have different frequencies. Thus, in this example, weakly nonlinear oscillations generate chimera state with strongly nonlinear coupling. In the second approach, we consider moderately relaxation oscillators. The parameters that favor chimera states are found with experiments with globally coupled oscillators in the form of co-existing one- and two-cluster states. Experiments with two groups oscillator confirm the weak chimera state, where one group is in one-cluster, and the other group is in a two-cluster state; the one and the two-cluster states have different frequencies. Thus, in this second example, strongly nonlinear oscillators generate chimera state with linear (difference) type of coupling. The generality of this chimera state is confirmed with a modified integrate-and-fire model.

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MS90

Synchronization and Multicellular Control in Quorum Sensing Networks of Toggle Switches in Synthetic Biology

In this talk I will present the results of the work carried out by my group within the scope of the EU project COSY-BIO (http://www.cosy-bio.eu) on control and synchronization in a consortium of bacterial populations endowed with a synthetic genetic toggle switch. The genetic toggle switch, which was first introduced by Garder and Collins [Nature, 2000], can be seen as a multi-input multi-output nonlinear system whose dynamics depend on the concentration of two inducer molecules, aTC and IPTG. We will discuss how to vary the inputs in order for a population of quorum sensing bacteria endowed with a toggle switch to reach a desired target region in phase space. The role of unavoidable stochastic effects will be discussed and taken explicitly into account to steer the dynamics of the population towards the desired collective behaviour. Different strategies will be presented to achieve this goal, one based on appropriate modulation of the inputs via a piecewise smooth pulsing strategy, the other via a multicellular approach where two bacterial populations interact with each other so that one steers the behaviour of the other. Both deterministic and stochastic models will be used for the analysis. Agent-based simulations and preliminary experimental results will be used to illustrate the theoretical approach.

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MS90

Synchronization in Quorum-Sensing Networks with Noise Diffusion

This talk is focused on the study of emerging behaviors in quorum-sensing networks affected by noise. A quorum sensing network is a form of communication system where nodes talk with each other through a shared environmental variable (or communication medium). This network structure naturally arises in many applications, such as bacterial quorum sensing, where diffusive population-measuring signals are exchanged in the extracellular environment, and in social networks, where decisions are made with the influence of certain shared media such as news stations and social networks. In this talk, we explore how the medium dynamics and certain noise diffusion processes play a key role in determining the emerging network behavior. In particular, we present a perhaps counter-intuitive result. Indeed we explore how, in the deterministic setting, the medium dynamics can destroy stability of the (desired) network synchronization/consensus manifold while the introduction of certain noise diffusion processes (also termed as relative-state-dependent noise) instead preserves stability of the synchronization/consensus manifold.

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MS90

A Transfer Entropy-Based Network Reconstruction Scheme Recognizing Time-Delayed Interactions Between Indirectly Connected Nodes

Transfer Entropy (TE) has proven to be a valuable tool to infer causal interactions between dynamical systems, especially in applications where one is reliant only on measurements. With the ability to infer such interactions, it then becomes possible to unveil the network graph under which the systems (or, nodes) interact one another. This approach has been successfully demonstrated to reveal network graphs, for example, arising in neuroscience, climatology, and in the study of animal groups. In the effort of network reconstruction, TE-based inference algorithms can be strengthened, and improved, by the fact that some nodes do not directly but only indirectly influence some other nodes. By accounting for the time-delays explaining such indirect interactions, one can incorporate the presence of time-delays in a TE-based inference framework to effectively reconstruct an unknown graph. For slowly varying dynamics, such a reconstruction effort can be further simplified by analytically showing how the number of walks from a node to another explains the change in TE-levels. Case studies are presented to demonstrate these results and their utility.

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MS90

Emergence of Metachronal Waves in Networked

Systems of Stiff Polymer and Axonemal Structures

General purpose robotic devices are attractive solutions for a variety of applications that include environmental monitoring and protection, civilian and military defence, and generally hazardous missions. Applications of miniaturized robotic devices are also emerging in healthcare and biotechnology, requiring specific solutions in terms if bio-affinity and miniaturization. For this class of devices it is desirable to decouple as much as possible the locomotion mechanics design from the characteristics of the environments, so that the device can robustly operate with high versatility and reliability. Robust and elegant solutions for locomotion mechanics have emerged in several small scale biological entities in the form of beating protrusions, such as cellular cilia and eukaryotic flagella. These protrusions are structurally characterized by a bundle of filaments internally connected by rod-like tubular elements called axonemes. The collective dynamics of cilia arrays reveals important features such as array alignments, two-phase asymmetric beating of individual filaments, and the emergence of metachronal coordination, which makes them suitable for bio-inspired terrestrial and aquatic locomotion. We present mechanical modeling of arrays of stiff filaments with axonemal connections that predict the emergence of metachronal synchronization with basal coupling. Deterministic and stochastic driving inputs are considered in connection to terrestrial locomotion.

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MS91

Homogenization of Spatial Stationary Gaussian Random Flow

We consider the problem of computing the effective diffusivity of the passive tracer model when the velocity field is a spatial stationary Gaussian random field. We also investigate the existence of the residual diffusivity. Namely, we want to find the limit situation when the molecular diffusivity is small, and the flow is dominated by the velocity field. We design efficient numerical integrators to approximate the random field and solve the target model problems and obtain some numerical results to show the existence of effective diffusivity.

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MS91

How do Tissues Maintain their Patterns with Stochasticity?

Precise and robust control of spatial and temporal organization of cells is critical to executing biological functions in organisms. How the stochasticity, which widely exists in biological systems, influences such patterns remains elusive. To investigate stochastic effects on pattern formation, we use the embryonic zebrafish hindbrain and the embryonic Drosophila wing discs as model systems, and use both stochastic PDE models and discrete-cell models as main tools. First, we dissect roles of different types of noise, and find that robust tissue homeostasis requires balanced levels of noises. Also, we investigate how cells generate sharp boundaries of gene expression precisely in spite of the inaccurate positional information from noisy morphogen gradient. The corporation between noise-induced cell fate transition and differential adhesionmediated cell sorting leads to sharp boundaries. In addition, we study regulatory mechanisms that improve the robustness of pattern in both time and space, and a regulator is found to play such a role by regulating morphogen gradient in a long range through its local effect. In conclusion, interplays between different types of noise, mechanical interactions between cells and regulatory mechanisms help tissues maintain their precise and robust organization of cells in pattern.

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MS91

A Minimum Action Method for Dynamical Systems with Constant Time Delays

In this work, we develop a minimum action method to search the most probable small-noise-induced transition path in dynamical systems with constant time delays. The method is based on the minimization of the Freidelin-Wentzell action functional. To deal with the time delay, we introduce an auxiliary path such that we can deal with the quasi-potential using the optimal linear time scaling. The connection between the auxiliary path and the original path is though a penalty term added to the action functional. Numerical results will be presented.

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MS92

Design of Central Pattern Generator for Locomotion

Abstract not available.

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MS92

Modelling the Swim Behavior of Dissected Sea Slug Ganglii

We present and analyze a model of the Central Pattern Generator (GPG) that controls the swimming pattern in the nudibranch species, Dendronotus Iris. We describe the modelling process in depth, with explorations of both the dynamics of the component cellular and synaptic models and the emergent dynamics of the complete CPG system. Particular emphasis is placed on the relationship between slow cellular dynamic and slow synaptic dynamics, and on the mechanism of control of the burst pattern. Multiple tools for visualizing the system are discussed, including an animation of the slow dynamics of the system.

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MS92

Modeling the Emergent Network Bursting in Swim Neural Circuits

Abstract not available.

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MS93

An Interacting Particle Model for the Capelin: Incorporating a Changing Climate

The capelin is a pelagic species of fish which serves an important role in the Arctic and subarctic ecosystems. There are several stocks worldwide: in the Barents Sea, near Iceland and Greenland, near Newfoundland and Labrador, and near Alaska. Each stock migrates hundreds of kilometers to feed on zooplankton and to spawn. Because of their key position on the trophic chain, the capelin inject otherwise inaccessible biomass from plankton blooms into the ecosystem as they are eaten by larger fish such as the cod and the herring. We have successfully modeled the spawning migration of the Icelandic capelin, depending heavily on oceanic currents and temperatures to guide the migration. In this talk, we will discuss our recent work to capture more of the capelin's life cycle and predict its response to changes in the marine environment. We include a Dynamic Energy Budget model in the simulations to track the physiology of the fish, creating triggers for the feeding and spawning migration and tying the maturity of each fish to the oceanic temperature in order to better capture the capelin's life cycle as the climate shifts.

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MS93

The Canary in the Coalmine: Capelin as a Probe for Climate Change

It was suggested by Rose (2005) that because of the migratory and responsive nature of the capelin, a small pelagic fish that is key to the ecology and fisheries of the North Atlantic, it can be viewed as the "canary in the coalmine" to detect signals of environmental changes in the Arctic Ocean. In this talk we will combine analysis of data and extensive simulations of the migrations of the capelin and its physiology to analyze the changes in the ocean environment taking place over the last half-century. The simulations are based on a dynamical systems theory of discrete particle systems and have a connection to competitive game theory. Our goals will be to understand and predict the migrations of the capelin and its interactions with the ocean environment. We will explain how these have changed over time and how they are likely to change in the future. Then we will explain how our simulations can be compared with data, with the aim of finding out the rate of the temperature changes in the Arctic Ocean and when thresholds for major disruptions in Arctic environments are likely to be reached.

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MS93

Data-Driven Modeling of Phytoplankton Blooms in the Ocean

Phytoplankton are the base of the marine food web. They are also responsible for almost half of the oxygen we breathe, and they remove carbon dioxide from the atmosphere. A macroscale plankton ecology model is constructed consisting of coupled, nonlinear reaction-diffusion equations with spatially and temporally changing coefficients. An example of an NPZ model, this model simulates biological interactions between nutrients, phytoplankton and zooplankton. It also incorporates seasonally varying, physically driven forces that affect the phytoplankton growth: solar radiation, diffusion and depth of the oceans upper mixed layer. The models predictions are dependent on the dynamical behavior of the model. The model is analyzed using seasonal oceanic data with the goals of understanding the models dependence on its parameters and of understanding seasonal changes in plankton biomass. A study of varying parameter values and the resulting effects on the solutions, the stability of the equilibrium states, and the timing of phytoplankton blooms is carried out. This modeling effort can be helpful for understanding the ecological structure of plankton communities and the timing of seasonal phytoplankton blooms, which are debated topics in oceanography.

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MS93

Computational Topology and the Prediction of Critical Transitions in Spatially Extended Marine Populations

The prediction of critical transitions, such as extinction events, is vitally important to preserving vulnerable populations in the face of a rapidly changing climate and contin-

uously increasing human resource usage. Predicting such events in spatially distributed populations is challenging because of the high dimensionality of the system and the complexity of the system dynamics. Here, we use computational topology to measure spatial features of population patterns and use these measurements to study pattern shifts as the system undergoes critical changes, including extinction events. We demonstrate this approach using simulations of a coupled-patch model with advection. Additional applications of this technique include analysis of spatial data (e.g., GIS) and model validation.

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MS94

Symmetry in Relative Equilibria in the (1+4)-Vortex Problem

We will consider the Hamiltonian point vortex problem with N=5 vortices, and specifically the limiting case where one vortex has circulation equal to 1 and four vortices have infinitesimal circulation, called the (1+4)-vortex problem. Configurations of the vortices in the limiting case are critical points of a potential-like function. We define symmetric configurations of the four infinitesimal vortices by a line of symmetry containing two vortices or no vortices, and by inscribing an isosceles trapezoid in a circle. Using techniques from algebraic geometry to find critical points of the potential-like function, we are able to find specific ratios of the circulation parameters in the four infinitesimal vortices that lead to symmetric configurations.

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MS94

Co-Rotating Vortex Filament Knots and their Stability

We consider co-rotating nearly-parallel vortex filaments. They are well known to satisfy a variant of the Helmholtz vortex motion equations with an additional diffusion in the third dimension. We show that every co-rotating stable vortex configuration can be extended into a twisted configuration of vortex filaments. We classify the stability boundaries of many of such filament configurations, including (p,q) toroidal knots.

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MS94

Discrete Symmetries and Homographic Invariant Manifolds

We discuss the method of discrete reduction applied to N-point vortex and filament problems. Given the invariance of the dynamics under rotational symmetry and point-relabelling, we obtain low dimensional invariant manifolds. We investigate the dynamics, in particular existence and bifurcations of relative equilibria and periodic orbits, on some of these manifolds.

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MS94

Noether Theorem for Magnetized Plasmas

In fusion plasmas, the strong magnetic field allows fast gyro motion to be systematically removed from the description of the dynamics, resulting in considerable model simplification and gain of computational time. This reduced model is called a gyrokinetic model. Using Lagrangian formalism to do the reduction allows control of the exactness of reduction procedure and gives robust models for numerical implementations. Fusion plasma experiments are costly, so the results of gyrokinetic (GK) simulations reduces costs by optimizing experimental setup. Confidence in predictions of experiments via numerical simulations requires a rigorous and systematic verification of the underlying model, particularly before any validation of the numerical results against experiments can be considered meaningful. In this talk, I present a new and generic theoretical framework and specific numerical applications to test the validity and the domain of applicability of existing GK codes. In particular, I will highlight the role of the energy invariants given by Noethers theorem. Analysis of energy balance and generic plasma instability mechanisms provide the ultimate connection between fundamental mathematical tools and practical implementations.

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MS95

Stable Planar Vegetation Stripe Patterns on Sloped Terrain in Dryland Ecosystems

In water-limited regions, competition for water resources results in the formation of vegetation patterns; on sloped terrain, one finds that the vegetation typically aligns in stripes or arcs. The dynamics of these patterns can be modeled by reaction-diffusion PDEs describing the interplay of vegetation and water resources, where sloped terrain is modeled through advection terms representing the downhill flow of water. We focus on one such model in the 'large-advection' limit, and we prove the existence of traveling planar stripe patterns using geometric singular perturbation techniques. We also discuss implications for the stability of the resulting patterns, as well as the appearance of curved stripe solutions.

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MS95

Bifurcation Analysis in NLS Systems using Deflated Continuation

Continuation methods are numerical algorithmic procedures for tracing out branches of fixed points/roots to nonlinear equations as one (or more) of the free parameters of the underlying system is varied. On top of standard continuation techniques such as the sequential and pseudo-arclength continuation, we will present a new and powerful continuation technique called the deflated continuation method which tries to find/construct undiscovered/disconnected branches of solutions by eliminating known branches. In this talk we will employ this method and apply it to the one-component Nonlinear Schrödinger (NLS) equation in two spatial dimensions. We will present novel nonlinear steady states that have not been reported before and discuss bifurcations involving such states. Finally, we will discuss about recent developments in the two-component NLS system by employing the deflated continuation method where the landscape of solutions in such a system is far richer.

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MS95

Existence of Transition Fronts between a Singular State and Steady State Solutions in Diffusive Holling-Tanner Model

We show existence of front solutions that are asymptotic to a singular point and a constant state and also fronts that are asymptotic to a singular point and a periodic solution in the diffusive Holling-Tanner model. We use a coordinate transformation to remove the singularity, then blow-up transformation along with multi-scale analysis to establish the existence results in the vanishing diffusive limit.

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MS95

Spectral Stability of Periodic Multi-Pulses in the 5th Order KdV Equation

The fifth-order Korteweg-de Vries equation (KdV5) is a nonlinear partial differential equation used to model dispersive phenomena such as plasma waves and capillary-gravity water waves. For certain parameter regimes, KdV5 exhibits multi-pulse traveling wave solutions. Linear stability of these multi-pulse solutions is determined by eigenvalues near the origin representing the interaction between the individual pulses. In the case of periodic boundary conditions, we are able to use Lin's method to locate these small eigenvalues. We give analytical criteria for the stability of these periodic multi-pulse solutions and also present numerical results to support our analysis.

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MS96

Relaxation Oscillation in Mechanical Oscillators, and Stick-Slip with Ducks

Two-stroke oscillations are periodic solutions with two distinct phases per cycle, occurring in applications which range from transistor and stick-slip oscillation to models for aircraft-ground dynamics. Despite the frequency of their occurrence in applications, however, their study by means of geometric singular perturbation theory (GSPT) is under-represented in the literature, at least when compared to the 'four-stroke' oscillation typified by Van der Pol type oscillators. The main obstacle seems to be that slow-fast structure which gives rise to two-stroke relaxation oscillation cannot be represented in terms of a global separation of slow and fast variables, and so the existing framework for GSPT cannot be applied directly. We show in generality how GSPT can be extended for the study of such problems, and use this more general setting to prove existence of two-stroke relaxation oscillations in a class of planar systems. Time permitting, we will also look at mechanism for the onset of these oscillations, which occurs by means of canard explosion a three-timescale problem.

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MS96

Switch-Like Oscillations in an NF - κB Signaling Model

GSPT and the blow-up method have been successfully used in many areas of mathematical biology, e.g. mathematical neuroscience and calcium signaling. However, slow-fast analysis and GSPT of mathematical models arising in cell biology is much less established. The main reason seems to be that the corresponding models typically do not have an obvious slow-fast structure of the standard form. Nevertheless, many of these models exhibit some form of hidden slow-fast dynamics, which can be utilized in the analysis. In this talk I will present a geometric analysis of a novel type of relaxation oscillations, involving two different switches, in a model for the NF - κB signaling pathway. The model is a new challenge for GSPT: it is a smooth (beyond the standard form) system for $\varepsilon > 0$ that limits on a non-smooth variant for $\varepsilon = 0$. Hence, Fenichel theory is not applicable in some regions of the phase space. I will illustrate how to overcome these difficulties and analyze the model in a framework of extended GSPT. In particular we give a detailed analysis of the two switches generating the oscillation.

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MS96

Existence of Relaxation Oscillations in Models with Rate-and-State Friction

In this talk, I will describe relaxation oscillations in The Burridge-Knopoff Model with separate rate-and-state friction models using geometric singular perturbation theory. These oscillations are of stick-slip type and are charac-

terized by increasing amplitudes as the small parameter ϵ diminishes. Often it is possible to capture increasing amplitudes in singular perturbed problems by performing an ϵ-dependent scaling of the variables. This is not directly possible in the present case, due to the fundamental logarithmic dependency on the relative velocity in the rate-and-state friction models. We therefore use a new approach, based on extending the phase space in such a way that scalings are applicable, to describe the oscillations in these models. The main results of the talk will be (a) an existence and uniqueness theorem and (b) new geometrical insight into the problem.

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MS96

Multiple Time Scales in a Calcium Dynamics Model

In classical slow-fast systems there is an explicit separation between slow and fast variables, and ideas from bifurcation theory and geometric singular perturbation theory (GSPT) can be used to analyze such systems. In this talk, I will present a three-dimensional ODE model, derived from a calcium dynamics model of hepatocytes, that does not have a clear separation of slow and fast variables; one variable can be either fast or slow, depending on the location in phase space. I will discuss two complementary approaches we have used for analysing this model. We used non-classical GSPT to help us identify different time scales in our model and to understand the dynamics of a closed cell version of the system. We also used classical GSPT by treating the speed-changing variable first as a globally fast variable and then as a globally slow variable, then combining knowledge of these two cases to explain the overall dynamics of the model better.

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MS97

Reconstruction and Control of Nonlinear Dynamics using Koopman Theory

Knowledge discovery and information extraction of large and complex datasets has attracted great attention in wide-ranging areas from statistics and biology to medicine. Tools from machine learning, data mining, and neurocomputing have been extensively explored and utilized to accomplish such compelling data analytics tasks. However, for time-series data presenting active dynamic characteristics, many of the state-of-the-art techniques may not perform well in capturing the inherited temporal structures in these datasets. In this paper, integrating the Koopman operator and linear dynamical systems theory with support vector machines, we develop a novel dynamic data mining approach to construct a low-dimensional linear model that approximates the nonlinear flow of high-dimensional time-series data generated by a nonlinear dynamical system. This dimensionality reduction enables applications of classification and pattern recognition for complex time-series data using trajectories generated by the reduced linear systems, which represent different dynamic behaviors. We demonstrate the applicability and efficiency of this approach through time-series classification in bioinformatics and healthcare applications. Furthermore, utilizing the Koopman operator theory, we introduce methods for the control of a nonlinear system through the control of the lifting maps (observables) defined on its state space.

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MS97

Gaussian Process for Koopman Spectral Analysis with Application to Smart Grids

We report our recent efforts on applications of Gaussian Process (GP) regression for spectral computation of the Koopman operators for nonlinear dynamical systems. GP regression is a powerful approach of Bayesian machine learning that models a predictive posterior of the prediction from a likelihood model of the training observations that can easily provide nonlinear versions through Mercer's kernels. We use the GP to estimate a finite-dimensional approximation of the action of a Koopman operator directly from observational data. The GP approach produces a regularized solution which is robust on situations of low data and outliers. This, together with the use of adequate kernels will provide a robust approach to the eigenvalue computation of the Koopman operators based on noisy data. Data-driven power grid applications include stability assessment of nonlinear power grids directly from observational data and forecasting of power generation or load. The GP can be extended to multi-task regression by using a simple approach based on the chain rule of probability to produce a multivariate posterior of the prediction, which fits the general formulation of the Koopman operator approach. This material is based upon work supported in part by the National Science Foundation EPSCoR Cooperative Agreement OIA-1757207.

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MS97

Data-Driven Participation Factors for Nonlinear Systems Based on Koopman Mode Decomposition

We will present a novel data-driven technique to compute participation factors for nonlinear systems based on Koopman mode decomposition (KMD) [M. Netto, Y. Susuki, L. Mili, "Data-Driven Participation Factors for Nonlinear Systems Based on Koopman Mode Decomposition," IEEE

Control Systems Letters, vol. 3, no. 1, pp. 198-203, 2019]. Participation factors are scalars intended to measure the relative contribution of system modes to system states, and of system states to system modes. They were originally developed for linear systems [I. J. Perez-Arriaga, G. C. Verghese, F. C. Schweppe, "Selective Modal Analysis with Applications to Electric Power Systems, Part I: Heuristic Introduction," IEEE Trans. Power Apparatus Systems, vol. PAS-101, no. 9, pp. 3117-3125, 1982], and are widely used by the electric power systems industry and research communities, as well as by the control systems community. A typical application is seeking strategic placement of controllers to damp out undesirable nonlinear oscillations. We will show that our technique based on KMD generalizes the original definition of participation factors, provided that certain conditions are satisfied. We will demonstrate our method via numerical results in various dynamical systems, including a canonical nonlinear dynamical system and a small-scale power grid. Since KMD is capable of coping with a large class of nonlinearity, the developed technique is able to deal with nonlinear oscillations that arise in practice.

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MS97

Theoretical Guarantees of Convergence and Approximate Subspace Closure for Deep Koopman Operator Learning

The Koopman operator has recently garnered much attention for its value in dynamical systems analysis and data-driven model discovery. However, its application has been hindered by the computational complexity of extended dynamic mode decomposition; this requires a combinatorially large basis set to adequately describe many nonlinear systems of interest. Often the dictionaries generated for these problems are manually curated, requiring domain-specific knowledge and painstaking tuning. In this paper we introduce a deep learning framework for learning Koopman operators of nonlinear dynamical systems, known as deep dynamic mode decomposition (deep DMD). We show that this novel method automatically selects efficient deep dictionaries, outperforming state-of-the-art methods. We also show that the appropriate choice of basis functions, learned by the neural networks, guarantee convergence of the algorithm. Furthermore, we show that a class of basis functions discovered using deep DMD exhibit properties of invariance, which provide a mathematical explanation for dictionary closure under properties of differentiation, multiplication, and addition. This finding illustrates that specific bases exhibit a closure property that enables state-inclusion and ultimately state recovery for direct analysis of the underlying physical system. We illustrate the method with several simulation systems.

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MS98

Characterization and Perturbations of the Lyapunov Spectrum of a Class of Perron-Frobenius Operator Cocycles

The Lyapunov spectrum of Perron-Frobenius operator cocycles contains relevant information about dynamical properties of time-dependent (non-autonomous, random) dynamical systems. In this talk we characterize the Lyapunov spectrum of a class of expanding maps of the circle, and discuss stability and instability properties of this spectrum under perturbations. (Joint work with Anthony Quas.)

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MS98

Trajectory-Based Study of Coherent Behavior in Turbulent Convection

We analyze large-scale patterns in 3D turbulent convection in a horizontally extended square convection cell by Lagrangian particle trajectories calculated in direct numerical simulations. Different computational methods are used to detect these turbulent superstructures of convection directly from trajectories that have been initialized on a 2D plane close to the bottom plate of the convection cell. Regions of initial strong separation are identified from finite-time Lyapunov exponents (FTLE), indicating the boundaries between convection rolls. Due to turbulent dispersion this method only gives insightful results on very short time scales. On time scales comparable to the characteristic time of the turbulent superstructures, a spectral clustering approach applied to the particle trajectories turns out be successful in detecting large-scale structures. These structures are found to agree very well with the Eulerian superstructures and appear to be bounded by regions of strong separation as measured by the FTLE field. For longer time periods beyond the characteristic time we use a density-based trajectory clustering by means of time-averaged Lagrangian pseudo-trajectories. A small coherent subset of the pseudo-trajectories is obtained in this way consisting of those Lagrangian particles that are trapped for long times in the core of the superstructure circulation rolls and are thus not subject to ongoing turbulent dispersion.

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MS98

Sparse Eigenbasis Approximation: Multiple Feature Extraction Across Spatiotemporal Scales with Application to Coherent Set Identification

The output of spectral clustering is a collection of eigenvalues and eigenvectors that encode important connectivity information about a graph or a manifold. This connectivity information is often not cleanly represented in the eigenvectors and must be disentangled by some secondary procedure. We propose the use of an approximate sparse basis for the space spanned by the leading eigenvectors as a natural, robust, and efficient means of performing this separation. The use of sparsity yields a natural cutoff in this disentanglement procedure and is particularly useful in practical situations when there is no clear eigengap. We introduce a new Weyl-inspired eigengap heuristic and heuristics based on the sparse basis vectors. We illustrate our separation procedure on examples from time-dependent dynamics. Transfer operator approaches are extensively used to find dynamically disconnected regions of phase space, known as almost-invariant sets or coherent sets. The dominant eigenvectors of transfer operators or related operators, such as the dynamic Laplacian, encode dynamic connectivity information. Our sparse basis methodology streamlines the final stage of transfer operator methods, namely the extraction of almost-invariant or coherent sets from the eigenvectors. It is particularly useful when used on domains with large numbers of coherent sets, and when the coherent sets do not exhaust the phase space, such as in large geophysical datasets.

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MS98

Exit Time Problems for Microswimmers

We examine a simple stochastic model for a microswimmer. The swimmer is modeled as a thin "needle" or ellipse moving at a constant speed, in a direction undergoing Brownian motion. The swimmer is constrained by boundaries via the no-flux boundary condition. This simple model is amenable to mathematical analysis, for instance by recasting it as a Fokker-Planck (or backward Kolmogorov) PDE, or by solving the SDE directly. We solve these equations in various limits, to answer questions such as the expected time taken for the microswimmer to reach a small exit.

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MS99

Topological Data Analysis of Biological Images using Persistence Landscapes

Biological images provide an important and interesting challenge for mathematicians. They are highly heterogeneous and have interesting structures at multiple scales. These shapes are informative to experts but are difficult to quantify. I will show how persistent homology, topological data analysis, and persistence landscapes can be used to provide summaries of the shape of biological images. These summaries can then be subjected to subsequent statistical analysis and machine learning.

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MS99

A Topological Study of Spatio-Temporal Pattern Formation

Spatio-temporal pattern formation appears in a range of natural applications, from Rayleigh-Bénard convection to vegetation patches. Many dynamical system models have been created and analyzed to better understand the evolution of these patterns. In this talk, we apply methods from topological data analysis to study the evolution of spatio-temporal patterns, such as spiral waves and zebrafish stripes. In particular, we apply persistent homology and utilize the topological properties of spatio-temporal patterns for classification tasks, stability analyses, and the quantification of pattern variability and robustness.

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MS99

Topological Techniques for Chracterization of Pattern Forming Systems

Complex spatial-temporal patterns can be difficult to characterize quantitatively. In particular, distinguishing between visually similar patterns formed under different conditions is challenging. These small differences are detectable by persistent homology. We describe how persistent homology can be used as a low-dimensional quantitative summary of topological structure of dynamic data. These summaries retain a remarkable amount of information that allows for the investigation of the influence of nonlinear parameters, classification of data by parameters, and study of defect evolution.

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MS99

Analyzing Spatial Patterns and Critical Transitions in Stochastic Populations with Cubical Homology

Predicting critical transitions in ecological systems is an active area of research. Understanding and predicting dynamical changes in spatially extended systems is particularly challenging due to their complex dynamics and high dimensionality. Here, using topological data analysis, we explore critical transitions (e.g., an extinction event) in a spatially extended population model with Ricker map growth and Gaussian kernel dispersal. The growth and dispersal components are both randomized. Using computational topology, we calculate β_1 and β_0 for binary images of the two-dimensional population distribution. We then construct Betti number time series and observe the change in Betti numbers corresponding with the change in population distribution patterns en route to an extinction event. Preliminary results indicate a characteristic change in Betti numbers that occur during an extinction event. We hope this technique will eventually be incorporated into the critical transition prediction "toolbox".

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MS100

Influence of Media on Opinion Dynamics in Social Networks

Many people rely on social networks (including Facebook and Twitter) as sources for news and information. The spread of media content with opinions across the political spectrum has influence over online discussions as well as impacting actions offline. In this work, we present a bounded confidence model of opinion dynamics on a social network, where media accounts are included as influencer nodes. Partisanship of media content is quantified as a continuous variable on the interval [-1,1], and we discuss higher dimensional generalizations to include content quality and more nuanced political positions. We show that media influence over the social network can be maximized by tuning the number of media accounts promoting the content and the number of followers each account has. This maximization depends on structural features of the network. Finally, we discuss the influence of including multiple media sources into the model.

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MS100

A Network Model of Immigration: Enclave Formation vs. Cultural Integration

Successfully integrating newcomers into native communities has become a key issue for policy makers. We develop an agent-based network model to study interacting "hosts" and "guests" and identify the conditions under which cooperative/integrated or uncooperative/segregated societies arise. Players are assumed to seek socioeconomic prosperity through game theoretic rules that shift network links, and cultural acceptance through opinion dynamics. We find that the main predictor of integration under given initial conditions is the timescale associated with cultural adjustment relative to social link remodeling, for both guests and hosts. Fast cultural adjustment results in cooperation and the establishment of host-guest connections that are sustained over long times. Conversely, fast social link remodeling leads to the irreversible formation of isolated enclaves, as migrants and natives optimize their socioeconomic gains through in-group connections. We discuss how migrant population sizes and increasing socioeconomic rewards for host-guest interactions, may affect the overall immigrant experience.

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MS100

The Effect of the Convergence Parameter in the Deffuant Model of Opinion Dynamics

In the Deffuant model of opinion dynamics, pairs of individuals interact if their difference in opinion is below some threshold. If interaction occurs, their opinion difference is reduced by an amount governed by a convergence parameter μ. A value of μ close to 0 corresponds to individuals having firmly held beliefs and so willing to change their opinion only slightly, while larger values of μ indicate greater openness to social influence. When $\mu = \frac{1}{2}$, the post-interaction opinion for each of the two individuals is simply the average of the two prior opinions (i.e., their opinions become the same), and the final opinion distribution consists of clusters of individuals with identical opinions. We investigate how the final opinion distribution changes when the convergence parameter is reduced. In particular, we consider a large population on a fully connected network, in which case the dynamics can be described by a rate equation for the opinion distribution; solutions to this equation provide useful insights into the final opinion distribution (and indeed the distribution at any time point).

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MS100

'Very Fine People on Both Sides' of Twitter: Analyzing the Network Structure of the Online Conversation about #Charlottesville

We study the Twitter conversation following the August 2017 'Unite the Right' rally in Charlottesville, Virginia, using tools from network science and data science to examine 486,894 tweets with the hashtag #Charlottesville posted by 270,975 accounts. Media preferences on Twitter were used to compute a 'Left / 'Right media score for the nodes. We find a striking degree of polarization in terms of this media score in the retweet network. Community detection using modularity maximization and a Louvain method yielded 228 communities that were largely homogeneous in terms of their media score. There were fewer large (> 1000 nodes) communities on the 'Right' (six) compared with on the 'Left' (35). Hyperlink-induced topic search (HITS) identified many more hubs on the 'Left' compared with the 'Right', suggesting broader appeal across communities on the 'Left'. Tweets about 'Trump' were widespread in both the 'Left' and 'Right', but the accompanying language was very different, being negative on the 'Left' (e.g. 'impeachment', 'repulsive') and positive on the 'Right' (e.g.

'MAGA', 'POTUS'). Support of Trump was a common thread amongst 'Right' communities, connecting neo-Nazi, alt-right, anti-Muslim, and far-right communities. This is joint work with Marisa Eisenberg, Sarah Cherng, and Mason Porter.

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MS101

Generating Graphs with Symmetry

Many real networked systems exhibit symmetries in the underlying topology from power grids to neural networks. For many such networks, the number of symmetries can be enormous (often $> 10^{100}$). Despite this, the present set of methods to generate artificial graphs meant to accurately represent these systems, such as the Erdős-Rényi model or the Barabási-Albert model, rarely produce graphs with any symmetries. Without symmetries present, these networks will lack the ability to reproduce some dynamical behavior. Here, we present a method that takes as input a feasible quotient graph and returns an undirected graph for which the orbits of the automorphism group can be described by the original quotient graph. We also present the algebraic requirements a quotient graph must satisfy for it to be considered feasible. We use this algorithm to generate graphs with complex symmetry patterns. Finally, we discuss the case when the minimal equitable partition and the orbits of the automorphism group align, and when they do not.

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MS101

Symmetries, Partitions, and Dynamics in Networks

The behavior of dynamical systems (nodes) that are coupled together in complex networks are greatly affected by the structure of those networks. Various patterns of synchronization and delayed synchronization among subsets of nodes are possible when the network has symmetries and input or balanced partitions. Symmetries and partitions will be introduced in this talk along with the dynamical patterns they can support. The basic machinery from group theory will be used to analyze the patterns, especially for their dynamical stability. This will serve as the starting point for many of the talks in the remainder of these minisymposiums.

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MS101

Algorithms and Experiments for the Approximate Balanced Coloring Problem

We describe the approximate balanced coloring problem, a generalization of the balanced coloring problem originally described by Belykh and Hasler. We describe a linear integer program that exactly solves this problem as well as heuristics that also provide solutions. We discuss our computational experiences as well as present complexity results.

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MS101

Cluster Synchronization in Multilayer Networks

We consider cluster synchronization in a network with different node types and different link types. Each link type corresponds to a specific layer of connectivity of a multilayer network. We describe the general conditions under which cluster synchronization can be observed in such a network, i.e., oscillators in the same cluster synchronizing on the same time-evolution, but oscillators in different clusters evolving on different time-evolutions.

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MS102

Amplitude and Phase Equations in Anisotropic Systems

The envelope formalism and its associated Ginzburg Landau-type amplitude equations offer a unifying framework for the study of universal primary and secondary instabilities of patterns linked to their symmetries in spatially extended systems. While in isotropic 2d systems a rigorous derivation of amplitude equations from a system of governing PDEs is problematic due to the degeneracy of a full circle of critical wave numbers, in anisotropic systems the minima of a neutral stability surface are generically isolated giving rise to a unique reduced description through Ginzburg Landau-type amplitude equations near the onset of patterning. In this talk an overview of the generic amplitude equations in anisotropic systems will be given along with the associated secondary instabilities encountered by them and the phase equations extracted from them in the case of long wave instabilities. The electroconvection of nematic liquid crystals serves as prototype example to which the reduced description through amplitude equations is applicable. This research is being supported by the National Science Foundation under Grant No. DMS-1615909.

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MS102

Stationary and Moving Defects in Oscillatory Media

In oscillating chemical reactions like the Belousov-Zhabotinsky reaction, impurities are known to act as pacemakers generating concentric waves that propagate away from the defect. When these impurities move at a critical speed, c*, they deform these patterns into a sonic cone. We show the existence of these sonic profiles and give an approximation for the value c* as a function of the defect's strength.

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MS102

Evidence of an Intrinsic Clock and Host-Parasite Coupling in the Intraerythrocytic Developmental Cycle of Plasmodium

Living things did not evolve and do not exist as autonomous elements, but instead represent the nodes of a complex network of interacting dynamical systems, coupled at multiple scales to each other and their environment. For instance, many biological organisms across kingdoms exhibit intrinsic, free-running circadian rhythms that are controlled by gene regulatory networks and are coupled to the rhythmic forcing of the day-night cycle. Although there is evidence that *Plasmodium*—the causative agent of malaria infection—leverages the intrinsic periodicity of the host for its own purposes, it remains unknown if these protozoans possess a regulatory network controlling the precise timing of their intraerythrocytic developmental cycles (IDC). In this talk we present analyses of *in vitro* time-course gene expression data collected from multiple strains of *P. falciparum*, which shows that the IDC exhibits properties that are consistent with those of known clocks. We also present a novel, model-free, analysis of a singular *ex vivo* experiment that captures the transcript dynamics of *P. vivax*, together with the dynamic gene expression of 9 human hosts, which provides evidence of host-parasite coupling at the level of their transcriptional programs.

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MS102

Pace and Patterns of Magnetic Swimmers in a Billiard Pool

We experimentally investigate magnetic surface swimmers on water. Those objects self-assemble from ferromagnetic micro-particles and a non-magnetic disc. They are floating on the liquid surface due to interface tension and move under the influence of an harmonically oscillating homogeneous magnetic field oriented vertically, which is distinguished by its amplitude and frequency. The speed of the surface swimmers strongly depends on these parameters. The functional dependencies between speed and amplitude and between speed and frequency are investigated by independently varying both control parameters. In the first case, the data obtained are in good agreement with the predicted scaling whilst there are some deviations in the latter case. Moreover, due to the interplay between the surface bound swimmers and the ascending liquid meniscus at the edge of the experimental vessel different dynamics can be realized. We observe periodic and quasiperiodic trajectories in a circular vessel and aperiodic trajectories in a vessel shaped like a Bunimovich-stadium.

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MS103

The Role of Synchrony in Pattern Formation

Electrophysiological brain recordings are dominated by oscillatory activity, spanning a wide range of temporal scales. These oscillations exhibit both spontaneous and event-driven fluctuations in amplitude, which are believed to arise from a change in the synchrony of underlying neuronal population firing patterns. Previous population level models of neural activity have failed to account for these fluctuations as they do not explicitly track the within-population synchrony. Starting with a network of spatially distributed synaptically coupled quadratic integrate-and-fire neurons, we use the Ott-Antonsen ansatz to reduce the population to a few variable mean field model, which takes the form of a standard neural field model coupled to dynamic equation for the population synchrony. This next generation neural field model allows for a tractable exploration of the role of synchrony in pattern formation. The model supports states above and beyond those seen in previous population level models, states more akin to spiking neural network models, highlighting the retention of information about the underlying spiking model in the reduced model. We explore how local changes in population synchrony may lead to the emergence of both spontaneous and event-driven standing and travelling waves, as a means to understand the fluctuations in electrophysiological brain recordings.

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MS103

Metastable Transitions in a Bistable Oscillator

Mathematicians and neuroscientists alike have worked together for years in order to understand how the brain transfers signals throughout the nervous system in order to enable an animal to perform basic functions. Numerous models have addressed neuronal activity through firing-rate models or even single neuron models like the Hodgkin-Huxley or Morris-Lecar models. Taking the single neuron perspective, signal transference is initiated through "spikes," characterized by sharp electrical potentials across its cell membrane, once the membrane voltage crosses a certain threshold. Thus, the neuron is in a "quiescent" state where no spiking is occurring until the threshold is crossed where it then enters a "spiking" regime. Inherent in this system, as in most biological processes, is the occurrence of noise and dynamic fluctuations which can greatly influence how and when spikes occur and is often ignored when studying general neuron models. Thus, the setting above can be mathematically thought of as a noisy system where the underlying deterministic dynamics contains two stable states corresponding to the quiescent state and the spiking state, respectively. In this talk, we will quantify stochastic transitions and transition rates for a general noisy bistable oscillator and discuss various spiking statistics unveiled during the calculation of these transitions.

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MS103
Linearity in Neuronal Networks

Neuronal network dynamics are generally nonlinear. However, various analysis methods based on linear models well capture some statistics of the network. Especially, second order moment constrained maximum entropy, Granger causality and spike-triggered regression. These three methods retrieval more and more detailed dynamics of the network compared to former one. The relationship between them are discussed, in the aspect of advantages or disadvantage in reconstructing network structure and inferring spike statistics.

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MS103
Chaotic or Nonchaotic Dynamics in Neuronal Networks?

In this talk, I will address two issues related to the dynamical stability of integrate-and-fire type neuronal networks. i) Whether there exists chaotic dynamics in I&F neuronal networks. It has been shown that a single integrate-and-fire (I&F) neuron under a general time-dependent stimulus cannot possess chaotic dynamics despite the firing-reset discontinuity. However, whether the network dynamics can be chaotic was an open question. Through correct renormalization and augmented dynamics, we extend the classical Lyapunov exponents (LEs) theory, which is established for smooth dynamical systems, to the I&F like network dynamics and provide a stable and accurate numerical algorithm to compute the LEs of these non-smooth dynamical systems. ii) Whether the irregular firing activity of balanced neuronal networks arise from chaotic dynamics. Some previous studies have shown that chaotic dynamics in the balanced state, i.e., one with balanced excitatory and inhibitory inputs into cortical neurons, is the underlying mechanism for the irregularity of neural activity. However, we show that the balanced state robustly persists in current-based integrate-and-fire neuronal networks with delta-pulse coupling within a broad range of parameters and mathematically prove that the largest Lyapunov exponent of this type of neuronal networks is always negative. Therefore, the irregularity of balanced neuronal networks need not arise from chaos.

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MS104
Bayesian Methods for Inferring Delay Distributions in Biochemical Reaction Networks

The dynamics of intracellular processes are determined by the structure and rates of interactions between molecular species. However, limitations of experimental methods make it difficult to infer the characteristics of these interactions from data. On the single-cell level, different molecular species can occur in small number, correlate with phenotype, and localize within different parts of the cell. As a result, averaging over fluctuations in time, or over the population can lead to inaccurate representations of the underlying biology. We thus need to fit stochastic models to data from single-cell assays to describe the dynamical processes within cells. To do so we propose a systematic way to derive the likelihood function corresponding to the non-Markovian distributed delay systems describing intracellular processes. We use this result to extend MCMC methods to perform efficient inference of both rate and delay parameters in biochemical reaction networks from measured species trajectories. We find that the method is robust, and that mean delay time is estimated well even when delay distributions are grossly misspecified. When only a scaled measure of species number or concentration is available, the measurement of dilution is necessary for precise estimation of time delay. Using experimental data we show that when cell growth rates are available, our algorithm successfully estimate the time delay for the synthesis of yellow fluorescent protein.

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MS104
Random Walking Around Delays

The main approach to understanding the systems with noise and delay is through stochastic differential equations with delay. We present here an alternative approach of considering random walks with a delay, which is termed as "Delayed Random Walks"[Delayed Random Walks, T.Ohira and J. G. Milton, Phys. Rev. E 52, 3277 (1995).,Delayed Stochastic Systems, T.Ohira and T. Yamane, Phys. Rev. E 61, 1247 (2000).]. With this random walk, we can grasp the oscillatory behaviors of the correlation function as well as obtaining a delayed Fokker-Planck equation. Also, a new resonance phenomenon with noise and delay was predicted[Resonance with Noise and Delay, T.Ohira and Y. Sato, Phys. Rev. Lett. 82, 2811 (1999).], which were confirmed by experiments. We will also present more recent results on Delayed Pursuit and Escape["Delayed pursuit-escape as a model for virtual stick balancing", J. G. Milton et. al., Nonlinear Theories and Its Applications, IEICE 4, 129 (2013).], Gambler's Ruins with Delay, and Delayed Random Relays["Delays in Gambler's Ruin and Random Relays", T. Ohira, IFAC PapersOnLine 51-14, 207 (2018).].

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MS104

Retrospective Bayesian Updating to Compensate Delays in Connected Vehicle Systems

Automated vehicles may sense their environment using sensors and make decisions based on the collected information. However, these sophisticated system are still limited by the line of sight of their sensors. Wireless vehicle-to-vehicle communication may help one to eliminate such limitations and allow connected automated vehicles to monitor and predict the motion of human-driven vehicles within and beyond their line of sight. However, such communication typically happens intermittently and it may take time to process the received information which introduces time delays into the system. Moreover, when predicting the motion of human-driven vehicles one must take into account uncertainties in human behavior. In this talk we explore the concept of retrospective Bayesian updating. Namely, we predict the motion of human-driven vehicles using stochastic differential equations (SDEs) until new data is received. Then, we perform a Bayesian update at the past time moment where the data was created and propagate the SDE forward until the current time. The deterministic equations for the first and second moments constitute a nonsmooth dynamical systems which can be analyzed using standard techniques. We demonstrate that this retrospective Bayesian approach allows connected automated vehicles to make better predictions of the traffic environment and such clairvoyance can help them to avoid safety critical situations.

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MS104

Stochastic Semi-Discretization for Stochastic Systems with Delay

There are several models in engineering and biology, which lead to delay differential equations (DDE), e.g., the models of machine tool vibrations, delayed control loops, traffic dynamics, predator-prey systems or neural networks. During the investigation of such delayed dynamical systems, stochastic effects are usually neglected, although, stochastic excitations often influence the behavior of these systems. The noise may appear not only as an external excitation, but also in the coefficients of the state variables. The linearized form of the mathematical models can be written in the form:

$$\dot{x}_t = (Ax_t + Bx_{t-\tau})\mathrm{d}t + (\alpha x_t + \beta x_{t-\tau} + \sigma)\mathrm{d}W_t,$$

where x_t is the vector of the state variables at the time t, W_t stands for the Wiener process, and τ refers to the delay. To analyze the stability and stationary solution of such systems, an efficient numerical method is presented, based on a special kind of discretization technique with respect to the past effects. The resulting approximate system is a high dimensional linear discrete stochastic mapping, which allows the investigation of the so-called moment stability and the determination of the stationary second moment. The efficiency and the high convergence rate of the method will be demonstrated through the stability chart and stationary second moment calculation of the stochastic delayed oscillator.

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MS105

Multiple Time Scales Underlying Pauses, Bursting and Depolarization Block in Midbrain Dopamine Neurons

Multiple time scales are inherent in the activity of midbrain dopamine (DA) neurons. In the absence of synaptic input, these neurons are spontaneous pacemakers. Salient and reward-related stimuli elicit bursts, which sometimes terminate in depolarization block. Finally, disappointment can elicit a pause in firing. Although DA neurons were once thought to be a homogeneous population, there is in fact significant diversity with the population with respect to the slow processes involved in pauses, bursts and depolarization block. For example, VTA DA neurons appear to have longer pauses than substantia nigra DA neurons, likely due to slower inactivation of KV4.3. Bursting plateaus can be supported by activation of NMDA receptors or CaV1.3, but the slow negative feedback process for initiating and terminating bursts is variable. For example, a metabolic feedback loop including the K-ATP channel is important for bursting in the medial but not the lateral nigra. Other candidates for burst repolarization mechanisms are KV7 and KV11. On the other hand, the negative feedback loop mediated by SK Ca2+ activated K+ usually operates on a time scale relevant to pacemaking rather than bursting. The main slow process involved in depolarization block appears to be a second, slower component of inactivation of the NaV channel. We present simulations and phase plane analyses to explain the role of interaction of time scales in the electrical activity of midbrain DA neurons.

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MS105

Smooth Fenichel Manifolds through Gevrey Analysis

Geometric singular perturbation theory often uses center manifold reduction techniques, based on center manifolds that are C^k smooth. In the analytic setting we present cases where the manifolds can be taken infinitely smooth and we discuss potential benefits of the gained smoothness in terms of dynamical properties, for example in the analysis of canards through nonresonant folded nodes.

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MS105

Bottom-Up Approach to Torus Bifurcation in Neuron Models

This presentation is mainly about the quasi-periodicity phenomena occurring at the transition between tonic spiking and bursting activities ranging from exemplary biologically plausible Hodgkin-Huxley type models and reduced phenomenological models of individual neurons with slow and fast dynamics. Using the geometric slow-fast dissection and the parameter continuation approach, we will show that the transition is due to either the torus bifurcation or the period-doubling bifurcation of a stable periodic orbit on the 2D slow-motion manifold near a characteristic fold. We will also show various torus bifurcations including stable and saddle torus-canards, resonant tori, the co-existence of nested tori and the torus breakdown leading to the onset of complex and bistable dynamics in such systems.

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MS105

Relaxation Oscillations and Canards in the Jirsa-Kelso Excitator Model: Global Flow Perspective

Fenichel's geometric singular perturbation theory and the blow-up method have been very successful in describing and explaining global non-linear phenomena in systems with multiple time-scales, such as relaxation oscillations and canards. Recently, the blow-up method has been extended to systems with flat, unbounded slow manifolds that lose normal hyperbolicity at infinity. Here, we show that transition between discrete and periodic movement captured by the Jirsa-Kelso excitator is a new example of such phenomena. We begin by deriving equations of the Jirsa-Kelso excitator with explicit time scale separation and demonstrate existence of canards in the systems. Then, we combine the slow-fast analysis, blow-up method and projection onto the Poincare sphere to understand the return mechanism of the periodic orbits in the singular case.

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MS106

Dynamical Description of Transient Processes in Shear Flows

Even at transitional Reynolds numbers, the dynamics of a turbulent shear flow is immensely complicated with no apparent temporal order. As a consequence, most of the turbulence literature is concerned with globally averaged quantities, such as the wall friction and energy dissipation, and their long-time statistics. An alternative approach is suggested by the discoveries of time-invariant solutions, such as equilibria and periodic orbits, which are transiently visited by turbulent dynamics. In the light of these developments, several research groups began to explore the possibility of modeling turbulent flows as Markov processes, where each state corresponds to a qualitatively different flow, which can be approximated by a distinct invariant solution. Until recently, recurrence-based methods have been primary tools for invariant solution searches in turbulent flows. While these methods enjoyed some success, they depend on an arbitrary choice of norm, which is uninformed of underlying geometry of the state space. In this talk, I will describe how data-driven model-reduction methods can be utilized to locate invariant solutions of turbulent flows, which can then be used to partition the state space into qualitatively different regions.

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MS106

A Spatiotemporal Theory of Turbulence in Terms of Exact Coherent Structures

The recurrent flows observed in moderate Reynolds number turbulence are shaped by close passes to unstable invariant solutions of Navier-Stokes equations. While in recent years many such solutions been computed, so far all have been confined to small computational domains. Pipe, channel and plane flows, however, are flows on infinite spatial domains. If the Navier-Stokes equations are recast as a space-time theory, with both space and time taken to infinity, the traditional Direct Numerical Simulation codes have to be abandoned. In this theory there is no time, there is only a repertoire of admissible spatiotemporal patterns. We sketch how these are to be encoded by spatiotemporal symbol dynamics, in terms of minimal exact coherent structures. To determine these, radically different kinds of codes will have to be written, with space and time treated on equal footing.

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MS106

Discovery of High-Order PDE Models with Latent Variables

Many phenomena are most naturally described by mathematical models that involve high-order partial differential equations and/or latent variables. Both of these aspects substantially complicate data-driven model discovery. As an example, symbolic regression-based algorithms such as SINDy have trouble reconstructing models such as the Kuramoto-Sivashinsky equation or the Navier-Stokes equation, especially in the presence of noise [Rudy et al. Science, 2017]. These algorithms are based on numerical evaluation of derivatives which is notoriously sensitive to measurement noise in the data. We show that, in some instances, both problems can be addressed rather elegantly using a weak formulation of the model. We illustrate this approach using a model for a quasi-2D turbulent fluid flow driven by a stationary body force. In particular, we demonstrate that the weak formulation can handle extreme noise levels as well relatively sparsely sampled data and, in particular, successfully reconstruct a model of an experimental flow using solely the measurements of the surface velocity.

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MS106

Design of Feedback Control Laws for Turbulent Post-Stall Separated Flows

Feedback control laws are designed for post-stall separated flows using a model-free self-learning cluster-based strategy. Hereby, the challenge of feedback control in direct numerical simulation using limited sensor measurements is addressed. On the one hand, the actuation mechanism is too complex and nonlinear for model-based control. On the other hand, limited CPU time must exploit somehow the smoothness of control laws, unlike machine learning control. The cluster-based control addresses these challenges with following enablers: (a) Defining a suitable feature space, (b) clustering the feature space of unforced data measurements enabling a low-dimensional interpolation scheme for control laws and (c) optimizing the control laws using a downhill simplex search scheme. This approach has been applied to two-dimensional and three-dimensional flows over a NACA0012 airfoil with large eddy simulations at angle of attack of 9°, Reynolds number, $Re = 23000$ and freestream Mach number, $M_\infty = 0.3$. Owing to the simplicity of the approach and limited data requirements, the proposed strategy can be utilized for numerous applications, both in direct numerical simulations and experiments.

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MS107

Pinning and Depinning in Dynamically Generated Media

I will present results on propagation of dissipative structures in inhomogeneous lattice systems, focusing on pinned fronts and depinning transitions. We model the spatial complexity in the medium as generated by a dynamical system, an approach which encompasses periodic, quasiperiodic, heteroclinic and homoclinic, and chaotic media. I will also compare results with those from media generated by simple random processes. Depinning bifurcations exhibit universal laws depending on extreme value statistics that are encoded in the dimension of ergodic measures, only. A key condition limiting this approach bounds spatial Lyapunov exponents in terms of interface localization, and I will discuss the breakdown of smoothness and universality when this condition is violated and fluctuations in the medium occur on length scales shorter than a typical interface width.

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MS107

Snakes and Lattices: Understanding the Bifurcation Structure of Localized Solutions to Lattice Dynamical Systems

A wide variety of spatially localized steady-state solutions to partial differential equations (PDEs) are known to exhibit a bifurcation phenomenon termed snaking. That is, these solutions bounce between two different values of the bifurcation parameter while expanding the region of localization and hence ascending in norm. The mechanism that drives snaking in PDEs has been understood by analyzing the evolution of the ordinary differential equation in the spatial variable governing steady-state solutions to the PDE. In this talk we extend this theory to lattice dynamical systems by showing that the associated steady-state equations in this context can be written as a discrete dynamical system. We can then interpret localized solutions to the lattice system as homoclinic orbits of the associated discrete dynamical system, and show that the bifurcation structure is determined by bifurcations of nearby heteroclinic orbits. We supplement these results with examples from a well-studied bistable lattice differential equation which has been the focus of many works to date.

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MS107

Dispersive Shock Waves in Nonlinear Lattices

Dispersive shock waves (DSWs), which connect states of different amplitude via an expanding wave train, are known to form in nonlinear dispersive media subjected to sharp changes in state. In this talk, DSWs in lattices of the Fermi-Pasta-Ulam-Tsingou type are explored. Various long-wave length approximations are used to describe the formation and structure of the DSWs. The analytical results are complemented by systematic numerical simulations and experiments.

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MS107

Traveling Pulses in Discrete FitzHugh-Nagumo Systems

We establish the existence and nonlinear stability of traveling pulse solutions for the discrete FitzHugh-Nagumo equation in different settings: we consider infinite-range interactions, periodic lattices and fully discrete systems. For the verification of the spectral properties, we need to study a functional differential equation of mixed type (MFDE), possibly with unbounded shifts. We avoid the use of exponential dichotomies and phase spaces, by building on a technique developed by Bates, Chen and Chmaj for the discrete Nagumo equation. This allows us to transfer several crucial Fredholm properties from the PDE setting to our discrete setting.

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MS108

The Kac Model and (Non-)Equilibrium Statistical Mechanics

We study the evolution of a system of N particles (modeled by the Kac master equation) in contact with a thermostat or with a finite heat reservoir with M¿¿N particles initially in equilibrium. We discuss and compare various notions of approach to equilibrium.

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MS108

Thermodynamic Laws from Interacting Kinetic Particles

Consider a long and thin tube that connects two heat baths with different temperatures at its ends. Assume this tube contains many kinetic gas particles whose only interactions are elastic collisions. Some simplifications are necessary to make this model mathematically tractable. We first localize particles by "trapping" them within a 1D chain of billiard tables. Then we use numerical simulations to reduce the localized billiard system to a stochastic energy exchange model. Many mathematical and computational justification can be made for this stochastic energy exchange model. In particular, I will show that the energy profile of this energy exchange model will follow a stochastic differential equation, called the mesoscopic limit equation, for a long time. Several macroscopic thermodynamic laws can be derived from this mesoscopic limit equation.

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MS108

Mathematicothermodynamics: Stochastic Laws

and Emergent Behavior of Population Kinetic Systems

There is a growing awareness toward a slow shifting in the foundation of the thermodynamic laws, from several macroscopic, empirical postulates concerning heat as a form of random mechanical motions, to derivable mathematical theorems based on stochastic dynamics of mesoscopic systems. It becomes increasingly clear that a stochastic dynamic description of the Nature is a very effective mathematical representation of the Reality. In this talk, I shall first introduce mathematicothermodynamics as a set of mathematical results in stochastic processes. The result is then applied to complex chemical kinetic systems. Via the limit by merely taking the molecular numbers to be infinite, we are able to derive J. W. Gibbs' macroscopic isothermal equilibrium chemical thermodynamics, as well as generalize it to mesoscopic nonequilibrium systems such as biological cells.

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MS108

Local Immunodeficiency: Minimal Network and Stability

We analyze the phenomenon of local immunodeficiency [P. Skums, L. Bunimovich, Y. Khudyakov, Antigenic cooperation among intrahost HCV variants organized into a complex network of cross-immunoreactivity (SKB)] generated by antigenic cooperation in cross-immunoreactivity networks. We prove that local immunodeficiency that's stable under perturbations already occurs in very small networks and under general conditions on their parameters. A major necessary feature of such networks is non-homogeneity of their topology. It is also shown that one can construct larger cross-immunoreactivity networks with stable local immunodeficiency by using small networks with it as building blocks. These results imply that stable local immunodeficiency occurs in networks with quite general topology. In particular the scale-free property of a cross-imunoreactivity network, assumed in [SKB], is not required.

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MS109

Stability of the Malvinas Current

Deterministic and probabilistic tools from nonlinear dynamics are used to assess enduring near-surface Lagrangian aspects of the Malvinas Current. The deterministic tools are applied on a multi-year record of velocities derived from satellite altimetry data, revealing a resilient cross-stream transport barrier. This is composed of shearless-parabolic Lagrangian coherent structures (LCS), which, extracted over sliding time windows along the multi-year altimetry-derived velocity record, lie in near coincidental position. The probabilistic tools are applied on a large collection of historical satellite-tracked drifter trajectories, revealing weakly communicating flow regions on either side of the altimetry-derived barrier. Shearless-parabolic LCS are detected for the first time from altimetry data, and their significance is supported on satellite-derived ocean color data, which reveal shapes that quite closely resemble the peculiar V shapes, dubbed "chevrons,' that have recently confirmed the presence of similar LCS in the atmosphere of Jupiter. Finally, using in-situ velocity and hydrographic data, conditions for nonlinear symmetric stability are found be satisfied, suggesting a duality between Lagrangian and Eulerian stability for the Malvinas Current.

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MS109

How do Coherent Sets Respond to Perturbations and how can I Separate Many Coherent Sets?

Finite-time coherent sets are regions in phase space that are maximally dynamically disconnected from the rest of phase space over a finite evolution time. They manifest in geophysical dynamics as fronts, eddies, and vortices and form a relatively predictable skeleton about which turbulent flow occurs. We address two questions. First, suppose one changes the dynamics (the model) or changes the time interval. What effect does this have on the identified coherent sets? Using ideas from linear response, we quantitatively answer this question in the context of coherent sets identified from eigenfunctions of the dynamic Laplacian. Second, we outline a simple and fast computational method to extract many coherent sets from large numbers of eigenvectors; in the process we identify natural spatial and temporal scales in the dynamics. This methodology will be further elaborated upon in the talk of Christopher Rock in the MS entitled "Probabilistic and geometric analysis of time-dependent dynamics'. We illustrate the answers to both of these questions using models of fluid flow and geophysical datasets.

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MS109

Spectral Approximation of Evolution Operators in

Reproducing Kernel Hilbert Space

We present a data-driven framework for spectral analysis of Koopman and transfer operators in measure-preserving, ergodic dynamical systems. This approach relies on a compactification of the skew-adjoint generator of the Koopman group, mapping it into a skew-adjoint, compact operator on a reproducing kernel Hilbert space of observables of appropriate regularity. Convergence results for the spectrum of the compactified generator, as well as its Borel functional calculus, are obtained in a limit of vanishing regularization parameter for systems with arbitrary (atomic or continuous) spectra of their Koopman group. These results lead naturally to schemes for statistical forecasting and identification of coherent observables under the dynamics, which we discuss and illustrate with numerical experiments.

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MS109

Long-Time Dynamical Estimates from Short-Time Data using Dynamical Galerkin Approximation

Understanding protein dynamics requires knowing dynamical statistics such as expected hitting times, reaction rates, and commitment probabilities. However, estimating these quantities from simulation is a complex forecasting challenge: important processes in protein dynamics happen on timescales orders of magnitude larger than we can currently simulate. To address this, we introduce a new meta-algorithm for solving for the dynamical statistics of stochastic processes, which we refer to as *Dynamical Galerkin Approximation*. By combining the theory of Feynman-Kac formulae with the techniques of Galerkin approximation and Monte Carlo integration, we can recover estimates of long-time statistics using short dynamical trajectories. Numerical examples show that these schemes can give good results even when we apply them in a space that is high-dimensional or does not completely capture the dynamics.

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MS110

Application of Manifolds to an Aperiodic 3D Flow: the Western Alboran Gyre

The Alboran Sea, just east of the Strait of Gibraltar, is where Atlantic water enters the Mediterranean in the form of the Atlantic Jet. After passing through the strait, this jet interacts with coastal recirculations, most notably the Western Alboran Gyre a persistent anticyclonic mesoscale eddy. Our work examines the near-surface exchange between the Atlantic Jet and the Western Alboran Gyre in a high-resolution regional run of the MIT general circulation model (Marshall et al. 1997). We use Lagrangian methods from dynamical systems theory, specifically manifolds , to define the moving gyre boundary and separate the stirring region, where exchanges with the Atlantic Jet occur, from the core of the gyre, where they do not. We then quantify tracer transport across the boundaries of this gyre using a gate, a non-Lagrangian boundary segment connecting segments of the stable and unstable manifolds. Finally, we explore a Lagrangian volume budget for the gyre and explain challenges related to baroclinicity and aperiodicity.

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MS110

Dynamics Near a Periodically Forced Attracting Heteroclinic Cycle

There are few explicit examples in the literature of non-autonomous vector fields exhibiting complex dynamics that may be proven analytically. In this talk, we present a careful analysis of the rich dynamics generated by a family of periodic perturbations of a weakly attracting robust heteroclinic network defined on the two-sphere. We derive the first return map near the "ghost" of the heteroclinic cycle and we reduce the non-autonomous system to a two-dimensional map. According to the magnitude of two small parameters, the associated flow may behave periodically, quasi-periodically or chaotically, depending on the specific character of the perturbation. We also provide a bifurcation study of the periodic solutions that emerge and coalesce near the robust cycle when the parameters vary. We reduce the study of the dynamics to other configurations where the dynamics is known. This is a joint work with Isabel Labouriau (University of Porto).

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MS110

Statistics Meets Geometry: Extreme Value Laws

in Dynamical Systems

Extreme value theory for chaotic, deterministic dynamical systems is a rapidly expanding area of research. Given a dynamical system and a real-valued function (observable) defined on its state space, extreme value theory studies the limit probabilistic laws obeyed by large values attained by the observable along orbits of the system. Under suitable mixing conditions, extreme value laws in dynamical systems are the same as those for time series of i.i.d. random variables. The aim of this talk is to show that extreme value laws for dynamical systems also depend on the specific geometry of the underlying attractor and of the level sets of the observable.

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MS110

The Role of Advection for Patterns Near Turing Instabilities in Planar Reaction-Diffusion Systems

Motivated by vegetation patterns on sloped landscapes, the effect of advection terms on the existence and stability of stripes has been studied in recent years. Here we add a refined analysis near the onset of a Turing instability that is perturbed by symmetry breaking advection in planar reaction-diffusion systems. We prove the bifurcation of stripes from the homogeneous solution at perturbed Turing-instability and derive the leading order velocities. Concerning stability of stripes, we prove that the advection term leads to a more intricate dependence on quadratic terms and the magnitude of advection. The analysis shows how stability boundaries change and lead to a selection of stripes over hexagons. We also present numerical computations that corroborate the analysis.

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MS111

Using Plankton as Biosensor

The general relationship between environmental perturbations and cellular shape and function is known but not completely understood. A general model of this relationship can be obtained using an inference based top-down approach. In this work we study the link between morphology and behavior of several aquatic microorganisms and perturbations in their environment by using new digital devices capable of acquiring high resolution stereoscopic videos of microscopic swimming organisms, both in a laboratory setting and in the field. We introduce a novel set of unsupervised machine learning algorithms which are able to scale up the analysis of large plankton image datasets and obtain precise quantitative measurements of plankton shape and motion. Using a dynamical systems based approach, we establish a baseline multidimensional morphology and motion feature space which can be used to infer anomalous behavior connected with an unexpected event. Our work may open new and exciting routes for real time in situ detection of environmental threats.

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MS111

An Integrated Approach to Coral-Algal Phase Shift Modeling: Numerical Methods Meets Data Science

Ecological phase shifts, from coral reefs to macroalgae dominated states, have drastically changed tropical coastal zones over the past 60 years. However, these shifts are not always immediate - macroalgae are generally present even when coral colonies are dominant, with algal distribution regulated by herbivorous fish. Current efforts in projecting coral-algal phase shifts utilize temporal mechanistic models and spatiotemporal statistical models, both of which fail to capture metastability between multiple steady states given a lack of spatial information and spatiotemporal resolution, respectively. To address these concerns, we build on these models to account for spatial variations and stochasticity, in combination with individual organisms and their mechanisms. Our model can project the percent cover and spatial distributions of coral, macroalgae, and algae turf as a function of three reef resilience indicators - herbivorous grazers, water quality, and coral demographics. Grazers are included using an individual-based kinetic model and interact with neighbouring benthic assemblages. Water quality and coral demographics are input parameters that can vary over time, allowing our model to be run for temporally changing scenarios that can be adjusted for different reefs. Finally, we apply our model in the context of a particular reef in the French Polynesia, using a transfer entropy method to parametrize our model with reef data.

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MS111

Small Organisms Causing Big Problems: Modeling Heterosigma Akashiwo

A specific species of phytoplankton, Heterosigma Akashiwo, has been the cause of harmful algal blooms (HABs) in waterways around the world causing millions of dollars in damage to farmed animals and destroying ecosystems. Developing a fundamental understanding of their movements and interactions through phototaxis and chemotaxis is vital to comprehending why these HABs start to form and how they can be prevented. In this talk, we attempt to create a complex and biologically accurate mathematical and computational model reflecting the movement of an ecology of plankton, incorporating phototaxis, chemotaxis, and the fluid dynamics that may be affecting the flow. We present and analyze a succession of models together with a sequence of laboratory and computational experiments that inform the mathematical ideas underlying the model. Lastly, we discuss further experiments and research necessary for our continued insight into problems that we are encountering, such as plankton's formation of aggregations, the gaps in-between those aggregations, and the difficulty of expanding our models to higher dimensions biologically, mathematically, and computationally.

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MS111

Oyster Population Persistence with Fluctuating Dispersal Rates

Adult oysters are non-motile, occurring in reefs. New individuals arise in the population when larvae, which are dispersed by water currents, settle on an existing reef. We begin with a stage-structured differential equation model for a single oyster reef. Due to positive feedback interactions between oysters, the model displays an Allee effect, in which populations above a threshold can grow but below the threshold approach extinction. We extend to a metapopulation model in which reefs are coupled by dispersal of larvae. Self-replenishment of a reef by its own larvae can also occur. Larval transport depends on rainfall, so we model stochastic fluctuations in reef connectivity due to fluctuating rainfall. Population persistence in the presence of fluctuating connectivity is explored.

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MS112

Interdisciplinary Inclusive Communities of Undergraduates doing Social-Justice Inspired Research

In 1996, the Mathematical and Theoretical Biology Institute or MTBI was established at Cornell University. The goal was to bring undergraduates from diverse backgrounds into the field of mathematics and its applications, particularly within the fields of computational, mathematical and theoretical biology. In this lecture, I will discuss how MTBI (mtbi.asu.edu) was established and how it has evolved over the past 24 years. The process of building interdisciplinary inclusive communities of undergraduate has been driven by their interest in social-justice inspired research. The emphasis on social-justice inspired student-driven research has built a resilient community of researches where underrepresented groups have played a central role. Through this model, MTBI has played a central role in the development of nearly 160 PhDs with about 100 going to URMs. The extraordinary social-justice student-driven research generated by over 500 undergraduate participants, working in collaborative projects, for a few weeks, is available at https://mtbi.asu.edu/tech-report

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MS112

A Topological Approach to Detecting Neighborhood Segregation

Understanding patterns of segregation and neighborhood formation is vital to inform civil-rights policies aimed at supporting communities of interest. Neighborhood segregation has a significant spatial component, so incorporating spatial along with demographic perspectives in segregation studies is necessary for understanding local-scale segregation. In this talk, I will be discussing the application of topological invariants to demographic data with spatial dimensions in order to identify neighbourhood racial segregation. By constructing topological spaces using both spatial and demographic information, tools such as homology can be used to probe spaces for obstructions and identify boundaries along which local segregation occurs. I will present applications of these ideas to real-world community-level data collected from U.S. cities including Washington D.C. and Chicago, and discuss the analysis in the context of historical and legal events shaping segregation in those cities. Lastly, I will outline an extension of this work which borrows ideas from cobordism theory to detect historical changepoints in segregation. This may be used to create a dictionary between our mathematical and social understanding of segregation.

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MS112

Quantifying Gerrymandering using Random Dynamics

In October 2017, I found myself testify for hours in a Federal court. I had not been arrested. Rather I was attempting to quantifying gerrymandering using a mathematical analysis which grew from asking if a surprising 2012 election was in fact surprising. It hinged on probing the geopolitical structure of North Carolina using a Markov Chain Monte Carlo algorithm. I will start at the beginning and describe the mathematical ideas involved in our analysis. The talk will be assessable, and hopefully interesting, to all including undergraduates. If fact, this project began as a sequence of undergraduate research projects and undergraduates continue to be involved to this day. That being said, this enterprise also raises some interesting mathematical questions around high dimensional spin-likesystem and algorithms used to sample their equilibrium measures.

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MS112

Forecasting U.S. Elections using Compartmental Models

U.S. election forecasting involves polling likely voters, making assumptions about voter turnout, and accounting for various features such as state demographics and voting history. While elections in the United States are decided at the state level, errors in forecasting are correlated between states. With the goal of better understanding the forecasting process and exploring how states influence each other, we develop a data-driven framework for forecasting U.S. elections at the level of states. We combine a two-contagion compartmental model with public polling data from HuffPost and RealClearPolitics to forecast gubernatorial, senatorial, and presidential elections. Our results for the 2012, 2016, and 2018 U.S. races are largely in agreement with those of popular pollsters (e.g., FiveThirtyEight.com), and we use our model to explore how subjective choices about uncertainty impact results.

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MS113

The Effect of Symmetry on Reservoir Computing

A reservoir computer is a network of nonlinear nodes with feedback. The network itself is stable, so it doesnt oscillate, but responds to an external driving signal. Reservoir computers are used to analyze time series signals. In the training stage, the network itself does not change; instead, the time series of the network variables are used to fit a training signal. The accuracy of the fit, which determines the accuracy of the reservoir computer, depends on the network. We show here that the presence of symmetries in the network leads to less accurate training. We use other measures to show that symmetries reduce the amount of variation in the network signals.

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MS113

Converse Symmetry Breaking: Demonstration and Application to Network Optimization

Symmetry breaking—the phenomenon in which the symmetry of a system is not inherited by its stable states—underlies pattern formation, superconductivity, and numerous other effects. Recent theoretical work has established the possibility of converse symmetry breaking, a phenomenon in which the stable states are symmetric only when the system itself is not. This includes scenarios in which interacting entities are required to be nonidentical in order to exhibit identical behavior, such as in reaching consensus. In this talk we present an experimental demonstration of this phenomenon. Using a network of alternating current generators, we show that their ability to achieve identical frequency synchronization is enhanced when the generators are tuned to be suitably nonidentical. This result is directly relevant for the optimization of power-grid networks—whose stable operation requires synchronization—which we demonstrate by analyzing several test and real networks.

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MS113

Benefits of Heterogeneity: Random Beats Design in Network Synchronization

A fundamental and widely held assumption on network dynamics is that similar agents are more likely to exhibit similar behavior than dissimilar ones, and that generic differences among them are necessarily detrimental to synchronization. In this presentation, I will show that this assumption does not hold in networks of coupled oscillators. This can be interpreted as a form of *converse symmetry breaking*, the phenomenon established in the next presentation in which the existence of a stable symmetric state requires system asymmetry. I will demonstrate, in particular, that random oscillator heterogeneity can consistently induce synchronization in otherwise unsynchronizable networks. Remarkably, at intermediate levels of heterogeneity, random differences among oscillators are far more effective in promoting synchronization than differences specially designed to facilitate identical synchronization. Our results suggest that, rather than being eliminated or ignored, existing mismatches can be harnessed to help maintain coherent network dynamics in experiments and real systems.

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MS113

Large Fluctuations and Rare Events in Complex Networks

Noise-induced large fluctuations occur in systems across many fields and different scales. For example, they are observed in spontaneous pattern switching in autonomous swarms, noise-induced switching in alternating coupled neurons used to model perception, as well as extinctions in large scale populations. An important inclusive class of dynamical systems that model such noise-induced behavior are general complex networks; that is, networks with very heterogeneous topological properties and noisy dynamics. The interplay between topology and noise can give rise to dramatic events such as extinction of an epidemic or species, switching between different collective network states, and/or complete collapse of network functionality and structure. In this talk, I will review some of our recent general results on noise-induced fluctuations in complex networks. In particular I will discuss how these results lead to new scalings of the probability of occurrence of rare large fluctuations in switching and control of large fluctuations in complex networks, and large fluctuations leading to extinction in adaptive networks. Tools to analyze such dynamic fluctuations include network model reduction and analysis near dynamic bifurcation points.

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MS114

Taming the Spatiotemporal Chaos in Nanoscale Topographies Produced by Ion Bombardment

Bombarding a solid surface with a broad ion beam can produce a variety of self-assembled nanoscale patterns, including surface ripples with wavelengths as short as 10 nanometers. The anisotropic Kuramoto-Sivashinsky (AKS) equation has long been used to model the formation of these ripples. In many applications, ordered patterns are essential and so ways of suppressing the spatiotemporal chaos generated by the AKS equation are needed. In this talk, I will discuss several methods of doing this. Surprisingly, we find that highly ordered ripples can be formed by periodically rocking the sample during bombardment, which makes the coefficients in the AKS equation periodic functions of time. In addition, bombarding a target material that is composed of two atomic species rather than one can yield highly ordered ripples. It can also produce hexagonal arrays of nanodots. The order in these arrays — which can be quantified using a method based on persistent homology — can be improved by using an ordered initial pattern with a spacing that is an integer multiple of the inter-dot spacing.

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MS114

Effects of Anisotropies in the Complex Ginzburg-Landau Equation

The isotropic complex Ginzburg-Landau equation (CGLE) has complex spatiotemporal dynamics including chaos and frozen states. The two types of chaos, phase and defect, are characterized by the absence or presence of regions of zero amplitude and are found in the Benjamin-Feir-Newell (BFN) unstable regime. Frozen states consisting of spiral waves and shock walls occur in the BFN stable regime. The anisotropic CGLE is studied numerically and the effects of the anisotropic terms are looked at in both the BFN stable and unstable regions.

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MS114

Chevron Structures in Passive and Active Liquid Crystals

Liquid crystals are a distinct phase of matter existing between the chaos of isotropic liquids and the order of crystalline solids. In addition to being partially ordered, they manifest sensitivity to changes in temperature, concentration, or electric and magnetic fields. These properties render liquid crystals useful in various optical and biological applications. V-shaped structures called chevrons have been observed in both categories of applications. In optical displays, chevron structures are defects that hinder the formation of clear images. In biological applications, however, such defects are favorable because they can attract and transport micro-cargo. In order to control the defects in either case, we need to understand the behavior of liquid crystal material in the presence of chevron structures. We study the dynamics of such systems through a gradient flow in the passive optical case and through a hydrodynamics model in the active biological case. Our results focus on the existence of solutions that represent chevron structures and we highlight advantages and challenges using each approach.

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MS114

Complex and Disordered Patterns in Pattern Formation with Two Length Scales

Why do some systems organise themselves into well ordered patterns with astonishing symmetry and regularity, while other superficially similar systems produce defects and disorder? In systems where two different length scales are unstable, the nonlinear interaction between the different modes is key: steady complex patterns can be stabilised when the modes act together to reinforce each other. But, if the two types of pattern compete with each other, the outcome can be considerably more complicated: a time-dependent disordered mixture of patterns constantly shifting and changing. In a small domain, the nature of the interaction between a small number of modes on each length scale can readily be computed. In a large domain, each mode can interact with hundreds of other modes, but the overall behaviour still appears to be guided by small-domain considerations. This talk will examine whether statistical descriptions, closure relations or insight from machine learning can help understand why this is so.

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MS115

A Role for Electrical Coupling in Cortical Networks

Electrical coupling between interneurons in the cortex has been shown to promote synchronous activity, which is thought to underlie cognitive processes such as learning and memory. Among pyramidal cells, however, the role of electrical coupling remains unknown. These electrical junctions between pyramidal cells occur transitively during the few first weeks of development, decreasing to very rare coupling probabilities in adults. This transitivity and low coupling probability make it a difficult endeavor for experimentalists to measure properties of, and uncover mechanistic roles for, such junctions. In this work, we use a mathematical neuronal network model to unveil plausible functional roles for electrical coupling among pyramidal cells in the cortex.

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MS115

Mathematical Model of Pain Processing in the Spinal Cord

Humans experience sensitivity to painful stimuli that exhibits a 24hr (circadian) rhythm, with a peak in sensitivity occurring in the middle of the night. In neuropathic patients, those who experience chronic pain usually accompanied by damaged nerve tissue, the sensitivity of pain follows a circadian rhythm of opposite phase, with a peak in pain sensitivity occurring in mid-afternoon. In this work, we build a firing-rate model of the neuronal populations that comprise the pain-processing circuitry in the human spinal cord. We show that this model can capture pain phenomena such as wind up and pain inhibition and use this model to propose a possible mechanism underlying the change in rhythmicity of pain sensitivity under neuropathic conditions.

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MS115

Reconstruction of Digital Systems by Transfer Entropy

Transfer entropy (TE) is a model-free method to reconstruct the structural connectivity of general digital systems. However it relies on high dimensions used in its definition to clearly distinguish the direct causality from the indirect and reverse direction causality which makes it almost inoperable in practice. We try to use a low order and pairwise TE framework with binary data filtered from the recorded raw signals to avoid the high dimensional problem. We find that the TE values from connected and unconnected pairs have a significant difference of magnitude, which can be easily classified by cluster methods. This phenomenon widely and robustly holds over a wide range of systems and dynamical regimes. We find that the TE value is quadratically related to the coupling strength and thus we establish a quantitative mapping between the causal and structural connectivity.

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MS115

Network Reconstruction in the Cerebral Cortex: Architectural and Functional Connectivity with Matrix Completion

We investigate the relationship between functional and architectural connectivity in the cerebral cortex by means of network reconstruction via time-delayed spike-train correlation. We begin by reconstructing the entire network, and then we sample the matrix randomly and use the tool of matrix completion to fill in the rest of the network. To be more experimentally valid, we next examine a small slice or submatrix of the network and determine how much information we can deduce about the whole network from this small piece. An examination of the spectral properties of connectivity matrices forms a major part of this analysis.

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MS116

Exit Problems and Rare Transitions in Noisy Heteroclinic Networks

I will talk about extending my earlier work on the vanishing noise limit of diffusions in noisy heteroclinic networks to longer time scales. In this field, the results are based on sequential analysis of exit locations and exit times for neighborhoods of unstable equilibria. The new results on exit times and the emergent hierarchical structure are joint with Zsolt Pajor-Gyulai.

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MS116

Dynamical Systems with Fast Switching and Slow Diffusion: Hyperbolic Equilibria and Stable Limit Cycles

I will talk about the long-term qualitative behavior of randomly perturbed dynamical systems. More specifically, I will look at limit cycles of certain stochastic differential equations (SDE) with Markovian switching, in which the process switches at random times among different systems of SDEs, when the switching is fast and the diffusion (Brownian) term is small. The two types of noise are tracked by two small parameters, epsilon and delta. One can associate to the system an averaged ordinary differential equation (ODE). Suppose that for each pair (ϵ, δ) of parameters, the process has an invariant probability measure $\mu^{\epsilon,\delta}$, and that the averaged ODE has a limit cycle in which there is an averaged occupation measure μ^0. I will show, under weak conditions, that if the averaged ODE has finitely many hyperbolic fixed points, then the family $(\mu^{\epsilon,\delta})$ converges weakly to μ^0 as epsilon and delta go to zero.

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MS116

Center Manifolds for Rough Differential Equations

Since the breakthrough in the rough paths theory there has been a strong interest in investigating rough differential equations (RDEs) using a completely pathwise approach. Here we analyze dynamical properties of RDEs and connect the rough paths, regularity structures and random dynamical systems approaches. In this talk emphasis is laid on center manifold theory for RDEs. By means of a Lyapunov-Perron-type method we prove the existence of local center manifolds for such systems and point out several properties and applications. This talk is based on a joint work with Christian Kuehn.

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MS116

Quasi-Stationary Monte Carlo Methods

The theory of quasi-stationarity has long been studied from a mathematical, probabilistic point of view. In recent years, quasi-stationarity has also found application in the field of Monte Carlo methods for performing Bayesian inference, giving rise to quasi-stationary Monte Carlo (QSMC) methods. These methods are particularly promising since they can be shown to scale well with the size of the data set. In this talk I will introduce these methods, and give some foundational results in the application of quasi-stationarity to Monte Carlo inference problems. Particular focus will be given to one novel QSMC method known as 'ReScaLE', based on a stochastic approximation approach to simulating from quasi-stationary distributions. This talk will be based on two pieces of work [Wang, Kolb, Roberts, Steinsaltz 2017] and [Wang, Roberts, Steinsaltz, 2018].

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MS117

When Three is a Crowd: Chaos from Clusters in Networks of Phase Oscillators with Inertia

Networks of phase oscillators with inertia capable of adjusting their natural frequencies are often used to model neural systems. In this talk, we discuss the emergence and co-existence of stable patterns of synchrony in two- and three-population networks of phase oscillators with inertia. The populations have different sizes and can split into clusters where the oscillators synchronize within a cluster while there is a phase shift between the dynamics of the clusters. Due to the presence of inertia, which increases the dimensionality of the oscillator dynamics, this phase shift can oscillate periodically or chaotically, inducing a chaotically breathing cluster pattern. We derive analytical conditions for the co-existence of stable patterns with constant and oscillating phase shifts in two- and three-population networks. We demonstrate that the multistable and possibly chaotic dynamics of the phase shifts in the three-population network are governed by two coupled driven pendulum equations. We also discuss the implications of our stability results to the stability of chimeras.

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MS117

Cellular Control of Network Rhythmic Activity

Nervous system functions are regulated by fast and localized modulation of neural network rhythmic activity. This feature is conserved amongst very different systems, ranging from invertebrate central pattern generators to mammal midbrain and cortical structures. These systems however strongly differ in their structure, function and physiological properties, and are regulated by a large number of interconnected mechanisms, which makes the extraction of key players in the robust regulation of rhythmic activity an arduous task. This talk will introduce a cellular dynamical property called slow regenerativity from which robust and tunable modulation of rhythmic activity can emerge in many different systems, both at the cellular and network levels. Slow regenerativity endows circuits with a shared cellular slow positive feedback that can switch population rhythms on and off at a cellular resolution. Such network switch is largely independent from other intrinsic neuronal properties, network size and synaptic connectivity. It is therefore robust to system specificities, and it is compatible with the temporal variability and spatial heterogeneity induced by slower regulatory functions such as neuromodulation, synaptic plasticity and homeostasis.

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MS117

Mathematical Tools for Phase Control in Transient

States of Neuronal Oscillators

Oscillations are ubiquitous in the brain. Although the functional role of oscillations is still unknown, some studies have conjectured that the information transmission between two oscillating neuronal groups is more effective when they are properly phase-locked. Thus, studying phase dynamics is relevant for understanding neuronal communication. The phase response curve (PRC) is a powerful and classical tool to study the effect of a perturbation on the phase of an oscillator, assuming that all the dynamics can be explained by the phase variable. However, factors like the rate of convergence to the oscillator, strong forcing or high stimulation frequency may invalidate the above assumption and raise the question of how is the phase variation away from an attractor. In this talk, I will present powerful computational techniques to perform the effective computation of the phase advancement when we stimulate an oscillator which has not reached yet the asymptotic state (a limit cycle). I will show some examples of the computations we have carried out for some well-known biological models and its possible implications for neural communication.

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MS117

Leveraging Machine Learning to Control Neural Oscillators

Machine learning is an area of research that has seen tremendous growth over the last several years. While there have been countless applications to problems such as computer vision and natural language processing, extensions into other areas such as neuroscience and control are still emerging. Here, we present a trained deep neural network capable of accurately estimating the effect of square-wave stimuli on a neuron's dynamics using minimal output information from the neuron. We then apply this network to solve several related control problems in desynchronization, including desynchronizing pairs of neurons and achieving clustered subpopulations of neurons. We also show how reinforcement learning can be used to develop a control strategy to switch between bistable neural states. Where possible, the results will be interpreted in terms of the fast-slow properties of neural dynamics.

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MS118

Probability r-Forms in Exterior Calculus, Lie Symmetries and a Generalized Liouville Equation

Abstract not available.

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MS118

Optimizing Finite-Time Coherence in Non-Autonomous Systems without Trajectory Integration

Understanding the macroscopic behavior of a dynamical system is important to unravel transport mechanisms in turbulent flows. A decomposition of the state space into coherent sets reveals essential macroscopic evolution. A next step is to quantify and optimize mixing properties of the underlying dynamical system. In order to utilize the full-time evolution of the time-dependent dynamical system for our analysis we consider the relevant transfer operators and their infinitesimal generators on an augmented space-time manifold. This space-time approach avoids trajectory integration, does not need averaging to handle the time-dependence and allows for a convenient linearization that leads to a neat and easy optimization problem. The structure of the resulting optimization problem enables us to directly and exactly optimize our quantifier of interest. We perform our optimization for a given space of velocity field perturbations directly on the operator level.

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MS118

A New Scalable Algorithm for Computational Optimal Control Under Uncertainty

Optimal control algorithms for stochastic dynamical systems often rely on sample paths to evaluate performance metrics. The number of such paths is typically problem-dependent, and it can grow exponentially fast with the dimension of the underlying phase space. State-of-the-art control algorithm based on probabilistic (spectral) collocation cannot handle such high-dimensionality, and often result in computationally intractable problems. In this talk, I will present a new potentially groundbreaking algorithm for computational optimal control under uncertainty based on interior point methods, common sub-expression elimination, reactive programming, and exact gradients obtained with computational graphs. The new algorithm has extremely low memory requirements and it allows us to rapidly process a massive number of sample paths, while determining performance metrics and associated optimal controls using multi-shooting. I will demonstrate the effectiveness of the new method in applications to stochastic path planning problems involving UAVs and UGVs.

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MS119

Nanopteron Traveling Waves for Mass-in-Mass Lattices in the Small Mass Limit

The mass-in-mass (MiM), or mass-with-mass, lattice consists of an infinite chain of identical particles that are both nonlinearly coupled to their nearest neighbors and linearly coupled to a distinct resonator particle. The MiM lattice is a prototypical model in the field of granular metamaterials, a large class of artificially constructed materials that possess certain highly tunable properties useful in experimental settings. This talk will present ongoing investigations into the existence and properties of traveling waves in the MiM lattice in the limit as the mass of the resonator goes to zero, at which point the MiM lattice reduces to a classical monatomic Fermi-Pasta-Ulam-Tsingou (FPUT) lattice. We are therefore interested in traveling waves in the MiM lattice whose profiles remain close to the well-known solitary wave that exists in the monatomic FPUT lattice. Following the methods of Hoffman and Wright for diatomic FPUT lattices with small mass ratio, we first discuss the existence of periodic traveling waves in this small mass limit and then construct from them nanopteron traveling waves, which are the superposition of one of these periodic waves, the FPUT solitary wave, and an exponentially decaying remainder.

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MS119

Wave Propagation in Peridynamical Media

Peridynamics is a modern branch of materials science which models the interactions in a spatially extended Hamiltonian systems by nonlocal integro-differential equations. In this talk we present a variational existence proof for solitary waves with unimodal profile functions. We also discuss the the numerical computation of those waves and study some asymptotic limits. (joint work with Karsten Matthies)

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MS119

Dynamics on Planar Lattices

We study dynamical systems posed on planar lattices. Throughout the talk we will explore the impact that the spatial topology of the lattice has on the dynamical behaviour of solutions. More specifically, we are interested in the behavior of deformed planar waves which arise as solutions to the Nagumo LDE. In contrast to previous work, the initial perturbation from the flat planar wave need only be bounded. We will make a connection between the evolution of the interface region and the solution of a discrete mean curvature flow with a drift term.

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MS119

Traveling Waves, Discrete Breathers and Shock Waves in Granular Crystals: Theory, Simulation and Experiments

In this talk, we will provide an overview of results in the setting of granular crystals, consisting of beads interacting through Hertzian contacts. In 1d we show that there exist three prototypical types of coherent nonlinear waveforms: shock waves, traveling solitary waves and discrete breathers. The latter are time-periodic, spatially localized structures. For each one, we will analyze the existence theory, presenting connections to prototypical models of nonlinear wave theory, such as the Burgers equation, the Korteweg-de Vries equation and the nonlinear Schrodinger (NLS) equation, respectively. We will also explore the stability of such structures, presenting some explicit stability criteria analogous to the famous Vakhitov-Kolokolov criterion in the NLS model. Finally, for each one of these structures, we will complement the mathematical theory and numerical computations with state-of-the-art experiments, allowing their quantitative identification and visualization. Finally, time permitting, ongoing extensions of these themes will be briefly touched upon, most notably in higher dimensions, in heterogeneous or disordered chains and in the presence of damping and driving; associated open questions will also be outlined.

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MS120

Entropy Production in Random Billiards and the Second Law of Thermodynamics

A random dynamical system is said to be time-reversible if the statistical properties of orbits do not change after reversing the arrow of time. The degree of irreversibility of a given system is captured by the notion of entropy production rate. We describe a general formula for entropy production that applies to a class of random billiard systems on Riemannian manifolds with boundary for which it is meaningful to talk about energy exchange between billiard particle and boundary. This formula establishes a relation between the purely mathematical concept of entropy production rate and physics textbook thermodynamic entropy. In particular, it recovers Clausius' formulation of the second law of thermodynamics: the system must evolve so as to transfer energy from hot to cold. We also demonstrate the relationship between entropy production rate and certain geometric and thermodynamic parameters of systems for some explicit examples.

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MS120

Thermodynamics of Random Billiards

Random billiards are mechanical systems consisting of rigid moving masses that interact through random collisions. These systems can provide simple and natural stochastic models of thermodynamic phenomena. In this talk I discuss a few fundamental concepts in stochastic thermodynamics within the context of random billiards, such as entropy production rate and the second law of thermodynamics. As examples I consider thermophoretic motors, which are simple random billiard systems that can operate as thermal engines. This is joint work with Tim Chumley.

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MS120

Averaging in Billiard-Like Systems

I will present an extension of the classical averaging principle to dynamical systems with singularities, in particular billiard systems. As an application I will present a derivation of Haff's law in a dissipative periodic 2-disk fluid.

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MS120

Diffusive Scaling Limit in a Slow-Fast Standard Map

We discuss a family of slow-fast twist maps that are conjugate to the Chirikov-Taylor Standard map with a large parameter. These maps can be viewed as a toy model for the phenomenon "cattering by resonance". For suitable parameters, we show that for a random initial condition, the evolution for the slow variable converges to a diffusion process.

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MS121

Lyapunov Vector Fields and Coarse-Grained Dynamics via the Spectral Exterior Calculus

Given data sampled from a manifold embedded in Euclidean space, the Spectral Exterior Calculus (SEC) gives a method of estimating the Laplacian on 1-forms with spectral convergence guarantees. The eigenforms of this operator form a basis for smooth 1-forms (and thus smooth vector fields) on the manifold. For a dynamical system generated by a smooth vector field, we can decompose the vector field in this basis. Given a noisy estimate of the vector field, we show how to denoise the estimate by imposing an appropriate decay on the coefficients in this basis (similar in principal to a low pass filter). Moreover, each vector field in the basis generates a simple, closed, dynamical system, so we explore using this representation of the dynamics to obtain coarse-grained dynamics. Finally, we show how to translate the problem of identifying Lyapunov vector fields into this basis.

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MS121

The Computation of Invariant Sets via Observations

Over the last couple of years a novel numerical framework for the computation of finite dimensional invariant sets of infinite dimensional dynamical systems has been developed. Within this framework classical *set oriented* numerical schemes (for the computation of invariant sets in finite dimensions) have been extended to the infinite dimensional context by utilizing appropriate *embedding techniques* which are based on observations. In this talk we will present new algorithmic improvements which address both a significant speedup of the computations and the identification of topological properties of the invariant objects. We will illustrate these new techniques by a couple of examples from fluid dynamics.

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MS121

On the Large Scale Flow Structure in Rayleigh–Bénard Convection: Manifold Learning and Transition Matrix Analysis

Utilizing sparse temperature measurement data from Rayleigh–Bénard experiments in a cylindrical container we find intrinsic embedding coordinates that parametrize the fuzzy attractor of the dynamics. From a discretization of the non-deterministic dynamics in the embedding space we uncover features dominating the long-term dynamical behavior.

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MS121

On the Slow Dynamics of Superstructures in Turbulent Convection

Turbulent convection flows tend to form large-scale patterns that evolve gradually in correspondance with the statistical symmetries in the flow configuration. For two examples, we discuss methods to reduce the degrees of freedom of the turbulent convection system in order to analyse the slow dynamics of the large-scale flow. (1) We apply a Koopman analysis for a turbulent Rayleigh-Bénard flow in a cubic cavity. A data-driven basis derived from diffusion kernels known in machine learning is employed to represent a regularized generator of the unitary Koopman group in the sense of a Galerkin approximation. The resulting Koopman eigenfunctions are grouped into subsets in accordance with the discrete symmetries in a cubic box. In particular, a projection of the velocity field onto the first group of eigenfunctions reveals the four stable large-scale circulation states in the convection cell. (2) We train a deep convolutional neural network (CNN) to reduce the complex three-dimensional large-scale pattern of a large-aspect-ratio Rayleigh-Bénard flow to a temporal planar network in the midplane of the layer - a data compression by more than 5 orders of magnitude at the highest accessed Rayleigh number. The application of a CNN with a U-shaped architecture consisting of a contraction and a subsequent expansion branch, results in a discrete transport network that is used to quantify the turbulent heat transferred by the superstructure.

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MS122

A Collective Coordinate Framework to Study the Dynamics of Travelling Waves in Stochastic Partial Differential Equations

We propose a formal framework based on collective coordinates to reduce infinite-dimensional stochastic partial differential equations (SPDEs) with symmetry to a set of finite-dimensional stochastic differential equations which describe the shape of the solution and the dynamics along the symmetry group. We study SPDEs arising in population dynamics with multiplicative noise and additive symmetry breaking noise. The collective coordinate approach provides a remarkably good quantitative description of the shape of the travelling front as well as its diffusive behaviour, which would otherwise only be available through costly computational experiments. We corroborate our analytical results with numerical simulations of the full SPDE.

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MS122

Travelling Waves in Reaction-Diffusion Equations Forced by Translation Invariant Noise

In previous work we showed how a stochastic phase adaptation can be used to understand the dynamics of traveling waves in stochastic Reaction-Diffusion equations forced by a single Brownian motion. In this talk we explain how this technique can be extended to equations forced by translation invariant Wiener processes. This extension is important, as translation invariant noise is most often used in applications. We will mainly focus on understanding the dynamics of the stochastic wave and we will show how it deviates from the deterministic wave. We briefly consider the technical difficulties that arise when studying equations forced by cylindrical Wiener processes.

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MS122

Dynamics of Reaction-Diffusion SPDEs

In this talk, I am going to provide a survey of some recent progress on dynamics of certain (still relatively elementary) classes of reaction-diffusion SPDEs obtained in recent years. Even the basic theory of what a "solution" should be is still under very active development and discussion; here I shall mention recent progress made for quasi-linear and nonlocal SPDEs. Then I shall focus in more detail on how to capture local fluctuations near deterministically stationary solutions from an analytical and a numerical standpoint. I am also going to provide a brief outlook towards travelling waves. This work provides one step towards the more general goal to provide a dynamical systems theory for SPDEs.

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MS122

Effect of Noise on Emergent Patterns in Reaction-Diffusion Systems and Neural Fields

In this work I outline a method for performing phase reduction of emergent phenomena in infinite-dimensional stochastic systems. In the first part, I look at the effect of additive space-time white noise on the position of traveling wave fronts in neural field equations. I decompose the noise into a perturbation of the position of the wavefront and an amplitude. Using this decomposition, I can bound the probability of the system leaving a close neighborhood (i.e. a ball of radius a) of a travelling wave solution after a time T, finding that it scales as $O(T\exp(-Cba^2))$, where b is the rate of decay of the transverse fluctuations. In the second part of this talk, I obtain similar bounds for a finite-particle discrete jump-Markovian reaction diffusion system.

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MS123

Emergent Space, Emergent Time - Data with Hidden Internal Order and Manifold Learning

Manifold-learning techniques are routinely used in mining complex spatiotemporal data to extract useful, parsimonious data representations. We focus here on the case of time series data that can ultimately be modelled as a spatially distributed system, but where we do not know the space in which this PDE should be formulated. Hence, even the spatial coordinates for the distributed system themselves need to be identified - to "emerge from"- the data mining process. We will first validate this emergent space reconstruction for time series sampled without space labels in known PDEs; this brings up the issue of observability of physical space from temporal observation data, by tuning the scale of the data mining kernels. Our illustrative examples include chimera states (states of coexisting coherent and incoherent dynamics), and chaotic as well as quasiperiodic spatiotemporal dynamics, arising in partial differential equations and/or in heterogeneous networks. We also discuss how data-driven "spatial" coordinates can be extracted in ways invariant to the nature of the measuring instrument (gauge-invariant data mining). This is joint work with Felix Kemeth, Sindre Haugland, Kevin Hoehlein, Katharina Krischer, Felix Dietrich, Qianxiao Li, Erik Bollt and Ronen Talmon

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MS123

Complex Network and Machine Learning Techniques for Extreme Climatic Events

We analyse climate dynamics from a complex network approach. This leads to an inverse problem: Is there a backbone-like structure underlying the climate system? For this we propose a technique which combines methods from complex networks and machine learning to reconstruct a complex network from data generated by such a spatio-temporal dynamical system. This approach enables us to uncover relations to global circulation patterns in oceans and atmosphere. This concept is then applied to Monsoon data; in particular, we develop a general framework to predict the onset of Indian Summer Monsoon much earlier than existing methods. Applying this approach to South America Monsoon data, we uncover a new mechanism of extreme floods in the eastern Central Andes which could be used for operational forecasts.

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MS123

Machine Learning Analysis and Prediction of Chaotic Systems

We present analysis and methods related to machine learning prediction and analysis of chaotic systems. Potential topics discussed may include parallel implementation of machine learning prediction application to spatiotemporal chaos, replication of ergodic properties from data, inference of Lyapunov exponents of dynamical systems from data, inference of the entropy rate of stochastic signals with memory,and inference of low dimensional dynamics of large complex systems. Collaborators on this work include J. Pathak, Z. Lu, S. Chandra, J. Hart, B. Hunt, M. Girvan, and R. Roy.

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MS123

Machine Learning in Controlling Coupled Complex Systems

In this talk, we will discuss some recent advances in controlling complex coupled systems by machine learning methods. Firstly, we consider multiobjective synchronization of coupled chaotic systems by considering two objectives in parallel, i. e., minimizing optimization of coupling strength and convergence rate. The coupling form and coupling strength are optimized by an improved multiobjective evolutionary approach. The constraints on the coupling form are also investigated by formulating the problem into a multiobjective constraint problem. We find that the proposed evolutionary method can outperform conventional adaptive strategy in several respects. Secondly, we consider the local controllability of complex networks by treating it into single-objective unconstrained optimization problem, constrained optimization problem, multiobjective optimization problem and robust multiobjective optimization problem. We have obtained a variety of results, showing the controllability of complex networks in terms of statistical properties. Thirdly, in order to achieve the autonomous objectives, we further discuss the formation control of drones via data fusion and computer vision techniques like visual odometry. The methods and results here would promote the coordination and information consensus of various kinds of real-world complex networks including transportation networks, genetic regulatory networks, and technical networks, etc.

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MS124

A Kinetic Contagion Model for Fearful Crowds

Interacting particle models can be used to describe the behavior of groups of individuals (from cells to animals or human beings). Individuals move following some basic rules and can generate interesting patterns. We are interested in studying the behavior of crowds in situations in which an emotional component is present, for example, when people are evacuating a plaza or a building under the threat of something dangerous happening in the area. When the number of individuals is large, techniques of kinetic theory can be used to analyze the behavior of the group. In this talk, we will present a Cuker-Smale-like individual based model for fearful crowds, where the dynamics are couple the interactions with the other individuals with an emotional component. We describe the corresponding kinetic version of the model and analyze the asymptotic behavior of the solutions. Numerical simulations will be used to exemplify our results.

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MS124

Temporal Dynamics of Human Emotional Re-

sponse to Aversive Stimuli

The onset of a crowd disaster is often preceded by a wave of emotional contagion that communicates fear information through a large group of people. While suppressing such waves of contagion seem near impractical once they are onset, slowing them down may be an achievable goal. In this context, emotion regulation, or our ability to control our emotional and behavioral response to a situation presents an opportunity to shape individual, and in turn, the collective reaction to a perceived threat. In this study we analyze the temporal dynamics of electroencephalography (EEG) data of human subjects as they are exposed to negative (aversive) images in a laboratory experiment. To assess the effectiveness of extrinsic emotion regulation strategies on the emotional response we further explore the effect of positive distracting cues placed at different locations within the visual field of view. Results from this study have applications in the design of cognitive crowd management strategies.

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MS124

How Curvature Measures and Geometric Structure Influence the Movement of Information in Social Groups

Geometric structure imposes fundamental constraints on the flow of information in complex systems. The importance of geometry is easily identified in cases where spatial structure is important, such as the movement of a large crowd through an environment where obstacles are present. Geometry is equally important to the study of social networks where an underlying structure is provided in the form of a graph. In both cases invariant geometric measures provide a basis to characterize structures and predict their growth. These structural effects can be linked to other aspects of the aggregate behavior. The fundamental relationship between curvature measures and connectivity is of particular interest. Movement of information within a structure depends on how an object is connected. Total curvature is directly related to topological properties. We illustrate this relationship by first considering how the evolution of two-dimensional spatial structures influences phase transition points determined from contact-based diffusion of information in an agent-based model. We further apply these concepts to study information diffusion within social networks based on publicly available data. Relying on the Ricci curvature to provide the geometric signature of a graph, we consider how geometric structure influences the susceptibility of particular social networks to external manipulation.

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MS124

Influence of Social Information on Network Dynamics in Human Groups

In animals and humans, social influence is one of the critical drivers that lead to emergent group behavior. However, a paucity of empirical work hampers our understanding of how social influence shapes the dynamics of inter-individual relationships. We performed a simple cognitive test where participants repeatedly guessed the number of dots flashed on the screen. At each round, we displayed the current answers of all participants and their past performance in selecting correct answers, and participants were allowed to change their answers using this information. We investigated the dynamics of inter-individual relationships through a network analysis by creating a directed link when participants changed their answers to match other group members. We found that the links emerged faster as time progressed, indicating that the rate of the network growth was not constant in time. Further, individuals with higher performance had higher network centrality as time progressed, underscoring the mechanisms of the emergence of leaders and followers. The observed network evolution was corroborated though a simulation study, where individuals change their answers using the information about the past performance of others, rather than a simple majority rule. Our findings demonstrate the adaptive dynamics of social networks, where good performers spontaneously emerge as leaders over time when individuals have access to information regarding the performance of others.

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MS125

Climate System Feedbacks and Their Role in Projections of Future Climate Change

Many positive and negative feedback processes have been identified in the climate system. A well-known positive feedback is the ice-albedo feedback where an increase in ice surface will lead to a higher albedo, reflecting more shortwave radiation, decreasing the surface temperature which leads to ice growth. An example of a negative feedback is the so-called Planck feedback where a surface temperature increase will lead to more outgoing longwave radiation decreasing the surface temperature. Both type of feedbacks are crucial for the internal (natural) variability in the climate system, associated to phenomena such as El Niño Southern Oscillation and the Atlantic Multidecadal Oscillation. In addition, the feedbacks will also determine the response of the climate system, e.g. the global mean surface temperature to increases in radiative forcing (e.g. due to greenhouse gases), and hence are important to assess climate sensitivity. In this talk, an overview will be given on the role of several important feedbacks on the natural and forced response of the climate system and the mathematical tools available to study these responses.

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MS125

Bifurcations and Multi-Frequency Tipping in a Periodically Forced Delay Differential Equation

We study a prototypical delay differential equation, which originally arose in conceptual modelling of the El Niño Southern Oscillation, and comprises of negative feedback and periodic forcing terms both important ingredients for conceptual climate models. For certain parameter values, we observe in simulations the sudden disappearance of (two-frequency dynamics on) tori. This can be explained by the folding of invariant tori and their associated resonance tongues. It is known that two smooth tori cannot simply meet and merge; they must actually break up in complicated bifurcation scenarios that are organised within so-called Chenciner resonance bubbles. We conduct a bifurcation analysis of such a resonance bubble in order to understand the dynamics associated with folding tori. Their role as a mechanism for multi-frequency tipping will be discussed in comparison with models for the Atlantic meridional overturning circulation.

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MS125

Stable Asymmetric Ice Belts in An Energy Balance Model of Pluto

We analyze a latitude-dependent energy balance model with two dynamic ice lines between the north and south poles and consider results for a range of parameter values, of which some may pertain to Pluto. Our analysis shows that for any albedo contrast, there are stable ice line equilibria where the northern and southern edges are not symmetric about the equator. In particular, we find a stable, asymmetric ice belt in roughly the same latitude ranges as Sputnik Planitia on Pluto.

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MS125

A Mid Pleistocene Transition by Frequency Locking in a Zonal Energy Balance Model with Ice Extent

Recent effort in modeling the glacial cycles incorporates the feedbacks from albedo and precipitation based on the mass balance principle and Budyko's energy balance formulation. The model utilizes a latitudinally dependent spatial variable, and therefore, it takes into account orbital contributions from obliquity and eccentricity in the calculation of the solar energy distribution. When ramping of a climate parameter is introduced, the model exhibits a transition both in frequency and amplitude, akin to that of the middle Pleistocene transition. In this talk I will discuss the model, the incorporated feedbacks, and the frequency locking phenomena that give rise to such transition.

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MS126

The Parameterization Method for Computing Periodic and Quasi-Periodic Orbits in Symplectic Maps without Using Symmetries

The search of periodic orbits of high order in symplectic maps has very often been restricted to problems with symmetries that help to reduce the dimension of the search space, in particular using reversibility of the maps. In this talk I will present a new method to compute high order periodic orbits in twist maps without using symmetries that exist in reversible maps. The method relies in a parameterization method implementation in Fourier space used in the past to compute quasi-periodic invariant circles in twist and non twist maps. We use the method to derive scaling exponents and properties of quasi-periodic orbits close to the breakdown of analyticity.

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MS126

Visualizing Chaotic and Regular Orbits in Three and Four Dimensional Maps

Volume preserving and symplectic maps arise naturally as discrete time versions of incompressible and Hamiltonian flows. Both classes have the property that orbits cannot be attracting. Moreover, with enough symmetry and invariants, these systems will be integrable implying that all orbits lie on invariant tori. Upon perturbation, these tori may persist–by KAM theory, or be destroyed–typically by resonance. The dynamics are strongly influenced by the ranks and strengths of these resonances. In the symplectic case the action drifts are constrained by Nekhoroshevs stability theorem, though exponentially long-time drifts due to Arnold diffusion are possible. For the volume-preserving case, these constraints no longer apply. Visualization of

this complex mix of chaotic and regular dynamics and the resulting transport can be aided by strategically computing properties such as Lyapunov exponents, drift times, exit time distributions, and frequency maps on two-dimensional slices. Combining these slices with projections using color maps to visualize the missing dimensions, can lead to a greater understanding of these structures.

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MS126

Rotation Vectors for Invariant Tori Using Weighted Birkhoff Averages

A trajectory is quasiperiodic if the trajectory lies on and is dense in some d-dimensional torus, and there is a choice of coordinates on the torus for which F has the form of a rigid rotation on the torus with rotation vector rho. Previous work with S. Das, Y. Saiki, and J. Yorke developed a fast method of computing rotation vectors using a weighted Birkhoff average method. This same method can be used to distinguish chaotic behavior from regular behavior. We apply this method to three- and four-dimensional maps with invariant two-dimensional quasiperiodic tori and chaotic behavior both occurring for the same parameter value (but distinct initial conditions). We are able to distinguish chaotic orbits from regular orbits and distinguish fully quasiperiodic tori from tubular tori. Inspired by previous work of Fox and Meiss, we use the number theoretic methods of Kim and Ostlund to study the rotation vectors of the most robust tori.

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MS126

Numerical Measures of Heterogeneity and Regularity of Chaotic Systems

Abstract. The dynamics on a chaotic attractor can be quite heterogeneous, being much more unstable in some regions than others. Some regions of a chaotic attractor can be expanding in more dimensions than other regions. Imagine a situation where two such regions and each contains trajectories that stay in the region for all time - while typical trajectories wander throughout the attractor. If furthermore arbitrarily close to each point of the attractor there are points on periodic orbits that have different unstable dimensions, then we say such an attractor is hetero-chaotic" (i.e. it has heterogeneous chaos). This is hard to picture but we believe that most physical systems possessing a high-dimensional attractor are of this type. We have created simplified models with that behavior to give insight to real high-dimensional phenomena. this is joint work with Miguel Sanjuan, Yoshi Saiki, and Hiroki Takahashi)

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MS127

A New View on Integrability: On Matching Dynamical Systems Through Koopman Operator Eigenfunctions

Matching dynamical systems, through different forms of conjugacies and equivalences, has long been a fundamental concept, and a powerful tool, in the study and classification of non- linear dynamic behavior. We will show that the use of the Koopman operator and its spectrum are well suited for this endeavor, both in theory, but also especially in view of recent data-driven machine learning algorithmic developments. Recall that the Koopman operator describes the dynamics of observation functions along a flow or map, and it is formally the adjoint of the Frobenius-Perrron operator that describes evolution of densities of ensembles of initial conditions. The Koopman operator has a long theoretical tradition but it has recently become extremely popular through numerical methods such as dynamic mode decomposition (DMD) and variants, for applied problems such as coherence and also in control theory. We demonstrate through illustrative examples that we can nontrivially extend the applicability of the Koopman spectral theoretical and computational machinery beyond modeling and prediction, towards a systematic discovery of rectifying integrability coordinate transformations.

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MS127

On the Koopman Operator of Algorithms

Most numerical algorithms are acting iteratively on a state variable. In this case, it is possible to treat the algorithm as a dynamical system, where the variable parametrizing integral curves is the iteration number instead of the time. This conceptual shift allows us to employ tools usually used for the study of dynamical systems in the study of numerical algorithms. One powerful tool is the Koopman operator associated to the system, which encodes the evolution of observables on the state. The operator acts linearly on the function space of observables, and thus is amenable to spectral decomposition. Its spectrum allows insight into the qualitative behavior of the underlying system, and even quantitative predictions are possible if enough eigenfunctions of the operator are available. In this talk, we explore the qualitative properties of several important algorithms in numerical optimization through the spectrum of their associated Koopman operator. We provide analytical formulations of the spectra for algorithms applied to convex objective functions and discuss that eigenfunctions - in case they span the function space - are optimal basis functions for forward uncertainty quantification. We also discuss that a crucial difference between iterative maps and continuous time flows leads to fractal structure in the eigenfunctions of many of the operators.

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MS127

Data-Assisted Reduced-Order Modelling of Complex Dynamical Systems

A variety of dynamical systems are characterized by high-dimensional state space and complex intrinsic dynamics. For these systems, numerous modeling approaches have been developed aiming at the reduction of their dimensionality by building directly on equations. However, there is a plethora of systems where this bottom-up approach presents significant limitations. In this talk we will examine the applicability and limitations of machine-learning methods for the development of reduced-order schemes that rely on data (instead of equations). We will begin by considering dynamical systems characterized by chaotic attractors with statistically stationary characteristics. Relying only on data, we will machine-learn the dynamics in reduced-order subspaces utilizing methods such as Gaussian Process Regression and Recurrent Neural Networks. While these approaches perform well for low-intrinsic dimensionalities this is not the case when we have: i) undersampled regions related to extreme/rare events, and ii) attractors with high-intrinsic dimensionality. For such cases we will move away from the purely data-driven philosophy, formulating blended approaches that combine equations with data. Specifically, we will demonstrate how machine-learning methods and imperfect models can be combined to result in accurate predictions schemes. This good performance is robust even for extreme events, where neither purely data-driven schemes nor purely equation-based models perform well.

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MS127

Dynamical Aspects of Reservoir Computing

Reservoir computing (RC) is a neuro-inspired information processing scheme based on the response of a high-dimensional dynamical system, the reservoir, to a real-world driving signal. Recently, reservoir computers have been employed in the context of chaotic time series prediction and reconstruction where they show remarkable performance. This approach allows for a systematic study of the working principles of RC in the language of dynamical systems. A requirement of a reservoir is a state of generalized synchronization with its drive, also known as the echo-state property. We discuss here the concept of consistency for RC, which is a measure for the degree of functional dependency on the driving signal obtained by replica tests. We study the consistency property for echo-state networks, a recurrent-neural network realisation of RC. Consistency at the micro-level of the individual reservoir nodes is distinguished from the emergent consistency of the trained readout. We show that consistency is closely linked to fading memory, tracing the signal propagation in the reservoir. We finally present the consistency profile as a comprehensive portrait of the response in a noisy or chaotic medium. The profile offers a distinguished and practical perspective on the echo-state property and points towards an enhanced understanding of the capacity of a reservoir.

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MS128

Modeling Lost Person Dynamics for Wilderness Search and Rescue

From the International Search and Rescue Incident Database (ISRID), it is known that the behavior of people lost in the wilderness significantly varies depending on characteristics like their age, activity, and mental status. Statistics from this database are an important resource for search and rescue teams, as they inform how the search space may be partitioned and prioritized when a person becomes lost. However, these statistics only describe where lost people are found and fail to recover how trajectories are traversed in the wilderness. Here, we present a dynamic model for a lost person's motion on a landscape using GIS data and statistics from the ISRID. We show that the model is able to recover qualitative characteristics of lost person behavior which can be extracted from the locations where they are found.

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MS128

Queuing Or Pushing: Pedestrian Behavior in Front of Bottlenecks

When people are confronted with a spatial bottleneck, they either follow the social norm of queuing or they start pushing leading to a high density of persons per square meter. Typical bottlenecks where pushing can occur are entrance gates to concert areas. In a recent experiment, we investigated the influence of the width of a corridor leading straight to an entrance gate on the behavior of participants. The corridor width was varied between 1.2 m and 5.6 m while the entrance was 0.5 m wide. The main question is whether there is a critical corridor width limiting queuing behavior and facilitating a pushing behavior. As participants, university students were recruited directly after their lectures. Each group of students had to perform two runs with the same corridor width but different degrees of motivation. For high motivation, the students had to imagine that they want to enter a concert and only the first persons to enter will have an undisturbed view of the stage. For low motivation, they were told that all persons will be able to see the stage. Our findings are mainly based on density and waiting-time measurements. It is shown that wide corridors and a high motivation facilitate a strong contraction followed by a high density indicating a pushing behavior. Narrow corridors and a low motivation lead to a medium density rather indicating a queuing behavior.

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MS128

Robust Social Forces in Agent-Based Models of Crowds

Understanding the various collective states for a crowd and the associated stability regions is crucial for control and optimization of pedestrian traffic in the built environment. Many agent-based social force models contain a large number of arbitrary parameters tuned to the specific situation being simulated. This approach is not very robust; new boundary conditions often require re-tuning of the paramters. In addition to this, unrealistic pathologies may still occur in a given simulation. We discuss here a new approach with a family of situation-dependent, piecewise-linear, and velocity-dependent force functions containing very few fixed parameters. We discuss how this may make simulations more robust as well as remove the most typical pathalogies. We discuss how one may standardize a comparison between social force models.

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MS128

An Experimental Evaluation of the Social Force Model

The Social Force model by Helbing *et al.* is a well-known model that captures the pedestrian flow dynamics. This model is mainly used for crowd evacuation simulations, and it recently has been implemented and tested in virtual reality experiments as well. Here, we evaluate the Social Force model by fitting the model to experimental evacuation data. We use the Wasserstein-2 Distance (or also called the earth movers distance) to find the best fit between the experimental data and Social Force model.

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MS129

Nonlinear and Nonsmooth Problems in Rotordynamics

In this talk I shall give an overview of recent advances in nonlinear problems in rotor dynamics. Among mechanical systems, such problems are unique because there is a large amount of energy in the rotational motion of the system that can excite lateral vibrations with significant amplitude. Also, when posed in a rotating frame, there are large gyroscopic coupling terms that lead to forward and backward whirling modes that are highly non-normal, with the possibility of flutter type instabilties. Nonlinear effects can occur due to the behavior of bearings, autobalancer mechanisms or due to contact with snubber rings or housings. I shall introduce a range of work by me and various collaborators on using techniques from nonlinear dynamics to understand the richness of behaviors. This will include chaotic behavior due to autobalancers, bifurcation between contacting whirling modes due to friction, and recent results on the onset of bouncing orbits away from the primary resonance. I shall explain that these are examples of nonsmooth bifurcations that can arise due to internal resonances.

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MS129

Rotordynamics Near Internal Resonance - When Impacting Orbits Degenerately Graze into Existence

The nonsmooth dynamics of bouncing orbits arisig in a two degree-of-freedom model of a rotating machine in the rigid-stator limit is analyzed. The system, which includes mass unbalance, gyroscopic effects, and damping, is formulated as a hybrid system to represent instantaneous contacts beween the rotor and the bearing. Using linearization techniques for nonsmooth systems a discontinuous map is derived to analyze transistions between non-contacting and contacting motions. We reveal that the interplay between varying the excitation frequency and damping is critical to understanding their effects on the nonsmooth dynamics and bifurcations. The focus of this analysis is a particular type of orbit with zero normal velocity at contact with the bearing, the so called grazing orbit. We show that above the critical speed the undamped system at internal resonance exhibits degenerate families of grazing orbits. However, when damping is introduced these families are eliminated giving rise to a stable periodically impacting but nongrazing orbit, i.e. a bouncing orbit, which can coexist with other impacting and nonimpacting orbits. The map is unfolded analytically and criteria for predicting the excitation frequencies at which bouncing orbits arise are derived. Detailed analytical and numerical results for the 2:1 and 3:2 resonance cases are compared and shown to agree. These results provide a crucial step towards understanding destructive machine vibration.

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MS129

Nonlinear Vibration Localisation in Rotors

Localized vibrations in cyclic and symmetric rotating structures, such as bladed disks of aircraft engines, have challenged engineers in the past few decades. In the linear regime, localised states may arise due to a lack of symmetry. However, when structures deviate from the linear behaviour, e.g. due to material nonlinearities, geometric nonlinearities like large deformations, or other nonlinear elements like joints or friction interfaces, localised states may also arise in perfectly symmetric structures. Here we present a system of coupled Duffing oscillators subjected to external travelling wave forcing. The system may be considered a minimal model for bladed disks in turbomachinery. We demonstrate that near resonances localised vibration states may bifurcate from homogeneous nonlinear travelling waves. Complex bifurcation diagrams result, comprising stable and unstable dissipative solitons.

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MS129

Blade-Tip/Casing Interaction: Phenomena Underlying Rub-Induced Vibrations in Turbomachinery

Occasional contact interactions between blades' tips and casing frequently occur in turbomachines as a result of tight tip clearances. The risk that a sustained regime of repeated contacts would occur is a major concern for engines' manufacturers in that prolonged high amplitude vibrations may threaten blades structural integrity due to high cycle fatigue. The dynamics of a single blade interacting with a casing is investigated in this work under the assumption of perfectly centered rotor. If lateral and longitudinal modes are coupled by the interaction with the casing, friction forces can sustain the motion as a results of mode-coupling instability. A numerical approach is adopted here to seek and trace periodic solutions of the system and assess the conditions under which such regime may exist.

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MS130

Isochrons: from Lie Symmetries to the Parameterization Method and Beyond

In this talk, we will first revise the geometrical ideas that inspired the method to compute the parameterization of isochrons that we proposed in [A. Guillamon, G. Huguet, "A computational and geometric approach to phase resetting curves and surfaces", SIAM J Appl Dyn Syst, 8, 1005-1042, 2009], which rely on both viewing isochrons (level curves of the phase function) as orbits of particular vector fields conjugated by Lie symmetries to the original system, and defining the amplitude on the isochrons by using the parameterization method, see [X. Cabré et al., "The parameterization method for invariant manifolds. III...", J. Differential Equations, 218, 444515, 2005]. Second, we will focus on the opportunities that this quantitative information about isochrons have allowed us to explore: construction of *transient* phase and amplitude response functions and comparison with standard phase response curves [Castejón et al, "Phase-amplitude response functions for transient-state stimuli", J. Math. Neuroscience 3, 2013], refinement of synchronization modes, that is, fine determination of regions in parameter space where oscillators synchronize to external stimuli [O. Castejón, Ph.D.thesis 2015], as well as a new procedure to enhance the accuracy of phase response curves (both for computational and experimental data).

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MS130

Phase-Amplitude Reduction of Rhythmic Patterns in Reaction-Diffusion Systems

The phase reduction method is a classical theory for analyzing synchronization properties of limit-cycle oscillators, which gives a simple one-dimensional phase equation approximately describing the oscillator dynamics. The method can be generalized to include amplitude degrees of freedom, which characterize deviation of the oscillator state from the limit cycle. Recent development in the Koopman operator approach to dynamical systems has revealed that the phase and amplitude variables correspond to Koopman eigenfunctions of the system. In this talk, generalization of the method to spatially extended reaction-diffusion systems with limit-cycle solutions, which correspond to rhythmic spatiotemporal patterns, is discussed. It is shown that phase and amplitude functionals can be introduced for a reaction-diffusion system with a stable limit-cycle solution, and that adjoint linear equations for the sensitivity functions of the phase and amplitudes, characterizing their response properties to weak perturbations, can be derived. Using these sensitivity functions, a set of phase and amplitude equations describing the system dynamics is derived and is used for analyzing synchronization dynamics of rhythmic spatiotemporal patterns.

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MS130

Hybrid Oscillators: Phase and Amplitude in a Class of Non-Smooth Systems

In the last few years there has been a growing interest in composition operator representations of dynamics, also known as 'Koopman Theory', where dynamics are encoded in a semigroup $\mathcal{K}^t$ which acts on 'observables' ψ by advancing them through time. The spectrum of the 'Koopman Operator' $\mathcal{K}$ and its eigen-observables lead to many useful applications when the spectrum is discrete. The case of 'principal' eigen-observables with discrete spectrum generalizes many known results from classical dynamical systems theory. We present some early results on Bouligand differentiable observables: functions which have a directional derivative which is also a first-order approximation. These functions arise more often than most realize – the flows of many hybrid systems [Burden, et.al. SIADS 2016], and most commonly used norms are in this class. Of particular interest to the workshop attendees is the latter observation, which is closely related to action variables in action-angle coordinates. We will show some cases where action-angle coordinates can be obtained for systems described in terms of Bouligand differentiable observables, and discuss some of the related Koopman theory.

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MS130

Understanding the Mechanisms of the East-West Asynchrony in Jet-Lag Recovery

It is well known jet-lag lasts longer after eastward travel as compared to westward travel. However, the exact mechanism behind this asynchrony is not well understood. Many dynamical systems explanations invoke the fact that the free-running period of our circadian cycles is about 24.5 hours (slightly longer than a 24 hour day), but these explanations do not match perfectly with experimental evidence. Here, an alternative mechanism is investigated. Specifically, in a phase-amplitude reduced model of circadian oscillations, it is observed that the amplitude coordinates are significantly altered during recovery from circadian misalignment. Subsequently, phase-amplitude coupling can impact recovery times. General results for collective phase sensitivity in weakly perturbed coupled oscillators will also be discussed.

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MS131

Multidimensional Manifold Continuation for Adaptive Boundary-Value Problems with COCO

COCO is a MATLAB-based software platform for constructing composite continuation problems, mapping out their solution manifolds, and locating special points on these manifolds. COCO's core provides general-purpose support for these tasks, making the platform versatile and flexible, even at run time. COCO toolboxes exemplify common classes of problems that arise in dynamical systems theory, e.g., bifurcation analysis and design optimization. COCO atlas algorithms characterize an implicitly defined manifold in terms of minimally overlapping charts, and implement iterative techniques for constructing atlases that cover portions of a manifold without redundancy or gaps. A COCO atlas algorithm originally developed in collaboration with Michael Henderson, Frank Schilder, and Erika Fotsch, and modeled on the Multifario package, accomplishes such an efficient coverage of arbitrary-dimensional manifolds for algebraic problems. It fails to accommodate continuation problems that change after each continuation step. Such changes can be associated with updated phase conditions in the study of periodic orbits, or with adaptive remeshing of the solution to a boundary-value problem. This presentation describes a new atlas algorithm, as well as its implementation in COCO, that overcomes this obstacle by analyzing the manifold geometry in a projected space, distinct from that in which a nonlinear solver is applied to a discretized version of an infinite-dimensional continuation problem.

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MS131

The Brain Dynamics Toolbox

The Brain Dynamics Toolbox is an open-source Matlab toolbox for simulating dynamical systems in neuroscience. Specifically, it solves initial-value problems in systems of Ordinary Differential Equations (ODEs), Delay Differential Equations (DDEs) and Stochastic Differential Equations (SDEs). It makes use of the existing Matlab ODE and DDE solvers (e.g. ode45, dde23) and provides new solvers for SDEs in Ito and Stratonovich form. The user defines their system of equations as a Matlab function using the conventional approach. The graphical interface allows any combination of display panels (plots) and numerical solvers to then be applied to that system of equations with no additional programming effort. This fosters intuitive exploration of the dynamics for both research and teaching purposes. Users can also augment the toolbox with custom display panels and solver routines. Large-scale simulations can be run from user-defined scripts without invoking the graphical interface. The toolbox can thus be used at all stages of the research cycle, from rapid explorations to systematic large-scale investigations.

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MS131

Applications of Spectral Submanifolds in Nonlinear Modal Analysis using SSMtool

SSMtool is a MATLAB-based computational tool for computing two-dimensional spectral submanifolds (SSMs) in nonlinear dissipative mechanical systems with arbitrary degrees of freedom. As shown recently, the reduced dynamics on SSMs (the smoothest nonlinear continuations of modal subspaces of the linearized system) provide mathematically exact reduced models for the nonlinear system. The graphical user interface of SSMtool allows the user to import/define their nonlinear mechanical system and compute the SSM over an arbitrarily chosen spectral subspace under appropriate nonresonance conditions. Additionally, SSMtool will compute the reduced dynamics on the SSM and extract associated backbone curves, i.e., instantaneous amplitude-frequency plots of the reduced motion. In this presentation, we demonstrate several applications of SSMs to multi-degree-of-freedom mechanical systems using SSMtool. In addition, we show how the current algorithm, which only covers autonomous systems, will be extended to the non-autonomous case.

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MS131

Emergence and Macroscopic Behavioural ExtRaction (EMBER): Challenges and Opportunities

EMBER (Emergence and Macroscopic Behavioural ExtRaction is a generalised analysis tool for numerical continuation and bifurcation analysis of nonlinear stochastic systems or those without a closed form solution or macroscopic equation of state. The code is based on equation-free techniques to side-step the need for a description in terms of differential or difference equations, so that path-following, location of codimension one bifurcations and extraction of statistical descriptors of a system or simulation model can be performed. EMBER includes a method for determination of appropriate algorithmic parameters based on the dynamics of the system and a robust continuation method to cope with highly noisy systems. EMBER is written in java for compatibility with windows, mac and linux operating system. It has an object-orientated design (OOD) to facilitate use with an application programming interface (API). The OOD enables aspects of the code to be encapsulated to increase code usability and upgrades. The current version includes an API for the well-known agent-based simulation package Netlogo.

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MS132

Boundary Update via Resolvent for Fluid-Structure Interaction

We present a Boundary Update using Resolvent (BOUR) partitioned method, second-order accurate in time, unconditionally stable, for the interaction between a viscous, incompressible fluid and a thin elastic structure. The method is algorithmically similar to the sequential Backward Euler - Forward Euler implementation of the Crank-Nicolson discretization scheme. (i) The structure and fluid sub-problems are first solved using a Backward Euler scheme, (ii) the velocities of fluid and structure are updated on the boundary via a second-order consistent resolvent operator, and then (iii) the structure and fluid sub-problems are solved again, using a Forward Euler scheme. The stability analysis based on energy estimates shows that the scheme is unconditionally stable. Error analysis of the semi-discrete problem yields second-order convergence in time. We will present two numerical examples confirming the theoretical convergence analysis results and showing an excellent agreement of the proposed partitioned scheme with a monolithic scheme.

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MS132

Control of Multiple Elastic Actuators by a Single Input via Interaction Between Viscosity and Bi-Stability

Fluidic actuation of elastic media is an effective actuation method in soft robotics and other applications. This actuation method is commonly based on a network of elastic chambers filled with a pressurized fluid. Creating complex deformation patterns requires large numbers of such actuators. Generally, the control of n chambers requires n pressure inlets in order to determine the pressure and deformation at each chamber, which greatly limits the applicability of such soft actuators. A possible solution is using bi-stable elements which have the ability to jump between different discrete equilibrium states due to stability transitions induced by their characteristic energy profile. The presented research combines experiments and mathematical modelling of a chain of bi-stable thin-shell hyper-elastic chambers connected in series to a single inlet with controlled input of pressure or flow rate. Viscosity of the fluid in connecting tubes is exploited for inducing delay in the elements response, which enables controlling the transitions between different combinations of the chambers' states in a desired sequence. The suggested technique has a promising potential for development of soft-actuators capable of generating complex deformation with a single control input relevant to applications such as soft-robotics and lab-on-a-chip microfluidic devices.

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MS132

Geometric Theory of Flexible and Expandable Tubes Conveying Fluid: Equations, Solutions and Shock Waves

We present a theory for the three-dimensional evolution of tubes with expandable walls conveying fluid. Our theory can accommodate arbitrary deformations of the tube, arbitrary elasticity of the walls, and both compressible and incompressible flows inside the tube. We also present the theory of propagation of shock waves in such tubes and derive the conservation laws and Rankine-Hugoniot conditions in arbitrary spatial configuration of the tubes, and compute several examples of particular solutions. The theory is derived from a variational treatment of Cosserat rod theory extended to incorporate expandable walls and moving flow inside the tube. The results presented here are useful for biological flows and industrial applications involving high speed motion of gas in flexible tubes.

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MS132

A Nonlinear ALE-FSI Solver for Cardiovascular Applications within the CRIMSON Framework

CRIMSON (CardiovasculaR Integrated Modelling and SimulatiON) is a three-dimensional modeling and simulation software environment for patient-specific computational hemodynamics. CRIMSON employs the Coupled Momentum Method (CMM) wherein the vessel wall is treated as a linear membrane exhibiting small deformations. This allows solving a fluid-structure interaction (FSI) problem without having additional degrees of freedom and with a fixed mesh. Overall, this approach has proven to be very robust and has provided numerous clinically relevant results, albeit in the infinitesimal strain regime. In this work, we extend the capabilities of CRIMSON to consider scenarios that exhibit large deformations of vessel wall, such as the motion of ascending thoracic aorta and venous system. We treat the vessel wall as a nonlinear membrane using a Total Lagrangian formulation based on convective coordinates, while the fluid is treated via an Arbitrary Lagrangian Eulerian (ALE) approach using stabilized finite element scheme. As in the CMM, the membrane degrees of freedom are shared with those of the fluid boundary, so no additional degrees of freedom are introduced for the solid. The mesh motion is handled using 3D linear elasticity and the time integration is performed using the generalized alpha method. We present specific benchmark cases demonstrating the accuracy of the implementation as well as applications of the ALE-FSI formulation for investigating patient-specific hemodynamics.

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MS133

Influence of Nonlinear Pump-Signal Wave Interaction on Non-Reciprocal Behavior in Modulated Spring-Mass Chains

Non-reciprocal acoustic and elastic systems have recently received great attention due to their potential to increase control over wave propagation and to have far-reaching impacts on engineering applications, such as more efficient acoustic communication devices and vibration isolation. One method of breaking reciprocity is to introduce spatiotemporal modulation of material properties in the medium carrying the signal of interest. This is typically done using electromagnetic actuation. Recent work presented a discrete lattice model for a tunable mechanical metamaterial as a platform to achieve non-reciprocity, where a slow, nonlinear pre-strain ("pump wave') caused modulations of the effective linear stiffness of fast, small-amplitude waves propagating in superposition ("signal wave') [S.P. Wallen and M. R. Haberman, arXiv:1808.04442, (2018)]. However, this analysis was restricted to slow, weak modulations, such that the pump wave could be treated as quasi-static and the signal wave could be described using an effective linear, time-dependent lattice model. In the present study, we extend this analysis to the case of stronger and faster modulation, such that the pump and signal waves become dynamically coupled via nonlinearity. We discuss the effect of increasing nonlinearity on the strength of non-reciprocity, highlighting example cases via direct numerical simulations. Work supported by NSF EFRI NewLAW program.

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MS133

Non-Reciprocal Acoustics in Nonlinear Lattices

Acoustic non-reciprocity in strongly nonlinear, damped lattices is considered. Specifically, breather arrest, localization and non-reciprocal wave transmission is demonstrated in non-symmetric, dissipative, strongly nonlinear lattices consisting of a repetitive number of identical cells of linearly grounded, large-scale particles nonlinearly coupled to small-scale particles, and linear intra-cell coupling. Insight into the non-reciprocal acoustics is gained by considering the topological features of the nonlinear passbands and stopbands of these lattices in the frequency-energy domain, and performing wavelet transforms of the lattice responses. Depending on the position of an applied impulsive excitation, acoustic non-reciprocity reveals itself either through energy localization at one of the lattice boundaries or breather arrest at the other. In addition, the surprising effects on the lattice acoustics of possible linear components in the nonlinear stiffnesses connecting the large and small scales within a cell are considered and investigated.

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MS133

Dynamic Response of Non-Linearly Coupled Chain of Parametrically Forced Oscillators

Dynamics of nonstationary regimes remains one of the intensively studied topics of applied physics and engineering sciences. These regimes are manifested by either weak or strong modulation of the response amplitude. In fact, there is a large amount of theoretical and experimental studies dedicated to understanding of these regimes in various systems. However, to the best of our knowledge, less attention has been paid to the effect of essentially nonlinear coupling and parametric forcing on the formation of these regimes in the homogeneous oscillatory chains. Present study concerns the analysis of stationary and nonstationary response regimes emerging in the dissipative, parametrically forced and nonlinearly coupled oscillatory models. We studied the formation and destruction of special regimes of intense nonlinear beats emerging in the two - and N - oscillator chains, assuming essentially nonlinear coupling. We expanded our study to include special localized solutions supported by the parametrically driven and the non-linearly coupled chains which are commonly referred to as discrete breathers. We showcase a very good correspondence between the results of the asymptotic and numerical analysis.

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MS133

Nonlinear Wave-Particle Resonances and Energy Exchange in the Earth's Magnetosphere

In this talk we discuss the resonant energy exchange between charged particles and electromagnetic waves in the earth's magnetosphere. We start with a review of magnetospheric settings where the resonant wave-particle interaction is significant. We illustrate the differences of the particles acceleration by trapping into resonance and scattering on resonance. We derive a Fokker-Plank-type of the equation for the probability distribution function (PDF). We consider particles acceleration by a couple of different types of the electromagnetic waves, such as whistler mode chorus waves and ultra-low-frequency waves. Finally we show how the evolution equation for particles PDF can be generalized for the case when multiple waves are present.

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MS134

A Mathematical Investigation of the Local/Nonlocal Interactions Behind the Sorting and Collective Movement of Dictyostelium Discoideum Aggregations

Collective migration is an important phenomenon in many biological processes: from morphogenesis to wound healing and even cancer metastasis. Here we focus on Dictyostelium Discoideum aggregations, which represent a classical toy model for understanding biological processes in development, in the context of heterogeneous populations. We develop a class of nonlocal transport models for cell movement that incorporate both chemotactic and mechanical cell-cell interactions. We then use these models to investigate and classify the biological mechanisms that control the movement and spatial segregation of cells, as well as their de-differentiation and proportionality inside moving cell aggregations.

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MS134

Confined Self-Propelled Objects: Some Exact Results and Some Fish Tracking

There's a growing realization that the collective behavior of self-propelled objects often cannot be properly understood without understanding their relationship to their confining boundary. I'll start with a few exact theoretical results on the way boundaries and confining potentials shape the behavior of self-propelled systems. Then I'll discuss my recent efforts to apply active matter paradigms to live fish behavior, from data collection, to wall interactions, to collective effects.

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MS134

Collective Motion of Coarse-Grained Simulated Bacterial Twitchers

Pseudomonas aeruginosa, like many baciliforms, are not limited only to swimming motility but rather possess many motility strategies. In particular, twitching mode motility employs hair-like pili to transverse moist surfaces with a jittery irregular crawl and plays a critical role in redistributing cells on surfaces prior to and during colony formation.

We combine molecular dynamics and rule-based simulations to study the twitching motility of model baciliforms and show that there is a critical surface coverage fraction at which collective effects arise. Our simulations demonstrate dynamic clustering of twitcher-type bacteria with polydomains of local alignment that exhibit spontaneous correlated motions, reminiscent of the rafts of many bacteria in bacterial communities. Although our study greatly simplifies twitcher-type bacteria by neglecting species-specific and biologically mediated complexities, we find cooperative action arising from physical mechanisms across all scales.

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MS134

Emergent Flows in Confined Incipient Active Nematics

Suspensions of bacteria such as Myxococcus xanthus and Paenibacillus dendritiformis that exhibit nematic alignment and velocity reversal, can be modeled at the hydrodynamic scale using the dynamic equations of a nematic liquid crystal coupled to an internally driven Stokes equation. We present a stable numerical method that uses an implicit time stepping scheme (arrived at through a convex splitting on the nematic free energy, which makes numerical stability possible at large time steps) and a multigrid solution method (which makes use of the fact that the equations involved have smooth solutions to speed up the iterative solution process) combined with a Vanka type box smoothing algorithm on a staggered grid (to solve the Stokes equation) for this model. Solving the hydrodynamic model for the special case of dilute suspensions of elongated particles that exert extensile stresses on their surrounding fluid, we find emergent flow patterns that depend on strength of the confinement and internal driving.

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MS135

Canards in Excitatory Networks

In this talk, I will study the slow-fast dynamics of a network of quadratic integrate-and-fire neurons and their excitability property, at both single node and network level, as well as in the mean-field limit.

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MS135

Mind the Canard: Taking An Aircraft for a Spin on the Ground

Aircraft are designed to fly but also need to operate efficiently and safely as vehicles on the ground. The tricycle configuration of commercial aircraft presents challenges for manoeuvres, such as high-speed turns off a runway. The bifurcation analysis of an industry-validated model shows that the sudden loss of lateral stability of a mid-size passenger aircraft turning on the ground is due to a canard phenomenon, which arises from a non-obvious slow-fast splitting. We present a canonical two-dimensional slow-fast vector field model that captures the key feature of a slow manifold with an asymptote. Physically, the canard phenomenon represents the saturation in quick succession of the lateral holding forces at both main landing gears.

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MS135

Advances in GSPT: Teaching New Tricks to an Old Dog

Due to the efforts of many people geometric singular perturbation theory (GSPT) has developed into a very successful branch of applied dynamical systems. GSPT has proven to be very useful in the analysis of an impressive collection of diverse problems from natural sciences, engineering and life sciences. Fenichel theory for normally hyperbolic critical manifolds combined with the blow-up method at non-hyperbolic points is often able to provide remarkably detailed insight into complicated dynamical phenomena, often even in a constructive way. Much of this work has been carried out in the framework of slow-fast systems in standard form, i.e. for systems with an a priori splitting into slow and fast variables. More recently GSPT turned out to be useful for systems for which the slow-fast structures and the resulting applicability of GSPT are somewhat hidden. Problems of this type include singularly perturbed systems in non-standard form, problems depending singularly on more than one parameter and smooth systems limiting on non-smooth systems as a parameter tends to zero.

Often several distinct scalings must be used to cover the dynamics of interest and matching of these different scaling regimes is carried out by the blow-up method. In this talk I will survey these developments and highlight some ongoing activities.

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MS135

Pseudo Singularities and Canards and Non-Standard Singular Perturbation Problems

This talk is concerned with dynamic (slow) forcing of an excitable system which is modelled as a singularly perturbed systems in non-standard form. We identify the key geometric elements to describe excitability. At the heart of the issue lies the relative position of the pseudo saddle canard that forms the threshold manifold in these models relative to the equilibrium state of the underlying excitable system before the slow modulation (forcing) kicks in. Dynamic forcing has the potential to create pseudo singularities and to form these effective separatrices or to change the global return mechanism. Hence, the specific nature of the dynamic forcing determines which local attractor states can be reached through global mechanisms. This point of view has profound consequences in the analysis of excitable systems.

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MS136

Derivation of Delay Equation Climate Models using Projection Methods

Delay equations have been frequently used to model feedback mechanisms and understand variability in climate. Often the delay is introduced in an ad-hoc manner based on physical reasoning. Projection methods can be used to give the use of these delay models a mathematical foundation. Through projecting a system onto a set of resolved variables, one can obtain a rewritten system containing a memory term which under some assumptions can be written as a delayed feedback term with discrete delay. We explore two projection methods; one based on the Mori-Zwanzig formalism and one using variation of constants. We apply these methods to a two-strip model of the El Nio Southern Oscillation and compare to a previously proposed delay differential equation model. The resulting delay differential model contains an additional term, leading to an increase in period. This makes the model closer to observational data. We discuss how these methods can be extended to general hyperbolic partial differential equations.

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MS136

Noise-Induced Tipping in a Periodically Forced System: The Noise-Drift Balanced Regime

We consider a simple periodically-forced 1-D Langevin equation, motivated by the feedback-driven Eisenman-Wettlaufer model, which possesses two stable periodic orbits in the absence of noise. We ask the question: is there a most likely transition path between the stable orbits that would allow us to identify a preferred phase of the periodic forcing for which tipping occurs? The regime where the forcing period is long compared to the adiabatic relaxation time has been well studied. Our work complements this by focusing on the regime where the forcing period is comparable to the relaxation time. We compute optimal paths using the least action method which involves the Onsager-Machlup functional and validate results with Monte Carlo simulations in a regime where noise and drift are balanced. Results for the preferred tipping phase are compared with the deterministic aspects of the problem. We identify parameter regimes where nullclines, associated with the deterministic problem in a 2-D extended phase space, form passageways through which the optimal paths transit. As the nullclines are independent of the relaxation time and the noise strength, this leads to a robust deterministic predictor of a preferred tipping phase for the noise and drift balanced regime.

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MS136

Permafrost Melt and its Effects on Planetary Energy Balance

We propose a conceptual model for permafrost melt as a single-column model of heat convection through frozen soil, with seasonally-varying forcing at the surface of the soil and constant heat flux from the mantle below. We simulate increasing greenhouse gases as changes to the boundary condition at the surface of the soil, which leads to permafrost melt from below. We will explore possible coupling between this equation and the Budyko-Sellers energy balance model and the added effect of permafrost melt on

feedbacks in the system.

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MS136

Dynamical Systems Analysis of the MaaschSaltzman Model for Glacial Cycles

The geological record shows great variability of Earths climate. During the Pleistocene Epoch, ice sheets expanded and contracted over significant areas, especially in the Northern Hemisphere, in a more or less cyclical fashion. In this talk I will discuss a conceptual model first presented by Maasch and Saltzman (1990) to explain this persistence of glacial cycles as the result of the interaction of atmospheric carbon dioxide and the strength of the North Atlantic overturning circulation.

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MS137

Lessons from a Systematic Cross-Industry Exploration of Historic Changes in Female Representation

Female representation has been slowly but steadily increasing in many sectors of society. Still, most fields struggle to reach gender parity. One field where one would not expect to observe a gender imbalance, however, is in motion picture casts. Indeed, while there are many areas of achievement where it is much easier to name prominent men than women, acting is not one of them. We studied the historical patterns of female representation among actors, directors, and producers and attempt to gain insights into the causes of the lack of gender parity in the industry. We investigated the impact of gender diversity within a movies producing team on the gender of the director and impact of producing team gender diversity and director gender on the gender balance of other movie-making functions. In both cases, we find strong, significant correlations suggesting an important role for the gender of decision makers on the gender balance of other industry functions. While specific to the movie industry, our study has broader implications because it suggests that periods in which an industry grows in importance, with increasing financial rewards, and with greater consolidation, may be particularly susceptible to collapses of diversity. Our findings can be added to the known examples of gender discrimination in such areas as computer science, medicine, and literature.

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MS137

Mathematical Model of Gender Bias and Homophily in Professional Hierarchies

Women have become better represented in business, academia, and government over time, yet a dearth of women at the highest levels of leadership remains. Sociologists have attributed the leaky progression of women through professional hierarchies to various cultural and psychological factors, such as self-segregation and bias. Here, we present a minimal mathematical model that reveals the relative role that bias and homophily (self-seeking) may play in the ascension of women through professional hierarchies. Unlike previous models, our novel model predicts that gender parity is not inevitable, and deliberate intervention may be required to achieve gender balance in several fields. To validate the model, we analyze a new database of gender fractionation over time for 16 professional hierarchies. We quantify the degree of homophily and bias in each professional hierarchy, and we propose specific interventions to achieve gender parity more quickly.

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MS137

The Dynamics of Unorganized Segregation

Schellings seminal work on segregation [Schelling, T. C. (1969). *Models of segregation*. The American Economic Review, 59, 488–493; Schelling, T. C. (1971). *Dynamic models of segregation*. The Journal of Mathematical Sociology, 1, 143–186] is well known for its use of agent-based modelling to explain unorganized segregation. What appears less well known is that in the same two papers, Schelling also introduced another model, the bounded neighbourhood model (BNM) of unorganized segregation. In this talk, we consider Schellings BNM from the perspective of dynamical systems. We carry out a complete quantitative analysis of the model for linear tolerance schedules. We derive a fully predictive model and associate each term with a social meaning. We recover and generalize Schellings qualitative results. For the case of unlimited population movement, we derive exact formulae for regions in parameter space where stable integrated population mixes can occur and show how neighbourhood tipping can be explained in terms of basins of attraction. When population movement is limited, we derive exact criteria for the occurrence of new population mixes. We also present results on the interaction of two or more neighbourhoods. See D. J. Haw & John Hogan (2018) *A dynamical systems model of unorganized segregation*. The Journal of Mathematical Sociology, 42, 113–127

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MS137

Creating Predictive Models for Racial Affirmative Action Policies in U.S. Undergraduate Admissions

Affirmative action refers to hiring and recruiting practices designed to combat discrimination against members of certain demographic groups. These policies are used in settings ranging from federal contractors to local employment to public education and can focus on race, ethnicity, or gender. Due to the broad applicability and direct social impact of affirmative action, substantial effort has gone into monitoring the necessity and effectiveness of these policies. We focus on the application of race-based affirmative action policies in U.S. public undergraduate college admissions, specifically through a case study of admissions to the University of California, Berkeley. We make three primary contributions to policy assessment. First, we introduce a quantitative framework through which to interpret a key concept used in contemporary affirmative action litigation: critical mass. Second, we construct a predictive model of college admissions demographics using Markov chains. Third, we bring together the two previous contributions, using our quantified version of the critical mass criterion as a benchmark for assessing the outcomes of the predictive model.

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MS138

Noisy Ensemble Kalman Inversion

Solving inverse problems without the use of derivatives or adjoints of the forward model is highly desirable in many applications arising in science and engineering. In this work, the objective is the construction of methods which generate approximate samples from the Bayesian posterior distribution that solves the inverse problem. The starting point is the continuous time limit of Ensemble Kalman Iversion (EKI). We introduce a specific form of additive noise to the deterministic flow, leading to a stochastic differential equation (SDE), and consider an associated SDE which approximates the original SDE by replacing function evaluation differences with exact gradients. We demonstrate that the nonlinear Fokker-Planck equation defined by the mean-field limit of the associated SDE has a novel gradient flow structure, built on the Wasserstein metric and the covariance matrix of the noisy flow. Using this structure, we investigate large time properties of the SDE in the case of a linear observation map, and convergence to an invariant measure which coincides with the Bayesian posterior distribution for the underlying inverse problem. We numerically study the effect of the noisy perturbation of the original derivative-free EKI algorithm, illustrating that it gives good approximate samples from the posterior distribution.

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MS138

State and Parameter Estimation for Sonar Bias Mitigation in Autonomous Underwater Navigation

Autonomous underwater navigation requires simultaneous estimation of the vehicle state and the surrounding environment. Underwater navigation typically depends on sonar readings and a bathymetric reference map, so that the problem of position estimation amounts to determining the most probable location of the sonar readings given all prior information. Matching sonar to map depends on the sonar path, which may be approximated as a straight line (with speed calculated from the average temperature in the water column), introducing a bias. This algorithm mitigates the bias of a straight line approximation of the sonar ray path by assigning the sensor data to multiple possible cells on the reference map in proportion to the probability of that path. This method is an extension of the Bayesian Occupancy filter.

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MS138

Projected Data Assimilation

I will derive the fundamental equations for a data assimilation problem in which the observations have been projected into a subspace of model space. The result is to obtain 'projected data' with dimension equal to the rank of the projection. The main application will be where the projection is into the subspace corresponding to the largest Lyapunov exponents of the model. In this case the formulation is a novel approach to the Assimilation in the Unstable Subspace methodology. This approach will be shown to greatly reduce filter degeneracy with increasing model/data dimension and consequently to improve the particle filter accuracy.

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MS138

Sequential Bayesian Drift Estimation and Model Selection in Stochastic Dynamical Systems

From a Bayesian perspective, data assimilation is used to estimate a posterior probability distribution over model states and parameters, conditioned on noisy data time series. The model itself must additionally be inferred from data if it is not fully specified, posing a significant challenge in nonlinear systems observed in discrete time at low frequency. In this context, we investigate the use of nonparametric, Bayesian sequential Monte Carlo methods for drift estimation and model selection in nonlinear stochastic differential equation (SDE) systems observed in discrete time, with a Gaussian process prior on drift functions. Computationally, difficulties arise in the nonparametric setting from the associated high-dimensional estimation problem, and additionally nonlinear drift terms make the likelihood difficult to compute and lead to non-Gaussian posterior distributions. We use several numerical examples in one and two dimensions to show under what conditions the drift is recoverable from data, in particular investigating the effects of various errors introduced by likelihood approximations, the influence of prior covariance and hyperparameter selection on posterior estimates, and the application of localization techniques to GP drift priors to improve computational efficiency and avoid issues of finite sample size in extended systems.

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MS139

Stabilization of Mechanical Systems with Broken Symmetry

Using the method of Controlled Lagrangians, we develop a general theory for stabilizing mechanical systems whose original configuration space is a semi-direct product $S = GV$ of a Lie group G and a vector space V, and their Lagrangian has broken symmetry due to the presence of gravity. By using advected parameters, we extend the configuration space to the semi-direct product SV^* to recover the symmetry of the system. The resulting Euler–Poincaré equations governing the system dynamics involve terms that account for the interaction of linear and rotational motions, where only the linear part is directly controlled. We obtain the matching condition for the controlled Lagrangian system as well as conditions for asymptotically stabilizing a heavy top spinning on a movable base.

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MS139

Variational Methods for the Dynamics of Porous Media

We use the variational approach to derive the equations of motion of compressible homogeneous elastic porous media filled with an incompressible non-viscous fluid. The total energy density equation is computed in the form of a conservation law. The linearization of the system of equations is found and investigated to confirm the stability of wave propagation. Phase and group velocities of $s-$ and $p-$ waves and corresponding attenuation coefficients are computed numerically for a number of non-dimensional parameter sets. We compared our linearized system with the equations of porous mechanics from Biot's 1962 paper and found a partial correspondence of our parameters with Biot's phenomenological coefficients.

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MS139

Dynamics of Mechanically Coupled Nonholonomic Systems

It's been known since the time of Huygens that pendulum clocks mounted to a common mantel will synchronize as a result of mechanical coupling. This talk will explore the influence of analogous coupling on the dynamics of wheeled vehicles rolling atop a common platform. The Chaplygin sleigh surmounted by an actuated rotor, in particular, has been shown previously to exhibit interesting properties as a nonlinear control system and as a simplified model for a rotor-driven aquatic vehicle. It will be shown that a passive version of such a device, involving a spring-loaded rotor, can be induced to reorient and follow an active version of the device when the two are coupled through a common support, recalling the entrainment of passive bodies by active bodies that's commonly observed, but attributed to more complicated coupling, in fluids.

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MS139

The Connections Between Discrete Geometric Mechanics, Information Geometry and Machine Learning

Geometric mechanics describes Lagrangian and Hamiltonian mechanics geometrically, and information geometry formulates statistical estimation, inference, and machine learning in terms of geometry. A divergence function is an asymmetric distance between two probability densities that induces differential geometric structures and yields efficient machine learning algorithms that minimize the duality gap. The connection between information geometry and geometric mechanics will yield a unified treatment of machine learning and structure-preserving discretizations. In particular, the divergence function of information geometry can be viewed as a discrete Lagrangian, which is a generating function of a symplectic map, that arise in discrete variational mechanics. This identification allows the methods of backward error analysis to be applied, and the symplectic map generated by a divergence function can be associated with the exact time-h flow map of a Hamiltonian system on the space of probability distributions

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MS140

Singular Perturbation Analysis of a Regularized MEMS Model

Micro-Electro Mechanical Systems (MEMS) are defined as very small structures that combine electrical and mechanical components on a common substrate. Here, the electrostatic-elastic case is considered, where an elastic membrane is allowed to deflect above a ground plate under the action of an electric potential, whose strength is proportional to a parameter λ. Such devices are commonly described by a parabolic partial differential equation that contains a singular nonlinear source term. The singularity in that term corresponds to the so-called touchdown phenomenon, where the membrane establishes contact with the ground plate. Touchdown is known to imply the nonexistence of steady state solutions and blow-up of solutions in finite time. In this talk we analyze a recently proposed extension of that canonical model, where such singularities are avoided due to the introduction of a regularizing term involving a small regularization parameter ε. Methods from dynamical systems and geometric singular perturbation theory, in particular the desingularization technique known as blow-up, allow for a precise description of steady-state solutions of the regularized model, as well as for a detailed resolution of the resulting bifurcation diagram. The interplay between the two main model parameters ε and λ is emphasized; in particular, the focus is on the singular limit as both parameters tend to zero.

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MS140

Dynamic Networks with Two Timescales

Dynamic consensus problems over a network concern interacting agents looking to achieve a common goal. Commonly, consensus problems are considered over graphs with fixed positive weights. In this talk we analyze a simple dynamic consensus problem defined over an undirected graph. The novelty is that one of the edges is dynamic itself taking values over the reals. Furthermore, it is assumed that the weight depends on a slow exogenous variable. This setting leads to the study of a fast-slow dynamical system defined over a network. We show that due to the dynamic nature of the weight, transition through a (degenerate) transcritical singularity leads to loss of consensus. A detailed analysis and description of the transition through the singularity is performed based on the blow-up method. We also describe what the blow-up transformation does to the network's structure. Interesting dynamic behavior including periodic trajectories and jumps shall be described as well.

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MS140

Mixed-Mode Oscillations and Bistability in a Predator-Prey Model with Two Time-Scales

A two-trophic ecosystem comprising of two species of predators competing for their common prey with explicit interference competition is considered. With a proper rescaling, the model is portrayed as a system of singularly perturbed equations with one-fast (prey dynamics) and two-slow variables (dynamics of the predators). In a parameter regime adjacent to the singular Hopf bifurcation, the model exhibits variety of rich and complex dynamics including mixed-mode oscillations (MMOs) and coexistence of chaotic dynamics with a periodic attractor. To analyze the bistable regime, the model is reduced to its normal form near the singular Hopf point. The normal form admits MMOs with unbounded number of small amplitude oscillations in their signatures suggesting that a Shil'nikov homoclinic orbit exists in a neighborhood of these MMOs. The singular Hopf point is ecologically significant as it serves as a tipping point, where a dramatic transition in population dynamics can occur with a tiny increment in an input parameter. The existence of the bistable regime near this tipping point can also provide useful insights for management options.

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MS141

A Multilayer Discontinuous Approach to Achieve Convergence in Networks of Piecewise-Smooth Systems

Mechanical gears, biological neurons, diodes, tectonic faults can all be modelled by sets of piecewise-smooth ODEs. Much effort has been devoted to characterise the nonlinear dynamics of a piecewise-smooth system, but the pressing open problem remains of studying the collective behavior of interacting ensembles of such systems. This is of practical importance in many applications. For example, synchronous neuronal spikes are thought to have a crucial role in activities such as vision and motor coordination, while load synchronization in power grids must be maintained despite a plethora of possible discontinuous macroscopic factors (power electronic devices, node failures etc.). In this talk, we will present our latest results on convergence of networks of diffusively coupled Filippov systems. Our emphasis will be on obtaining sufficient conditions for global transversal stability of the synchronization manifold. We will start by investigating the critical coupling gain necessary to achieve bounded synchronization. Then, we will show that the addition of a discontinuous coupling layer can be effective to achieve global asymptotic convergence to the synchronization manifold, despite the presence of switching and heterogeneities among the nodes. Moreover, we will discuss how the structure of this additional coupling layer can affect the dynamics of the network under different circumstances. All theoretical results will be illustrated via numerical simulations.

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MS141

Swings, Spiders and Piecewise-Smooth Models of

Actuated Pendulums

Children adjust their position on playground swings to create oscillations. Spiders shake their webs to confuse predators using a similar strategy. Adapting an approach of Wirkus, Rand and Ruina (S. Wirkus, R. Rand and A. Ruina, 1998, How to pump a swing, College Math. Journal **29** 266-275) we develop piecewise smooth models for the spiders' strategies and investigate the 360 degree turnover problem for a playground swing. A real 360 degree swing reveals an interesting (i.e. dangerous) instability at the pivot of the swing, and we describe possible mathematical mechanisms for such instabilities.

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MS141

Towards a General Bifurcation Theory for Equilibria of Piecewise-Smooth Odes

In this talk I'll give an introduction to bifurcation theory for piecewise-smooth ODEs — how it is different to smooth systems, why this is important, and how this is useful. I'll describe recent advances for boundary equilibrium bifurcations — where an equilibrium collides with a switching manifold as parameters are varied. Such bifurcations can create chaotic attractors and even multiple attractors. I'll survey geometric mechanisms for the creation of a small-amplitude limit cycle (Hopf-like bifurcations). Different mechanisms yield different scaling laws for the amplitude and period which may be detected from experimental observations. Finally I'll highlight unique problems arising when dimension reduction is attempted for slow-fast piecewise-smooth ODEs.

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MS141

Rotation Theory and Applications of Piecewise-Smooth Maps

In this talk we will speak about principally on the dynamic behavior, as bifurcations and periodic orbits of one-dimensional piecewise-smooth maps and about the possibilities of generalizing the results known to two - dimensional piecewise-smooth maps. Also we will give some examples applied to the control theory. This study is realized using some theoretical tools as the Rotation Theory, in the circle and the annulus and also Symbolic Dynamics.

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MS142

Balanced Neuronal Dynamics Facilitate Reconstruction of Recurrent Network Connectivity

Recovering structural connectivity in large neuronal networks is an unresolved yet fundamental problem in characterizing neuronal computation. Utilizing the prominence of sparsity in neuronal connectivity, we develop a framework for reconstructing recurrent neuronal connections. Measuring the evoked network dynamics in response to a small number of random stimuli, we reconstruct model network connectivity using compressive sensing theory. We show that when the network dynamics are in a balanced operating regime, high fidelity reconstructions are achieved. We expect this framework to be experimentally feasible, and hypothesize the balanced state has arisen as an evolutionarily advantageous mechanism for network information encoding.

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MS142

Coding Properties of Firing Rate Models with Low-Rank Synaptic Weight Matrices

Hebbian theory proposes that ensembles of neurons, that is, groups of co-active neurons, form a basis for neural processing. We model the collection of all possible ensembles of neuronsknown as permitted sets, Pas a collection of binary strings that indicate which neurons are deemed active. We construct P by imposing a threshold on the responsiveness of the neuron to input at the steady state. We investigate how synaptic strengths shape that collection. When the synaptic weight matrix is almost rank one, we prove two main results about P. First, P is a convex code, which is a combinatorial neural code that arises from a pattern of intersections of convex sets. Second, P exhibits nesting, meaning that a permitted set with k co-active neurons contains a permitted subset of k-1 co-active neurons. Our results are applicable to neuronal networks whose activation function is C1 with finitely many discontinuities.

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MS142

Role of the Locus Coeruleus in the Emergence of Power Law Wake Bouts in a Model of the Brainstem Sleep-Wake System Through Early Infancy

Infant rats randomly cycle between sleep and wake states, which are tightly correlated with the activity of mutually inhibitory brainstem sleep and wake populations. From P2-P10, sleep and wake bout lengths are exponentially distributed with increasing means, while during P10-P21, the sleep bouts remain exponential while wake bouts gradually transform to power law. The locus coeruleus (LC), via an undeciphered interaction with sleep and wake populations, has been shown experimentally to be responsible for the exponential to power law transition. Concurrently during P10-P21, the LC undergoes striking physiological changes – the LC exhibits strong global 0.3 Hz oscillations up to P10, with rising frequency and diminishing synchrony from P10-P21. In this work, we construct a Wilson Cowan-style model of the LC, sleep, and wake populations. We show that noise and strong reciprocal inhibition can lead to switching and exponentially distributed sleep and wake bouts as during P2-P10. We then show that the changing physiology of the LC from P10-P21, coupled with reciprocal excitation between the LC and wake population, can explain the shift to power law of the wake bout distribution. To our knowledge, this is the first study that proposes a plausible biological mechanism, which incorporates the known changing physiology of the LC, for tying the developing sleep-wake circuit and its interaction with the LC to the transformation of sleep and wake bout dynamics from P2-P21.

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MS142

Dynamical and Coupling Structure of Pulse-Coupled Networks in Maximum Entropy Analysis

Maximum entropy principle (MEP) analysis with few non-zero effective interactions successfully characterizes the distribution of dynamical states of pulse-coupled networks in many experiments, e.g., in neuroscience. To better understand the underlying mechanism, we found a relation between the dynamical structure, i.e., effective interactions in MEP analysis, and the coupling structure of pulse-coupled network to understand how a sparse coupling structure could lead to a sparse coding by effective interactions. This relation quantitatively displays how the dynamical structure is closely related to the coupling structure.

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MS143

A Brief Introduction to Julia and Applications to Dynamical Systems

This talk will give a brief introduction to Julia, a dynamic programming language designed for scientific computing. We will explore the uses of Julia within the dynamical systems community and the opportunities that it offers through generic programming and how that enables the easy composition of different packages to enable fast and effective creation of numerical software. As a small case study, we will present the development of a flexible numerical continuation code for bifurcation analysis and show how it can be combined with other packages to perform, for example, bifurcation analysis with extended precision variables. This talk is intended to be accessible to all, whether or not you have prior experience of Julia.

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MS143

Large-Scale Numerical Investigations into the Dynamics of Nonlinear Classical Systems

In this talk I will report a series of detailed numerical results on the phase space structure of a classical mechanical system. Its associated Hamiltonian is widely used in nuclear physics to describe the quadrupole nonlinear surface vibrations of nuclei. To this end, I will employ three dynamical coefficients which quantify the folding and stretching of pairs of trajectories and thereby provide a comprehensive image of the underlying chaotic regime. The results on the classical system will be complemented by a series of numerical investigations into the energy spectra of its quantum sibling to identify fingerprints of classical dynamics in quantum behavior. The results in my presentation (see [S. Micluta-Campeanu et al., Rom. Rep. Phys. 70, 105 (2018)]) rely on large scale numerical simulations performed using Julia's packages of differential equations (DifferentialEquations.jl) and dynamical systems (DynamicalSystems.jl). The main message conveyed by the numerical results is that for the differential equations with Hamiltonian structure that we have investigated computationally, all integrators provided the desired accuracy albeit with different computing times. One conclusion is that explicit time integrators in DifferentialEquations.jl provide a good balance between computing time and numerical accuracy and are an effective replacement of symplectic integrators.

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MS143

Handling Multiscale Stochastic Differential Equations in Julia

Multiscale models of biological dynamical systems have been increasingly used for the purpose of incorporating differing levels of omic data into biological theories. The goal of this talk is to show how recent developments in numerical integrators for stochastic differential equations can be integrated into non-array biological multiscale models in a manner that does not require re-implementation of the state-of-the-art techniques on a model-by-model basis. In this talk we will discuss the multiscale models that are being used to directly simulate and estimate the protein transcription levels for a population of cells undergoing epithelial to mesenchymal transitions (EMT), and how this is being linked to data through newer biological technologies such as single-cell RNA sequencing. Recent adaptive methods for high strong order integration of stiff stochastic differential equations and their mixture with continuous-time Markov chains will be described and an efficient Julia implementation will be demonstrated. It will be detailed how the AbstractArray typing formulation of the Julia integrator implementation allows the same integrator code to automatically adapt from solving array-based models to efficiently solving multiscale discontinuous data structures used for representing the biological model, along with the ability of the integrator to allow for dynamic resizing of the equations for cell births and deaths.

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MS143

Rigorous Location of Periodic Orbits with Interval Methods

Interval arithmetic allows us to perform rigorous numerical calculations on sets using floating-point arithmetic. We will review how methods from interval analysis may be used to rigorously locate periodic orbits of dynamical systems by solving the nonlinear equations defining the orbits; in particular, the interval Newton method can prove the existence and uniqueness of roots. Using the `IntervalArithmetic.jl` and `IntervalRootFinding.jl` packages, written in the Julia programming language, we will show how to find periodic orbits of maps which have regions of phase space in which they are undefined, such as billiard models. To do so, we use the method of *decorations* described in the IEEE Std 1788-2015 for Interval Arithmetic. These are flags which track the provenance of an interval during a calculation and can indicate when an intermediate operation was not completely defined. Affiliation: Departamento de Fsica, Facultad de Ciencias

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MS144

Computational, Asymptotic, and Rigorous Analysis of Fully Implicit Time Stepping for Allen-Cahn Dynamics

The Allen-Cahn equation (AC) and Cahn-Hilliard equation (CH) describe phase separation phenomenon in a binary mixture. These equations are of gradient flow type and so corresponding energy functionals decrease in time. Literature for computational methods for (AC) and (CH) dynamics is dominated by the proposal, use, and analysis of energy stable schemes, which guarantee energy decrease no matter what time step is chosen but this is a desirable property not shared by fully implicit time stepping methods. However, we will show that in the metastable dynamic regime of (AC), fully implicit methods are actually more computationally efficient than energy stable schemes, asymptotically more efficient as the order parameter $\varepsilon \to 0$. We use a combination of asymptotic analysis and careful computational work to back up our claim. Moreover we also give a rigorous proof in the radial geometry that shows that larger time steps than previously expected can be used to preserve the metastable solution structure and have energy decay. In fact we will derive rigorous asymptotic evolution of a radially symmetric profile for a family of implicit first order schemes for (AC).

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MS144

Amphiphilic Structures in Multiphase Density Functional Models

Density functional theory for heterogeneous polymer systems describes the free energy of multiphase mixtures, including both hydrophobic and hydrophilic interactions with a solvent (or homopolymer) phase. When both types of interactions exist within the same molecular architecture, amphiphilic bilayers and micelles arise naturally as energy minimizing configurations. Equilibrium solutions with codimension 1- 2- and 3- geometries are found explicitly, including their bifurcation behavior. Implications for dynamical evolution and morphological preference will be discussed.

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MS144

Micro-Macro Models for Two-Phase Flow of Dilute Polymeric Solutions

The rheology of fluids may be heavily affected by dissolved polymer chains. In this talk, we shall discuss the case of two-phase flow of dilute polymeric solutions. By applying Onsager's variational principle, a thermodynamically consistent micro-macro model can be derived, which combines a phase-field approach for the evolution of the fluids with a FENE-dumbbell model for the description of the dissolved polymer chains. An energetic description of the solubility properties of the polymer chains allows to confine the chains to only one fluid phase. Therefore, the arising model covers the case of one Newtonian fluid and one dilute polymeric solution as well as the case of two dilute polymeric solutions. In our talk, we will provide an overview over the derivation of the model, discuss the existence of solutions, and present numerical simulations to show that an energetic description of the solubility properties is indeed sufficient to confine the polymers to one specific phase and to illustrate the influence of the polymer chains on the rheology.

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MS144

Toll Roads and Freeways: Defects in Bilayer Interfaces in the Multi-Component Functionalised Cahn-Hilliard Equation

We study a multi-component extension of the functionalised Cahn-Hilliard (fCH) equation, which provides a framework for the formation of patterns in fluid systems with multiple amphiphilic molecules. The assumption of a length scale dichotomy between two amphiphilic molecules allows the application of geometric techniques for the analysis of patterns in singularly perturbed reaction-diffusion systems. For a generic two-component system, we show that solutions to the four-dimensional connection problem provide the leading order approximation for solutions to the full eight-dimensional barrier problem, which can be obtained through a perturbative expansion in the layer width. Moreover, we show that a saddle-node bifurcation of bilayer solutions in the four-dimensional connection problem acts as a source of so-called defect solutions, i.e. solutions to the barrier problem that are not also solutions to the connection problem. The analysis combines geometric singular perturbation theory with centre manifold theory in an infinite-dimensional context.

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MS145

Escape Dynamics in Harmonically Forced Systems

The talk addresses the escape dynamics in generic single-well potential wells under harmonic forcing. It is demonstrated that main qualitative features of such dynamics can be demonstrated already for simple model with truncated parabolic potential. The model is solvable exactly, and one encounters distinct asymptotic limits of small and large frequencies, as well as transient behavior associated with primary, subharmonic and superharmonic resonances. All these features reveal themselves for more realistic smooth potential wells. The example of quartic potential well is treated in details.

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MS145

Vibration Absorption of a Two Degree-of-Freedom Pendulum with a Nonlinear Energy Sink

Nonlinear vibratory energy exchanges between a two degrees of freedom pendulum and a nonlinear energy sink with an arbitrary orientation is studied. In one of the directions, the pendulum is subjected to a constraint due to the semi-rigidity of the base joint. The pendulum is excited by a generalized force and by the horizontal and vertical displacements of the base. The external generalized force reads $F(t) = F_0 \sin(\Omega t)$ where t is the time and F_0 and Ω are respectively the amplitude and the frequency of the force. The displacements of the base of the pendulum are imposed and can be decomposed in the form of Fourier series in three directions as:
$x(t) = \sum_{k=-\infty}^{\infty} x_k e^{ik\Omega t}$, $y(t) = \sum_{k=-\infty}^{\infty} y_k e^{ik\Omega t}$, $z(t) = \sum_{k=-\infty}^{\infty} z_k e^{ik\Omega t}$
The aim is to carry out the passive control of oscillations of the pendulum under external forces and/or parametric excitations by the nonlinear absorber. The complexified forms of system equations are treated with a multiple scale method. Only the first harmonics are kept. At fast time and slow scales, the slow invariant manifold of the system and characteristic points of system are detected. Moreover, at the slow time scale, the frequency response curves are traced thanks to detection of the equilibrium points. Finally, numerical integrations are performed to verify the relevance of the analytical study and efficiency of passive control.

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MS145

Strongly Nonlinear Periodic System Exhibiting Giant Breaking of Reciprocity with Robust Signal Integrity

Reciprocity is a property of linear, time-invariant systems whereby the energy transmission from a source to a receiver is unchanged after exchanging the positions of the source and receiver. Non-reciprocity, on the other hand, violates this property and can be introduced to systems if time-reversal symmetry and/or parity symmetry is lost, or by introducing nonlinearity. While many studies have induced non-reciprocity by active means, considerably less attention has been given to acoustical structures that passively break reciprocity. In this talk, we will discuss a passive, strongly nonlinear periodic structure which exhibits giant reciprocity breaking under harmonic excitation. Numerical means are employed to generate dispersion curves, as a function of wave energy, which differ for left-to-right from right-to-left propagation. These dispersion curves become reciprocal at the limiting cases of low and high energy, which can be shown analytically. In between, varying degrees of non-reciprocity can be achieved, and in some regimes, giant reciprocity breaking is achieved with very little harmonic distortion. This suggests many possibilities for passive, non-reciprocal devices that operate with near-linear behavior.

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MS145

Geomaterial-Inspired Nonlinear Mechanical Meta-Structures

Geomaterials such as sedimentary rocks have meso- and micro-scale features, such as crack interfaces, that cause a rich variety of nonlinear wave propagation responses, ranging from harmonic generation, resonant frequency shifts, and slow dynamics. Here, we study how periodic arrangements of synthetic geomaterial microstructures, specifically

crack interfaces, can be used to engineer global nonlinear responses in mechanical meta-structures. In this way, we aim to combine the amplitude-dependent mechanical responses of such features with the frequency-dependent properties of periodic media. We construct a discrete mass-spring model that represents a periodic arrangement of rough contact interfaces, modeled as pressure-dependent spring with quadratic nonlinearity. We use approximate analytical solutions validated by numerical models to understand how transmission and harmonic generation depend on excitation frequency and amplitude, precompression, and strength of the nonlinear contact. Models are informed by mechanical tests on contact interfaces to characterize their nonlinear stress-strain response. These nonlinear meta-structures have potential applications in damage-tolerant and protective materials and tunable vibration mitigating materials.

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MS146

Multiple Dose Pharmacokinetic Models Predict Bioavailability of Toxins in Vertebrate Herbivores

A compartmental pharmacokinetic model is built to predict the concentration of toxic phytochemical in the gastrointestinal tract and blood following orally intake by an individual vertebrate herbivore. The existing single and multiple dose pharmacokinetic models are extended to incorporate the physiological factor that toxins can be excreted unchanged in feces due to gastrointestinal motility by impulsive differential equations. An index is defined to be the fraction of the toxin in the blood (i.e., bioavailablity) attributed to the excretion effect. Sensitivity analysis is conducted and it is found that for any toxin, the coefficient of bioavailability which is attributed to the elimination effect of gastrointestinal motility depends mostly on absorption rate of toxin from GIT into the blood, frequency of elimination due to gastrointestinal motility, and the frequency of toxin intake.

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MS146

Spreading Speeds in Random Environments

Integrodifference equations have been widely used to model the invasion of species, the spread of diseases, etc. Traditional models assume the environment is temporally constant. In this work, we study a class of integrodifference equations with random coefficients in order to understand the consequences of random fluctuations.

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MS146

Turing Type Bifurcation in Reaction-Diffusion Model with Nonlocal Interactions

In reaction-diffusion models describing biological and chemical interactions, some dispersal and interaction can be of nonlocal nature. We show that when a nonlocal dispersal occurs instead of classical diffusion, how the mechanism of Turing diffusion-induced instability and pattern formation changes.

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MS146

Mimetic Method on Reaction Diffusion Equation of the Tumor Growth in Cornea

We use a Mimetic Finite difference method (MFD) to study and solve a Tumor problem in cornea that describes the effect of hypoxia on pathological angiogenesis. The MFD method allows us to tackle problems with more complex geometry. We compare the results to standard methods.

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MS147

DMD Based Control of Multiway Dynamical Systems

In complex biological and engineering systems, structure, function, and dynamics tend to be highly coupled. Such interactions can be naturally and compactly captured via tensor based state space dynamic representations. However, identifying such representations from data is not amenable to the standard system and controls framework which require the state to be in form of a vector. In order to address this limitation we explore a new class of multiway dynamical system in which the states, inputs and outputs are tensors. We extend the notion of Dynamic Mode Decomposition (DMD) with and without control for such tensor based dynamical system representations, and develop numerical procedures to compute DMD tensor modes/eigenvalues based on recent advances in computational tensor algebra. Compared to standard DMD which fits vector or matrix models to vectorized tensor time series data, the proposed tensor DMD approach provides more natural, compact and accurate representation of tensorial data with fewer model parameters. We illustrate such benefits of the proposed approach on some real world datasets.

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MS147

Koopman Based Control: Bilinearization, Controllability and Optimal Control of Control-Affine Nonlinear Systems

Nonlinear systems are ubiquitous in real world applications, but the control design for them is not an easy task. Hence, methods are sought to transform a control-affine nonlinear system into linear or bilinear forms to alleviate the problem of nonlinear controllability and control design. While there are linearization techniques like Carleman linearization for embedding a finite-dimensional nonlinear system into an infinite-dimensional space, they depend on the analytic property of the vector fields and work only on polynomial space. The Koopman-based approach described here utilizes the Koopman Canonical Transform (KCT) to transform the dynamics and ensures bilinearity from the projection of the Koopman operator associated with the control vector fields on the eigenspace of the drift Koopman operator. The sufficient conditions for exact bilinearization are derived. Even if the conditions are not fully met, the approximate bilinearization can also be posed as an optimization problem. The resulting bilinear system is then subjected to controllability analysis using the Myhill semigroup method and Lie algebraic structures. Using the same Myhill semigroup structure, we also seek to prove the existence of an energy-only optimal control.

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MS147

Controlling Dynamical Systems with the Koopman Operator: An Overview

A key point of the Koopman operator framework is to turn nonlinear systems into higher-dimensional linear systems. Through this framework, classic linear methods can therefore be used in a systematic way to study and control nonlinear dynamical systems. In this context, this talk will provide an introduction to the framework and a broad review of its recent applications in control theory. First, we will introduce lifting techniques and finite-dimensional approximation methods. These methods will be illustrated by considering several problems (e.g. stability analysis, identification) and by briefly reviewing recent applications in control theory. We will also discuss the main shortcomings of the methods, which are inherent to the infinite-dimensional nature of the operator, and present convergence results and estimation of finite-dimensional approximation errors. Finally, future challenges and open problems will be discussed.

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MS147

Systems Theoretic Aspects of Koopman Operator Theoretic Frameworks

Understanding and subsequently controlling particularly nonlinear dynamic phenomena in a general, holistic manner is still portraying a significant challenge after decades of intense research. This circumstance has recently sparked a very fruitful investigation of more advanced operator theoretic methods from dynamical systems theory that combined with the increased availability of computational power and data has evolved into a highly promising direction for both fundamental research, as well as for practical solutions to application problems. In this talk, I will focus on highlighting a connection between the recently flourishing consideration of Koopman operators for data-driven investigations of dynamic phenomena and classical systems theoretic concepts such as aggregation and observability decompositions of nonlinear systems. The exploration of this newly unveiled cross-connection promotes a cross-fertilization of different methodologies and ideas intrinsic to the two different frameworks, resulting in a deeper understanding of both domains.

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MS148

Manifold Learning and Detection of Sloppiness

Large scale dynamical systems (e.g. many nonlinear coupled differential equations) can often be summarized in terms of only a few state variables (a few equations), a trait that reduces complexity and facilitates exploration of behavioral aspects of otherwise intractable models. High model dimensionality and complexity makes symbolic, pen–and–paper model reduction tedious and impractical, a difficulty addressed by recently developed frameworks that computerize reduction. Symbolic work has the benefit, however, of identifying both reduced state variables and parameter combinations that matter most (*effective parameters*, "inputs"); whereas current computational reduction schemes leave the parameter reduction aspect mostly unaddressed. As the interest in mapping out and optimizing complex input–output relations keeps growing, it becomes clear that combating the curse of dimensionality also requires efficient schemes for input space exploration and reduction. Here, we explore systematic, data-driven parameter reduction by means of *effective parameter identification*, starting from current nonlinear manifold-learning techniques enabling state space reduction. Our approach aspires to extend the data-driven determination of effective

state variables with the data-driven discovery of *effective model parameters*, and thus to accelerate the exploration of high-dimensional parameter spaces associated with complex models.

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MS148

Using the Zero-Curvature Set to Organize Phase Space

Recent work has commented on an apparent connection between the zero-curvature set and the slow manifold of a multiple time-scale system. In this talk, we introduce a new change of coordinates, which we term local orthogonal rectification or LOR, that can be applied at any selected manifold in the phase space of a dynamical system. LOR yields a coordinate system, the LOR frame, which allows us to rigorously study dynamics near the selected manifold. We have used the LOR approach to derive a novel definition for rivers, long-recognized but poorly understood trajectories that locally attract other orbits yet need not be related to invariant manifolds or other familiar phase space structures, and to identify rivers within several example systems. We also demonstrate a connection between the asymptotics of river solutions and slow manifolds.

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MS148

Computational Singular Perturbation Method for Nonstandard Slow-Fast Systems

In families of multiple-timescale dynamical systems, theorems by Fenichel assert the existence of locally invariant slow manifolds and transverse fast fibers. These objects help us to understand such systems via a reduction into simpler subsystems. However, actually finding an invariant manifold (say, writing it down as the graph of a function) is a highly nontrivial task for a typical dynamical system. This talk concerns the computational singular perturbation (CSP) method, which has been used in chemical kinetics to categorize reactions by their characteristic timescales. We discuss how to adapt the CSP method to iteratively approximate the slow manifold and fast fibers of a multiple-timescale dynamical system. We pay special attention to the case of nonstandard scale splitting, where there need not be a clear, global separation of slow and fast components throughout the phase space. Examples are worked out in detail to demonstrate the method, and along the way we highlight the complications that arise when we apply CSP in this new context.

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MS148

A Surface of Heteroclinic Connections in a 4D Slow-Fast System

We investigate a mechanism for a mixed-mode oscillation (MMO) in the four-dimensional, slow-fastOlsen model for peroxidase-oxidase reaction.This model features twoone-dimensional saddleslow manifoldsof different stability. One saddle slow manifold has a three-dimensional stable and a two-dimensional unstable manifold and the other has a two-dimensional stable and a three-dimensional unstable manifold. Numerical continuation methods and appropriately-defined boundary-value problems are used to compute chosen two-dimensional submanifolds of the three-dimensional stable and unstable manifolds. We then use a Lins method approach to compute the two-dimensional intersection surface of the three-dimensional stable and unstable manifolds, which is comprised of heteroclinic connections between thesaddle slow manifolds. This surface is a saddle object that is repelling in forward and backward time. The flow on the surface evolves on an intermediate timescale. Certain MMO periodic orbits track the surface of heteroclinic connections for transitions from a region near one slow manifold to a region near the other slow manifold.

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MS149

Effects of a Rogue Star on Earths Climate

Consider a star passing through our solar system ”close enough” to disturb the orbital elements of Jupiter. We will look at how Jupiter's orbital elements change as time progresses from the past to the future. Changes in Jupiter's orbital elements could lead to potential changes in Earth's orbital elements and hence Earth's climate. We wish to study the effects of this passing star on Earth's climate and try to see if any past climate data matches with such an event happening.

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MS149

The Snowball Bifurcation on Tidally Influenced

Planets

The ice-albedo feedback on rapidly rotating terrestrial planets in the habitable zone can lead to abrupt transitions (bifurcations) between a warm and a snowball (ice-covered) state, bistability between these states, and hysteresis in planetary climate. This is important for planetary habitability because snowball events may trigger rises in the complexity of life, but could also endanger complex life that already exists. Recent work has shown that planets tidally locked in synchronous rotation states will transition smoothly into the snowball state rather than experiencing bifurcations. Here we investigate the structure of snowball bifurcations on planets that are tidally influenced, but not synchronously rotating, so that they experience long solar days. We use PlaSIM, an intermediate-complexity global climate model, with a thermodynamic mixed layer ocean and the Suns spectrum. We find that the amount of hysteresis (the range in stellar flux for which there is bistability in climate) is significantly reduced for solar days with lengths of tens of Earth days, and disappears for solar days of hundreds of Earth days. These results suggest that tidally influenced planets orbiting M and K stars that are not synchronously rotating could have much less hysteresis associated with the snowball bifurcations than they would if they were rapidly rotating.

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MS149

Modeling Martian Climate with Low-Dimensional Energy Balance Models

Low-dimensional energy balance models are used to investigate the past and present climate on Mars, with particular attention given to the effects caused by changes in the obliquity of the planet (ranging from 24° to 82°). We apply the Budyko-Widiasih model for the global average surface temperature of the planet as a function of latitude, coupled with the movement of an ice line (the border between a CO_2 ice cap and no ice). Nadeau's insolation distribution formula, which is a Legendre series expansion in the latitude and obliquity β, is applied to capture the changes in climate arising from different values of β. The number and stability of equilibria is investigated as a function of several parameters. Further adjustments to the model, e.g., assuming a non-symmetric temperature distribution and incorporating multiple ice lines, are also considered.

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MS149

Ice Caps and Ice Belts: The Effects of Obliquity on Ice-Albedo Feedback

Planetary obliquity determines the meridional distribution of the annual mean insolation. For obliquity exceeding 55, the weakest insolation occurs at the equator. Stable partial snow and ice cover on such a planet would be in the form of a belt about the equator rather than polar caps. An analytical model of planetary climate is used to investigate the stability of ice caps and ice belts over the widest possible range of parameters. The model is a nondimensional diffusive Energy Balance Model, representing insolation, heat transport, and ice-albedo feedback on a spherical planet. A complete analytical solution for any obliquity is given and validated against numerical solutions of a seasonal model in the deep-water regime of weak seasonal ice line migration. Multiple equilibria and unstable transitions between climate states (ice-free, Snowball, or ice cap/belt) are found over wide swaths of parameter space, including a Large Ice-Belt Instability and Small Ice-Belt Instability at high obliquity. The Snowball catastrophe is avoided at weak radiative forcing in two different scenarios: weak albedo feedback and inefficient heat transport (favoring stable partial ice cover), or efficient transport at high obliquity (favoring ice-free conditions). From speculative assumptions about distributions of planetary parameters, three-fourths to four-fifths of all planets with stable partial ice cover should be in the form of Earth-like polar caps.

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MS150

Rare Events Associated with Human Mobility

Human mobility plays an important role in estimating activities of residents in cities. We go to somewhere to work, meet someone, eat, have fun, and do other activities. The human mobility has been analyzed through various data sources. Traditionally census data have been employed, but large-scale surveys are expensive, and their spatial and temporal resolutions are not necessarily satisfactory. Recently, development of mobile devices enabled us to analyze detailed features of human mobility in urban regions. Cities face risks of events which may destroy the lives of the residents. Such rare events can be caused by the human mobility. Some examples include spread of emergent infectious diseases, and efficient evacuation strategy in case of a severe disaster, such as earthquakes, hurricanes, some of which occur more frequently due to the climate change. In order to prevent catastrophic damage, it is striking to uncover the statistical property of the human mobility and prepare for a control method in advance. In this talk, I report the recent results of the analyses of the human mobility data using the network theory, e.g. network community detection and scaling analysis of the percolated clusters. Possible applications to real problems are discussed.

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MS150

Phase Coherence Between Precipitation in South America and Rossby Waves

The dominant mode of intraseasonal precipitation variability during the South American monsoon is the so-called precipitation dipole between the South Atlantic Convergence Zone (SACZ) and southeastern South America (SESA). It affects highly populated areas that are of significant importance for the regional food supplies. Previous studies using Principal Component Analysis or Complex Networks were able to describe and characterize this variability pattern. In particular, this region is vulnerable to extreme rainfall and associated floods and landslides, but also to drought events in other years. While Complex Network approaches were successful in predicting extreme rainfall in some of the affected areas, crucial questions remain open regarding the responsible physical mechanism. Here, we use phase synchronization techniques to study the relation between precipitation in the SACZ and SESA on the one hand, and southern-hemisphere Rossby wave trains on the other hand. In combination with a conceptual model, this approach demonstrates that the dipolar precipitation pattern is caused by the southern-hemisphere Rossby waves. The results hence show that Rossby waves are the main driver of the monsoon season variability in South America, which has important implications for synoptic-scale weather forecast.

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MS150

Detecting Rare Dynamical Regime Shifts in Complex Systems

Paleoclimate datasets are rich sources for advancing our knowledge of the climate system. However, paleoclimate datasets suffer from many limitations such as uneven sampling, insufficient data, missing values and uncertainty in estimates. These limitations lead to various challenges in the application of dynamical systems based methods to the study of paleoclimate data. For example, while using nonlinear time series analysis, we require phase space reconstruction, which is a formidable task in the presence of uneven sampling and missing values. We will present techniques based on nonlinear manifold learning which simplify phase space reconstruction, particularly in the presence of uneven sampling and missing values. Furthermore, we will integrate classification and clustering techniques from machine learning with recurrence plot analysis to automatically identify rare dynamical regime shifts in paleoclimate time series. We anticipate these methods will find applications in studying dynamical regime shifts in different types of complex systems.

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MS150

Early Warning and Diagnosis in Complex High Dimensional Systems

Predicting changes in a system is broadly important in widely ranging applications such as structural health monitoring as well as sustainability and environmental management. Previous work has focused dominantly on the characterization of early warning signals (EWS), indicators that a system is approaching a bifurcation describing a tipping point. However for many complex systems, EWS may not provide sufficient information regarding underlying causes of the changes, making it impossible to pinpoint crucial failure modes and effective control strategies or policies. This becomes especially challenging and concerning when the system is high dimensional and complex. In this work, we develop a model-free framework that simultaneously monitors the interaction topology of a complex high dimensional system as well as the strength of interactions. Our method thus enables not only early warning but also diagnosis of precursors of a systems changing behavior, including detection of the loss of critical structural connections and varying interaction strength, both of which can cause a system to undergo sudden abrupt changes.

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MS151

A Bayesian Approach to Quantifying Uncertainty

in Divergence-Free Flows

We treat the statistical regularization of the ill-posed inverse problem of estimating a divergence free flow field u from the partial and noisy observation of a passive scalar Θ. Our solution is Bayesian posterior distribution, a probability measure μ which precisely quantifies uncertainties in u once one specifies models for measurement error and prior knowledge for u. We present some of our recent work which analyzes μ both analytically and numerically. In particular we discuss a posterior contraction (consistency) result as well as some Markov Chain Monte Carlo (MCMC) algorithms which we have developed and refined to effectively sample from μ. This is joint work with Jeff Borggaard and Justin Krometis (Virginia Tech).

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MS151

Ensemble Kalman Inversion: A Derivative-Free Technique for Machine Learning Tasks

The standard probabilistic perspective on machine learning gives rise to empirical risk-minimization tasks that are frequently solved by stochastic gradient descent (SGD) and variants thereof. We present a formulation of these tasks as classical inverse or filtering problems and, furthermore, we propose an efficient, gradient-free algorithm for finding a solution to these problems using ensemble Kalman inversion (EKI). Applications of our approach include offline and online supervised learning with deep neural networks, as well as graph-based semi-supervised learning. The essence of the EKI procedure is an ensemble based approximate gradient descent in which derivatives are replaced by differences from within the ensemble. We suggest several modifications to the basic method, derived from empirically successful heuristics developed in the context of SGD. Numerical results demonstrate wide applicability and robustness of the proposed algorithm.

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MS151

Feature-Based Data Assimilation Example: Estimating Parameters of the Nonlinear Cloud and Rain Equation from Large-Eddy Simulations

Many applications in science require that computational models and data be combined. In a Bayesian framework, this is usually done by defining likelihoods based on the mismatch of model outputs and data. However, matching model outputs and data in this way can be unnecessary or impossible. In some cases, these issues can be addressed by selecting features of the data and model, and defining likelihoods based on the features, rather than by the usual mismatch of model output and data. The goal is to present the key ideas in feature-based data assimilation through a example in cloud microphysics. Emergent behavior of stratocumulus clouds can be qualitatively described by simplified, predator-prey models, with rain acting as a predator of the clouds. This work turns a specific predator-prey model into a quantitative tool by estimating the parameters that define the model from a time series of cloud depth. We use a large eddy simulation (LES) as the ground truth and extract cycles of cloud growth and decay from the simulation. Our method treats the cycles as features and subsequently performs a Bayesian inversion to compute posterior probabilities for the model parameters. The resulting model whose parameters are distributed according to the posterior distribution, exhibits cloud cycles with similar statistics as the LES, in terms of period, amplitude, and growth and decay times.

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MS152

Dynamics of Circulant Systems of ODE's

We consider certain circulant systems of ODE's inspired by equations studied in the synthetic biology literature. For a particular case study of interest we analyze its invariant sets, bifurcation behavior, long time asymptotics and the existence of periodic orbits. We develop the theory and present simulations.

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MS152

Integrability and Chaos in Figure Skating

We derive and analyze a three dimensional model of a figure skater. We model the skater as a three-dimensional body moving in space subject to a non-holonomic constraint enforcing movement along the skate's direction and holonomic constraints of contact with ice and pitch constancy of the skate. For a static (non-articulated) skater, we show that the system is integrable if and only if the projection of the center of mass on skate's direction coincides with the contact point with ice and some mild (and realistic) assumptions on the directions of inertia's axes. The integrability persists for an arbitrary lean of the center of mass to the side of the skate. The integrability is proved by showing the existence of two new constants of motion linear in momenta (gauge integrals), providing a new and highly nontrivial example of an integrable nonholonomic mechanical system. We also consider the case when the projection of the center of mass on skate's direction does not coincide with the contact point and show that this non-integrable case exhibits apparent chaotic behavior, by studying the divergence of nearby trajectories We show the intricate behavior during the transition from the integrable to the chaotic case. Our model shows many features of real-life skating, especially figure skating, and we conjecture that real-life skaters may use the discovered mechanical properties of the system for the control of the

performance on the ice.

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MS152

Reduced-Order Models for Locomotion in the Perturbed Stokes Regime

For those creatures living "life at low Reynolds number,' locomotion is friction-dominated in the sense that without power expenditure they quickly come to a halt. It is known that for swimming at the viscous or *Stokesian limit* (zero Reynolds number), motion is purely kinematic and governed by the *viscous connection* of geometric mechanics (Kelly and Murray, CDC, 1996). Assuming this reduced-order connection model, Bittner et al. developed an algorithm to estimate the dynamics near a periodic orbit ("gait cycle') directly from observational data of shape and body motion (J. Non. Dyn., 2018). In recent work, we extended this algorithm for the *perturbed Stokes regime* – where Reynolds number is small but nonzero – using a "corrected' reduced-order model (J Non. Dyn., submitted). Applications include the study of gait optimality in biology and "hardware-in-the-loop' robotics (with respect to chosen goal functionals). In this talk, we discuss the mathematical foundations of this reduced-order model, which extend work of Eldering and Jacobs (SIADS, 2016). Using noncompact normal hyperbolicity theory in a singular perturbation context, we show that for locomotion in the perturbed Stokes regime having a cocompact symmetry group, there exists an exponentially stable slow manifold which serves as a corrected reduced-order model. This yields a functional relationship between shape velocity and body velocity, but which is no longer connection-like.

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MS152

Geometric Kinematic Control of a Spherical Rolling Robot

I will present some mathematical results on kinematic control a spherical rolling robot like the Sphero, i.e., a rolling sphere controlled by internal wheels. We formulate the system as a kinematic control system on a principal bundle, and analyze its controllability using the connection naturally defined by the system as well as its curvature. We also consider an optimal control problem of the system and discuss its integrability.

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MS153

Multi-Cluster Structures in Slowly Adapting Networks of Coupled Oscillators

Dynamical systems on networks with adaptive couplings appear naturally in real-world systems such as power grid networks, social networks as well as neuronal networks. We investigate collective behavior in a paradigmatic network of adaptively coupled phase oscillators. The coupling topology of the network changes slowly depending on the dynamics of the oscillators. We show that such a system gives rise to numerous complex dynamics, including relative equilibria and hierarchical multi-cluster states. Parameter regimes of high multi-stability are found. An analytic treatment for equilibria as well as multi-cluster solutions reveals that existence and stability of those states crucially depend on the slow-fast time separation. Our treatment allows for the interpretation of equilibria as functional units in multi-cluster structures. The results contribute to the understanding of mechanisms for pattern formation in adaptive networks, such as the emergence of multi-layer structure in neural systems.

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MS153

Discretized Fast-Slow Systems Near Singularities

We show how to extend slow manifolds near various kinds of singularities in fast-slow systems given by time discretizations of the corresponding continuous-time normal form. The analysis applies the blow-up method, which has so far mainly been used for flows, to fast-slow dynamical systems induced by maps and uses direct trajectory-based estimates. For transcritical and pitchfork singularities, we prove that the qualitative behaviour is preserved by any time-discretization, where the step size is fully quantified relative to the time scale separation. For canard points at folds, we demonstrate that, due to a formal conserved quantity, the Kahan discretization and related symplectic methods preserve canard solutions for relatively large step sizes and long times as opposed to, for example, the Euler method.

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MS153

Slow-fast systems on a Möbius band

The goal of our talk is to study 1-canard cycle and 2-canard cycle bifurcations on a non-orientable two-dimensional manifold (e.g. the Möbius band) by using the notion of slow divergence integral. The focus is on smooth slow-fast models with a Hopf breaking mechanism. We give a simple sufficient condition, expressed in terms of the slow divergence integral, for the existence of a period-doubling bifurcation near the 1-canard cycle. We also prove the finite cyclicity property of singular 1- and 2- homoclinic loops.

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MS153

Temporal Multiscale Methods for a Plaque Model

This talk discusses how temporal multiscale methods can improve models for atherosclerotic plaque and the challenges of applying multiscale methods to this multiphysics system. Atherosclerosis is a disease in which plaque forms and grows in artery walls, which may lead to the complete blockage of the blood flow. It is hypothesized that mechanical stresses exerted by the pulsatile blood flow on the wall have an important impact on the location and speed of plaque growth. This naturally leads to multiple temporal scales since the growth happens over the course of months and years. Contemporary models for plaque growth are complex multiphysics systems: They model the blood flow, the elastic artery wall with growth due to plaque and multiple substances and cell species involved in the growth process. Understanding the solutions to such systems is often limited to numerical simulation, where the timescale separation creates practical difficulties which are often resolved through heuristic simplifications. Using simplified models we explore different aspects of this multiphysics system and derive formal and rigorous limits, which are better suited also as a base for simulation. We prove rigorous convergence results and investigate numerical aspects of the arising systems.

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MS154

Filippov System that Models the Interaction Between CBB Affected by Capture and a Natural Predator

The coffee industry is very influential in the Colombian economy, because coffee is the second most exported product nationwide, after oil. Unfortunately, this agricultural product is affected by different pests, being the most critical worldwide a beetle which is popularly known as coffee berry borer (CBB). The coffee industry has developed different strategies to counteract its effects, among which social control and biological control stand out. Biological control consists in the introduction of other living beings in the coffee plantations to prevent the effects of the coffee berry borer, giving rise to different types of interactions such as, for example, depredation. Thus, a mathematical model based on ordinary differential equations is proposed to describe a prey-predator interaction where the ants consume the coffee bit. It is also considered a constant capture of drills by alcohol traps, whose implementation depends on the level of infestation is greater than or equal to 5%, which gives rise to a system of differential equations is not soft which is performed the analysis of Filippov. The study of the model is analytic, and the results are illustrated with numerical simulations, in addition to accompanying the respective biological interpretations.

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MS154

Fake Discontinuities in Piecewise Linear Memristor Oscillators

Rigorous mathematical results regarding the rich dynamics of piecewise linear memristor oscillators will be shown, justifying the existence of an infinite family of invariant manifolds. The dynamics on such manifolds can be modeled without resorting to discontinuous models. Our approach provides topologically equivalent continuous models with one dimension less but with one extra parameter associated to the initial conditions. It is so possible to confirm previous numerical results by going much further and proving the existence of closed surfaces in the state space which are foliated by periodic orbits. The important role of initial conditions that justify the infinite number of periodic orbits exhibited by these models, is stressed. Multistable regimes under specific configurations of parameters are also obtained.

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MS154

Linearising Nonsmooth Flows with Stochastic Discontinuity Boundaries

In a smooth dynamical system the characteristics of a reference trajectory with a given starting point can be determined by examining the linearised system about the reference trajectory. We can approximate the deviations of trajectories after a fixed time, with starting points close to the reference starting point, by multiplying the fundamental matrix solution (FMS) of the variational equation along the reference trajectory by the initial deviations. This form of analysis cannot be used in piecewise-smooth systems as the vector field is not everywhere differentiable. To account for this, we can derive the zero-time discontinuity mapping associated with the discontinuity boundary. The Jacobian derivative of this mapping is known as the saltation matrix. This matrix can be composed with the FMSs of the flows on either side of the discontinuity boundary in order to determine the overall FMS of a crossing trajectory. Here we derive a saltation matrix for a piecewise-smooth dynamical system in which the position of the discontinuity boundary varies according to a mean-reverting stochastic process. The derived matrix contains the effect of both the discontinuity and the noise introduced into the system by

the noisy boundary, and is composable with the deterministic FMSs of the individual flows to give the overall FMS of a crossing trajectory. We then present some examples of piecewise-smooth systems with noisy boundaries, analysed using the derived random saltation matrix.

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MS154

Periodic Orbits Bifurcation in Hysteretic Systems with Real Eigenvalues

Bidimensional piecewise linear systems with hysteresis are considered. These systems come from a dimensional reduction of symmetric 3D systems with slow-fast dynamics. We concentrate our attention on the saddle and node dynamics cases, determining the existence of periodic orbits as well as their stability, and possible bifurcations. Our analysis rigorously shows, apart from standard bifurcations, as saddle-node bifurcation of periodic orbits and homoclinic and heteroclinic connections, the existence of a specific grazing bifurcation. Also, a pitchfork bifurcation of periodic orbits has been detected, leading to the coexistence of up to four periodic orbits. We illustrate the usefulness of the achieved theoretical results by justifying the existence of several periodic orbits in a concrete 3D system.

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MS155

Binocular Rivalry in Macaque V1

Binocular rivalry (BR) happens whenever two rivalrous stimuli (colors, orientations or objects) coincide in the receptive field of two monocular neurons of the opposite eyes. As they innervate the same binocular neuron, perceptually, one would experience one of the “stimulus” 2s before switching to the other “stimulus” (composite). BR come in various scales and exists at different levels in the visual cortex and higher cognitive areas. Although the properties of BR in V1 have been studied for decades, the underlying circuit mechanism only have two possible theories that can account for both rivalry and fusion: opponency neuron model by Said & Heeger, PLOS 2013, and XOR gate model by Blake Psychol. Rev. 1989. However, neither has a biophysically realistic model nor experiment supports for the functional type of neuron or structure. Here we build a large-scale model for Macaque V1, extending our previous comprehensive large-scale model of layer 4Calpha to layer 4Cbeta and 2/3 with ocular dominance columns to explore the mechanisms underlying binocular rivalry without compromising the existing emergent properties that match with the experiment results. This is a modeling and simulation work in progress, we hope that with enough experimental findings, we can bring some insight to the underlying mechanism of BR in V1 for the proposed theories or whatever that emerges from our experimentally constrained and comprehensive large-scale model, as well as verifiable predictions.

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MS155

Dendritic Computation Captured by An Effective Point Neuron Model

The complexity of dendritic properties in general presents a formidable challenge to understand neuronal information processing. To circumvent the difficulty, a prevalent viewpoint is to simplify the morphology of a neuron as a point representing the soma, and the excitatory and inhibitory synaptic currents originated from its dendrites are linearly summed at the soma. Despite their extensive applications, the existing point neuron models fails to characterize the spatial aspects of synaptic integration at dendrites supporting rich computations, e.g., motion detection and sound localization. Using theoretical analysis, electrophysiological experiments, and realistic neuronal simulations, here we derive a novel form of synaptic integration current within the point neuron framework being capable of capturing spatial dendritic effects. In the form, the spatiotemporal interaction between each pair of synaptic inputs on the complex nonlinear active dendrites can be reliably parameterized by a single coefficient. Point neuron models with the synaptic integration current incorporated can capture the computational ability of a spatial neuron with dendrites, including direction selectivity, coincidence detection, logical operation, countering dendritic filtering, and a bilinear rule of dendritic integration discovered in a recent experiment. Our work amends the modeling of synaptic inputs and improves the computational power of a modeling neuron within the point neuron framework.

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MS155

Structural Reorganizations During Continuous Learning and Sleep in Spiking Neural Networks

Continuous learning is a striking ability of the brain which is capable of the encoding of new memories avoiding significant interference of previously acquired knowledge. However, the mechanisms of how the brain achieves this are poorly understood. Existing artificial neural networks tend to face the same problem - catastrophic forgetting - however no generic solutions are available. Here we developed a thalamocortical network model consisting of recurrently connected conductance-based neurons that is able to learn memories using spike timing-dependent plasticity rule in awake state and memory replay in sleep-like state. We explored the role of sleep in storing competing memories. While the performance of the network to recall old memories could be significantly reduced by new learning in awake state, there was consolidation of both previously and newly learned memories when sleep followed training. We analyzed the structural changes of the network connectivity as the network experienced different activation states and we found that recurrent synaptic connections were segregated during slow-wave sleep to favor one or another memory. At the end of sleep each memory was represented by a unique set of synaptic connections. The study highlights the role of slow-wave sleep in protecting memories from interference and presents a possible mechanism of how the brain achieves continuous learning.

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MS155

Nonuniform Sampling Granger Causality Analysis for Pulse-Coupled Nonlinear Network Dynamics

The Granger causality (GC) analysis is an effective approach to infer causal relations for time series. However, for data obtained by uniform sampling (i.e., with an equal sampling time interval), it is known that GC can yield unreliable causal inference due to aliasing if the sampling rate is not sufficiently high. To solve this unreliability issue, we consider the nonuniform sampling scheme as it can mitigate against aliasing. By developing an unbiased estimation of power spectral density of nonuniformly sampled time series, we establish a framework of spectrum-based nonparametric GC analysis. Applying this framework to a general class of pulse-coupled nonlinear networks and utilizing some particular spectral structure possessed by these nonlinear network data, we demonstrate that, for such nonlinear networks with nonuniformly sampled data, reliable GC inference can be achieved at a low nonuniform mean sampling rate at which the traditional uniform sampling GC may lead to spurious causal inference.

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MS156

GPU-Accelerated Implicit/Explicit Solvers for Cardiac Modeling

Realistic modeling of cardiac electrical activity is crucial in advancing our understanding of the physiology of a healthy heart and the pathophysiology of various arrhythmias and is the key to planning patient-specific treatments. These models are composed of a large number of stiff ODEs coupled via transmembrane potential to form a system of PDEs. Simulating these systems in a reasonable time requires massively parallel architectures, such as Graphics Processing Units (GPUs). Julia is a modern scientific programming language designed to be expressive and nearly as fast as C. Our goal is to assess the suitability of Julia in solving stiff PDEs, especially those that arise from cardiac electrophysiology. Our approach is to employ the method of lines to convert the PDE into an ODE problem, which can be split into implicit and explicit parts. The implicit part is integrated on a CPU using optimized implicit solvers provided by JuliaDiffEq, a suite of Julia libraries for solving ODEs. The explicit part is perfectly-parallel and is integrated by an exponential method on a GPU with the help of the CUDAnative library that translates Julia code directly into GPU instructions. We show that such mixed implicit on CPU/explicit on GPU architecture results in a 6x speedup in solving a typical cardiac model, the Beeler-Reuter ionic model, compared to a CPU-only option. The bottleneck is GPU/CPU memory transfers. We expect an order of magnitude speedup with a GPU-only solver.

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MS156

Improving Low-Energy Defibrillation Using WebGL

Low energy anti-fibrillation pacing (LEAP) has been suggested as an alternative method to traditional defibrillation method, which applies a strong electric pulse to terminate the arrhythmia. LEAP delivers multiple low amplitude electric shocks through field electrodes close to, or inside the tissue. The main goal of this talk is to investigate the mechanism of LEAP and to suggest ways to improve it using WebGL accelerated simulations. We first verified that the simulations can reproduce two important characteristics associated with virtual electrode: the minimum radius of the heterogeneity to generate virtual electrode and the excitation time for the wave to propagate through the whole domain as a function of electric field strength. Then we showed that LEAP works better in simulations with longer pacing period. This is because longer period shocks are less likely to re-initialize spiral waves when the spirals are in a highly-breakable regime. Furthermore we demonstrated that larger domains with more waves fit in them are harder to defibrillate. Then using COMSOL simulations and the method of images, we showed that the uniform electric field have the best defibrillation results and except for Plane-Plane electrode configurations, other shapes of electrodes do not change the defibrillation results much. Finally, we conducted 3D simulations to demonstrate the termination of fibrillation by detaching the vorticess filaments from the depolarized surface.

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MS156

Real-time Interactive Computations of Fractals, Turing Patterns, and Cardiac Arrhythmias using WebGL 2.0

Whether it is mere artistic interest, simple curiosity, or understanding diseases and a yearning to save lives, fractals, Turing patterns, and cardiac arrhythmias have been of significant interest for several decades. The common thread all of these systems is the huge computational cost of their numerical modeling. They usually require small discretization sizes that lead to a large computational grid. To further complicate the time-dependent class of problems, usually, there is a wide range of time scales in such problems which requires using a small temporal discretization to advance the solution for a much larger temporal range. These challenges make these systems unsuitable for traditional serial computing. However, they can significantly benefit from parallel computing. Modern Graphics Processing Units (GPUs) can provide significant parallelization via their several hundred to thousands of internal computational cores. In this talk, we will present how we can program GPUs on personal devices using WebGL 2.0 to study problems that can benefit from parallelization, including fractals, the Turing patterns, and cardiac arrhythmias. We will show how our in-house library Abubu.js can be used to simplify the programming process to study these systems interactively. Since the WebGL codes run in the browser without the need to explicitly compile the codes or install any plugins, our codes will be cross-platform and even run on cell-phones.

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MS156

Chirality as a Destabilizer of Electrical Waves in Cardiac Tissue

Electrical processes that cause an arrhythmic contraction of cardiac muscle are not well understood yet. These arrhythmias are attributed to electrical coherent structures known as spiral waves that drive the system at a higher frequency than the sinoatrial node. In thick ventricular tissue, three-dimensional effects allow for more complex structures called scroll waves, which extend the number of possible ways to initiate an arrhythmia. In the absence of spatial electrical measurements of intramural tissue, we turn to numerical simulations which let us capture the full dynamical evolution of the waves. We have developed high resolution simulations with high order numerical schemes to solve the equations of the Fenton-Karma model. To increase the speed of the computations we have implemented these simulations in parallel architectures with graphic processing units.With this numerical setup, we are able to trace in real time the dynamics of the scroll waves phase singularities, which simplifies the system stability analysis.We have observed that he chirality of the scroll waves changes the threshold for wave breakup and can lead to the system into fibrillation.We have characterized the contribution of chirality to the stability of the systems with various tissue thickness, excitability and fiber rotation rates. We propose that building a reduced model that captures the effects of thickness, excitability,fiber rotation and chirality could provide more insight in future works.

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MS157

Curve Lengthening and Shortening in Strongly FCH

We rigorously derive curve lengthening and shortening in mass-preserving L^2-gradient flow of strongly FCH. More precisely, under different regime of initial background state, the initial circle shrinks(by releasing mass) or meanders and expands(by absorbing mass) to another circle while the background state is pushed to an equilibrium. This simulates the dynamics of biological membrane immersed in a solvent. This is a joint work with Prof. Promislow.

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MS157

Codimension One Minimizers of Highly Amphiphilic Mixtures

We present a modified form of the Functionalized Cahn Hilliard (FCH) functional which models highly amphiphilic systems in solvent. A molecule is highly amphiphilic if the energy of a molecule isolated within the bulk solvent molecule is prohibitively high. For such systems once the amphiphilic molecules assemble into a structure it is very rare for a molecule to exchange back into the bulk. The highly amphiphilic FCH functional has a well with limited smoothness and admits compactly supported critical points. In the limit of molecular length $\varepsilon \to 0$ we consider sequences with bounded energy whose support resides within an ε-neighborhood of a fixed codimension one interface. We show that the FCH energy is uniformly bounded below, independent of $\varepsilon > 0$, and identify assumptions on tangential variation of sequences that guarantee the existence of subsequences that converge to a weak solution of a rescaled bilayer profile equation, and show that sequences with limited tangential variation enjoy a $\liminf$ inequality. For fixed codimension one interfaces we construct bounded energy sequences which converge to the bilayer profile and others with larger tangential variation which do not converge to the bilayer profile but whose limiting energy can violate the $\liminf$ inequality, depending upon the energy parameters.

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MS157

Bifurcation and Competitive Evolution of Network Morphologies in the Functionalized Cahn-Hilliard

The FCH is a higher-order free energy for blends of amphiphillic polymers and solvent which balances solvation energy of ionic groups against elastic energy of the underlying polymer backbone. Its gradient flows describe the formation of solvent network structures which are essential to ionic conduction in polymer membranes. The FCH possesses stable, coexisting network morphologies and we characterize their geometric evolution, bifurcation and competition through a center-stable manifold reduction which encompasses a broad class of coexisting network morphologies. The stability of the different networks is characterized by the meandering and pearling modes associated to the linearized system. For the H^{-1} gradient flow of the FCH energy, using functional analysis and asymptotic methods, we drive a sharp-interface geometric motion which couples the flow of co-dimension 1 and 2 network morphologies, through the far-field chemical potential. In particular, we derive expressions for the pearling and meander eigenvalues for a class of far-from-self-intersection co-dimension 1 and 2 networks and show that the linearization is uniformly elliptic off of the associated center stable space.

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MS157

A Two-Component Functionalized Cahn-Hilliard Equation with Generic Pearling Inhibition

End-cap structures are universal structures in amphiphilic mixtures. An end-cap defect typically admits a neck region joining the micelle (co-dimension 3) and filament (co-dimension 2) structures. We study such defects in the phenomenological Funcitonalized Cahn-Hilliard model which admits various co-dimensional structures with non-zero thickness. End-cap defects correspond to local minimizer profiles at the neck region whose traces and normal derivatives agree with those of the pore solution and those of the micelle solution respectively on its two sides adjacent to both structures, and tend to the appropriate background state at the far field. We will talk about how to develop an asymptotic double well which reduce the oscillations in the neck and minimize the neck length.

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MS158

On the Interplay between Intrinsic and Extrinsic Instabilities of Spatially Localized Patterns

Spatially localized dissipative structures are observed in various fields, such as neural signaling, chemical reactions, discharge patterns, granular materials, vegetated landscapes and binary convection. These localized patterns are not living cells, however they seem to inherit several characteristic living state features, such as existence of boundaries separating inside and outside, self-replication, self-healing, generation of patterns and robustness as a system. Adaptive switching of dynamics can also be observed when these structures collide with each other, or when they encounter environmental changes in the media such as spatially and/or temporal inhomogeneities. These behaviors stem from an interplay between the intrinsic instabilities of each localized pattern and the strength of external signals. To understand such an interplay, one of the powerful methods is to explore the global geometric interrelation amongst all relevant solution branches of a corresponding system with respect to approximate parameters. This allows us not only to unveil the relation between input and output at the event, but also to find candidates of organizing center producing complex dynamics. We review the recent development in this direction.

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MS158

Dynamics of Fronts in 1D Allen-Cahn Equations with Large Scale Coupling

When weakly coupling the classical one-dimensional Allen-Cahn interface model to large scale fields, the dynamics drastically changes. For linear coupling this can be rigorously analysed in a rather explicit way. Combining various methods allows to detect and unfold degenerate Takens-Bodganov points for the interface dynamics. This features various periodic, homoclinic and heteroclinic solutions. This is joint work with Martina Chirilus-Bruckner, Peter van Heijster and Hideo Ikeda.

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MS158

Using Geometry to Detect Stability: The Riccati-Evans Function

Travelling wave solutions to partial differential equations appear in myriad applications, from biology to ecology and physics. However, establishing the stability of such waves can be difficult. Motivated by the dynamical systems theory for ordinary differential equations (ODEs), a natural first step in this process is to determine the spectral stability of the solution via the spectrum of the linearised operator. This presents a numerical challenge, particularly in locating the point spectrum, as existing methods often require the solution of stiff (ODEs) associated with the linearised operator. In this work, we expand on a new method for locating the point spectrum developed by Harley et. al. (2015). This method, called the Riccati-Evans function, uses geometric insights to simplify computations, making them efficiently tractable. We then demonstrate the efficacy of this method by analysing the spectral properties of a system of two partial differential equations used to model cancer invasion driven by haptotaxis, derived by Perumpanani et al (1999) and further studied by Harley et al. (2014).

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MS158

Limit Classfication on Eigenfunctions for 1-Dimensional Reaction-Diffusion System

The linearized eigenvalue problems for stationary front/pulse solutions of the 1-dimensional reaction-diffusion systems are considered. In the single equation case with special nonlinearities $f(u) = \sin u$ and $f(u) = u - u^3$, S. Yotsutani and the author has obtained all of eigenfunctions for the homogeneous Neumann boundary value problem in terms of elliptic functions, and have classified them through the asymptotic properties on eigenpairs when the diffusion coefficient is sufficiently small. In this talk we will consider the asymptotic properties on eigenpairs associated with n-front/pulse stationary solutions for a wider class of reaction-diffusion equations. Using a dynamical system approach by Ei, we will derive the asymptotic formulas for the fitst n eigenpairs. This talk is based on a jointwork with Shin-Ichiro Ei (Hokkaido Univ., JAPAN) and Haruki Shimatani (Hokkaido Univ., JAPAN).

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MS159

Homogenization for Some Nonlocal Stochastic Partial Differential Equations

We establish homogenization principles for nonlocal stochastic partial differential equations with oscillating coefficients, by a martingale approach. This is motivated by data assimilations with non-Gaussian observations. The nonlocal operators in these stochastic partial differential equations are the generators of non-Gaussian Lévy processes of either integrable or non-integrable jump kernels. In particular, this work leads to homogenization of nonlocal Zakai equations, in the context of data assimilation with α-stable Lévy fluctuations. The homogenized systems are shown to approximate the original systems in the sense of probabilistic distribution.

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MS159

Effects of the Climate Change on the Nonlocal Population

Consider a patch of favorable habitat surrounded by unfavorable habitat and assume that due to a shifting climate, the patch moves with a fixed speed in a one-dimensional universe. Let the patch be inhabited by a population of individuals that reproduce, disperse, and die, where the long-distance disperse has been taken into account. Will the population persist? How does the answer depend on the length of the patch, the speed of the movement of the patch, the net population growth rate under constant conditions, and the mobility of the individual? In this talk, we will answer these questions in the context of a simple dynamic profile model with nonlocal operators that incorporates climate shift, population dynamics, and long-range migration.

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MS159

The Role of Shelter

This talk presents our recent study on the impacts of a shelter Ω_0 on spatial patterns of coexistence states of two nonlocal diffusive predator-prey models with Holling type II functional responses and the Dirichlet boundary condition. These model assume that the motions of both prey and predator are governed by a Lévy $2s$-stable process, and a portion of the prey's habitat is shared by both species while the remainder serves as a shelter for the prey. It is shown that an adequate shelter provides needed protection for the prey community in the face of strong growth of the predator. In particular, the minimal patch size of Ω_0 is determined by the principal eigenvalue $\lambda_1(\Omega_0)$ of the restricted fractional Laplacian pertained to the Dirichlet boundary condition, which is of critical importance to the survival of the prey.

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MS160

Discovering Conservation Laws from Data for Control

Conserved quantities, i.e. constants of motion, are critical for characterizing many dynamical systems in science and engineering. These quantities are related to underlying symmetries and they provide fundamental knowledge about physical laws, describe the evolution of the system, and enable system reduction. In this work, we formulate a data-driven architecture for discovering conserved quantities based on Koopman theory. The Koopman operator has emerged as a principled linear embedding of nonlinear dynamics, and its eigenfunctions establish intrinsic coordinates along which the dynamics behave linearly. Interestingly, eigenfunctions of the Koopman operator associated with vanishing eigenvalues correspond to conserved quantities of the underlying system. In this paper, we show that these invariants may be identified with data-driven regression and power series expansions, based on the infinitesimal generator of the Koopman operator. We further demonstrate the use of these intrinsic coordinates to develop a model predictive controller to track a given reference value.

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MS160

Optimal Sensor and Actuator Placement using Balanced Model Reduction

Optimal sensor and actuator placement is a central challenge in high-dimensional estimation and control. Nearly all subsequent control decisions are affected by these sensor/actuator locations, and optimal optimal placement amounts to an intractable brute-force search among the combinatorial possibilities. In this work, we exploit balanced model reduction and greedy optimization to efficiently determine sensor and actuator placements that optimize observability and controllability. In particular, we determine locations that maximize the volume of the balanced observability and controllability ellipsoids via greedy matrix QR pivoting on the dominant modes of the direct and adjoint balancing transformations. Pivoting runtime scales linearly with the state dimension, making this method tractable for high-dimensional systems. The results are demonstrated on the linearized Ginzburg-Landau system, for which our algorithm approximates well-known optimal placements computed using costly gradient descent methods.

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MS160

Data Driven Feedback Control of Nonlinear PDEs using the Koopman Operator

In this talk we present a data driven reduced order modeling approach for control of nonlinear PDEs which relies on the Koopman operator. We construct a bilinear surrogate model via linear interpolation between two Koopman operators corresponding to constant controls. Using a recent convergence result for Extended Dynamic Mode Decomposition, optimality of the reduced order model based control problem can be guaranteed if the control system depends linearly on the input. If this is not the case, we can alternatively transform the control problem into a switching time problem for which optimality can be shown. The resulting feedback controllers are used to control the Burgers equation as well as the flow around a cylinder governed by the Navier-Stokes equations.

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MS160

Expansion Formula of the Resolvents of Koopman Operators: Towards Applications in Analysis and Synthesis of Nonlinear Dynamical Systems

The motivation of our research is to establish a frequency-domain theory that provides methodology and tools to analyze and synthesize systems with nonlinear dynamics. A class of composition operators defined for dynamical systems, called the Koopman operators, plays a central role in this research. In this talk, based on characterization of such systems via spectral properties of the Koopman operators in literature, we address the resolvents of the Koopman operators for continuous- and discrete-time dynamical systems, and we provide their expansion formula for several important classes of the systems with nonlinear dynamics. The formulas are utilized for structural analysis of the systems such as location of modes (poles), which are parallel to frequency-domain analysis of LTI systems, and numerical computation of modes, in particular, transient modes directly from data. A direction of this research on controlled systems with nonlinear dynamics will be also discussed in this talk.

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MS161

Frequency-Ranked Data-Driven Stochastic Modeling, and Applications to Climate Dynamics

In this talk, the data-driven stochastic modeling problem of atmospheric or oceanic observations will be presented as a determination problem of reduction coordinates aimed at simplifying the learning effort of the right-hand side for the unknown SDEs. In that respect and to cope with the multiscale nature of the underlying complex datasets, a general approach for the determination of frequency-ranked empirical modes will be introduced. The reduction coordinates are then obtained as projection of the dataset onto these modes. These reduction coordinates will be shown to be efficiently modeled by SDEs that consist of coupled, nonlinear stochastic oscillators that are frequency-ranked, and whose collective behavior across a frequency band is driven by a same noise realization. This decomposition of the signal into frequency-ranked stochastic oscillators offers a broad range of possibilities to analyze and model the multiscale interactions between variables composing the dataset. Applications to datasets issued either from observations or numerical simulations of Arctic sea ice and ocean dynamics, will be briefly discussed. This talk is based on a joint work with Dmitri Kondrashov and Michael Ghil.

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MS161

Data-Driven Correction Reduced Order Models for Fluid Flows

In this talk, we address the following question: Given a nonlinear equation u' = f(u) and a basis of fixed dimension r, find the best Galerkin model of dimension r. We present the answer proposed by our group for reduced order models (ROMs), supporting numerical results, and open questions. Specifically, we propose a data-driven correction ROM (DDC-ROM) framework, which can be formally written as DDC-ROM = Galerkin-ROM + Correction. To minimize the new DDC-ROM's noise sensitivity, we use the maximum amount of classical projection-based modeling and resort to data-driven modeling only when we cannot use the projection-based approach anymore (i.e., for the

Correction term). The resulting minimalistic data-driven ROM (i.e., the DDC-ROM) is more robust to noise than standard data-driven ROMs, since the latter employ an inverse problem (which is sensitive to noise) to model all the ROM operators, whereas the former solves the inverse problem only for the Correction term. We test the novel DDC-ROM in the numerical simulation of a 2D channel flow past a circular cylinder at Reynolds numbers Re = 100, Re = 500, and Re = 1000.

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MS161

Dynamic Stochastic Model Order Reduction with Adaptive Data-Driven Closures for Geophysical Flows

Dynamical systems for optimal stochastic model order reduction are presented. Adaptive data-driven closures, retractions, and numerical schemes are developed and utilized to maintain the dynamic reduced order model in a neighborhood of the true optimal subspace. Results are presented for nonlinear dynamical systems and simulated geophysical flows in diverse regimes.

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MS161

An Artificial Compression Based Reduced Order Model

In recent years there has been a growing interest in incorporating pressure data into reduced order models for incompressible flows. Due to the lack of fulfillment of the discrete inf-sup condition, a naive incorporation of pressure basis functions will lead to spurious oscillations in the reduced order solution. Some popular approaches for overcoming this issues include the Pressure Stabilization Petrov Galerkin approach, supremizer stabilization, or penalty schemes. Depending on the application these methods can be too expensive to implement, or require parameters that have a dependency which may ruin the offline/online decomposition of the reduced order approach. In an attempt to overcome these issues, we present a new artificial compression based reduced order model known as AC-ROM. AC-ROM is notable for its computational efficiency and convergence even when the basis does not fulfill the discrete inf-sup condition.

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MS162

Modeling the Mid Pleistocene Transition in a Budyko-Sellers Type Energy Balance Model using the LR04 Benthic Stack

A conceptual model of the Plio-Pleistocene glacial cycles is developed based on the Budyko-Sellers type energy balance model. The model is shown to admit a phenomenon like the Mid-Pleistocene transition, capturing the essence of the albedo and the temperature precipitation feedbacks. In this talk, I will give a brief discussion of the model as well as how the LR04 benthic stack was utilized in the making of the model.

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MS162

The Geological Orrery: Mapping the Chaotic History of the Solar System using Earths Geological Record

The Geological Orrery is a network of geochronological and orbitally-paced climate proxy data developed to address inherent limitations of orbital solutions for planetary orbits beyond 60 Ma due to the chaotic nature of Solar System motion. We use results from two coring experiments in early Mesozoic continental strata, the Newark Basin Coring Project and the Colorado Plateau Coring Project, as a geological interferometer to precisely and accurately resolve the secular fundamental frequencies of precession of perihelion of the inner planets and Jupiter for the Late Triassic and Early Jurassic epochs. Due to chaos, the values differ considerably from the present, but they are robust, reflecting an independent U-Pb-based age model, paleomagnetic polarity correlations, and tuning the Newark data to the Venus-Jupiter cycle of 405 ky. The overdetermined Solar System frequencies, faithfully recorded in Newark climate proxy data, have deviations between calculated and measured frequencies of only $< 0.04\%$. To determine the secular fundamental frequencies of the precession of the orbital planes of the planets and their secular resonances with the precession of perihelion, a contemporaneous high-latitude geological archive recording obliquity pacing of climate will be needed. These results form a proof-of-concept of the Geological Orrery interferometer and lay out an empirical framework to map the chaotic evolution of the Solar System.

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MS162

Forcing-Induced Transitions in a Paleoclimate Delay Model

We present a study of a delay differential equation (DDE) model for the glacial cycles of the Pleistocene climate. The model is derived from the Saltzman and Maasch 1988 model, which is an ODE system containing a chain of first-order reactions. Feedback chains of this type limit to a discrete delay for long chains. We approximate the chain by a delay, resulting in a scalar DDE for ice mass with fewer parameters than the original ODE model. Through bifurcation analysis under varying the delay, we discover a previously unexplored bistable region and consider solutions in this parameter region when subjected to periodic and astronomical forcing. The astronomical forcing is highly quasiperiodic, containing many overlapping frequencies from variations in the Earth's orbit. We find that under the astronomical forcing, the model exhibits a transition in time that resembles what is seen in paleoclimate records, known as the Mid-Pleistocene Transition. This transition is a distinct feature of the quasiperiodic forcing, as confirmed by the change in sign of the leading finite-time Lyapunov exponent. We draw connections between this transition and non-smooth saddle-node bifurcations of quasiperiodically forced 1D maps.

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MS162

A Conceptual Glacial Cycle Model with Diffusive Heat Transport

We present a new conceptual glacial cycle model focusing on the coupling of zonally averaged surface temperature and a dynamic albedo line. The meridional transport of heat by the ocean and atmosphere is modeled as a diffusive process. A critical mass balance switching mechanism is introduced to switch from advancing to retreating ice sheets. The role played by the Milankovitch cycles in the timing and duration of the glacial cycles will be in investigated.

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MS163

Mechanisms of the Emergence of Extreme Harmful Algal Blooms

Blooms of toxic or harmful phytoplankton (known as harmful algal blooms or HABs) are showing a significant and increasing threat to human health and fisheries throughout the globe. The most interesting feature of these HABs is its irregularity, in terms of both magnitude and frequency of occurrence that makes the prediction of HABs difficult. Since HABs are, in general, related to a very large abundance of the toxic species, they can be considered as extreme events in marine ecosystems. Compared with the usual spring bloom of phytoplankton they occur quite rarely. The mechanisms of the irregularities of the emergence of HABs are still not well understood. We study a simplified food web model containing nutrients, toxic and non-toxic phytoplankton as well as zooplankton as a grazer to investigate the possible role of toxins/allelopathic substances on the emergence of HABs. It is assumed that these toxic substances suppress the grazer population either by affecting their mobility, fertility, or even kill the grazer. We analyze the impact of toxins on the grazer and its consequences for the frequency, timing and magnitude of bloom events of toxic species. Our results show that the presence of high toxicity makes the bloom dynamics of toxic phytoplankton irregular and more severe while the non-toxic phytoplankton bloom regularly. In fact, the higher the toxicity, the more seldom and more severe toxic blooms are.

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MS163

Prediction of Abnormal Cardiac Rhythms with a 1D Dynamical Model

Sudden cardiac arrest, which is a leading cause of death in the industrialized world, often results from ventricular fibrillation (VF), a dangerous cardiac arrhythmia that produces uncoordinated contractions of heart muscle. Instances of VF are typically rare and difficult to predict, even in individuals who are known to be predisposed toward VF. To gain a better understanding of the mechanisms behind VF, a nonlinear model of action-potential (AP) propagation along a one-dimensional cardiac fiber was examined. The model, which is based on AP duration and conduction velocity restitution functions, is referred to as a coupled maps model. VF is often preceded by short sequences of premature beats, and in previous studies, the coupled maps model was shown to be able to predict which combinations of premature beat timings were more likely to lead to VF in canine hearts *in vivo*. More recently, the model has been compared with *in vitro* optical mapping data from canine right ventricles, and assessed for its ability to predict precursor events, such as discordant alternation and conduction block, in addition to VF. The focus of the present study is to characterize the impacts of parametric variations, such as changing the fiber length, and varying restitution parameters over space or across individuals, on the model's predictive capabilities.

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MS164

Forecasting Nonlinear Time Series with Koopman Shifted Kernel Regression

Kernel methods are a data-driven and non-parametric method for extracting and predicting principal features of nonlinear dynamical systems. These methods rely on the so-called "kernel trick", which embeds data into a rich feature space before employing linear methods like spectral decomposition. Kernel regression techniques, such as Kernel Ridge Regression (KRR) and Kernel Principal Components Regression (KPCR), use this trick to approximate the conditional expectation of an observable with respect to a carefully selected time-lagged state space variable. Time series forecasts are obtained by applying kernel regression to Koopman-shifted signals, which may themselves be subject to a kernel-based analysis such as Extended Dynamic Mode Decomposition (EDMD). This talk will exploit infinite dimensional reproducing Kernel Hilbert Spaces (RKHS) to provide a fully operator-theoretic treatment. Such a perspective makes more apparent the dependency of various convergence results on properties inherent to the dynamical system. This framework, moreover, highlights the separate roles of the regression and Koopman operators, and is suggestive of new algorithms that combine different estimators for each. Applications to the Lorenz-63 system will be presented, along with applications to real climate data related to atmospheric variability in the tropics (e.g. the Madden-Julian Oscillation and El Nino) and sea ice variability in the Arctic.

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MS164

Hierarchical Dynamics Encoders Learning of Collective Variables to Understand and Accelerate Biomolecular Folding

The variational approach to the molecular kinetics of reversible, stationary processes provides a framework within which the leading eigenfunctions of the transfer operator can be estimated by direct analysis of molecular dynamics simulation data. A linear solution of the variational problem within a pre-selected basis-set leads to time-lagged independent component analysis (TICA). Kernel TICA enables automated nonlinear coordinate discovery using the kernel trick, but is computationally expensive and often requires extensive tuning of the kernel and model parameters. Recently, neural networks have been used to estimate transfer operator eigenfunctions as nonlinear functions of the input basis set, but do not provide estimates of the complete spectrum of orthogonal eigenfunctions. In this work, we introduce a novel neural network architecture and loss function that we term the hierarchical dynamics encoder (HDE) to estimate within the variational approximation the full orthogonal spectral hierarchy of transfer operator eigenfunctions. The latent space embedding of the simulation trajectory into the leading eigenfunctions can be used directly to efficiently model the dynamical evolution of the system, or serve as a basis for the construction of high-resolution Markov state models (MSMs). We demonstrate HDEs for 1D and 2D toy systems where the true eigenfunctions are known, and in molecular dynamics simulations of peptides and proteins of varying degrees of complexity.

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MS164

A Local Metastability Detection Method Using Koopman Operators

The Koopman operator formalism, or other closely related approaches such as Markov State Models or the Variational Approach to Conformational Dynamics, are routinely used to explore the slow dynamics of materials as they can be used to approximate the slow eigenspace of the generator of the dynamics. This decomposition can then be used to derive compact and interpretable models in terms of discrete metastable states and of transitions between these states. Such an approach is well suited to post-mortem situations where a large quantity of data (e.g., from direct molecular dynamics simulations) is first generated, and then reduced into a more compact global map of configuration space. In this talk, building on a rigorous local definition of metastability, we show how Koopman operators can also be used to define metastable states and identify inter-state transitions on-the-fly using only local information. This method can be used for in situ data analysis of individual simulations or as a basis for novel long-time simulation methods.

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MS164

Variational Approach to Markov Processes and Its Applications in Molecular Dynamics

Inference, prediction and control of complex dynamical systems from time series is important in many areas, including financial markets, power grid management, climate and weather modeling, or molecular dynamics. The analysis of such highly nonlinear dynamical systems is facilitated by the fact that we can often find a (generally nonlinear) transformation of the system coordinates to features in which the dynamics can be excellently approximated by a linear Markovian model. Moreover, the large number of system variables often change collectively on large time- and length-scales, facilitating a low-dimensional analysis in feature space. We develop a variational approach for Markov processes (VAMP) that allows us to find optimal feature mappings and optimal Markovian models of the dynamics from given time series data. The key insight is that the best linear model can be obtained from the top singular components of the Koopman operator. This leads to the definition of a family of score functions called VAMP-r which can be calculated from data, and can be employed to optimize a Markovian model. In addition, applications of VAMP to analysis of molecular dynamics are introduced.

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MS165

Rate-Induced Tipping in Multi-Dimensional Phase Space: Is this how a Hurricane Dies?

Rate-induced tipping in one-dimensional systems is relatively well-understood, but there is still much to learn about this phenomenon in multi-dimensional systems. To this end, we look at the possibility of rate-induced tipping in Kerry Emanuel's two-dimensional FAST hurricane model, which measures wind speed and inner core moisture. Two parameters, potential intensity and wind shear, are correlated positively and negatively, respectively, to the strength of a hurricane. Allowing these parameters to vary in time will never create a hurricane, but increasing the parameters in time at a sufficiently fast rate may cause a hurricane to die. Thus, rate-induced tipping can kill a hurricane.

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MS165

Buckling of Spherical Shells under Dynamically Increasing Pressure

Buckling of structures is a phenomenon where the difference between the quasi-static loading scenario and a dynamic loading scenario are known to be extreme. We consider the case of a rotationally and equatorially symmetric spherical shell that has a small local imperfection and is subject to radially symmetric inward pointing pressure. When the pressure is increased slowly buckling occurs at a critical pressure corresponding to a fold bifurcation. When the pressure is increased instantaneously (in a rapid ramp up to a pressure below static critical pressure) no unique threshold exists. Rather, we have a large number of threshold values, each corresponding to a trajectory that converges to the center-stable manifold of a saddle-center equilibrium. These thresholds are all far away from the static critical pressure but also far away from threshold estimates based on the energy barrier posed by the saddle. The reason for the discrepancy between quasi-static and dynamic behaviour is the close-to-zero level of damping, making the shell a small perturbation of a conservative system.

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MS165

Tipping Phenomena in Typical Dynamical Systems Subjected to Parameter Drift

Tipping phenomena, i.e. dramatic changes in the possible long-term performance of deterministic systems subjected to parameter drift, are of current interest but have not yet been explored in cases with chaotic internal dynamics. Based on the example of a paradigmatic low-dimensional dissipative system subjected to different scenarios of parameter drifts of non-negligible rates, we show that a number of novel types of tippings can be observed due to the topological complexity underlying general systems. Tippings from and into several coexisting attractors are possible, and one can find fractality-induced tipping, as well as tipping into chaos. Tipping from or through an extended chaotic attractor might lead to random tipping into coexisting regular attractors, and rate-induced tippings appear not abruptly as phase transitions, rather they show up gradually when the rate of the parameter drift is increased. Since systems of arbitrary time-dependence call for ensemble methods, we argue for a probabilistic approach and propose the use of tipping probabilities as a measure of tipping. We numerically determine these quantities and their parameter dependence for all tipping forms discussed.

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MS165

Rate-Induced Tipping: Beyond Classical Bifurcations in Ecology

In the first part of the talk, we demonstrate the nonlinear phenomenon of rate-induced tipping (R-tipping) in a simple ecosystem model where environmental changes are represented by time-varying parameters [Scheffer et al. Ecosystems 11 2008]. We define R-tipping as a critical transition from the herbivore-dominating equilibrium to the plant-only equilibrium, triggered by a smooth parameter shift. We then show how to complement classical bifurcation diagrams with information on nonautonomous R-tipping that cannot be captured by the bifurcation analysis. We also produce tipping diagrams in the plane of the magnitude and 'rate of a parameter shift to reveal non-trivial R-tipping phenomena. In the second part of the talk, we develop a general framework for R-tipping based on thresholds, edge states and a suitable compactification of the nonautonomous system. This allows us to define R-tipping in terms of connecting heteroclinic orbits in the compactified system, which greatly simplifies the analysis. We explain the key concept of (forward) threshold instability and give rigorous testable criteria for R-tipping in arbitrary dimensions.

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MS166

Modeling the Role of Feedback in the Adaptive Response of Bacterial Quorum Sensing

Bacterial quorum sensing (QS) is a communication mechanism that relies on the detection of diffusive signals called autoinducers to regulate gene expression based on cell density, which leads to group behaviors such as biofilm formation, bioluminescence and stress response. In a number of bacterial QS systems, including V. harveyi, multiple signaling pathways are integrated into a single Phosphorylation-dephosphorylation cycle. In this project, we propose a weight control mechanism, in which QS uses feedback loops to 'decode' the integrated signals by actively changing the sensitivity in different pathways. We first use a slow/fast analysis to reduce a single cell model to a planar dynamical system involving the concentrations of phosphorylated signaling protein LuxU and a small non-coding RNA. We then combine the slow/fast analysis with a contraction mapping theorem in order to reduce a population model to an effective single-cell model, and show how the weight control mechanism allows bacteria to have a finer discrimination of their social and physical environment.

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MS166

Spatial Patterning from a Toggle Switch

Bistability is a ubiquitous feature in biological systems. Furthermore, it can be readily engineered into cellular systems. For example, the genetic toggle switch was one of the first genetic networks built *de novo* and expressed in a host organism, pioneering the field of synthetic biology. In this talk we present an extended study showcasing the potential for Turing-like patterns from a toggle switch induced by cell-to-cell communication, a collective phenomenon derived from a toggle switch at the single cell level. An analytical approach to a synonymous system shows that the patterns are not stable but can persist for an extended period of time, which supports its potential relevance in organismal development.

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MS166

Moran Model of Spatial Alignment in Microbial Colonies

We describe a spatial Moran model that captures mechanical interactions and directional growth in spatially extended populations. The model is analytically tractable and completely solvable under a mean-field approximation and can elucidate the mechanisms that drive the formation of population-level patterns. As an example we model a population of *E. coli* growing in a rectangular microfluidic trap. We show that spatial patterns can arise as a result of a tug-of-war between boundary effects and growth rate modulations due to cell-cell interactions: Cells align *parallel* to the long side of the trap when boundary effects dominate. However, when cell-cell interactions exceed a critical value, cells align *orthogonally* to the trap's long side. This modeling approach and analysis can be extended to directionally-growing cells in a variety of domains to provide insight into how local and global interactions shape collective behavior.

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MS166

Microbial Population Dynamics via Cell-Shape Modulation in Negative-Feedback Networks

Rod-shaped bacteria exhibit remarkable regularity in their cell shape and division length maintenance when in suitable growth conditions, while also demonstrating notable plasticity in these characteristics when subjected to growth-altering environmental perturbations. Despite its ubiquity in these organisms, spatio-temporal cell shape uniformity and its selective advantage to bacteria are not well understood. Here, we present models and computer simulations of synthetic microbial consortia in microfluidic traps where cell aspect ratio is dynamically modulated in simulated genetic circuits via quorum sensing signaling in various feedback topologies. Our results show that population dynamics in bacterial consortia can be radically altered by asserting an aspect ratio change in one of the strains. Experimental synthetic biology often relies on distributed functionality among distinct engineered strains whose spatial separation or relative population fraction is critical to maintaining desired functionality. Our simulations demonstrate the ability to controllably alter a population's strain-ratio in a microfluidic trap experiment while using a purely mechanical interaction. The ability to control a bacterial strain's population fraction can lead to new directions of exploration in experimental synthetic consortia and further, help to better understand the role of cell shape in both cooperative and competitive natural environments.

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MS167

Time Delayed Feedback: Control, Synchronisation, and Spectroscopy

Time delayed feedback provides an adaptive mechanism to control complex dynamical systems. In addition such setups can provide insight of the underlying dynamics if time delayed feedback is used for spectroscopic purposes. We illustrate such aspects by analytic and experimental means. Among others we will consider synchronisation in oscillator systems, for instance in heterogenoues networks, and the use of time deayed feedback to control and to analyse complex dynamical behaviour.

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MS167

Control Based Continuation of Unstable States in Particle Based Pedestrian Models

An evacuation scenario were pedestrians have to reach the exit of a corridor after manoeuvring (left or right) around a triangular obstacle is studied. The macroscopic variable of interest is the flux difference between the route choice of every pedestrian. A hysteresis phenomenon was observed by slowly changing the position of the triangle which acts as the parameter of the system. The control-based analysis reveals that a branch of unstable steady states is connected with two branches of stable ones though two saddle-nodes. Control-based continuation can be used to track branches of stable and unstable steady states from a physical experiment without the need of an accurate mathematical model. To do so, a control signal is fed to the system to track and stabilize unobservable steady states. This control signal is designed such that it vanishes on the steady states of the uncontrolled system. The presented modification of this method does no require derivative information and uses the system parameter as an additional dynamical variable to track curves that backfold on themselves.

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MS167

Hysteresis and Unstable Pedestrian Flow Situations in Experiments

Maneuvering of pedestrians around obstacles is very relevant for evacuations of mass events or daily commuting problems in densely populated regions. To avoid severe accidents it is relevant to get some general understanding of pedestrian behavior. A carefully constructed experiment is studied which represents a simplified evacuation scenario and permits the isolation and investigation of the relevant effects. For this a long corridor with a triangular obstacle and a well defined pedestrian influx is investigated where the pedestrians have to reach the end of the corridor. The obstacle position is slowly moved so that the symmetry of the problem is changed and the flux difference of pedestrians left and right of the obstacle is investigated depending on the position of the obtacle. The experiments clearly show nonlinear effects, namely bistability and a hysteresis behaviour of the flux difference depending on the position of the obstacle. This indicates in addition to the stable states the existence of unstable pedestrian flow states which separate the two stable states. Mathematical methods to analyze these states directly in the experiment will be discussed.

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MS167

Pattern Formation in an Annular Corridor of Repulsive Particles Modelling Pedestrian Flow Dy-

namics

The dynamics of pedestrian flow can be modeled by considering each individual pedestrian as a particle moving according to Newtons second law, influenced by social forces and a preferred direction of walk. The later force is pointing in the direction of a target for the pedestrian to reach and it includes a reaction time. The social forces are finite range forces describing our desire not to come too close or collide with other pedestrians. Similarly, we have a force avoiding collision with corridor walls. The social force is typically asymmetric as a pedestrian will pay attention only to the other pedestrians in sight. Results of simulations will be presented demonstrating transitions from one- to multi-lane behavior including multistability for varying pedestrian density and for a varying curvature with fixed density. In the asymmetric case we reveal an inhomogeneous new phase, a traveling wave reminiscent of peristaltic motion. The study is also of relevance for systems of repulsive particles in general.

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MS168

New Algorithms for Refinable, Adaptive Tracking of Self-Consistent Coherent Kinetic Structures in High Energy Density Plasmas: Physics Based Machine Learning

When plasmas execute collective excitations due to the infusion of coherent energy, for instance, due to lasers, highly nonlinear, kinetic and complex behavior in phase space ensues. To simulate the long-time behavior of such systems it is imperative to adapt the tiling of phase space to parsimonious subsets which track the trajectories that most easily capture the essence of the dynamics in a successively refinable manner. Such adaptive tiling has to be learned and it can be used to solve nearby problems with far less effort than starting from scratch each and every time. The latter is the Von Neuman paradigm of computing that has long dominated the field. It emphasizes geometric ordering or taming by making fixed grid choices and reducing the problem to one of linear algebra. But for highly volatile geometry problems, with positive Lyapunov exponents and phase space volume preservation, for instance, it is more advantageous to learn from nearby cases and to refine the algorithms based on these learned prescriptions. This is here demonstrated for the solution of the Vlasov equation where collective, nonlinear, kinetic waves are generated, made to interact, merge, self-organize and self-sustain far from equilibrium, through the action of intense coherent fields. Another advantage of this approach is that homotopic connections between solutions, ROMs (Reduced Order Models) and UQ (Uncertainty Quantification) become byproducts of the iteratively learned process.

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MS168

Symplectic Methods for Drifting Instabilities in Magnetized High Energy Density Plasmas

Starting from a variational principle we obtain a Hamiltonian, self-consistent, macro-particle model of a plasma. Although this system has a large number of degrees-of-freedom, the equations of motion can be integrated using conventional symplectic methods. As a result, the Poincaré invariants of the combined phase space of macro-particles and fields are exactly preserved. We apply this model to the Buneman instability, which arises due to an electron-ion drift. We study the nonlinear evolution of this processes in the presence of externally imposed transverse magnetic fields. We compare the macro-particle model to Vlasov-Maxwell calculations as well as to traditional (i.e., non-Hamiltonian) macro-particle models. Ion to electron mass ratios of 1, 10 and 100 will be considered. Supported by the NSF under contract no. PHY-1104683 and the US DoE under contract no. DE-SC0018363

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MS168

Multidimensional Confinement of Self-Consistent Particle Orbits in Coherent Phase Space Plasma Structures

Crossing, intense laser beams in high energy density plasmas lead to the generation of nonlinear kinetic plasma waves (NL-EPW). The usefulness of such plasma structures depends on their long-time stability. This can be ensured in a variety of ways. Two under consideration in this presentation are (i) externally imposed axial magnetic (B) fields and (ii) density troughs in transverse dimensions. We show how B field and density well designs, which confine multidimensional NL-EPW, both in the trapping regime and when vortex merger and vortex destruction due to sideband instabilities are prevalent. These studies employ self-consistent particle simulations and the use of reconstructed particle orbit dynamics from the self consistent electric and magnetic fields. (Work supported by a grant from AFOSR

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MS168

Spectrally Accurate Methods for Kinetic Electron Plasma Wave Dynamics

We present two numerical methods for computing solutions of the Vlasov-Fokker-Planck-Poisson equations that are spectrally accurate in all three variables (time, space and velocity). The first is a Chebyshev collocation method for solving the Volterra equation for the space-time evolution of the plasma density for the linearized, collisionless case. This is then used to efficiently represent the velocity distribution function in Case-van Kampen normal modes. The second is an arbitrary-order exponential time differencing scheme that makes use of the Duhamel principle to fold in the effects of collisions and nonlinearity. We investigate the emergence of a continuous spectrum in the collisionless limit and the embedding of Landau's poles in this general setting. We resolve the effects of filamentation, phase mixing, and Landau and collisional damping to arbitrary order of accuracy, focusing on echoes and trapping phenomena.

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MS169

Dynamics of Pulses for Mass-Conserved Reaction-Diffusion Systems Related to Cell Polarity

We consider a Mass-conserved Reaction-diffusion system on a circle arising in biological problems related to cell polarity, in which a single pulse solution corresponds to a cell polarity. We will analyze the interaction of two single pulses on different circles and show that the anti-phase is a stable state of two single pulses.

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MS169

On Compact Traveling Waves for a Mean-Curvature Flow with Driving Force

Traveling waves appear in various phenomena Here we pay attention to traveling wave solutions for mean curvature flow with a driving force. As is well known, Grim reaper and V-shaped traveling front are typical examples of traveling wave solutions for mean curvature flow and eikonal-curvature flow, respectively. However there are defined in whole space and not compact. In some phenomena such as cell locomotion, we can observe traveling waves composed of closed hypersurface. In recent years, the authors have studied about the existence and uniqueness of traveling waves composed of Jordan curve in two-dimensinoal space, called "compact traveling wave', under a general driving force. In this talk, we consider the same problem in more than three-dimensional space. In particular, we show the existence and uniqueness of axisymmetric compact traveling waves, which is symmetric with respect to traveling direction, for the mean curvature flow equation with driving force. This is a joint work with Hirokazu Ninomiya.

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MS169

Monotone Traveling Waves for a Bistable Lattice Dynamical System

Three species competition in a discrete patch environment is modeled by a 3-component lattice dynamical system of competition type. For such an ecological system, it is important to know which species will survive eventually and hence traveling waves play an important role to understand the competition mechanism. In this talk, we study the stability of monotone traveling waves for general cooperative lattice dynamical systems. Since the above-mentioned 3-component competition system can be converted to a 3-component cooperative system under some conditions, our results are applicable to show the asymptotic stability of traveling waves for the 3-component competition system. This talk is based on a joint work with Jong-Shenq Guo (Tamkang University), Toshiko Ogiwara (Josai University) and Chin-Chin Wu (National Chung Hsing University).

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MS169

Pulse Dynamics in Reaction-Diffusion Equations with Strong Spatially Localised Impurities

In this talk, I will discuss a general geometric singular perturbation framework to study the impact of strong, spatially localised, nonlinear impurities on the existence, stability and bifurcations of localised structures in systems of linear reactiondiffusion equations. By taking advantage of the multiple-scale nature of the problem, I derive algebraic conditions determining the existence and stability of pinned single- and multi-pulse solutions. Our methods enable us to explicitly control the spectrum associated with a (multi-)pulse solution. In the scalar case, I show how eigenvalues may move in and out of the essential spectrum and that Hopf bifurcations cannot occur. By contrast, even a pinned 1-pulse solution can undergo a Hopf bifurcation in a two-component system of linear reactiondiffusion equations with (only) one impurity. This is joint work with A. Doelman from Leiden University and J. Shen from Fujian

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MS170

Quantifying Lagrangian Uncertainty and Robust Sets from Noisy Unsteady Eulerian Data

Observational velocity data in geophysical fluids is unsteady, and has uncertainties because of observational error, deviation from geostrophy, and importantly, subgrid effects owing to the spatial resolution scale of the data. Therefore, any conclusions on finite-time Lagrangian trajectories imputed from this Eulerian data will inherit an uncertainty. Allowing for a spatio-temporally dependent noise model, a stochastic differential equation framework for quantifying the statistical distribution of each eventual Lagrangian trajectory is developed. This captures the displacement's variance in each direction ('anisotropic variance') as well as an explicit optimized measure across all directions ('stochastic sensitivity'). The latter concept generates a field across all initial conditions, from which it is possible to identify evolving flow regions which are robust with respect to a user-specification of length-scale and noise-level in the data. It is expected that these will be invaluable new tools in ascribing uncertainties to Lagrangian coherent structures.

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MS170

Using Control to Shape Stochastic Escape and Switching Dynamics

We present a strategy to control the mean stochastic switching times between metastable states for dynamical systems subjected to Gaussian white noise. The control can either enhance or abate the probability of escape from the deterministic region of attraction of a stable equilibrium in the presence of external noise. With the proposed controller, we are able to achieve a desired mean switching time, even when the strength of noise in the system is not known. The control method is analytically validated using a one-dimensional system and its effectiveness is numerically demonstrated for an unmanned sensor operating in a geophysical flow.

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MS170

Exploring use of Machine Learning Towards Weather Prediction

The volume and diversity of environmental data obtained from a variety of Earth-observing systems, has experienced a significant increase in the last couple years with the advent of high spectral, spatial, and temporal resolutions sensors. This trend is expected to continue and complement traditional environmental data. Yet, the data volume presents already a significant challenge. Satellite measurements input to data assimilation algorithms for instance, need to be aggressively thinned spatially, spectrally and temporally; only a fraction of satellite data gets actually assimilated. Taking full advantage of the observations as much as possible requires exploring new approaches for processing the data, from ingest to dissemination. We present in this study the results of a pilot projects effort to use cognitive learning approaches for numerical weather prediction applications. The approach relies on training a deep-layer neural network on a set of inputs from nature run (i.e., sampling of the synthetic atmosphere) as well as operational analyses (i.e., sampling of the real atmosphere), along with corresponding observations simulated using the observation operators. The present study demonstrates the proof of concept and shows that use of machine learning holds significant promise in potentially addressing the vexing issue of computational power and time requirements needed to handle the extraordinarily high volume of environmental data, current and expected.

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MS170

Machine Learning and Trajectory Prediction in Geophysical Flows

We extend the machine learning technique of reservoir computing (RC) to individual trajectories and ensembles of trajectories found in two elementary models of ocean circulation: the well-known double-gyre stream function model with time-variable forcing and a one-layer quasi-geostrophic (QG) basin model. In both cases, the models are used to generate two-dimensional flow field data, i.e. a flow map, from which trajectories are computed. The physical model parameters are used to sample a range of dynamical behaviors corresponding to various geophysical flow regimes. In particular, the quasi-geostrophic PDE system has dimensionless parameters which can select Munk type or Stommel type solutions. We present results on the effectiveness of the RC approach in capturing the characteristics of trajectories and their maps in geophysical model flows; we assess the predictive power of the RC models against other predictive and descriptive models, including FTLE results, and the role of both physical and numerical parameters on these results.

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MS171

First-Order Phase Transitions in the Kuramoto Model with Compact Bimodal Frequency Distri-

butions

The Kuramoto model of a network of coupled phase oscillators exhibits a first-order phase transition when the distribution of natural frequencies has a finite flat region at its maximum. First-order phase transitions including hysteresis and bistability are also present if the frequency distribution of a single network is bimodal. In this study we are interested in the interplay of these two configurations and analyze the Kuramoto model with compact bimodal frequency distributions in the continuum limit. As of yet, a rigorous analytic treatment has been elusive. By combining Kuramoto's self-consistency approach, Crawford's symmetry considerations, and exploiting the Ott-Antonsen ansatz applied to a family of rational distribution functions that converge towards the compact distribution, we derive a full bifurcation diagram for the system's order parameter dynamics. We show that the route to synchronization always passes through a standing wave regime when the bimodal distribution is compounded by two unimodal distributions with compact support. This is in contrast to a possible transition across a region of bistability when the two compounding unimodal distributions have infinite support.

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MS171

Understanding Chimera States via Reduction to Kuramoto and Stuart-Landau Models

Networks of coupled oscillators exhibit a variety of dynamical synchronization behaviors that are of significance in nature and technology. The emergence of chimera states - patterns with coexisting coherent and incoherent domains - has been demonstrated recently in experiments using mechanical oscillators [Martens et al., Proc. Natl. Acad. Sci., 110 (2013)]. Here, we provide an intuitive explanation for the emergence of chimera states based on fundamental mechanical principles, identifying resonance as a physical mechanism leading to chimera states. Thereby, we establish a rigorous link between the Newtonian model presented in Martens et al. (2013) and abstract mathematical models in which chimera states were discovered originally, i.e., (i) Stuart-Landau oscillators [Laing, Phys. Rev. E, 81 (2010).] and (ii) Kuramoto oscillators [Abrams et al., Phys. Rev. Lett., 101 (2008); Martens et al., Chaos, 26 (2016); Bick et al., Chaos, 28 (2018)], and we explore for what parameter regimes such a mapping is valid. The resulting mechanical theory likely translates to a large range of domains in nature and technology.

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MS171

Perturbation Theory for the Kuramoto-type Models of Coupled Oscillators Beyond the Ott-Antonsen Ansatz

Kuramoto model and its extensions describe effects of global coupling in populations of phase oscillators. The Ott-Antonsen (OA) ansatz allows for a description of the dynamics of such populations within a simple equation for the complex order parameter. However, this reduction is possible under special conditions only. Here we present a perturbation theory on top of the OA ansatz based on the circular cumulant representation. As an example, noisy oscillators are considered. Here a truncation of the cumulant hierarchy at the second term gives a very good approximation to the full dynamics.

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MS171

Collective Dynamics of Stuart-Landau Oscillators in Between Phase and Amplitude Oscillators

Collective properties of oscillators are often analysed by running simulations for increasingly large ensembles of elements. Therefore, analytical approaches/results are definitely welcome, as they can be used as references for validating otherwise purely numerical observations. Here we show that the well known model of mean-field coupled, Stuart-Landau oscillators can be semi-analytically studied at a macroscopic level in an intermediate regime, where the oscillators maintain some typical features of phase-oscillators (remaining aligned along a closed smooth curve **C**), accompanied by amplitude oscillations that manifest themselves as fluctuations of the curve **C**. Our approach leads to exact evolution equations for the collective dynamics which take the form of two partial differential equations. The study of the model for increasing values of the coupling strength reveals a first transition from a splay state to a self-consistent partial synchrony, followed by increasingly complex regimes, which include an intriguing form of collective-chaos, characterized by a small number of positive Lyapunov exponents and a seemingly high-dimensional dynamics.

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MS172

Data Assimilation for Chaotic Geophysical Dynamics - An Overview

We refer to state estimation theory in geosciences as data assimilation (DA). DA is standard practice in numerical weather prediction, and its application is becoming widespread in many other areas of climate, atmosphere, ocean, and environment modelling; in all circumstances where one intends to estimate the state of a large dynamical system based on limited information. Atmosphere and ocean, are examples of chaotic dissipative dynamics: error dynamics is extremely sensitive to the initial condition and highly state-dependent. Dealing with such a flow-dependent error growth is a challenge for DA: one must in fact be able to properly track and incorporate this dependency in the DA process. A situation that is made even worse by the large size of the geophysical models. This talk will recall the unique challenges that chaotic environmental systems have posed to the development of adequate DA and predictability tools and will provide an outlook on one of such approach, the assimilation in the unstable subspace and on its applications in atmospheric and ocean systems.

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MS172

Data Assimilation with Stochastic Model Reduction of Chaotic Systems

Due to limited computational resources, reduced models, especially coarse-grid models, are often used in data assimilation. However, model error due to the unresolved variables largely affects the prediction accuracy. To account for the model error, a major challenge is the memory effects of the unresolved variables when there is no scale separation. We propose a stochastic parametrization method which accounts for the memory effects by nonlinear autoregression moving average (NARMA) type models. We demonstrate by examples that the resulting NARMA type stochastic reduced models can capture the key statistical and dynamical properties, and therefore can improve the accuracy of ensemble prediction in data assimilation. The examples include the Lorenz 96 system and the Kuramoto-Sivashinsky equation of spatiotemporally chaotic dynamics.

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MS172

The Dynamic Likelihood Filter

A Bayesian data assimilation scheme is formulated for advection-dominated or hyperbolic evolutionary problems, and observations. It uses the physics to dynamically update the likelihood in order to extend the impact of the likelihood on the posterior, a strategy that would be particularly useful when the the observation network is sparse in space and time and the associated measurement uncertainties are low. The filter imparts phase information contained in the data which can then have a positive effect on the estimated wave speed. The updates of the likelihood are available between observations, as well as into the future, thereby providing the posterior with a more informative Bayesian product. The added computational expense of the method is linear in the number of observations and thus computationally efficient, suggesting that the method is practical even if the space dimensions of the physical problem are large. The filter is applied to a problem with linear dynamics and Gaussian statistics, and compared to the exact estimate, a model outcome, and the Kalman filter estimate. The example will be used to highlight qualitative differences between the familiar estimate and the dynamic likelihood approach to filtering.

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MS172

Projected Particle Filters

We introduce a framework for Particle Filtering, PF-AUS, in which only the components of data corresponding to a set number of the unstable and neutral modes are assimilated. This is a novel application of AUS, Assimilation in the Unstable Subspace, that has been thoroughly explored in recent years for Extended Kalman Filter techniques. PF-AUS is implemented as a reconfiguration of the data model employed by a Particle Filter. The PF-AUS implementation is identical to assimilating observations of a lower dimension, corresponding to the number of positive, zero, and weakly negative Lyapunov exponents. The dimension of the observations is crucial in the collapse of the (standard) Particle Filter, and this approach is a framework to mitigate that collapse while preserving as much relevant information as possible, in that the unstable and neutral modes correspond to the most uncertain model predictions. Since PF-AUS is developed as a change to the data model, any Particle Filter can then be applied in the PF-AUS framework.

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MS173

Agent-Based and Continuous Models of Locust Hopper Bands: Insights Gained through the Lens of Dynamical Systems

Locust swarms pose a major threat to agriculture, notably in northern Africa, the Middle East and Australia. In the early stages of aggregation, locusts form hopper bands. These are coordinated groups that march in columnar structures that are often kilometers long and may contain millions of individuals. We report on two models for the formation of locust hopper bands. The first is a two-dimensional agent-based model (ABM) that incorporates intermittent motion, alignment with neighbors, and social attraction/repulsion, all behaviors that have been validated in experiments. Using a particle-in-cell computational method, we simulate swarms of up to a million individuals, which is several orders of magnitude larger than what has previously appeared in the locust modeling literature. We observe hopper bands in this model forming as an instability. Our model also allows homogenization to yield a system of partial integro-differential evolution equations. We identify a bifurcation from a uniform marching state to columnar structures, suggestive of the formation of hopper bands. The second is a one-dimensional ABM that introduces a resource (food) and includes foraging. Here homogenization yields a hyperbolic system of PDEs. Both the ABM and the PDEs manifest pulse solutions which are reflective of field observations. We reflect on the fact that both these models allow reductions that can be analyzed via methods from the study of dynamical system.

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MS173

Dynamics of Religious Group Growth and Survival

We model and analyze the dynamics of religious group membership and size. A groups is distinguished by its strictness, which determines how much time group members are expected to spend contributing to the group. Individuals differ in their rate of return for time spent outside of their religious group. We construct a utility function that individuals attempt to maximize, then find a Nash Equilibrium for religious group participation with a heterogeneous population. We then model dynamics of group size by including birth, death, and switching of individuals between groups. Group switching depends on the strictness preferences of individuals and their probability of encountering members of other groups. We show that in the case of only two groups one with finite strictness and the other with zero there is a clear parameter combination that determines whether the non-zero strictness group can survive over time, which is more difficult at higher strictness levels. At the same time, we show that a higher than average birthrate can allow even the highest strictness groups to survive. We also study the dynamics of several groups, gaining insight into strategic choices of strictness values and displaying the rich behavior of the model.

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MS173

A Birth-Jump Processes in Plant Dynamics

Motivated by the importance of understanding the dynamics of the growth and dispersal of plants in various environments we introduce and analyze a discrete agent-based-model based on a *birth-jump process*, which exhibit

wave-like solutions. To rigorously analyze this traveling-wave phenomena we derive the diffusion-limit of the discrete model and prove the existence of traveling wave solutions (sharp and continuously differentiable) assuming a logarithmic-type growth. Furthermore, we provide a variational speed for the minimum speed of the waves and perform numerical experiments that confirm our results.

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MS173

Microbial Biofilm Colony Dynamics

Most microorganisms like bacteria and yeast live in multicellular communities known as biofilms. These films are widespread in natural, industrial, and medical environments. Examples include pond scum, dental plaque, and the human microbiome. Here, we will present experimental results of biofilm spreading dynamics that reveal how individual biofilm colonies spread without the use of active motility. We will also present an investigation into how individual biofilm colonies interact and explore available space and nutrients. Interacting microbial colonies represent a class of biological systems where knowledge of system dynamics requires consideration of non-local interactions.

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MS174

(Un)-Supervised Structure Learning of Biochemical Reaction Networks

Network inference from time resolved gene expression measurements is a long-standing challenge in systems biology. Recently, supervised learning has proven its potential for this task. However, obtaining the appropriate volume of informative training data constitutes a key limitation for such methods. We propose a supervised gene network inference approach based on exclusively synthetic training data, termed surrogate learning. We systematically investigate simulation configurations for biologically representative time series of transcripts, and augmentation of the data with a measurement model. As classifiers, we consider hybrid convolutional recurrent neural networks, random forests and logistic regression. For an E. coli gene expression dataset, we find that synthetic training data generated with multi-gene perturbations and a measurement model is best suited for network reconstruction. For the same dataset, we demonstrate superiority of our supervised approach to multiple unsupervised, state-of-the-art methods. We expect surrogate learning to be generally applicable for network reconstruction where experimental training data is difficult to attain, but simulation of representative synthetic data is possible.

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MS174

Uncovering Conspiracy Theories: How to Deal with Latent Confounders in Dynamical Systems

A common assumption in structure inference of dynamical systems from temporal measurements is the absence of latent confounders. A latent confounder is an unobserved quantity that directly affects at least two measured ones. In this talk, we will briefly introduce the problem of sparse learning of dynamical systems and then present a novel methodology on how to deal with latent confounders. A mathematical theory which determines how many latent confounders are present as well as an algorithm that infers both the dynamical system and the latent confounders will be given. We demonstrate the capabilities of the proposed approach on a synthetic example from non-linear biochemical reaction networks as well as on stock prices data.

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MS174

Sparse Learning with Mixing Data and Outliers

Learning a generating function from a finite set of input-output observations is an important but challenging task in various scientific disciplines. In general, this data-based learning problem is ill-posed due to the nonlinearity of the unknown function and the complicated properties of given data (possibly noisy, corrupted, or correlated). One of the main directions is to investigate the sparsity-of-effect in the data-driven methods to select a suitable model. Along this direction, we study the problem of learning nonlinear functions from identically distributed but not independent data that is sparsely corrupted by outliers and noise. The learning problem is written as a parameter estimation problem where we incorporate both the unknown coefficients and the corruptions in a basis pursuit denoising framework. The main contribution of this work is to provide a reconstruction guarantee for the associated l1-optimization problem, provided that the data is bounded and satisfies a suitable concentration inequality. Applications to various type of mixing data such ash exponentially strongly alpha-mixing data, geometrically C-mixing data, and uniformly ergodic Markov chain will also be discussed. This is joint work with Rachel Ward (UT Austin) and Hayden Schaeffer (CMU).

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MS174

Extracting Structured Dynamics from Very Few Samples

We present a random sampling method for learning structured dynamical systems from under-sampled and possibly noisy state-space measurements. The learning problem takes the form of a sparse least-squares fitting over a large set of candidate functions. We provide theoretical guarantees on the recovery rate of the sparse coefficients and the identification of the candidate functions for the corresponding problem. This formulation has several advantages including ease of use, theoretical guarantees of success, and computational efficiency with respect to ambient dimension and number of candidate functions.

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MS175

Canards and Slow Passage Through Bifurcations in Infinite-Dimensional Dynamical Systems

I will present a rigorous framework for the local analysis of canards and slow passages through bifurcations in a large class of infinite-dimensional dynamical systems with time-scale separation. The framework is applicable to models where an infinite-dimensional dynamical system for fast variables is coupled to a finite-dimensional dynamical system for slow variables. I will discuss examples where the fast variables evolve according to systems of reaction-diffusion-advection PDEs, integro-differential equations, or delay-differential equations. This approach opens up the possibility of studying spatio-temporal canards and slow passages through bifurcations in spatially-extended systems, and it provides an analytical foundation for several numerical observations recently reported in literature.

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MS175

Delayed Hopf Bifurcations in Excitable Nerve Cables

In delayed Hopf bifurcation problems the transition to large amplitude oscillations may not occur until a slowly changing parameter is considerably beyond the value predicted from a straightforward static bifurcation analysis (delay effect), and the onset may be dependent on the initial value of the slow parameter (memory effect). Following a brief introduction to delayed Hopf bifurcation problems in excitable nerve cells, we show some recent numerical and analytic results that apply to threshold and accommodation dynamics in axonal and dendritic cables. Specifically, we show that for nerve cable models, where the reactive (excitable) and diffusive portions of the nerve are weakly coupled, the onset of large amplitude oscillations in response to a slow current ramp can occur at a significant spatial distance away from the input site (spatial delay effect). Furthermore, the onset location depends on the initial value of the current (spatial memory effect). Other reaction diffusion systems may exhibit these properties if the reactive and diffusive portions of the system are weakly coupled.

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MS175

Multi-Mode Steady State Solutions in Excitable Spatially Extended Systems

The canard phenomenon is robust in singularly perturbed ODEs that have a critical manifold that is at least 2D. Canards have been used to explain the origin and properties of pseudo-plateau bursting rhythms in ODE models of the electrical activity in pituitary cells. In this work, we report on a novel class of spatiotemporal canard attractors, called multi-mode steady states (MMSS), in a PDE model for the electrical activity in a pituitary lactotroph clonal cell line. Key features of the MMSS are (i) they exhibit different modes of pseudo-plateau bursting activity in different regions of the spatial domain, and (ii) they represent a novel form of diffusion-induced oscillation. We compare the MMSS to the twisted invariant slow manifolds from the ODE setting, and provide a geometric explanation for the behaviour of the PDE. Moreover, we show that the MMSS are robust and occur in other contexts, such as in arrhythmogenesis in cardiac tissue models.

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MS175

Delayed Loss of Stability due to Slow Passage through Hopf Bifurcations in Reaction-Diffusion Equations

In analytic ODEs, it is known that the onset of oscillations can be significantly delayed when a bifurcation parameter slowly passes through a Hopf bifurcation. In this work, we present the delayed loss of stability due to slow passage through Hopf bifurcations in reactiondiffusion equations with slowly-varying parameters. We focus on the Hodgkin-Huxley, cubic Complex Ginzburg-Landau, and Brusselator PDEs. For these systems, the delayed loss of stability impacts the frequency and amplitude of the observed oscillations, and can create a novel pulse-generating mechanism. Solutions which are attracted to quasi-stationary states (QSS) sufficiently before the Hopf bifurcations remain near the QSS for long times after the states have become repelling, resulting in a significant delay in the loss of stability and the onset of oscillations. Space-time boundaries are identified that act as buffer curves beyond which solutions cannot remain near the repelling QSS, and hence before which the delayed onset of oscillations must occur, irrespective of initial conditions. We derive asymptotic formulas for the buffer curves, and find excellent agreement with the numerics.

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MS176

Integrative Modeling of Synthetic Gene Circuits

One fundamental challenge in synthetic biology is the lack of quantitative tools that accurately describe and predict the behaviors of engineered gene circuits. This challenge arises from multiple factors, among which the complex interdependence of circuits and their host is a leading cause. Here we present a gene circuit modeling framework that explicitly integrates circuit behaviors with host physiology through bidirectional circuithost coupling. The framework consists of a coarse-grained but mechanistic description of host physiology that involves dynamic resource partitioning, multilayered circuithost coupling including both generic and system-specific interactions, and a detailed kinetic module of exogenous circuits. We showed that, following training, the framework was able to capture and predict a large set of experimental data concerning the host and its foreign gene overexpression. To demonstrate its utility, we applied the framework to examine a growth-modulating feedback circuit whose dynamics is qualitatively altered by circuithost interactions. Using an extended version of the framework, we further systematically revealed the behaviors of a toggle switch across scales from single-cell dynamics to population structure and to spatial ecology. This work advances our quantitative understanding of gene circuit behaviors and also benefits the rational design of synthetic gene networks.

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MS176

Modeling and Parameter Estimation for Synthetic Microbial Consortia

We provide models for microbial consortia (a combination of two or more interacting microbial colonies growing in the same environment) and based on these models and experimental data, we estimate the values of parameters of interest. In particular, we study microbial consortia with different network structures where signaling between bacterial strains is enabled by quorum sensing. The quorum sensing molecules diffuse out of the cell and into other neighboring cells activating their transcription factors. We use deterministic models consisting of ordinary differential equations. Our models are simple mechanistic models that are useful for prediction and design purposes for microbial consortia with different network structures. Our parameter inference method that is developed based on Bayesian parameter estimation techniques can infer parameter values efficiently from limited experimental observations. In the core of the Bayesian parameter estimation method, we use Markov Chain Monte Carlo (MCMC) sampling techniques, such as Metropolis sampling. We infer parameters such as cell growth rates, protein synthesis rates, quorum sensing molecules synthesis rates, and parameters that characterize the response of bacterial strains to input quorum sensing signals such as Hill coefficients. Our models together with our efficient parameter estimation method provide a tool for the analysis, design, and control of the dynamics of microbial consortia.

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MS176

Dynamical Modeling to Bridge Spatial and Temporal Scales in Multicellular Collective Behavior

Multicellular systems engage in a wide range of collective behaviors such as group migration, synchronized signaling, and coordinated pattern formation and development. These behaviors are challenging to understand because they are mediated by the dynamics of complex biochemical signaling networks acting on a timescale of seconds inside single cells, but coordinate behaviors happening over hours and days across populations many orders of magnitude larger. One of the most striking examples of these behaviors is the transition from an independent, single-celled state to a multicellular aggregate in the social amoebae *Dictyostelium discoideum*. We have devised a simple dynamical model that accurately recapitulates experimentally-observed *Dictyostelium* single-cell signaling behaviors. By using the single cell model as a building block for a multicellular model, we are able to predict and experimentally verify novel population-level behaviors. The multicellular model predicts that stochasticity is a key player in the coordination of collective behaviors, allowing cells to communicate in high background environments. We are now working to identify the control parameters single cells modulate to change group-wide pattern formation. Our results lay the groundwork for using these types of models to identify common principles of how collective cellular behaviors arise in nature.

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MS176

From Molecules to Development: Understanding How Biological Oscillators Function and Coordinate

We study biological oscillations and self-organization phenomena in both artificially constructed mitotic cells and live zebrafish embryos. We focus on how the network structures of biological clocks are linked to their functions, such as tunability and robustness, and how individuals coordinate through biochemical and mechanical signals to generate collective spatiotemporal patterns. To pin down the physical mechanisms that give rise to these complex phenomena, we integrate modeling, time-lapse fluorescence microscopy, microfluidics, and systems and synthetic biology approaches. Although central architectures drive robust oscillations, networks containing the same core vary drastically in their potential to oscillate. We computationally generate an atlas of oscillators and found that, while certain core topologies are essential for robust oscillations, local structures substantially modulate the degree of robustness. Strikingly, two key local structures, incoherent inputs and coherent inputs, can modify a core topology to promote and attenuate its robustness, additively (Cell Systems 2017). Experimentally, we developed an artificial cell-cycle system to mimic the real mitotic oscillations in microfluidic droplets (eLife 2018). The innate flexibility makes it key to studying clock functions of tunability and stochasticity at the single-cell level. We now combine this platform with mathematical modeling to elucidate the topology-function relation of biological clocks.

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MS177

Synchronization in Models of Sleep-Wake Dynamics

Various nonlinear dynamical models have been explored in recent years in order to investigate how the brain shifts between sleeping and waking states. We investigate the maintenance of, and transitions between, wake and sleep states using models based on ensembles of coupled individual neurons. Using the Hodgkin-Huxley-like Huber-Braun model, which allows fine-tuning of various bursting states, we first characterize sleep dynamics using two neural ensembles, representing sleep- and wake-promoting nuclei within the brain. These regions mutually excite and inhibit each other, modulated by an external circadian drive. An extended and more biologically realistic version of the model includes neural ensembles representing the ventrolateral preoptic nucleus, orexinergic neurons in the lateral hypothalamic region, the monoaminergic nucleus, and the median preoptic nucleus, as well as the homeostatic drive (sleep pressure). We characterize changes in synchronization within and between these different regions as the system undergoes transitions between sleep and wake. We discuss the implications of the model for studies of unihemispheric and asymmetric sleep, as well as the possible role of chimera states in mediating such asymmetries.

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MS177

Modulator Induced Transitions between Neuronal Activities

Transitions between neuronal activity states are associated with sleep and wakefulness, brain seizures, thalamocortical information processing, and are common in sensory and motor systems. During transitions, neurons often exhibit irregular firing patterns before settling on well-defined rhythmic regimes. Although computational models suggest that these irregular firing patterns may be evidence of chaos and serve as a means by which transitions in activity can occur, what happens in biological systems is not well-studied. We address this problem by examining neuropeptide-induced activity transitions in a motor system with individually identifiable neurons. In the biological system, the neuropeptide increases neuronal firing rates and elicits a transition from tonic (single spikes) to bursting (sequences of multiple spikes) activities via an inward modulator-induced current (IMI). Further, increases in the neuropeptide concentration result in smaller windows of irregular activity. In a single-neuron Huber-Braun model, increasing IMI increases firing rate, but elicits bursting-to-tonic transitions. The model also suggests that the chaotic window during transitions depends on the interaction between the excitability of the neuron and IMI. We are currently studying how IMI contributes to activity transitions and whether its interactions with cell excitability acts to reduce irregular neuronal activity.

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MS177

Synchronous Neuronal Transitions Mediated by Chaos

No two neurons are the same. However diverse neurons may be, they can work in synchrony, performing functions crucial for the sustaining of life. Importantly, neurons in synchrony may undergo transitions that allow them to perform tasks related to changes in the rate and in the pattern of their firing. Transitions between tonic (fixed rate spiking) and bursting (trains of fast spiking alternated with quiescence) are present in thalamocortical neurons at sleep-wake transition states. These transitions may also play a role in sensory-motor nuclei generating tremors in Parkinson's disease. Although of high relevance, little is known about the mechanisms underlying this type of neuronal transition. Here we use a biophysical model to investigate neuronal tonic to bursting transitions, exploring aspects found in the dynamical evolution of the firing rate. Usually, the tonic to bursting transition starts with a period doubling cascade going into chaos with the well-known windows of periodicity, eventually reaching a regular bursting regime. The transition is therefore mediated by chaos, where a critical firing rate is present. This critical firing rate found initially as a signature of the individual neuron actually is passed on to the collective of distinct networked synchronous neurons (Shaffer et al. PRE 2016; Shaffer et al. EPJST 2017; Follmann et al. Chaos 2018). We discuss additional features including how temperature may play a role in the setting off of the transition.

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MS177

Bursting Synchronization in a Neuronal Network Model for Cortical Areas of the Human Brain

The cerebral cortex plays a key role in complex cortical functions. It can be divided into areas according to their function (motor, sensory and association areas). In this paper,the cerebral cortex is described as a network of networks(cortex network),we consider that each cortical area is composed of a network with small-world property(cortical network). The neurons are assumed to have bursting properties with the dynamics described by the Rulkov model. We study the phase synchronization of the cortex network and the cortical networks. In our simulations, we verify that synchronization in cortex network is not homogeneous.Besides,we focus on the suppression of neural phase synchronization. Synchronization can be related to undesired and pathological abnormal rhythms in the brain. For this reason, we consider the delayed feedback control to suppress the synchronization. We show that delayed feedback control is efficient to suppress synchronous behavior in our network model when an appropriate signal intensity and time delay are defined.

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MS178

Lagrangian Chaos and Passive Scalar Advection in Stochastic Fluid Mechanics

We study the Lagrangian flow associated to various models of fluid mechanics subject to suitably non-degenerate stochastic forcing in a periodic box. We prove that these (random) flows are almost surely chaotic in the sense that the top Lyapunov exponent is strictly positive. Our results hold for the 2D and 3D Navier-Stokes equations at arbitrary Reynolds number (with arbitrarily small hyper-viscous regularization in 3D). We further apply these results to passive scalar turbulence modeled by statistically stationary solutions to the advection-diffusion equation driven by these velocities and subjected to random sources. The chaotic Lagrangian dynamics are used to prove a version of anomalous dissipation in the limit of vanishing diffusivity, which in turn, implies Yaglom's law of passive scalar turbulence – the analogue of the celebrated Kolmogorov 4/5 law. Key features of our study are the use of tools from ergodic theory and random dynamical systems, namely the Multiplicative Ergodic Theorem and a version of Furstenberg's Criterion. These are combined with tools from stochastic calculus, for example, infinite-dimensional Malliavin calculus and elementary, but nevertheless illuminating, approximate control arguments.

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MS178

Satisfying Temporal Resolution Criteria in Rela-

tivistic Particle-in-Cell Simulations with a High-Intensity Laser Field

Particle-in-cell (PIC) codes are now standard tools for studying laser-plasma interactions. Classical PIC methods employ a leap-frog time-integration scheme, which advances both field and particle quantities in lock-step. The typical criterion for the timestep is, apart from the CFL condition of the field equations, commonly set to have minimum numerical dispersion errors for propagating light waves. Using the timestep for integrating (with the leapfrog scheme) the relativistic particle equations of motion can be inaccurate under strong laser fields. A new temporal resolution criterion [1] is necessary to capture particle acceleration with improved accuracy with increasing laser field amplitude. Such a separation of timescales is implemented and tested in the iVPIC code where particle orbits are integrated in a sub-stepping and energy-conserving way. We perform a few test problems demonstrating the accuracy properties of the algorithm. [1] Arefiev, A.V., Cochran, G.E., Schumacher, D.W., Robinson, A.P. and Chen, G., 2015. Temporal resolution criterion for correctly simulating relativistic electron motion in a high-intensity laser field. Physics of Plasmas, 22(1), p.013103.

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MS178

Compressed Representation of Nonlinear Dynamics in Non-Linear Coherent Plasma Waves using Lagrangian Particles

In High Energy Density Plasmas, waves driven by crossing laser beams possess nonlinear phase space structures which are localized to a small region of the overall phase space. Such structures also often possess multiscale dynamics. This makes uniform discretization (or phase space tiling) wasteful in memory usage and computational effort since it treats all of phase space and all of time identically. Starting with the Shape Function Kinetics (SFK) uniform tiling code, we construct a sparser representations of the dynamics of nonlinear electron plasma waves (NL-EPW) with Lagrangian particles in the trapping region evolving on two scales and at two different rates. Special attention is paid to particles in the separatrix region and thus a "three classes of particles" representation is obtained. Untrapped, deeply trapped and loosely trapped particles making up a typical NL-EPW. The spatially averaged part of the distribution function will require coarse scale particles only, while the disturbed wave structures will require fine scale particles for proper representation. Work supported by a grant from the AFOSR and by DOE NNSA-FES Joint program in HEDLP.

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MS179

Stability of Growing Stripes in the Complex Ginzburg-Landau Equation

Quenching interfaces have been proposed as a simple way to experimentally and theoretically caricature pattern formation in growing domains. Here a spatial inhomogeneity travels through the domain suppressing patterns in one subdomain and exciting them in the complement. In examples such as light-sensitive reaction-diffusion systems, or evaporative chemical deposition, one then aims to understand how the speed of the interface can mediate and select patterns in the wake. We consider stability and dynamics of pattern-forming fronts in the Complex Ginzburg-Landau equation with such a quenching mechanism. In the regime where the inhomogeneity between domains travels with speed near the natural invasion speed of patterns, the front interface locks far away from the interface, leaving a long plateau state lying near an absolutely unstable homogeneous equilibrium. Technically, this leads to eigenvalues accumulating on weakly absolute spectrum and the loss of analyticity in the Evans function. We show how a projective blow-up and Riemann surface re-parameterization of the eigenvalue problem can be used to unfold the linear dynamics and study point spectrum.

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MS179

Nonlinear Stability of Layers in Precipitation Models

Standing layers are known to exist in models arising in chemical conversion equations in closed reactors. We explore various concepts of stability such as spectral, linear and nonlinear stability.

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MS179

Topologically Protected Defects

Codimension two (or higher) defects arise in many pattern forming systems, often coexisting with codimension one defects (domain walls). These codimension two defects usually carry a topological "charge" which strongly constrains their dynamics. I will talk about point defects in various 2D systems (convection patterns, liquid crystals, and thin hyperbolic elastic sheets). I then discuss the nontrivial ways in which the underlying topology of these defects governs their birth, dynamics, stability, and their role in applications.

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MS179

Imperfect Hexagons Deformed by Spatial Inhomogeneity

When Bénard heated a shallow plate of fluid, the resulting convection formed hexagonal cells and launched a century of experimental and theoretical investigations. How does heating only half the plate affect the hexagons? How does suppressing pattern formation in half the domain change the remaining patterns? To address these questions we quantify the deformations caused by spatial inhomogeneity in a universal model for pattern formation, the Swift-Hohenberg equation. Using spatial dynamics, explicit normal form computations, and a far-field/core decomposition, we determine a relation between the horizontal shift (phase) and the aspect ratio (wave vector) of the hexagonal patterns.

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MS180

Distributed Sampling and Tracking of Dynamic Processes with Robot Teams

We present a strategy to enable mobile robot teams to adaptively sample and track a dynamic process. We propose a distributed strategy, where robots collect sparse sensor measurements, create a reduced-order model (ROM) of a spatio-temporal process, and use this model to estimate missing measurements of the dynamic process. The robots then use the estimates to adapt the model and reconfigure their sensing locations. The key contributions of this process are two-fold: 1) leveraging the dynamics of the process of interest to determine where to sample and how to estimate the process, and 2) maintaining fully distributed models, sensor measurements, and estimates of the time-varying process. We illustrate the application of the proposed solution in simulation and compare it to centralized and global approaches. We also test our approach with physical marine robots tracking a process in a water tank.

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MS180

Lagrangian Incoherence: How Submesoscale Divergence and Deformation Erode Mesoscale Coherence

The complexity of geophysical flows has led to a variety of techniques to identify Lagrangian Coherent Structures (LCS) that organize material transport. One of the most popular methods has been the Finite Time Lyapunov Exponent (FTLE). Initially, FTLE were designed to capture flow deformation in divergence-free conditions, thereby becoming surrogates for transport barriers. In mesoscale ocean flows, FTLE have proven successful in locating LCS. However, recent studies (e.g., Haza et al., 2016) have suggested that at submesoscales the ocean is much less coherent than expected: FTLE ridges create a complex tangle instead of clearly defined transport barriers, and eddies outlined by mesoscale FTLE turn out to be leaky. Simultaneously, alternate metrics have been suggested to target particular LCS characteristics. Thus, dilation – path-integrated divergence – has been shown to be better suited for detecting clustering regions. Similarly, path-integrated vorticity has been successfully applied for detecting coherent vortices. This raises the question of the role of the remaining kinematic property, the deformation (shear and normal). Both deformation and divergence have been observed to be significantly larger at submesoscales than at the mesoscale, and the FTLE can be considered an average of Lagrangian divergence and deformation effects. We seek to quantify the relative importance of each of these in the rise of Lagrangian incoherence due to smaller scale motions.

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MS180

PDE-Based Bayesian Learning and Generative Modeling for Stochastic Lagrangian Transport

We present principled PDE-based and generative methods for the probabilistic prediction, optimal sampling, and learning of Lagrangian transport in geophysical fluid flows. Objective diagnostics for the characterization of coherence and mixing are discussed. Results are presented for simulated geophysical flows and for real-time at-sea experiments with autonomous sensing platforms in diverse ocean regions and dynamical regimes.

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MS180

Improving Accuracy of Motion Tomography

Motion Tomography (MT) algorithm is founded on tomography theory to reconstruct the ocean flow field in a relatively small region. The MT algorithm reconstructs the Autonomous Underwater Vehicle (AUV) trajectory using surfacing position data and its predicted motion. The MT algorithm solves a nonlinear inverse problem in an iterative scheme that comprises a forward step of trajectory estimation and an inverse step of flow estimation. We present recent extensions made to this algorithm that incorporates vehicle traveling time in addition to the location information to more accurately estimate the AUV trajectory and improve the accuracy of the reconstructed flow field. We derive a new procedure to trace the AUV trajectories, which can replace the numerical simulator previously used in the forward step. This trajectory tracing mechanism illustrates the nonlinear relationship between the predicted flow and the underlying trajectory, and provides new insight into convergence of the algorithm. Experimental results are collected on a set of autonomous blimps to demonstrate that the algorithm can be applied to reconstruct wind field in an indoor lab.

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MS181

Atmospheric Pollution Transport Patterns Obtained via Generalized Coherent Structures for Chemical Species

Identifying atmospheric transport pathways is important to understand the effects of pollutants on weather, climate, and human health. The atmospheric wind field is variable in space and time and contains complex patterns due to turbulent mixing. In such a highly unsteady flow field, it can be challenging to predict material transport over a finite time interval. Particle trajectories are often used to study how pollutants evolve in the atmosphere. Nevertheless, individual trajectories are sensitive to their initial conditions. Lagrangian Coherent Structures (LCSs) have been shown to form the template of fluid parcel motion in a fluid flow. LCSs can be characterized by special material surfaces that organize the parcel motion into ordered patterns. These key material surfaces form the core of fluid deformation patterns, such as saddle points, tangles, filaments, barriers and pathways. Traditionally the study of LCSs has looked at coherent structures derived from integrating the wind velocity field. It has been assumed that particles in the atmosphere will generally evolve with the wind. Recently, researchers have begun to look at the motion of chemical species, such as water vapor, within atmospheric flows. By calculating the flux associated with a species, a new generalized velocity field can be obtained. This work looks at analyzing coherent structures associated with generalized velocity fields from chemical species in order to find their pathways in the atmosphere.

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MS181

Manifolds, Reaction Barriers, and Active Mixing in Laminar Flows

We present experiments on the effects of laminar flows on the spreading of the excitable Belousov-Zhabotinsky chemical reaction and on the motion of swimming organisms. The results of these experiments have applications for a wide range of systems including microfluidic chemical reactors, cellular-scale processes in biological systems, and blooms of phytoplankton in the oceans. To predict the behavior of reaction fronts, we adapt tools used to describe chaotic fluid mixing in laminar flows. In particular, we propose "burning invariant manifolds' (BIMs) that act as one-way barriers that locally block the motion of reaction fronts. These barriers are measured experimentally in a range of vortex-dominated 2- and 3-dimensional fluid flows. A similar theoretical approach predicts "swimming invariant manifolds' (SwIMs) that are one-way barriers the impede the motion of microbes in a flow. We are conducting experiments to test the existence of SwIMs for bacillus subtilus and brine shrimp in hyperbolic and vortex-dominiated fluid flows.

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MS181

Pro-Active Engineering of Scalar Transport in Reoriented Fluid Flows

Scope is enhancement of scalar transport (heat, chemical species) in engineered flow systems by reorientations of a laminar base flow. Practical applications include mixing in inline heat exchangers by downstream reorientation of baffles, stirring in bio-reactors by cyclic repositioning of impellers, and subsurface chemicals distribution for in situ minerals mining by unsteady pumping schemes. Reorientation generally follows a fixed protocol (typically periodic in space or time) designed to accomplish chaotic advection. However, whether this approach indeed yields optimal scalar transport for significant diffusion and/or chemical reactions is unclear. The present study explores an alternative approach: pro-active reorientation based on the state of the scalar field. The control strategy concerns step-wise activation of the specific reorientation that gives optimal scalar transport for a certain time horizon. Key enabler is a compact model for efficient prediction of the scalar evolution based on its spectral decomposition in the base flow. The control strategy is investigated for a representative problem: enhanced heating of a cold fluid in a 2D circular domain by an unsteady flow driven by stepwise activation of moving boundary segments. This reveals that pro-active reorientation can substantially accelerate the heating compared to time-periodic activation designed for chaos and thus demonstrates its potential for attaining optimal scalar transport in reoriented flows.

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MS182

Accuracy of Some Approximate Gaussian Filters for Dissipative Dynamical Systems with Model Error and Spatially Sparse Nodal Observations

Bayesian estimation of a dynamical system obtained by combining its approximation with a stream of noisy measurements is important in many geophysical and engineering applications. Key challenges in such data assimilation/filtering approaches are high dimensionality of the state space, sparse observations, and model error in the approximate forward dynamics. We consider the filtering problem with linear observations so that the nonlinear filter equations can be derived by exploiting connections to a dual stochastic control problem. Two stochastically parameterised filtering algorithms are compared with 3DVAR - a prototypical time-sequential algorithm which is known to be accurate for filtering infinite dimensional dissipative systems for a suitably chosen background covariance in an idealised scenario when enough low Fourier modes are observed. We derive rigorous criteria for accuracy of 3DVAR estimates from spatially sparse observations which inevitably mix up the dynamics of low and high Fourier modes. Moreover, we provide the first evidence that the stochastically parameterised algorithms, which do not rely on detailed knowledge of the underlying dynamics, can compete with an optimally tuned 3DVAR algorithm, and they can overcome competing sources of error in a range of dynamical scenarios of dissipative PDE dynamics.

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MS182

A Detectability Criterion for Sequential Data Assimilation

In recent work [J. Frank & S. Zhuk, A detectability criterion and data assimilation for nonlinear differential equations, *Nonlinearity*, 2018] we propose a new continuous-time sequential data assimilation method having the general form of a Kalman-Bucy filter. The method is designed so that the Lyapunov exponents of the corresponding estimation error dynamics are negative, i.e. the estimation error decays exponentially fast. The latter is shown to be the case for generic regular flow maps if and only if the observation matrix H satisfies detectability conditions: the rank of H must be at least as great as the number of nonnegative Lyapunov exponents of the underlying attractor.

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MS182

Coherent Structure Identification from Macro Data: Inverse Problem Approach

A number of recent developments have brought advanced methods to approximate finite-time coherent structures from tracer trajectory data (e.g. diffusion map and fuzzy k-mean clustering). We consider a similar problem but assuming that only available data is the time-series of "unlabelled" tracer trajectory; in other word, we only observe the evolution of empirical distribution of tracers. Thus this type data must be considered as an information on a simplex and requires a special treatment in order to extract coherent structures. We contrast various approaches to this problem.

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MS182

Routes to Long Term Predictability in Multi-Scale Systems Analysis of the Ocean-Atmosphere System

The low-frequency variability (LFV) of the atmosphere at mid-latitudes develops on a wide range of time scales. One particularly interesting indicator of this variability is the North Atlantic Oscillation index measuring the fluctuations of predominant weather patterns in the course of the years over the Atlantic and Western Europe. The source of variability is, however, controversial and several possibilities have been envisaged. Recently we have demonstrated that genuinely coupled LFV can emerge in a very idealized low-order, nonlinear, coupled ocean-atmosphere model of the North Atlantic basin. This LFV concentrates on and near a long-periodic, attracting orbit. This orbit combines atmospheric and oceanic modes, and it arises for large values of the meridional gradient of radiative input and of the frictional coupling. Chaotic behavior develops around this orbit as it loses its stability. This behavior is still dominated by the LFV on decadal and multi-decadal time scales that is typical of oceanic processes. This feature opens the possibility for long term predictions. This analysis is then extended to another geometry with open channel flow for both the ocean and the atmosphere. In this case LFV can also be found, now associated to intermittent transitions from a highly chaotic dynamics to the neighborhood of an unstable periodic orbit. This leads to situations that can be predicted for very long times, while others display a very short predictability time.

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MS183

Why do Supermodels Surpass Combinations of Model Outputs?

A perfect model synchronizes with a real system perfectly; an imperfect model does so imperfectly, thus providing perhaps the ultimate application of the synchronized chaos paradigm. If we let alternative models of the same objective process assimilate data from one another in run time, we have a supermodel that can potentially resolve differences among climate models of the class used in practice to predict climate change, and achieve consensus. While supermodeling offers improved numerical weather prediction, the application to climate projection has attracted more interest, but requires attractor matching rather than strict synchronization. The usual approach to combining models is to combine the statistics of their attractors *ex post facto*. One can argue that nonlinearities imply an advantage in dynamically combining the models instead, but what precisely is the nature of these nonlinearities? We answer this question for the case of two climate models coupled via a common ocean component, with different atmosphere models. The two models make the *same* type of qualitative error in the pattern of sea surface temperature, a double intertropical convergence zone, so that any averaging of model outputs must fail. The supermodel exhibits the correct single zone pattern. We show that the two models make the same mistake for different reasons, and argue that this is a general situation in modeling an open system whose true behavior tends toward criticality.

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MS183

Supermodeling as the Second Level of Abstraction in Data Assimilation for Dynamic Systems

Data assimilation is a key component of computer simulation that synchronizes a model with a real system based on limited observations. However, in data assimilation to match parameters, the solution space exponentially expands with the number of parameters. This "curse of dimensionality" can result in a prohibitively long computations and inaccuracies in prediction. Supermodeling, in which different "sub-models" partially synchronize with one another, is a second abstraction layer to existing data assimilation procedures, which can improve their performance. The supermodel is more complicated than a single model because the additional layer of abstraction, i.e. the parameters defining coupling between the sub-models, need be adjusted. However, with a proper choice of fixed sub-models and restricted couplings between them, the number of free parameters is substantially reduced. First, we use a standard iterative data assimilation algorithm to produce the sub-models. They can be the prototype solutions obtained after, e.g., the first 100 iterations. For 3 sub-models, the supermodel is constructed by coupling them via the most sensitive dynamical variables. This way, only 3 coupling factors need be matched to data. We present results for three toy models: disturbed Lorenz, cancer treatment, human-nature systems, in terms of execution time and prediction accuracy. We discuss the use of supermodeling for a complex spatio-temporal model of melanoma dynamics.

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MS183

Efficient Algorithms to Train Supermodels

Given a set of imperfect weather or climate models, predictions can be improved by combining the models dynamically into a so called supermodel. In a supermodel, the models exchange information during the simulation. This is different from the standard multi-model ensemble approach (MME) where the model output is statistically combined after the simulations. Instead the supermodel creates a trajectory with statistical properties closer to observations than any of the imperfect models. The supermodel is a weighted superposition of the time-derivatives of the imperfect models. To obtain optimal weights, we perform a training with two different methods. The first method updates the weights during training such that the supermodel synchronizes with the truth. The second method is based on an idea called Cross Pollination in Time, where models exchange states during the training. The techniques are applied in a perfect model setting to different versions of a global coupled atmosphere-ocean-land model. Both training methods result in supermodels that outperform the individual models and the MME in short term as well as long term simulations. Both methods could in principle be applied to state-of-the-art models. Data-assimilation techniques enable exchange of state information between models that are structurally different. Real-world observations are noisy and incomplete. Preliminary results suggest that the supermodel approach can improve predictions in this case as well.

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MS183

Assimilation of Coherent Mesoscale Ocean Eddies

Mesoscale eddies are one of the dominant sources of variability in the worlds oceans. With eddy-resolving global ocean models it becomes important to assimilate observations of mesoscale eddies to correctly represent the state of the mesoscale. Here we investigate strategies for assimilating a reduced number of sea-surface height observations by focusing on the coherent mesoscale eddies. The study is carried out in an idealized perfect-model framework using two-layer forced quasigeostrophic dynamics, which captures the dominant dynamics of ocean mesoscale eddies. We study errors in state-estimation as well as error growth in forecasts, and find that as fewer observations are assimilated, assimilating at vortex locations results in reduced state estimation and forecast errors. Similarly, supermodeling would be improved by performing the inter-model assimilation at vortex locations.

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MS184

Processing of Multimodal Sensory Information in a Motor Control Center

Nervous systems constantly receive and process input from various sensory modalities. Incoming information converges at many neural centers, including those directly control motor output and behavioral plasticity. How multisensory inputs are encoded to allow organisms to carry out appropriate behavioral responses is poorly understood. To address this, we use network analysis to investigate responses to two distinct sensory modalities in neurons that control aspects of feeding in the crustacean stomatogastric system. Our analysis is applied to a ganglion where a population of fewer than 220 neurons processes mechanosensory and chemosensory information. Stimulation of these two sensory modalities is known to produce distinct motor outputs. We use optical imaging to access neuronal population activity in both unimodal and multimodal conditions. We provide evidence that differences between modalities are encoded in the combination of activated neurons. We found a new combination of excitation and inhibition for each modality and when both pathways were activated simultaneously [Follmann et al., PLOS Biology 16(10): e2004527, (2018)]. Our results are consistent with the idea that this small sensorimotor network encodes different sensory modalities in a combinatorial code of neurons. This provides the downstream motor networks with the ability to differentially respond to distinct categories of sensory conditions.

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MS184

Alterations in Brain Connectivity due to Plasticity and Synaptic Delay

Brain plasticity refers to brains ability to change neuronal connections, as a result of environmental stimuli, new experiences, or damage. In this work, we study the effects of the synaptic delay on both the coupling strengths and synchronization in a neuronal network with synaptic plasticity. We build a network of Hodgkin-Huxley neurons, where the plasticity is given by the Hebbian rules. We analyze the role of the time delay. In special, we consider its effect on the synchronization.

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MS184

Collective Dynamics in Random Trees of Coupled Stochastic Excitable Elements

We study the collective dynamics of diffusively coupled excitable elements on small tree networks with regular and random connectivity. The peripheral nodes receive independent random inputs which may induce large spiking events propagating through the branches of the tree, eventually firing the central node in the tree network. This scenario may be relevant to action potential generation in certain sensory neurons, which possess myelinated distal tree-like arbors with excitable nodes of Ranvier at peripheral and branching points and exhibit noisy periodic sequences of action potentials. Examples of such neurons include touch receptors, muscle spindles, and some electroreceptors. We developed a theory that predicts the collective spiking activity in the physiologically-relevant strong coupling limit. We show that the mechanism of coherent firing is rooted in the synchronization of local activity of individual nodes, even though peripheral nodes may receive random independent inputs. The structural variability in random trees translates into collective network dynamics leading to a wide range of firing statistics and response gains, which is most pronounced in the strong coupling regime.

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MS184

Dynamics of Spontaneous Activity in Networks of Two-Dimensional Integrate-and-Fire Neurons

We study the dynamics of spontaneous activity patterns in random networks of excitatory and inhibitory two-dimensional integrate-and-fire neurons with synaptic noise. We localize the different activity patterns on the parameter diagram spanned by relative inhibitory synaptic strength and synaptic noise intensity. In the noiseless setup, networks display transient activity, either asynchronous and non-oscillatory or oscillatory. For weak noise, activity patterns are asynchronous non-oscillatory independently of the synaptic strengths. For stronger noise, patterns have oscillatory and synchrony characteristics that depend on the relative inhibitory synaptic strength. In the inhibition-dominated region of parameter space and for moderate noise intensities, networks display intermittent switches between oscillatory and low activity (quiescent) states. In the oscillatory state the neuronal voltages alternate between hyperpolarized and depolarized values, and in the quiescent state they fluctuate around the resting state. Increase in noise intensity favors transitions from the quiescent to the oscillatory state and hinders the reverse transitions. The oscillatory and quiescent patterns and transitions between them are explained by using a phenomenological global description of the network state combined with a local descriptions of individual neurons in their single-neuron phase space.

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MS185

N-Body Dynamics on an Infinite Cylinder: The Topological Signature and the Stability of a Ring

Abstract not available.

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MS185

Four-Body Central Configurations with One Pair of Opposite Sides Parallel

We study four-body central configurations with one pair of opposite sides parallel. We use a novel constraint to write the central configuration equations in this special case, using distances as variables. We prove that, for a given ordering of the mutual distances, a trapezoidal central configuration must have a certain partial ordering of the masses. We also show that if opposite masses of a four-body trapezoidal central configuration are equal, then the configuration has a line of symmetry and it must be a kite. In contrast to the general four-body case, we show that if the two adjacent masses bounding the shortest side are equal, then the configuration must be an isosceles trapezoid, and the remaining two masses must also be equal.

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MS185

Self-Similarity in the Kepler-Heisenberg Problem

The Kepler-Heisenberg problem is that of determining the motion of a planet around a sun in the Heisenberg group, thought of as a three-dimensional sub-Riemannian manifold. The sub-Riemannian Hamiltonian provides the kinetic energy, and the gravitational potential is given by the fundamental solution to the sub-Laplacian. The dynamics are at least partially integrable, possessing two first integrals as well as a dilational momentum which is conserved by orbits with zero energy. The system is known to admit closed orbits, which all lie within a fundamental integrable subsystem. Here, we present new results on the self-similarity and quasi-periodicity of all zero energy orbits.

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MS185

Central Configurations in the Collinear N-Body Problem

Central configurations play a central role in the understanding the global properties of N-body problem. The question on the finiteness of the number of central configurations is a challenge problem for 21st century mathematician. Moulton (1910) proved that for a fixed mass vector and a fixed ordering of the bodies along the line, there exists a unique collinear central configuration (up to translation and scaling). He also studied the inverse problem of the collinear central configurations and his results are conditioned on various Pfaffians which properties are studied by Buchanan (1909). However, Albouy and Moeckel (2000) pointed out that the argument by Buchanan is incorrect and they proved analytically for $n \leq 4$ and numerically for n=5 and 6. Xie (2014) give a simple analytical proof for $n \leq 6$. In this talk, we discuss the properties of the collinear central configurations for odd number bodies if all associated Pfaffians for 2N bodies are nonzeros. Some results on the existence and classifications of super central configurations are also presented.

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MS186

Solitary Wave Solution of the Camassa-Holm Equa-

tion with Distributed Delay

Camassa-Holm equation is a model for shallow water waves. We first give an introduction to the shallow water equations, among which the Camassa-Holm is of special interests for its various physics and mathematical properties. We then discuss the solitary wave and prove the existence of solitary wave solutions for the equation with distributed delay applying geometric singular perturbation theory, in which a double reduction by the geometric singular perturbation theory is used.

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MS186

A Nonlocal Interfacial Approach to Stripe Patterns

Biological pattern formation has been extensively studied using reaction-diffusion and agent based models. In this talk we will discuss nonlocal pattern forming mechanisms in the context of bacterial colony formation and surface striping on animals with an emphasis on arrested fronts. This will lead to a novel nonlocal framework to understand the interfacial motion in biological systems. We will then use this approach to model an interesting bacterial phenomenon, and to understand simple microscopic requirements for flat stripe solutions to persist in nature. We will then examine moving defect patterns in the nonlocal framework.

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MS186

Surface Tension and Surface Transport in Defective Networks

Lipids form network structures within the endoplasmic reticulum that are characterized by surface tension, defect generation, and surface diffusion. We present a model that incorporates fixed and dynamic junctions and characterizes the the network evolution as a gradient flow of mass preserving energy. We show that an intrinsic surface tension and a dominance of surface diffusion over bulk diffusion can be achieved by a balance between high single-molecule energy and low single molecule mobility. The balance provides a uniform mobility with fluxes that are uniformly proportional to gradients in densities. We investigate the role of episodic arrival of lipid mass membrane dynamics and the development of network defects.

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MS186
Patterns on Conics

Cells on flower petal surfaces assume conical shapes upon unfolding. Ripple patterns on these cells act as diffraction gratings. We study the nonlinear optics of polarized light and a class of plant pigments called anthocyanins interacting with these patterns and their defects.

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PP1
A Mathematical Model for Sea Slug Swim CPGs

Central pattern generators(CPGs) are neural networks which can produce rhythmic activity in isolation and responsible for behaviors like walking, breathing, and swimming. The underlying mechanism of rhythm generation in CPGs is poorly understood. Understanding simple structured invertebrate CPGs provide insight into more complex structures in the vertebrate central nervous system. We have developed a Hodgkin-Huxley type highly detailed and biologically plausible mathematical model using the extensive data recorded from swim CPG of the sea slug Melibe leonine and study the rhythmogenesis of oscillatory patterns emerging in network motifs composed of half-center oscillators. Half-center oscillators are the building blocks of larger neural networks including CPGs controlling swim locomotion of the sea slug Melibe leonine. To couple four interneurons forming Melibe swim CPG which are endogenous tonic spiking cells in isolation, the alpha, and dynamic synapses are used.

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PP1
Dynamics of a Producer-Grazer Model Incorporating the Effects of Phosphorus Loading on Grazer's Growth

Recent work in ecological stoichiometry has indicated that consumer dynamics are not only affected by insufficient food nutrient content (low phosphorus (P): carbon (C) ratio) but also by excess food nutrient content (extremely high P:C ratio). This phenomenon is known as the "stoichiometric knife edge'. While the Peace et al. (2014) model has captured this phenomenon, it does not explicitly track

P loading of the aquatic environment. Here, we extend the Peace et al. (2014) model by mechanistically deriving and tracking P loading in order to investigate the growth response of the grazer to the producer of varying P:C ratios. We analyze the dynamics of the system such as boundedness and positivity of the solutions, existence and stability conditions of boundary equilibria. Bifurcation diagram and simulations show that our model behaves qualitatively similar but quantitatively different to the Peace et al. (2014) model. Furthermore, the structure of our model can easily be extended to incorporate seasonal phosphorus loading.

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PP1

Symbolic Representation of Neuronal Dynamics and Network Behaviors

We demonstrate a GPU-based symbolic toolkit to study a whole range of dynamical behaviors occurring in individual neuron models and small networks of central pattern generators (CPGs). We employ periodicity detecton, hashing, and Lempel-Ziv complexity algorithms to process symbolic sequences extracted from wave-form traces using voltage and time interval partitions. This allows the detection diverse behaviors such as quiescence, bursting, tonic spiking and chaos in individual neurons, as well as distinct phase locked states and their temporal characteristics in network CPGs.

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PP1

Adaptive Models for Collective Decision Making in Swarms

Honey bees make decisions in changing environment while searching for a new home site or foraging. Scout bees use a waggle dance to communicate their confidence in the foraging or nest site they have chosen. Decided bees can also influence those with opposing opinions to change their minds via “stop-signals.” Most previous experimental studies test the decision making of bee swarms in static environments, but most natural environments are dynamic. In such cases, bees should adapt to new evidence by abandoning their current opinion and restarting the evidence accumulation and decision process. Incorporating these behaviors into a dynamical model leads to a collective decision-making process that discounts previous evidence and weights newer information more strongly. We investigate how bees tune these “forgetting”, “stop signaling” and “recruiting” processes to improve a swarms performance on a foraging task in a dynamic environment. We also study the impact of two different sources of stochasticity inherent to swarm decisions. Finite-size effects arise when a group is small enough that an individuals decision variability can sway the opinion of the entire group. In addition, the environment itself may change stochastically, requiring the swarm to adapt to changes that occur at unpredictable times. Our results suggest efficient means of making group decisions in changing environments and provide experimentally testable hypothesis about group foraging strategies.

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PP1

Synaptic Dynamics and Bursting in Neural Networks

We study emergent network bursting in swim central pattern generators with distinct architectures and individual interneurons that never burst endogenously. We have devised a hybrid toolkit integrating voltage intercellular recordings into a simulation to parametrize and graduate membrane and synaptic properties and train the developed models against the experimental data. We perform a series of fact checks to validate the network models including their qualitative and quantitative responses to perturbations similar to experimental setups.

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PP1

The 3D Painlevé Paradox

Every mathematician knows all too well that chalk can judder and squeal when pushed along a blackboard. This phenomenon is linked to the Painlevé paradox, where no unique forward solutions exist to certain rigid body problems with unilateral constraints in the presence of friction. The Painlevé paradox has been a curiosity of mathematicians and engineers alike for over a century. But recently, due to advances in mathematical techniques and the growth of the field of robotics where the problem may be especially important, there has been a surge in the study of the Painlevé paradox, both experimentally and theoretically. In this contribution, we consider a stiff and slender rod, slipping along a rough surface. Results from developments in the 2D problem are generalised to the full 3D system. We show analytically how the planar case is singular, that the introduction of the other spatial dimension complicates the dynamics and that, whilst in 2D no trajectories can enter the inconsistent region, in the 3D system, trajectories can enter the inconsistent region in finite time. In order to “resolve’ this paradox, we regularize (smooth) the system by adding a small compliance, leading to a slow-fast system.

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PP1

Dynamics of Delayed Mathematical Model of Tumor Growth

“Cancer or malignant tumor” is still a leading health problem and showing the cause of death of millions of people all over the world. Immune system excites the tumor-promoting and tumor-inhibitory factors. Role of pro-tumor factors and anti-tumor factors are important in tumor dynamics. De-Pill and Radunskaya proposed a model governing by effector cells, tumor cells, and host cells. We introduce Michaelis-Menton form kinetics for clearance of tumor cells by effector cells due to the saturated effect of effector cell and to immune suppressive effect of pro-tumor factors. In this paper, we study a modified deterministic mathematical model governing interactions between tumor cell(TCs), effector-cells(ECs) and host cells(HCs). The time delay is considered for the decay of effector cells to observe the influence of cellular phenomena. Positivity and boundedness have been verified. We investigate local stability at equilibria. An occurrence of Hopf bifurcation with respect to a discrete time delay which has been investigated analytically and numerically. The length of discrete time delay has been measured explicitly to preserve the stability of periodic solutions in the viewpoint of bifurcation. This illustrates the mechanism of action to keep control the oscillation in tumor growth. We perform fascinating computer simulations using MATLAB to validate the key findings and investigate the change of dynamic behavior with biological importance.

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PP1

Leveraging Topological and Geometric Features of Sunspots for Solar Flare Prediction

On a magnetograma 2D image of the magnetic field on the surface of the sunsunspots manifest as large-scale, high-magnitude dipolar structures. These shapes and their evolution provide important clues that may help predict flares that can erupt from these regions, which can have dire impacts on Earth-based technological systems. In some cases, for instance, a large number of smaller structures appear around the bigger spots just before they flare. We use topological data analysis to characterize the evolving structure of solar magnetogram data from the Helioseismic and Magnetic Imager (HMI) instrument on the NASA Solar Dynamics Observatory satellite. To compute the topology of a data set requires an interpolation scheme; the theory of persistent homology leverages this to describe shape as a function of scale, as encoded in a persistence diagram. Topology alone, however, is not enough to fully capture the salient features of sunspot evolution. We extend the methods of persistent homology to include additional physically relevant geometrical information such as the critical relative positions of the regions of different polarities, as well as the progression through time of the geometry and topology of those regions. This analysis reveals clear topological changes emerging in a 2017 sunspot almost two days before it flaredwell in advance of the prediction horizons offered by the traditional approaches used in the space-weather community.

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PP1

Macroscopic Analysis of a Neural Network in the Olfactory Bulb Using Equation-Free Methods

The olfactory bulb's neural network with individually firing neurons, which is responsible for odor recognition, is a good model system to study the brain's performance with a well-defined input and output. The detection of an odor depends on the fire rates in different areas of the neural network.
If one considers the distinction of two different odors, both, biological measurements and direct simulation, show the same macroscopic behavior. If one odor is dominant and the concentration ratio for the two odors is slightly changed, the first one's respective area is longer dominantly active as if the other odor was first dominant. We consider the difference of the fire rates of their different appendant areas as the macroscopic variable.
By direct simulation, one can already get the stable branches of the fire rates. In an odor concentration/fire rate difference-diagram, hysteresis behavior can be observed. This indicates the existence of at least one unstable branch between the stable ones. Our aim is to track the unstable branches by implicit equation-free methods. For this, we need to use an altered Newton method, which has to deal with noisy derivative information due to the cells' fire rates.

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PP1

Reconstruction a 2D Incompressible Flow Field Based on Sparse Frequency-Domain Measurements

MRI is a widely-used technique in medical imaging for diagnostic purposes. A major drawback of the technique is its lengthy data acquisition time. One possible workaround is to reduce the acquisition time by reducing the number of phase-encoding steps. MRI data acquisition is performed in the frequency domain. The data acquisition time may be reduced by sampling a portion of the frequency domain rather than the whole and then, trying to reconstruct the scanned region through post-processing. This results in shorter scan time at the expense of further processing time. In this study, a scheme is proposed for reconstructing a 2D incompressible fluid flow by taking a series of sparse noisy measurements performed in the frequency domain while accounting for the dynamics of the flow. Our scheme takes advantage of a Kalman filter and smoother combined with the Forward-backward DMD (fbDMD) method for denoising the noisy measurements and reconstructing them based on the set of POD basis vectors. Then, the POD vectors are reconstructed in Cartesian space in full through l_1-regularization. Since a 2D incompressible fluid flow is studied, a custom set of divergence-free basis vectors are developed based on DCT basis vectors. The custom set of divergence-free basis vectors is used as the reconstruction basis. The results show the proposed scheme can recover the dominant dynamic features of the flow field in the Cartesian space.

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PP1

Principles for Making Half-Center Oscillators

The half-center oscillator, made up from two identical neurons connected by reciprocal inhibitory synapse, is a fundamental building block in various neural circuits. When functioning, the two neurons burst alternatively. This poster will show how to build an oscillator from two intrinsically non-bursting model neurons via different mechanisms and how to understand the related neuron dynamics.

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PP1

The Efficiency of Food Distribution via Trophallaxis in Honeybees: An Agent-Based Model Approach

Trophallaxis is the mutual exchange and direct transfer of liquid food among members of eusocial insect societies, such as ants, termites, wasps and bees. This process allows efficient dissemination of nutrients and is crucial for the colony's survival. We use agent-based modeling to simulate trophallaxis in a group of honeybees, tracking the individual interactions and the overall patterns of food distribution. Our model provides a useful benchmark to assess how the patterns in food distribution depend on model parameters, such as the fraction of donor bees in the initial population, the movement patterns of each bee, and the duration and amount of food transfer at each interaction. We perform experiments with honeybees (*Apis Mellifera L.*) to obtain physically realistic parameter values for our computational model and to validate its results. We find that the efficiency of food distribution through the entire group is enhanced if donor bees do not always feed their immediate neighbors, but instead prioritize longer motions, sharing their food with more-distant bees at later times. This local pattern enhances the overall probability that all of the bees, regardless of their position in the colony, will be fed efficiently.

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PP1

Dynamic Complexity of Two Coupled Photonic Crystal Nanocavities

We study the dynamics of two coupled nanocavities in a photonic crystal that are optically driven. This optical device was designed and manufactured to operate with only a few hundred photons, and it has been shown experimentally to exhibit bistable behaviour and spontaneous symmetry breaking. However, its more complex dynamics had not yet been characterised. Mathematically, the overall behaviour of this type of device is captured by a four-dimensional vector field model. We conduct a bifurcation analysis to determine the dynamics that arises when intensity and frequency of the optical input are varied, while the other parameters are fixed to values as in the experiment. We find transitions via Shilnikov bifurcations to chaotic attractors with different symmetry properties, where the dynamics is either mainly confined to one cavity or corresponds to irregular switching between the two cavities. We present and characterise how (global) bifurcations are organised in parameter space by bifurcations of higher codimension. Moreover, we discuss evidence for higher-dimensional chaos in this concrete mathematical model arising from an application.

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PP1

Data-Driven Order Parameters for Coupled Oscillator Models

Coupled oscillator models are a useful testbed for studying temporal coordination in complex systems with many agents. Typically, an order parameter for such a model is based off of the centroid of oscillators travelling around the unit circle in the complex plane. While this centroid approach works well for oscillator models where oscillators are equally likely to be at any point on the circle, it is inappropriate for measuring coordination in many-agent models where the underlying dynamical structure is uneven. In this setting, the traditional order parameter method can artificially report coordination in regions of the cycle where oscillators spend a disproportionate amount of time. We propose the creation of a data-driven order parameter to address these issues, taking a model of the reproductive behavior of *Fundulus heteroclitus*, commonly known as mummichog, as a practical example. Additionally, we explore different implementations of data-driven order parameters and consider the possibility of different order parameters providing orthogonal information, thus yielding a more complete informational picture of coordination within a system. We anticipate that developing data driven order parameters will be an important advancement for the study of complex systems with agents whose individual behavior is nontrivial.

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PP1

A Closed-Form Solution of How the Differential Equation for Tendon Dynamics Affects Kinematic Approximations of Muscle Lengths

Simulations of neuromuscular systems need to consider muscle mechanics, or more specifically muscle lengths and velocities, in order to calculate muscle forces. This is usually done implicitly within the numerical optimization of the dynamical equations of the system, which include muscle and tendon lengths as states. An alternative clinical approach is to measure limb kinematics and EMG in a given patient to estimate muscle mechanics. Regardless of which approach is used, muscle length calculations will vary depending on the measured limb kinematics and calculated tendon tensions. We show that the difference between kinematics-based approximations for muscle mechanics and those found by the numerical optimization can be quantified using the differential equations that govern tendon tension. Intuitively, these differences depend on the tension required to generate the dynamics of the movement which kinematic calculations cannot capture. The significance of these differences can then be evaluated objectively on the basis of the scientific or clinical question being asked.

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PP1

Adapting Foraging Strategies in a Heterogeneous Environment

Plants cultivate an arsenal of defenses for themselves. Meanwhile, their mere existence can provide associational resistance for their neighbors. Grouping different numbers of discrete plant neighbors into patches, we build a model of insect forager behavior in a heterogeneous environment. As the insect forages, it learns about its patch and overall habitat through experience, updating its energy intake expectations. We analyze how the insects optimal strategy changes over time, dependent on local and global properties of the plant neighborhoods.

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PP1

A Wave of Locusts

Juvenile locusts gather together and march through fields in a hopper band. By doing so, they form a wave of advancing insects which we examined in two ways: using an agent-based model and a set of partial differential equations. The agent-based model is based on observations of individual locust behavior from biological data while the PDE gives insight into collective behavior of the front of the band of locusts. In this poster, we will present the creation of the models and how we can determine the speed of the wave of locusts and the amount of food left behind.

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PP1

Teaching Dynamical Systems: a Flipped Class with

Limited Prerequisites

I want to share what is happening in my dynamical systems classroom and get input from others on the course. I'll present information about the format of the course, topics, assessment , and project work. Students entering my course range from sophomores who have completed (and perhaps struggled in) multivariable calculus and linear algebra to graduate students with an interest in dynamical systems topics. I use a flipped classroom for this course, partly to take advantage of the diversity of mathematical backgrounds of my students. Implementing a flipped class for dynamical systems is aided by a series of 75-minute lectures, posted to youtube by Steve Strogatz, that align with his textbook. I excerpt most out of class preparatory material from those videos. Because of the different background preparation of my students, I have produced some additional videos. Using someone else's videos shifts our classroom dynamic, decentering the instructor (me) as the source of content (and of confusion) and turning me into an ally in grappling with the material. Challenges include: selecting topics (for some it will be their first, and only, exposure to differential equations), designing problem sets that involve an appropriate amount of out-of-class work, constructing an assessment structure that incentivizes learning core procedural skills, and structuring a project so that students can explore their ideas but are also engaging with the content of the course.

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PP1

Frequency Response Analysis of Mosquito Swarming over a Marker

Insect swarms are a model system for understanding collective behavior that occurs close to complete disorder. Although it appears uncoordinated, an insect swarm is often robust to environmental perturbations in the form of ambient wind and sound. In mosquitoes, understanding the swarming behavior has an additional medical relevance since swarming often precedes mating in the wild, thus constituting an important stage to intercept for controlling their population. We use linear system identification to characterize the strength of the coupling between mosquitoes and high-contrast regions called markers, over which they typically swarm. A laboratory microcosm is built to stimulate swarming in the malarial mosquito Anopheles stephensi. The setup is used to conduct experiments where a mosquito swarm is filmed as a marker is moved sinusoidally with different frequencies. We analyze and compare the effect of marker frequency on the movement of individual mosquito and the swarm. Our preliminary results show that the mosquito-marker relationship can be captured in the form of a second-order dynamical system and that the frequency of marker movement affects the cohesiveness of the swarm and the height at which individual mosquitoes fly. Results from this study can be used to better understand how swarming insects perceive and interact with their environment.

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PP1

Hipsters on Networks: How a Minority Group of Individuals can Lead to an Antiestablishment Majority

The spread of opinions, memes, diseases, and alternative facts in a population depends both on the details of the spreading process and on the structure of the social and communication networks on which they spread. We explore how antiestablishment nodes (e.g., hipsters) influence the spreading dynamics of two competing products. We consider a model in which spreading follows a deterministic rule for updating node states in which an adjustable probability of the nodes in a network are hipsters, who choose to adopt the product that they believe is the less popular of the two. The remaining nodes are conformists, who choose which product to adopt by considering which products their immediate neighbors have adopted. We simulate our model on both synthetic and real networks, and we show that the hipsters have a major effect on the final fraction of people who adopt each product: even when only one of the two products exists at the beginning of the simulations, a small fraction of hipsters in a network can still cause the other product to eventually become the more popular one. We use analytical estimates of the spreading of products to scrutinize this major impact of a few individuals. Our simple model and analysis may help shed light on the road to success for antiestablishment choices in elections, as such success can arise rather generically in our model from a small number of antiestablishment individuals and ordinary processes of social influence on normal individuals.

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PP1

Parameter Estimation in ODEs with Neural Networks

The Augmented Ensemble Kalman Filter (AEnKF) is a standard technique that estimates parameters arising in ODEs from noisy, incomplete observations. It relies on information about linear relations between state, parameter and observations. In this work we provide a neural network based approach to estimate parameters from noisy incomplete observations, where parameters arise in nonlinear terms of the underlying ODE. This approach is able to recognize nonlinear interactions between state, parameter and observations. We begin by training a neural network to approximate the inverse of the observation map for a fixed nearby parameter. The nonlinear ODE and the known observation map is then applied to the approximated state, thus forming a shift map with respect to the observations. This network is then retrained to obtain the unknown parameters. We present examples to demonstrate the limits of the AEnKF against the neural network approach. We conclude by demonstrating how we estimated parameters in a new single cell model of the excitatory tripartite synapse.

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PP1

Computational Techniques for Analytic Solution of Delay Differential Equations

Delay differential equations are extensively used for mathematical modeling of many fields. But many delay differential equations cannot be solved analytically or it is very difficult to solve due to the dependence on previous data. An algorithm for the analytic solution of delay differential equations with impulses at fixed moments is presented. The result shows that the present method is more efficient and accurate as compared to the existing literature. The application of this method is illustrated with the help of an example.

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PP1

A Transfer-Operator Based Computational Study of Periodically Forced Mixers

We study mixing by advection in open systems with constant in- and outflow. The systems we consider contain an inlet and an outlet flow region as well as a mixing region. This is modelled by a translational base flow, with a time-periodic velocity field superimposed in the mixing region. When two different types of particles are continuously sent through this mixing region, a periodic pattern is formed at the outlet of the mixer after some time. An affine operator describes the evolution of mass distribution in the open system. The linear part of this operator is a transfer operator and the translation part describes the new mass released into the system. The spatially discretized approximation of the transfer operator defines the transition matrix of an absorbing Markov chain restricted to finite transient states. We conduct parameter studies for example mixers and quantify the mixing of the resulting patterns by classical measures like the variance of concentration field and by the Mix-Norm, that is equivalent to a negative Sobolev norm.

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PP1

Data Assimilation with Adaptive Moving Meshes

This study combines adaptive moving mesh and data assimilation techniques to accurately and efficiently apply data assimilation techniques to physical models given by time dependent partial differential equations (PDEs). Adaptive moving mesh techniques adaptively update spatial mesh locations when discretizing time dependent PDEs. We consider Ensemble Kalman Filter techniques in which each ensemble member may evolve on their own spatial mesh. Our focus is on determining time dependent references meshes upon which we form the mean and covariance. We develop an approach based upon determining the reference mesh that is in some sense the average of the ensemble meshes. We compare our results to recent work of Bonan et al. on a one space dimension idealized sea ice model. We also show the utility of our technique for other physical PDE models in one and higher space dimensions.

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PP1

Mixing in Cutting and Shuffling Systems with Diffusion

The main mechanism of mixing in fluids is the stretching and folding of fluid elements, although this is not the only mechanism to achieve complicated dynamics. Mixing by cutting and shuffling occurs in many situations; such as card shuffling, granular mixing or cut-and-recombine stirring devices, however, the dynamics of this mechanism are subtle and not well understood. Analytical results on the mixing rates of cutting and shuffling systems focus on asymptotic time and are sensitive to infinitely small tuning of parameters. Thus, computational results addressing the rates of finite time mixing in systems in which cutting and shuffling is the dominating stirring mechanism are presented. The time to achieve a mixed condition is shown to be $t = C\kappa^{-\beta}$, where κ is the diffusion coefficient and $0 < \beta < 1$. The constant C is shown to be sensitive to the initial condition. Comparison of this relation to the leading eigenvalue of the advection-diffusion transfer operator suggests the dominant mixing mechanism in the long-time limit may apply throughout the whole mixing time. The effect of parameters on mixing rates are discussed.

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PP1

Numerical Continuation of Amplitude Vacillating Flow in Sheared Annular Electroconvection

We investigate amplitude vacillating flow (amplitude-modulated waves) in sheared annular electroconvection using matrix-free numerical bifurcation methods based on time-integration. In particular, we study a model that simulates the flow of a liquid crystal film in the Smectic A phase suspended between two annular electrodes, and subjected to an electric potential difference and a radial shear. Due to the Smectic A nature of the liquid crystal, the fluid can be considered two-dimensional and is modelled using the 2-D incompressible Navier-Stokes equations coupled with an equation for charge continuity. A Newton-Krylov method is implemented for the continuation of solutions and the identification of the flow transitions that re-

sult due to changes in the model parameters. The method exploits specific features of the flow type to make the computations more tractable. The amplitude vacillating flow equilibrates via a transition from rotating waves, which corresponds to a bifurcation from a periodic orbit to a 2-torus. An appropriate choice of preconditioner enables the computation of the branch of vacillating solutions through the full range of parameter values for which it is stable.

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PP1

Mathematical Models and Tools for Understanding the Entrainment of Hierarchical Circadian Systems

The ability of a circadian oscillator to entrain to a 24-hour light dark (LD) cycle is one of its most important properties. A new tool, a 1-dim entrainment map, introduced by Diekman and Bose (2016), determines the phase of the LD cycle at which entrainment occurs for a single oscillator. The map also determines the reentrainment time after a phase shift of the LD cycle. Here we generalize the map to a coupled hierarchical circadian system where one circadian oscillator receives direct LD input, and a second circadian oscillator is coupled to the first. The generalized map is a 2-dim nonlinear circle map for a 5-dim dynamical system. We derive methods allowing us to determine conditions for the existence and stability of fixed points of the map. These fixed points correspond to periodic entrained solutions of the original system with specific phase relationships between the LD input and the two circadian oscillators. Our analysis reveals the existence of a stable entrained solution, as well as several unstable entrained solutions, two of which have saddle structure. Using the map, we calculate reentrainment times after a phase shift in the LD cycle, which in turn allows us to understand geometric properties regarding the stable manifolds of the saddle points.

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PP1

A Reduced Order Mathematical Model of Platelet Aggregation in an Extravascular Injury and the Effects of ADP-Dependent Platelet Activation

We present a temporally varying reduced order mathematical model of primary hemostasis in an extravascular injury. Blood moving through a vessel initially escapes through a hole in the wall and out into extravascular space. The model consists of a system of ordinary differential equations (ODEs) describing platelet accumulation (deposition and ADP-dependent activation) and flow through the injury. Specifically, we couple the contribution of increased resistance due to growth of the platelet aggregate to the flow through the injury using a Brinkman-Stokes-Brinkman calculation. Flow and aggregate calculations are calibrated using an analogous partial differential equation (PDE) model. Computational experiments with constant ADP-dependent platelet activation produce accumulation with occlusion of the injury, a result in agreement with the PDE model. We explore the effects of evolving ADP concentration and various activation rates on aggregate growth.

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PP1

A Pharmacokinetic Model of Lead-Calcium Interactions

Lead is a naturally-occurring element. It has been known to man for a long time, and it is one of the longest established poisons. The current consensus is that no level of lead exposure should be deemed “safe.” New evidence regarding the blood levels at which morbidities occur has prompted the CDC to reduce the screening guideline of 0.01 mg/dl to 0.002 mg/dl. Measurable cognitive decline (reduced IQ, academic deficits) have been found to occur at levels below 0.01 mg/dl. Knowledge of lead pharmacology allows us to better understand its absorption and metabolization mechanisms that produce its medical consequences. Based upon an original and simplistic compartmental model of Rabinowitz (1973) with only three major compartments (blood, bone and soft tissue), extensive biophysical models sprouted over the following two decades. However, none of these models have been specifically designed to use new knowledge of lead molecular dynamics towards understanding its deleterious effects on the brain. We will present and analyze a compartmental model of lead pharmacokinetics, focused specifically on neurotoxicity. Our model captures mathematically the complex nonlinear interaction between lead and calcium along their dynamic trajectory through the body. We will focus on showing how an imbalance in this interaction may readily lead to the neuro-behavioral effects.

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PP1

Host-Pathogen Dynamics: Quantifying Process-Level Variation using a System-Specific Dynamical Model in a Non-Linear Mixed Effects Modeling Framework

After jumping host species in 1994 from poultry to songbirds, the bacterium *Mycoplasma gallisepticum* (MG) has become an epidemic disease among House Finches (*Haemorhous mexicanus*) in North America. This research aims to develop a new approach to data analysis for this immune-mediated system and use it to identify key characteristics of the host-parasite interaction driving individual-level variation in disease progression. This will be accomplished by adapting a previously developed mechanistic model for use as a statistical model. First, structural and practical identifiability analysis was performed on the model to check if there is a best fit parameter set, making it appropriate to use. Next, the model will be fitted, in R, to individual data previously collected to be used as a baseline for individual parameter estimates. Ultimately, a nonlinear mixed effect model will be implemented for estimating individual-level parameters as well as group-level parameters using data from all individuals simultaneously. Some implications of this work are to account for individual heterogeneity in the data analysis versus group-level averaging, and to lay the groundwork for other researchers to apply this approach to analyze similar data sets.

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PP1

The Dynamical and Biophysical Mechanism for Camp Overshoot in Ventricular Myocytes Following β_1-Adrenergic Stimulation

The sympathetic nervous system (SNS) regulates cardiac function by activating β-adrenergic receptors (β-ARs) and thus increasing cAMP production. However, SNS input to the heart can sometimes trigger arrhythmias. In particular, certain motifs of SNS input cause large transient increases (i.e., overshoots) of cAMP concentration in cardiac ventricular cells, which can induce ectopic beats. The specific conditions promoting such proarrhythmic activity are unclear. Stimulation of β_1ARs leads to a cascade of intracellular reactions: adenylyl cyclase activated by stimulatory G-protein increases production of cAMP, which activates PKA; PKA then phosphorylates calcium and potassium channels, ryanodine receptors, troponin, and β_1-ARs. Detailed computational models have been used to describe this signaling process, but the complexity of these models obscures the mechanisms underlying subtle behavior, such as cAMP overshoots. Here, we exploit multiple timescales to reduce the 16-variable adrenergic signaling component of the Soltis-Saucerman model to a system of two differential equations for cAMP and active β_1-AR concentrations. We analyze the reduced model to reveal the mechanism for cAMP overshoot in response to β_1-AR activation and identify parameters that modulate the magnitude of the overshoot. Our results provide predictions for how pharmacological methods can be used to deter the potential proarrhythmic effects of SNS input to the heart.

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PP1

Dynamics from Ranking Problems

A *ranking problem* is to produce a linear ordering of a set of items that is as consistent as possible with data that includes pairwise comparisons between some of the items. Data may include noise and contradictory information. The linear ordering predicts the outcomes of future comparisons between the items. Finding the absolute best ordering is generally NP-hard. I will present dynamical systems built from ranking problems. Each item v is represented by a particle at $q_v(t) \in \mathbf{R}$ in a potential well. Each given comparison $u \preceq v$ contributes terms to the potential that push q_u to the left and q_v to the right. The initial formulation is Hamiltonian, but damping terms can be added so that energy leaks from the system, which causes the particles settle to a stable rest state that represents a linear ordering of the items. In benchmarks, the resulting orderings score reasonably well, especially given how quickly trajectories can be computed. Furthermore, the dynamical behavior itself is interesting. Including further terms in the Hamiltonian leads to low-dimensional systems of oscillators with unusual couplings. The ranking dynamics are related to the Kostant-Toda lattice, which suggests that there may be some unexpected underlying geometry.

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PP1

Community Structure and Structural Balance in Signed Networks

Structural balance theory asserts that, for a signed network, stable triads are characterized by a positive product of ties. This behavior implies that a network will typically divide into two antagonistic factions with only positive intra-faction ties and negative inter-faction ties. This outcome has been demonstrated using the dynamical system $\frac{dX}{dt} = X^2$ where X is the signed adjacency matrix. We investigate structural balance dynamics in the presence of initial community structure as generated using a two-community stochastic block model. Specifically, we consider how the dynamically-evolved network relates to the initial communities as gauged by the assortativity metric. We vary the "bias' parameter, which controls the probabil-

ity of positive initial ties within communities and negative ties between them, and the network density. Simulation results show a sharp transition from a non-assortative final network to a highly assortative one as the bias is increased. This transition stems from the eigenvalue spectrum of the initial network and is related to the threshold for the detection of community structure. An analytical formula for the transition is in good agreement with simulation. Our results shed light on the dynamics of cooperation and conflict in social systems that possess community structure due to, for example, ethnic, religious, or ideological differences.

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PP1

Topological Vortex Dynamics Described with Bifurcation Theory

Vortices are a major component of almost any flow and their interactions with each other determine the overall organization, distribution and characteristics of a flow. In our research we make use of a topological approach to describe the qualitative changes in the structure of a given flow. The topology of a given vortex structure is inextricably linked to the way we choose to define vortices mathematically. In a two dimensional flow a vortex can be viewed either as a closed region or as an isolated point. As an example it is common to define a vortex as a region where $\det(\nabla \mathbf{v}) > 0$. Another usual perspective is, however, to identify vorticity extrema as feature points of vortices. With a dynamical system approach any sudden change of the vortex topology can be viewed as a bifurcation of the system. To present a precise criterion for the merging or creation of a new vortex we study under which conditions bifurcations occur in the system. Having established all possible types of topological changes for a given vortex structure, it is possible to give an exhaustive description of a flow in the form of a bifurcation diagram. We have employed this approach to analyse numerical simulations of various fluid mechanical problems such as vortex merging, boundary layer eruption and exotic wakes.

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PP1

Sensing Environmental Changes using Plankton

Plankton is at the bottom of the food chain. Microscopic phytoplankton account for about 50% of all photosynthesis on Earth. Plankton is also the food for most species of fish, and therefore it represents the backbone of the marine environment. Thus, monitoring plankton is paramount to infer potential dangerous changes to the ecosystem. In this work we present a new system to monitor plankton's shape and behavior in real time. Videos are acquired using a lensless microscope. A baseline of plankton shapes and behavior is established, and a neural-network based method of anomaly detection is presented. Our results show that the developed system can be used to accurately detect, identify and classify known species of plankton, as well as provide a semi-supervised method to identify plankton anomaly. An anomaly can be referred as events or observations which raise suspicions by differing significantly from most of the data. Hence, the detection of an anomaly can either correspond to new species (i.e., species not included into the training set) or samples belonging to known classes, whose morphological-behavioral features are so different from the average that the correspondent detectors were unable to classify them. Our hypothesis is that a significant percentage of anomaly can be associated to environmental threat, so that, our system could be used to continuously and in real-time monitoring the health of plankton, and hence, the condition of our oceans.

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PP1

Melnikov Theory for 2D Manifolds of Three Dimensional Non-Volume Preserving Flows

We present a new Melnikov method to analyze 2-dimensional stable and unstable manifolds associated with a saddle point in a 3-dimensional autonomous systems. Moreover, non-volume preserving flows are considered under the general time dependent aperiodic perturbations. This Melnikov theory is derived using the normal displacement of the stable and unstable manifolds. The theory is illustrated and verified in several examples.

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PP1

Data Fusion Reconstruction of Spatially Embedded Complex Networks

Inferring networks from data (e.g., estimation of brain connectivity via fMRI is important in many practical applications, especially when direct invasive measurements are infeasible. Given time series data collected on the nodes of a spatial network, the problem is to infer the underlying interaction structure of the network. A main challenge is that the amount of data in practice is typically small comparing to the size of the network, rendering reliable inference a difficult and sometimes impossible task. Recognizing that many real world networks are spatially embedded, this project utilizes such information to develop a kernel-based spatial network inference framework that significantly improves inference outcome. Our new approach enables efficient and accurate reconstruction of large spatial networks from limited data even when the exact spatial distribution of the embedded edges are not known. The results have potential impacts on biological and engineering applications where big data is being continuously collected.

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PP1

On Edges PageRank, Hashimoto Non-Backtracking Matrix and Multilayer Networks

In recent years, network scientists have turned their attention to the multiplex character of real-world systems and have explicitly considered the multilayered nature of networks. On the other hand, Hashimoto's non-backtracking matrix is a representation of the link structure of a network that is an alternative to the adjacency matrix. A non-backtracking walk on a network is a walk that does not come from a i node to a j node just to immediately return to the i node. In this poster we will present some relationships, properties and applications of various extensions of the non-backtracking random walks to the context of multilayer networks and line-graphs. In fact, several real life examples will be presented and analyzed through these new concepts and also some extensions of this kind of random walkers to the context of multilayer networks and line-graphs will be presented.

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PP1

Temporal Patterning of Intermittent Synchronization Between Coupled Predator-Prey Oscillators

The mechanisms and properties of synchronized population dynamics attract attention because it is a fairly common phenomenon and because spatial synchrony may elevate a risk of extinction and may lead to other environmental impacts. Conditions for stable synchronization in a system of dissipative coupled predator-prey oscillators has been considered in the past. However, this coupling (primarily realized via migration between spatially distinct populations) is usually relatively week, so it may not necessarily lead to a stable synchrony. If the coupling between oscillators is too weak to induce a stable synchrony, oscillators may be engaged into intermittent synchrony, when episodes of synchronized dynamics are interspersed with the episodes of nonsynchronized dynamics. In the present study we consider the temporal patterning of this kind of intermittent synchrony in a system of two dispersal-coupled Rosenzweig-MacArthur predator-prey oscillators. We consider the properties of the distributions of durations of desynchronized intervals and their dependence on the model parameters.

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PP1

Management Practices on Flow Kick Dynamics

Using flow kick dynamics to simulate ecosystem management practices, we show that discrete shocks may be an effective strategy to restore biodiversity. Experiments at Cedar Creek Ecosystem Science Reserve in Minnesota indicate that nitrogen addition can lead to exotic invasion of native grasslands and reduction in biodiversity [Isbell et al., Low biodiversity state persists two decades after cessation of nutrient enrichment, Ecology Letters 16:454-460, 2013]. It has been shown in a 10 year experiment of nitrogen addition to grasslands that exotic species can thrive in a high nitrogen environment and invade and lead to a decrease of biomass of native species. However, even after 20 years of cessation of adding nitrogen, the exotic species remain dominant to the natives, resulting in a decreased level of biodiversity. It has been hypothesized that dead plant biomass, or litter, inhibits plant growth, especially the native plants. To model these effects, we use a five-dimensional ODE model to represent the native and exotic plant biomass, the inorganic nitrogen levels, and the litter generated by the plants. We examine the system with an equilibrium analysis when no perturbation is involved, and simulate the system with regular kicks (as an example haying), which are characterized by proportionally removing living plants and litter while leaving the level of nitrogen intact.

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PP1

A New Computational Approach for the Solutions of Dynamical Systems with Impulsive Effects

The study of dynamical systems with impulsive effects is of great importance because of its relevance to the real life situations. But, sometimes such systems cannot be solved analytically or it is very difficult to solve due to the discontinuity at impulse moments. In this paper, R-K method of fourth order and Milne's predictor-corrector methods are applied to the system of impulsive differential equations. It is shown with the help of numerical examples and diagrams that the solutions obtained with these methods may or may not be stable. The study further shows that the impulses do contribute to improve the accuracy of numerical solutions and numerical techniques can be a better alternative to analyze the existing literature.

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PP1

The Lotka Model: One Century Later

One century later, the prevalence of computational machinery allows a substantial sub-set of our species to have access to hardware that is able to adequately handle the numerous sequential steps required to analyze the solution structure of related differential-equation relationships. An arrangement related by Dr. Ilya Prigogine in the third edition of "An Introduction to Thermodynamics of Irreversible Processes" - one whose structure is simply an ornamentative modification to the arrangement Dr. Alfred Lotka formally related in his 1,920 contribution "Undamped Oscillations Derived from the Law of Mass Action" - was un-packed more fully with the aid of contemporary machinery. Two interests currently seem to both have had been nourished and continue to be nourished with this project: 1) exposure to and development of numerical algorithms related to the deconstruction of the solution sets associated with collections of differential-equation relationships (a two dimensional differential-equation collection with three parameters was partially deconstructed) and 2) an explicit grounding in the terms and logic utilized in the non-equilibrium thermodynamics lineage (one of the aspects Dr. Prigogine emphasized in the analysis he relates are the associated thermodynamically grounded conjectures and their place within the context of the associated kinetic differential-equation system. The generality potential associated with these thermodynamic constructs merits the investment.

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PP1

Data-Driven Reduced-Order Modeling for Select Features of Complex Flows

When producing reduced-order models for complicated systems like turbulent fluid flow, it is often desirable to model the structured part of the dynamics while neglecting the seemingly random part (e.g. mixing, small-scale turbulent eddies). Data-driven techniques for obtaining useful reduced-order models that keep the structured part of the dynamics while discarding the random parts have been developed using ideas related to the graph Laplacian. These techniques are demonstrated on example problems including basic advection-diffusion and more complex cases.

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PP1

On the Analysis of Earthquakes using Mutual Information

Aftershocks predictions of earthquakes are an interesting topic among scientists. We study the interactions between regional earthquakes using information-theoretical methods. The k-mean clustering method was used to categorize the earthquakes that happened during the last 50 years around the world. Mutual information interactions among these categorized variables are measured using a nonparametric estimator. We proposed a technique called optimal mutual information interactions (oMII) to prune away indirect interactions between the categorized variables. Our results demonstrated that the proposed method is well suited for describing aftershock earthquake interactions.

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PP1

Finding Complete Characterizations Of Explicit

Symmetry Breaking

Much work has already been done on the application of group theory to the study of equivariant systems with high degrees of symmetry. Representation theory can help to explain the effects of explicit symmetry breaking terms on the equivariant bifurcation of previously symmetric systems. For a variety of symmetric systems, we find a complete characterization of such symmetry breaking for anisotropies belonging to every possible irreducible representation.

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PP1

A Mathematical Model of Flagellar Gene Regulation and Construction in *Salmonella Enterica*

Millions of people world-wide develop foodborne illnesses caused by *Salmonella enterica* (*S. enterica*) every year. The pathogenesis of *S. enterica* depends on flagella, which are appendages that the bacteria use to move through the environment. Interestingly, populations of genetically identical bacteria exhibit heterogeneity in the quantity of flagella. To understand this heterogeneity and the regulation of flagella quantity, we propose a mathematical model that connects the flagellar gene regulatory network to flagellar construction. Flagellar assembly is controlled by a complex regulatory network involving more than 60 genes. The most important member of the network is the master operon, *flhDC*, which encodes the $FlhD_4C_2$ protein. $FlhD_4C_2$ controls the construction of flagella by initiating production of hook basal bodies (HBBs), protein structures that anchor the flagella to the bacterium. By connecting a model of $FlhD_4C_2$ regulation to a model of HBB construction, the roles of various feedback mechanisms are investigated. Analysis of our model suggests that a combination of regulatory mechanisms at the protein and transcriptional levels induce bistable *flhDC* transcription and heterogeneous numbers of flagella. Also, the balance of regulatory mechanisms that become active following HBB construction could provide a counting mechanism for controlling the total number of flagella produced.

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PP1

Network Analyses of 4D Genome Polymer Models Automate Detection of Community-Scale Gene Organization

Chromosome conformation capture and Hi-C technologies provide gene-gene proximity datasets of stationary cells, revealing chromosome territories, topologically associating domains, and chromosome topology. Imaging of tagged DNA sequences in live cells provides dynamic datasets of chromosome positions. We investigate how polymer modeling of chromosomes compares with experimental images and highlight the challenges of image-based analysis. We then consider the analysis of position time-series data using more sophisticated network-based tools as an alternative to gene-gene proximity statistics and visual structure determination. Temporal network models and community detection algorithms are applied to 4D modeling of G1 in budding yeast with transient crosslinking of 5kb domains in the nucleolus, analyzing datasets from four decades of transient binding timescales. Network tools detect and track transient gene communities (clusters) within the nucleolus, their size, number, persistence time, and frequency of gene exchanges. An optimal, weak binding affinity is revealed that maximizes community-scale plasticity whereby large communities persist, frequently exchanging genes.

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PP1

Logic Behind Neural Control of Breathing Pattern

In this talk, I will discuss a new framework for neural control of breathing pattern. Our model is able to capture many features in the respiratory network and provide novel insights and testable predictions.

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PP1

Multilevel Monte Carlo for Spiking Networks

A common task in large-network models is to collect dynamical statistics like firing rates and correlations. This can be computationally expensive if the system is complex. It is especially the case for spiking network models, which typically involve interactions over a wide range of scales.
Multilevel Monte Carlo (MLMC) is a numerical method accelerating simulation-based statistical estimation. The basic idea for MLMC is to make a larger-biased estimate using large timesteps, then make a correction using smaller numbers of more expensive, small-timestep runs. MLMC is not always applicable: its effectiveness depends on the dynamics. Here, we assess the utility of MLMC for leaky-integrate-and-fire (LIF) spiking-neuron networks. Our main findings are: 1. Analysis of a Fokker-Planck equation for coupling single cells proves that MLMC is effective under broad conditions and provides significant speed-up. By induction, MLMC is also effective for feed-forward networks (also can be effective for predominantly feed-forward networks). 2. Numerical studies of randomly-connected recurrent networks have shown that the effectiveness MLMC depends strongly on the parameter regime. For systems dynamics in a homogeneous, "mean-field"-like regime where cells are weakly correlated, we found MLMC to be rather effective. In contrast, for networks operating in partially-synchronous regimes, MLMC is less effective, and more work is required to develop efficient algorithms.

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PP1

A Nonlinear Dynamical Systems Approach to Bird Song Analysis

Songbird vocal production is a complex nonlinear phenomenon. However, acoustic studies of bird vocalization have mostly been based on linear spectral analysis. Such methods of analysis necessarily fail to capture the information content of birdsong, and therefore are not effective probes of the means by which songbirds communicate. We propose a novel approach to the analysis and classification of songbird vocalization using nonlinear time series analysis techniques. In this approach, time-delay embedding is used to construct a new coordinate system in which to view waveform time series. The number of coordinates required to unfold the dynamics represents the dimensionality of the new geometric space, wherein songs' attractors can be visualized. We show that the reconstructed phase space representation of bird vocalization can reveal information that is hidden in traditional linear analysis.

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PP2

Synaptic Plasticity in Correlated Balanced Networks

Neurons in the cortex exhibit temporally irregular, but correlated spiking during ongoing sensory experiences. It is still unclear what mechanisms drive the emergence of global activity patterns, while supporting local fluctuations. Models that exhibit an emergent balance between excitation and inhibition produce responses remarkably similar to those in the cortex, but in their original version, they lead to asynchronous states. Recently, mechanisms supporting correlated activity have been proposed. Yet no theories about how this activity is maintained and shaped by changes in synaptic weights exist. How do emergent patterns in correlated activity drive changes in synaptic architecture, and how do these changes, in turn, shape the activity of the network? Could changes in synaptic architecture self-amplify, and drive the network out of balance? To answer these questions, we develop a general theory of plasticity in correlated balanced networks. We show that balance is attained and maintained both in asynchronous and correlated states. We find that spontaneous correlated activity does not drive significant changes in the synaptic connectivity and firing rates. However, for stimulus-evoked activity, changes in synaptic weights can considerably dampen both firing rates and correlations. Our general framework allows us to describe how stimuli interact with correlated activity to drive changes in synaptic connectivity, which in turn, shape activity patterns in balanced networks.

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PP2

Towards Understanding the Genetic Divergence of Shellfish Symbionts using Ocean Models

The abalone symbiont, Boccardia proboscidea is dispersed along the South African coast both by oceanic currents and by human trade routes. In recent years, marine biologists have posited that human activity has a much stronger influence on marine biogeographic patterns than thought before (so-called cryptic dispersal). The long-term focus of our research is to couple analysis of oceanic coherent structures with population dynamics to establish what the dispersal patterns would look like without human influence. This presentation will explain the dynamics of ocean structures that are thought to contribute to natural dispersal. The first stage of research uses two different methods to understand the barriers to material transport by ocean movement: Finite Time Lyapunov Exponent (FTLE) and Ulam approximation of Perron-Frobenius transfer operator over the biologically-relevant timescales. The second stage of research is to modify these techniques to account for the physical and biological properties, such as density/mass, biological age, and genetics of the symbionts. The results are used to formulate statistical hypotheses about the degree of human contribution in dispersing in shellfish symbionts.

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PP2

How Entropic Regression Beats the Outliers Problem in Nonlinear System Identification

System identification (SID) is central in science and engineering applications whereby a general model form is assumed, but active terms and parameters must be inferred from observations. Sparse SID has recently become an important approach for SID such as in compressed sensing and Lasso methods. For the current state-of-art methods, it is still challenging to maintain the effectiveness of the methods under realistic scenarios where each observation is subject to non-trivial noise amplitude and sporadically further contaminated by even large noise and outliers. To mitigate such issues of large noise and outliers, we develop an entropic regression approach for nonlinear SID, whereby true model structures are identified based on relevance in reducing information flow uncertainty, not necessarily (just) sparsity. The use of information-theoretic measures as opposed to a metric-based cost function has a unique advantage, thanks to the asymptotic equipartition property of probability distributions, that outliers and other low-occurrence events are conveniently and intrinsically de-emphasized.

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PP2

Stability Analysis of Abstract Ecological Networks and the Beaufort Sea Food Web

Food webs are ecological networks in which the vertices represent trophospecies and the edges encode dynamical equations that describe interspecific interactions, such as predator-prey relationships. Not all the terms in these equations are known, so integrating the system is not possible. Despite this, insights can still be gained from a local stability analysis thanks to the powerful method of generalized modeling and bifurcation theory. Network modularity and stratification as well as specialization of individual species are found to impact the stability of food webs.

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PP2

Dynamics Near the Leapfrogging Vortex Quartet

A vortex pair of equal and opposite circulation moves in parallel at a uniform speed. Each vortex is moved along by the other, and the closer they are, the faster they move. Taking two identical pairs, initially arranged colinearly and symmetrically at $t = 0$, the vortices have the possibility of 'leapfrogging'. If a faster (closer together) pair approaches a slower (further apart) pair along their common center line, the pair behind can pass through the pair in front as it widens and slows down. The vortex pair that had been in front is behind and the process repeats itself. This periodic motion is only possible if the ratio of the distances between vortex pairs in the initial collinear arrangement is sufficiently large. The stability of this motion is also dependent on this ratio, as was demonstrated by Acheson (2000) who produced simulations suggesting that this behavior is stable only if this ratio is above ϕ^2, where ϕ is the golden ratio. Below this ratio, a variety of complicated behavior is exhibited as the vortices pair up to form bounded 'walkabout' orbits or 'disintegrate' as two pairs that escape to infinity in different directions. Our goal is to understand the nature of the algebraic bifurcation value ϕ^2 and to understand the relationships between the different types of behavior when the solution becomes unstable.

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PP2

Encoding Plankton Behavior in Videos for Environmental Health Monitoring

Plankton behavior can act as a forerunner of environmental perturbations. In order to elucidate this link we use a novel AI system that can analyze the motion and shape dynamics of a plankton population from video images. Such temporal attributes can act as the fundamental signatures of plankton behaviors. The workhorse of such an AI system is robust computer vision technologies that can reliably detect and track moving objects for a reasonably long time. However, the tremendous variety of motion patterns, along with the presence of noisy background, often make long-term tracking of plankton hard. Also the desired objective to run such algorithm on low powered microscopic devices compounds the challenge. In this work we have used an efficient but robust (pose and motion based) tracker solves the data-association problem to track multiple objects at the same time. The derived motion signatures in this dynamical system serve as tell-tale signs of any environmental changes. We have illustrated our idea with a working prototype of a water quality monitoring system while subjecting the large single cell ciliate Stentor Coeruleus to a library of toxic compounds. The behavioral changes captured successfully indicate the change in the environment. The design of the proposed system can allow large screening of hundreds of chemicals of environmental interest, such as insecticides, pesticides, flame retardants, that may creep into water habitats through various channels.

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PP2

Identifying Important Edges in Complex Networks

We present edge centrality concepts as well as a decomposition method to identify edges/groups of edges that are important between other pairs/groups of vertices in complex networks. At the example of prototypical networks, we address the questions as to whether there is a relationship between importance of edges and nodes and whether important edges highlight topological aspects of the network. Moreover, we investigate the local structures revealed by the network decomposition. Analyzing empirical networks, we demonstrate the utility of our novel concepts.

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PP2

Are the SDGs Self-Consistent and Mutually Achievable?

In response to the UN's Sustainable Development Goals (SDGs), launched in 2015, the then International Council for Science (ICSU, now ISC) published a detailed commentary on the SDGs and the linkages between them (as identified by a broad panel of experts). One issue raised by the ICSU Report is the possibility that the SDG framework as a whole might not be internally self-consistent, and the report itself calls for a wider systems perspective. In this paper we use the ICSU commentary as the basis for a theoretical analysis of the SDGs from a network perspective. We provide a mathematical definition of self-consistency and show that the linkages we infer from the ICSU-ISSC report imply that the SDGs are not self-consistent. A very simple dynamical model shows that network effects could be used to secure better outcomes on every Goal than would be possible if linkages between Goals did not exist at all. These better outcomes would be possible through an unequal, targeted re-allocation of direct efforts, opening up the possibility of making the SDGs mutually achievable.

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PP2

A Novel Explanation for Young's Single Photon Experiment

A dynamical system may be defined as a function that relates position as time evolves: f(t) = x, x denoting position; as in Young's single photon experiment. A novel explanation for the pattern of interference found in the classical double-slit experiment first performed by Thomas Young in 1701, involving single photons, may be found by postulating the existence of a quantum-mechanical time-operator. To explain the trajectory of a single photon through a double slit, there are three factors to consider: (1) the nature of the photon emitted; (2) how a single photon is emitted (a technical point currently in debate); and (3) the forces that interact to shape its trajectory. The existence of Planck's constant, with its units of energy multiplied by time; along with the concept of quantization of energy, clearly suggest time quantization; or rather, time-energy quantization. The many-worlds interpretation of Young's experiment seems too speculative. Another interpretation is that we are observing the wave-particle duality of a single photon in the interference pattern. However, given the minute wavelenghts involved, the patterns observed do not correspond in size. We will attempt to explain how a time operator, along with the concept of angular momentum, may be considered to explain the interference pattern for a single photon emitted through a double slit.

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PP2

Molding the Asymmetry of Localized Frequency-Locking Waves by a Generalized Forcing and Implications to the Inner Ear

Frequency locking to an external forcing frequency is a well-known phenomenon. In the auditory system, it results in a localized traveling wave, the shape of which is essential for efficient discrimination between incoming frequencies. An amplitude equation approach is used to show that the shape of the localized traveling wave depends crucially on the relative strength of additive versus parametric forcing components; the stronger the parametric forcing, the more asymmetric is the response profile and the sharper is the traveling-wave front. The analysis qualitatively captures the empirically observed regions of linear and nonlinear responses and highlights the potential significance of parametric forcing mechanisms in shaping the resonant response in the inner ear.

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PP2

Invasion and Extinction in Stochastic Food Webs

Climate change, habitat destruction, disease, invasion, and many other factors often cause species extinctions within large ecosystems. The initial loss of one species in a food web often triggers a cascade of secondary extinctions, thereby threatening the stability and survival of the ecosystem in question. In order to improve our understanding of ecological systems and their stability and response to perturbations, we consider a wide range of empirical and synthetic food webs, accounting for full dynamics with stochasticity. Here, we investigate the effects of a control on the severity of a secondary extinction cascade within these stochastic systems. These possible controls are not always obvious given the dynamics of the predator-prey network. We also analyze the role of ecosystem mechanisms in the overall stability of a food web. Finally, we introduce invasion by an external species in order to determine the vulnerability of a food web to such events.

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PP2

Nonequilibrium Statistical Mechanics and Data Assimilation of Sudden Stratospheric Warming

Climate models are often perturbed by stochastic forcing to capture uncertainty, unresolved processes, and possible regime shifts. Examples include rapid intensification of hurricanes and sudden stratospheric warming (SSW), which develop through complex pathways in high-dimensional phase space. The rarity of such events poses a particular challenge for classical data assimilation schemes, which by design track expectations, not anomalies. We explore the forecasting utility of transition path theory, a mathematical framework of nonequilibrium statistical mechanics to calculate reaction rates and most-probable paths. We compute these dynamical quantities both for the stochastically forced quasi-geostrophic potential vorticity model from Birner & Williams (2008), and observational data from the NOAA SSW Compendium. Transition path theory allows us to forecast SSW probabilistically given the initial state of the atmosphere, using a "reaction coordinate" for monitoring progress toward a transition. In the context of DA schemes such as particle filtering, this coordinate provides a criterion for enhanced sampling of possible transitionary trajectories. We also reconstruct a probability distribution of reaction paths, which reveals coherent structures (e.g. eddies) that typically accompany SSW events. In this way, transition path theory offers a data-driven perspective on physical onset mechanisms of SSW.

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PP2

Machine Learning to Improve Data Assimilation for Arctic Sea Ice

Sea ice concentrations derived from passive microwave satellites are one of the most widely available and useful data sets for assimilation in large scale sea ice models. These data are derived using the contrast in the microwave signatures of sea ice and open ocean. In winter the retrievals are accurate, however, during the melt season snow melt collects on the surface of the ice forming melt ponds. These ponds have the same microwave signature as open water obscuring the ice beneath, leading to as much as 30% error. This can adversely affect sea ice forecasts when this incorrect data is assimilated. To improve the assimilation of this data, we propose to develop an observation operator which takes the model state directly to the satellite radiances avoiding the assimilation of incorrect values. This operator is difficult to model, computationally expensive, and depends on many parameters not included in current sea ice models. To circumvent this, we propose to machine learn this operator based on currently used sea ice state variables. As a first step, we study a simplified system based on a modified version of the sea ice energy balance model presented in (Eisenmann & Wettlaufer 2009). This modified system is Filippov and produces data which mimics that of ice and observable satellite radiances under ponded conditions. We will present our results using learned observation operators for this proxy system and discuss how to extend the methodology to large scale models.

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PP2

Combining Diffusion Maps and Set Oriented Numerics for the Approximation of Invariant Sets

In the last few years classical *set oriented* numerical methods for the approximation of invariant sets of finite dimensional dynamical systems have been extended to the infinite dimensional setting. This novel approach is based on *embedding techniques* that allow the definition of an equivalent dynamical system - the so called *core dynamical system* - on an appropriate finite dimensional space. In this work we will show how the core dynamical system can be combined with *diffusion maps* to approximate the object of interest in its intrinsic coordinates. We will illustrate the feasibility of this approach by examples from fluid dynamics.

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PP2

Dynamics of Dual Strain Toggle Consortium

Synthetic biologists aim to design and construct dynamical biocircuits. Early constructs, such as the dual-feedback oscillator of Stricker et al. and the toggle switch of Gardner, operate in a single bacterial strain. Efforts to build more complex circuits have led to a distributed approach: Circuit function is partitioned among several bacterial strains that communicate with one another via chemical signaling. Here, we describe recent efforts to construct and model a dual-strain toggle switch. We show that the strain which will have larger number of cells will dominate over the other and this domination persists after removal of inducer molecules. We build a deterministic model for the two strain microbial consortium and use experimental data to estimate the parameters our model. Our main goal is to study the bistability for the two bacterial strains in the experiment, for which we examine the bifurcation regions by varying the parameters in our model. Furthermore, we study the dynamical nature of our system under different conditions. We use Bayesian inference method to analyze the experimental data and estimate the parameters. An application of bistability for bacterial toggle switch could be the gut, which already contains certain kind of bacteria and if we want to switch on or off its action by introducing specific bacterial cells from outside could be established through our hypothesis.

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PP2

Using Exact Coherent Structures to Tile the Infinite Spacetime Kuramoto-Sivashinsky Equation

Exact coherent structures have been the subject of many recent investigations in fluid dynamics. One of the many reasons that these solutions are important is because their stable and unstable manifolds shape the geometry of the solution space,thereby playing an important role in the dynamics. While these exact coherent structures have proved to be important, finding them has proved to be a very difficult computational problem. The difficulty is significant enough that exact coherent structures have only been found for the smallest computational domains for three dimensional fluid flows. We attempt to circumvent this computational difficulty by developing a spatiotemporal theory which forgoes chaotic dynamics in favor of treating space and time on equal footing. We will formulate our theory in the context of the spatiotemporal Kuramoto-Sivashinsky equation; this equation serves as a simpler starting place than the $(3+1)$ dimensional Navier-Stokes equation. This investigative effort focuses on finding, studying, and utilizing doubly periodic spatiotemporal solutions of the Kuramoto-Sivashinsky equation. Our hypothesis is that the behavior on infinite spatiotemporal domains can be explained via the shadowing of invariant 2-tori solutions. This work will present current results of this formulation which include new methods for finding doubly periodic solutions on arbitrary domain sizes as well as constructing new solutions from combinations of old solutions.

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PP2

Influence of Astrocytes in Neuronal Network Synchrony

Previously, we have performed a detailed modeling of local ionic concentrations (calcium, sodium and potassium) in and nearby astrocytes, and the diffusion of particles in the synaptic cleft. From these studies we were able to extract the specific effects an astrocyte may have on the adjacent synapse and the nearby neurons. We show that the astrocyte proximity to a synapse makes synaptic transmission

faster, weaker, and less reliable. It also changes excitability of postsynaptic cells by altering extracellular ion concentrations. All these influences can then be captured in a neuronal network model by including an "effective' astrocyte on every synapse, parametrized only by the degree of astrocytic proximity at that synapse. This endows each synapse with its own properties and results in a highly heterogeneous network. The experimental evidence suggests that the number of synapses wrapped by astrocytes and the degree of astrocyte proximity are altered in some diseases (e.g., epilepsy). We consider corresponding synaptic changes in the model, and characterize, through a combination of theory and simulations, the resulting changes in synchronization properties of such a network.

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PP2

Existence of Blenders in a Hénon-Like Family: Geometric Insights from Invariant Manifold Computations

A blender is an intricate geometric structure of a diffeomorphism of dimension at least three. Its characterizing feature is that its invariant manifolds behave as geometric objects of a dimension that is larger than expected from the dimensions of the manifolds themselves. We introduce an explicit Hénon-like family of three-dimensional diffeomorphisms and show that it has a blender in a specific parameter regime. Advanced numerical techniques for the computation of one-dimensional stable and unstable manifolds enable us to present images of actual blenders and their associated manifolds. Moreover, these techniques allow us to present strong numerical evidence for the existence of the blender over a larger parameter range, as well as its disappearance and geometric properties beyond this range.

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PP2

Nonlinear and Branching Dynamics of Terrestrial Landscape Evolution

The formation and evolution of the topographic features such as channels, valleys, and hillslopes are of great importance in hydrology and geomorphology due to their direct effect on sediment and water transport and ecosystem regulation. The evolution of landscape is governed by the fluvial erosion due to water movement on the surface, diffusive transport of sediment in form of e.g. creep and rain splash and tectonic uplift. The resulting hierarchy of channel networks in landscapes displays features that are characteristic of nonequilibrium complex systems and are described by a dimensionless number, analogous to a Reynolds number, accounting for the relative role of diffusive soil creep, runoff erosion, and tectonic uplift. Numerical experiments show a sequence of increasingly complex ridge and valley networks, analogous to the vortex cascade in fluid turbulence, which proceeds until diffusion dominates at small scales. The regularity of the patterns is indicative of the tendency to evolve toward optimal configurations, with anomalies similar to dislocation defects generally observed in the pattern forming systems. The choice of specific geomorphic transport laws and boundary conditions is shown to strongly influence the resulting channelization cascade, the spatial organization of the topographic patterns, and their hypsometric curves, thus revealing the nonlocal and nonlinear character of the underlying dynamics.

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PP2

Periodic and Quasiperiodic Dynamics of Optoelectronic Oscillators with Narrowband Time-Delayed Feedback

We present a detailed study of instabilities arising in optoelectronic oscillators with a single narrowband time-delayed feedback loop. Such optoelectronic oscillators produce periodic solutions and may be useful as high-purity signal generators but their nonlinear dynamics sets limits on available signal amplitudes. Starting from an integro-differential model, we utilize approximate analytic solutions to find the stability boundaries of the periodic solutions as well as regions of multistability. Our analytical predictions are confirmed by numerical simulations and experiments.

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PP2

Heteroclinic Networks with Noise and Input

Heteroclinic networks are structures within dynamical systems that have a variety of applications in physical systems, including designing neural networks. The dynamics of heteroclinic networks have been studied in depth for several decades, however, the effects of noise on the networks is not well understood. In my poster, I will present how small noise and/or inputs affect a relatively simple heteroclinic cycle, called the Guckenheimer-Holmes Cycle. This cycle consists of three equilibria and the heteroclinic connections between them. As time evolves, trajectories spend longer and longer time near each equilibrium. When noise or inputs are added, this slowing down no longer occurs.

Future work will include studying how the interactions between noise and input affect the cycle, and other dynamical networks.

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PP2

A Computer-Assisted Study of Red Coral Population Dynamics

We consider a 13-dimensional age-structured discrete red coral population model varying with respect to a fitness parameter. Our numerical results give a bifurcation diagram of both equilibria and stable invariant curves of periodic orbits, showing that these periodic orbits reach a point of extinction. We use computer-assisted proofs techniques to rigorously validate the set of equilibria and bifurcations for the bifurcation diagram. This is joint work with H.K. Kim, University of Minnesota, and E. Sander and T. Wanner, George Mason University.

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PP2

Mechanisms of Frequency and Intensity Regulation in Spinal Cord Central Pattern Generator

The rhythmic activity of a heterogeneous network of adaptive exponential integrate-and-fire (AdEx) neurons coupled electrically and chemically is investigated to understand the mechanisms controlling the timing and intensity of activity observed in central pattern generators in the zebrafish larvae spinal cord. Motivated by the observed types of neurons, we consider three different types of neurons with distinct spiking pattern under constant input: tonic, adapting and bursting. Depending on the coupling and the form of input, the network exhibits various frequencies of activity and phase relations between the different types of neurons. These neurons typically exhibit distinct spiking pattern from each other during their active phase. Using analytical and numerical techniques, we show how these different activity patterns arise and what are the critical components in shaping each type of network behavior. We discuss what class of input and interconnection are needed for the network to replicate the observed activity of the central pattern generator, including frequency and phase relation between different types of neurons, in the zebrafish larvae spinal cord during adaptive swimming.

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PP2

Stable Stripe Patterns in a Generalized Gierer-Meinhardt Model

Plant growth in desert-like conditions exhibits spatial patterns such as waves, dots and stripes. The time evolution of this vegetation can be modeled by the Gierer-Meinhardt equations a set of reaction-diffusion equations describing a system of an activator (water) and an inhibitor (vegetation). In this model the localized stripe pattern is described as a one-dimentional pulse solution that is translation invariant in the second spatial direction. Unfortunately, however, it can be shown that stripe patterns of this type are unstable with respect to Turing type 'Pearling' instability along the stripe, despite experimental confirmation of their existence. We study a class of singularly perturbed reaction-diffusion systems that generalize the one-dimensional Gierer-Meinhardt equations. Using geometrically singular perturbation theory we show that, aside from the slow-fast single loop homoclinic pattern, these systems can exhibit a (slow-fast) double front solution as well. When extended to two spatial dimensions both patterns can be seen as localized stripe solutions, but the double front stripe can be expected to be stable with respect to the Turing instability, which we investigate with an Evans function approach. It is the subject of the present study to understand this transition between these two types of stripe patterns, with particular focus on the (dis)appearance of the lateral Turing instability.

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PP2

Mixed Global Dynamics of Harmonically Forced Vibro-Impact Oscillator with Dry Friction

We consider a well-known model of a harmonically forced vibro-impact oscillator with Amonton-Coulomb friction. In a vast majority of previous studies, this model also includes viscous friction, and its global dynamics in the state space is governed by periodic, quasiperiodic or chaotic attractors. We demonstrate that removal of the viscous friction leads to qualitative modification of the global dynamics. Namely, the state space is divided into the regions with dissipation, *i.e.* "regular" attraction to the aforementioned special solutions, and the regions of volume-preserving dynamics. The latter regions contain structures typical for forced Hamiltonian systems: stability islands, extended non-attractive chaotic regions etc. We prove that such local Hamiltonian behavior occurs in trajectories with non-vanishing velocity. Stability analysis for the periodic orbits confirms the statement above. It is also demonstrated that similar mixed global dynamics can be observed in a broader class of models, namely with the potential depending on the position.

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PP2

Pedestrian-Induced Vertical Vibrations of Footbridges

While the study of lateral pedestrian-bridge oscillations has received a great deal of attention in the mathematical and engineering literature, there is a critical gap in modeling the vertical component of pedestrian gait and predicting the dynamical vertical response of a footbridge. In this work, we develop a model of vertical pedestrian-bridge interactions and show similarities and differences in the pedestrian response to lateral and vertical vibrations.

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PP2

Contagion Dynamics on Adaptive Networks: Norovirus as a Case Study

Classical contagion models, such as SIR, and other infectious disease models typically assume a well-mixed contact process. This may be unrealistic for infectious disease spread where contact structure changes when individuals are aware of other individuals infection status, individuals showing symptoms isolate themselves, or individuals are aware of an ongoing epidemic in the population. Here we investigate contagion dynamics in an adaptive network context, meaning that the contact network is changing over time due to individuals responding to an infectious disease in the population. We consider norovirus as a specific example and investigate questions related to disease dynamics and applications to public health.

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PP2

Robustness of Planar Target Patterns

Planar target patterns are radially symmetric time-periodic structures that connect a core region with a spatially periodic traveling wave in the far field. These patterns arise in a number of different applications, including chemical reaction patterns. We are interested in understanding the robustness of these patterns (eg do these patterns select the wave number of the asymptotic wave train or do they come in one-parameter families) and their stability with respect to small perturbations. Existence and robustness of small target patterns was previously studied near degenerate oscillatory instabilities. Here, we study the large-amplitude case and use a combination of spatial dynamical systems and Fredholm techniques to prove that target patterns uniquely select the asymptotic wave number provided the asymptotic wave trains have positive group velocity and are spectrally stable.

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PP2

Model Order Reduction in the Frequency Domain via Spectral Proper Orthogonal Decomposition

We propose a new model order reduction framework for harmonically and randomly forced dynamical systems. Specifically, we emphasize the usage of spectral proper orthogonal decomposition (SPOD), recently revived by Towne et. al. (2018). SPOD results in sets of orthogonal modes, each oscillating at a single frequency, that are said to optimally represent coherent-structures evolving in space and time. However, reduced-order models (ROMs) using SPOD modes have not yet been developed. Hence, in this study we are investigating the potential of a novel approach utilizing SPOD modes to construct the lower-dimensional subspace for ROMs. Upon the discrete-time Fourier-transform (DFT) of the governing ODE system, we perform an orthogonal projection onto the SPOD modes, analogous to POD-Galerkin ROMs, but compressing the system at each discrete frequency within the frequency domain. The ROM is solved at each frequency and after the inverse DFT of the spectral solution matrix we obtain the entire solution for a given timespan at once, with no time integration necessary. Our approach is demonstrated using typical PDE examples such as the convection-diffusion equation and Burgers equation. Herein, we use a modeling approach for the quadratic nonlinear term in the frequency domain that becomes a convolution of different prior frequency ROM solutions. Finally, we compare the performance of our ROM with other existing ROM approaches in terms of accuracy and computational speed up.

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PP2

Analysis of Reaction-Diffusion PDE Models for Localized Pattern Formation in Cells

We study a system of reaction-diffusion PDEs, which models the dynamics of small GTPases, a family of signalling proteins. The system is composed of 3 fully coupled quantities, a fast-diffusing active protein, a slow-diffusing inactive form (with nonlinear interconversion term) and slow negative feedback from a and a non-diffusive quantity (F-actin). We explore the system's bifurcation behaviors using local perturbation analysis (a shortcut to probe the growth/decay of localized spikes), and look for spatio-temporal patterns using numerical simulations. The results have biological applications toward understanding cell motility phenomena.

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PP2

Noisy Heteroclinic Networks

Structurally stable heteroclinic networks are invariant sets that can act as attractors in nonlinear dynamical systems with symmetry. These networks are useful as models of dynamic physical, biological and cognitive processes. The deterministic behavior of these systems is, in some cases, well-understood. However, with the addition of noise to the system their behavior can change significantly. The noisy system may exhibit dynamics such as switching between the networks sub-cycles, a change in the residence times of trajectories near the states of the network, and memory. Recent research has shown that complex graphs may be realized as robust heteroclinic networks for flows generated by a dynamical system. This increases the applicability of heteroclinic networks in fields such as biology and cognitive science. This poster will demonstrate some of the effects that the introduction of small-amplitude noise to a dynamical system has on its heteroclinic network, and consider the application to a cognitive model of introducing noise to a system of ODEs which realize a graph.

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PP2

Hebbian Model of the Structural Plasticity in the Olfactory System

How animals can discriminate between different sensory stimuli, e.g. similar odors, is an intriguing question. In the olfactory system the olfactory bulb is the first brain area to receive sensory input from the nose. It exhibits persistent structural plasticity: i) synaptic connections between excitatory principal neurons and inhibitory interneurons are formed and eliminated, ii) interneurons are added and removed from the network. This structural plasticity is crucial for the learning of certain odor tasks. Here we present a Hebbian-type model to understand how synaptic structural plasticity can contribute to this learning. Based on experiments, we assume that synaptic structural plasticity follows Hebbian-type rules: co-activation of a principal cell and an interneuron leads to the formation of a synapse connecting them; if the principal cell is active, but not the interneuron, the connecting synapse is removed; if the principal neuron is not active the synapse is unchanged. In addition, the total number of synapses of each interneuron is limited. Experiments show that during learning the responses of the principal cells and the discriminability of odors change qualitatively in a different way depending on the difficulty of the task. Our model captures the key aspects of these results if we allow the network to be exposed to other stimuli before the learning of the relevant tasks. This suggests that previous memory influences the behavior during learning.

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PP2

From Theory to Application: Case Studies of Resilience Metrics

We live in a world of shifting disturbances, from increasing frequency and severity of storms to rising pressure on the systems that feed our growing human population. Repeated and continual disturbances drive many natural systems away from long-term equilibria, to regions of state space where interactions between disturbances and short-term recovery processes drive outcomes. Recent mathematical work revisits classical notions of stability to develop metrics of resilience tailored to modern environmental change (e.g. [Meyer et al., Quantifying resilience to recurrent ecosystem disturbances using flow-kick dynamics. Nature Sustainability 1(11):671-678, 2018]). New approaches expand our focus beyond invariant sets to probe transient dynamics within an entire domain of attraction. How might this growing collection of resilience metrics inform management actions to strengthen desired states against perturbations (e.g. controlling pollution levels) or to escape undesired states via disturbances (e.g. removing invasive species)? This poster examines the implications of new resilience metrics in several case studies.

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PP2

Cardio-Respiratory Interactions: Neural Mechanisms

The respiratory and cardiovascular systems are integrated physiologically to oxygenate tissues and remove carbon dioxide. Brainstem neural circuits control cardio-respiratory functions, generate rhythms endogenously and integrate central and sensory input to maintain gas homeostasis. However, no quantitative mechanistic description was suggested to explain specific aspects of the cardio-respiratory interactions. Cardio-ventilatory coupling (CVC) is a form of partial synchronization between cardiac and respiratory rhythms that is characterized by an increased probability of a heartbeat occurring at specific phases of the respiratory cycle. Previously, we suggested that baroreceptor input facilitates the activity of an inhibitory neuronal population of the respiratory central pattern generator (rCPG) that is active during the expiratory phase. Here, we introduce a closed loop model of the integrated respiratory and cardiovascular control system to describe our hypothesized mechanism for CVC. In this model, CVC is mediated by the pulsatile inputs from arterial baroreceptors to neurons of the respiratory central pattern generator. Projections from 2nd order barosensitive neurons of the nucleus of solitary tract (NTS) excite a population of expiratory neurons in the rCPG. Excitation of these rCPG expiratory neurons makes the onset of inspiration less likely to occur right after the heartbeat thus reproducing a characteristic structure of the heartbeat probability distribution.

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PP2

Optimizing Sequential Decisions in the Drift-Diffusion Model

Two alternative forced choice tasks are often used to identify strategies humans and other animals use to make decisions. Experiments have shown that subjects can learn the latent probabilistic structure of the environment to increase their performance. However, a lack of systematic analyses of normative models makes it difficult to study whether and how subjects' decision-making strategies deviate from optimality. To address this problem, we extend drift-diffusion models to obtain the normative form of evidence accumulation in serial trials whose correct choice evolves as a two-state Markov process. Ideal observers integrate noisy evidence within a trial until reaching a decision threshold. Their initial belief is biased by their choice and feedback on previous trials. If observers use fixed decision thresholds, their bias decreases decision times, but leaves the probability of correct answers unchanged. To optimize reward rate in trial sequences, ideal observers adjust their thresholds over trials to deliberate longer on early decisions, and respond more quickly later in the sequence. We show how conflicts between unreliable feedback and evidence from previous trials are resolved by marginalization. Our findings are consistent with experimentally observed response trends, suggesting humans often assume correlations in task environments even when none exist.

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PP2

Convergence of Ginelli's Algorithm for Covariant Lyapunov Vectors

Linear perturbations of solutions of dynamical systems exhibit different asymptotic growth rates, which are naturally characterized by so-called covariant Lyapunov vectors (CLVs). Due to an increased interest of CLVs in applications, several algorithms were developed to compute them. The Ginelli algorithm is among the most commonly used ones. Although several properties of the algorithm have been analyzed, there exists no mathematically rigorous convergence proof yet. Our recent advances extend existing approaches in order to construct a projector-based convergence proof of Ginelli's algorithm. One of the main ingredients is an asymptotic characterization of CLVs via the Multiplicative Ergodic Theorem.

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PP2

Modelling Blood and the Dynamics of Hematopoietic Stem Cells

The human body produces blood through a process known as hematopoiesis. Understanding the process in detail could lead to improved treatment of the hematopoietic malignancies, such as acute myeloid leukemia (AML) or the myeloproliferative neoplasms (MPNs). Mathematical models of hematopoiesis include, among other types, systems of both partial and ordinary differential equations. Andersen et al (PLoS One 12(8), 2017) introduces a mechanism-based model of the development of MPNs through a system of ordinary differential equations. The model describes the dynamic behaviour of both normal (healthy) and MPN-mutated hematopoietic cells, coupled through a novel type of inflammation-dependent feedback. During investigations of clinical data, we observed behaviour for some patients that differed from the behaviour of the model. Present work extends the model and analyses the resulting dynamics. In particular, the behaviour of stem cells is extended in two ways. The first considers quiescent stem cells, featured as a separate compartment, connected to the active stem cells. The other extension includes the physical competition for space in the stem cell niche, inspired by the work of Stiehl et al (Haematologica 102(9), 2017). Investigating the suggested model extensions provides insight into the importance of the mechanisms. The extended model allows for improved agreement with clinical data, and shows promise for modelling of other hematopoietic malignancies apart from MPNs.

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PP2

A Dynamical Systems Approach to Questionnaire Data

We study the effectiveness of the Gang Reduction and Youth Developments prevention program by analyzing the change in estimated risk factor from periodic questionnaire data. We view the evolution of the question responses as a dynamical system and utilize Dynamic Mode Decomposition to find the inherent temporal patterns. We compare participants in the program to non-participants. We are able to identify attitudes that are resilient to change, which may identify common themes that need to be addressed by the program. We develop a predictive model for the change in a youths attitudes and behaviors after six months of participation in the program. This model yields a similar predictive power as a shallow neural network but with faster run time. Additionally, our model quantifies the systems decay and lack of periodicity. We also observe a potential for the energy of the system to increase before decay, indicating the program may be effective for youth who initially increase in risky behavior.

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PP2

Stability and Nonlinear Waves in Damped Driven Rotating Shallow Water Models

In the investigations of currents in the ocean and atmosphere, large scale phenomena are of primary interest. Linear waves in different geophysical flow models often characterise these motions. Nevertheless the small scale regime has important effects on the large scale and thus cannot be neglected. A major problem is to determine adequate damping and driving terms that respect energy balances and subscale features. We investigate some models of this kind with a focus on modifications of the single-layer and two-layer rotating shallow water equations. We are particularly interested in finding and analysing nonlinear waves and therefore we investigate special solutions with zero material derivative as well as stability and bifurcation behavior from linear waves. Numerical tools are also used in order to study the stability and bifurcations in these models.
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PP2

Dynamics and Topological Entropy of 1D Greenberg-Hastings Cellular Automata

We present our recent results on the recurrent dynamics and topological entropy for a family of cellular automaton models for excitable media which we relate to waves and wave interaction dynamics. This includes an explicit characterization of the non-wandering set by showing a decomposition using graphs for communicating classes. On each of these classes we give explicit formulae for the topological entropy which can be compared in order to prove that the system's topological entropy is readily determined by a Devaney-chaotic closed invariant subset of the non-wandering set; this subset consists of colliding and annihilating travelling waves and is conjugate to a skew-product dynamical system of coupled shift-dynamics.

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PP2

On the Effect of Forcing on Fold Bifurcations and Early-Warning Signals in Population Dynamics

The classical fold bifurcation presents a paradigmatic ex-

ample of a critical transition. It has been used in a variety of contexts, including in particular ecology and climate science, to motivate the role of slow recovery rates and increased auto-correlations as early-warning signals of such transitions. We study the influence of external forcing on fold bifurcations and the respective early-warning signals. Thereby, our prime examples are single-species population dynamical models with Allee effect under the influence of either quasiperiodic forcing or bounded random noise or both forcing processes we refer to as "hybrid' forcing. We show that the presence of these external factors may lead to a so-called *non-smoothness* of the fold bifurcations resulting into the formation of strange non-chaotic attractors, and thereby has a significant impact on the behavior of the Lyapunov exponents (and hence the recovery rates). In particular, it may lead to the absence of critical slowing down prior to population collapse. More precisely, unlike in the unforced case, the question whether slow recovery rates can be observed prior to the transition crucially depends on the chosen time-scales and the size of the considered data set.

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PP2

Parametrically Excited Bi-Rhythmic Generalised Van Der Pol Model

Bi-rhythmic oscillator is a variant of van der Pol oscillator as proposed by Kaiser to model enzyme reaction in bio-system can provide complex response dynamics. Our goal is to characterise bi-rhythmic oscillator in terms of the sub-harmonic resonance behaviour. From their stability and bifurcation scenario, one can identify excitation induced oscillation between two stable limit cycles. Unlike the resonance and anti-resonance features here we find nonlinear resonances which are obtained analytically from Krylov-Bogoliubov(KB) analysis.

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PP2

Using Diffusion Maps in Equation-Free Modeling

In many high-dimensional dynamical systems interactions between microscopic particles lead to low-dimensional macroscopic behaviors. Equation-free modeling estimates this macro-level behavior through a coarse time stepper in three steps: (1) lift: build the microstate from the macrostate, (2), evolve: simulate the microsystem for short bursts, and (3) restrict: estimate the macrostate from the evolved microstate. Choosing appropriate macroscopic variables for equation-free modeling can be a difficult task, but nonlinear dimension reduction techniques such as diffusion maps can identify potential candidates; however, even with the appropriate macroscopic variables identified, defining the lifting and restriction operators can be quite difficult. Therefore, we present application independent diffusion map-based lifting and restriction operators. To illustrate these new operators and demonstrate their effectiveness, we apply them to a traffic model where we use them to compute and continue traffic jam solutions.

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PP2

Inhomogeneous Domain Walls in Spin-Tronic Nanowires

The Landau-Lifshitz-Gilbert-Slonczewski equation describes magnetization dynamics in a ferromagnetic body in the presence of an applied field and a spin polarized current. In the case of axial symmetry and with focus on one space dimension, we study the existence and stability of inhomogeneous domain wall-type coherent structure, whose profiles asymptote to wavetrains or the constant up-/down-magnetizations. Decisive for the solution structure is the polarization parameter as well as size of anisotropy compared with the difference of field intensity and current intensity normalized by the damping.

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PP2

Analysis of Some Non-Smooth Bifurcations with Applications to Ship Maneuvering

The super/subcriticality of a Hopf bifurcation in a generic smooth 2D system can be readily determined by the sign of the first Lyapunov coefficient. However, for a system of continuous but non-smooth equations this cannot be applied in general. We show new results for autonomous systems of arbitrary finite dimension with focus on non-smooth nonlinearities of the form $|u_i|u_j$. This is motivated mainly by models for ship maneuvering and its control. We present the unfolding of Hopf-type bifurcations for such systems and discuss generalizations to bifurcations at switching points for continuous piecewise smooth systems.

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PP2

Mode Interactions and Superlattice Patterns

Pattern formation in systems in many real world systems such as neural-field models, reaction-diffusion systems and fluid systems such as the Faraday wave system have separation of scales leading to nonlinear modal interactions. A general analysis of possible terms that can arise via modal interactions is subject to both the choice of a lattice grid and the ratio between the two length scales q. Motivated by the observance of different grid states and superlattice states in experiments of the Faraday wave system, here we consider a hexagonal lattice grid and identify families of amplitude equations for different values of the ratio in the range $0 < q < 1/2$. We find that the ratio of $q = 1/\sqrt{7}$ gives rise to the maximum number of terms in the amplitude equations (up to third order terms) and that other families of amplitude equations can be recovered by setting the coefficients of certain modal interactions in this 'general' form to vanish. For the case with $q = 1/\sqrt{7}$, we use equivariant bifurcation analysis to investigate the existence and stability of different patterns over a range of marginally stable growth rates for both the length scales. We also contrast our results with a codimension-1 analysis which assumes that only one of the length scales is marginally stable.

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PP2

Transient Activity Patterns in Synaptically Coupled Morris-Lecar Neuron Networks

A ring network of excitatory neurons exhibits transient spatiotemporal chaos with system intrinsic collapses to asymptotic pulse and rest states. Chaos in two synaptically coupled networks is also transient and exhibits similar collapses to states that may no longer be asymptotic. Our findings show increased neuron activity as a response to pulse destabilization by inhibitory synapses, system-intrinsic switching between neuron activity patterns, and localized oscillations in the presence of strong excitatory synapses.

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PP2

Analysis of Hippocampal Calcium Imaging Data

Calcium imaging is capable of recording simultaneous activity of hundreds of neurons, resulting in complicated and high dimensional data sets. In the hippocampus, neuronal activity is known to be associated with encoding and retrieving contextual memory, but the precise meaning of this activity is not clear. We apply novel theoretical tools to imaging data recorded during fear conditioning in two strains of mice that show different levels of ability to generalize memories. First, we apply a new algorithm to detect cell assemblies, which are groups of cells working together and being proven to associate with cognitive tasks. We show that algorithm can be applied to wider class of data sets than anticipated by the author. The result shows that cells participating in assemblies are more spatially coherent, and that the spatial coherences are different between two strains. Second, we apply Poisson linear dynamic system (PLDS) model with external input to construct a low dimensional representation of neuron populations activity. The result from analyzing latent variables show that the difference in shock responses can distinguish two strains and are significantly good predictors freezing level in the context test, and context/altered discriminant index.

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PP2

Inherently Complex Quantum Dynamics

Time series of qubits are a key part of important quantum computation protocols, such as quantum key distribution. This has driven the experimental development of single photon sources, such as color centers, which output time series in which the experimenter has no control over the state of the outgoing photons. If a classical observer performs measurements on the output qubits, the outcomes of such measurements generate a time seriesa classical stochastic process. The aim of our work is to understand the apparent randomness and complexity of the output qubit process when observed through measurement. For this purpose we use simple hidden Markov models to generate qubit time series and study the properties of those processes when measured by an observer. We show that, in general, the observed classical processes are highly complex. Specifically, they have positive Shannon entropy rate and require an infinite number of predictive features for optimal prediction. We identify the specific mechanisms for the resulting complexity and examine the influence that the choice of measurement has on the randomness and structural complexity of the observed classical process.

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PP2

Nontwist Maps with Even Power Winding Number

Profiles

Area-preserving nontwist maps are discrete models of Hamiltonian systems that locally violate a non-degeneracy condition. Of particular interest in these maps are shearless invariant tori which correspond to local extrema of the winding number. Most studies have looked at quadratic extrema, but in some relevant applications, the winding number profile in the vicinity of the extremum is almost flat. To model a locally flatter profile and compare it to one with a quadratic extremum, we study maps with quartic and higher even power winding number profiles.

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PP2

Refractory Dynamics on Networks: Role of Network Structure

The relationship between structural properties of a complex network and dynamics over such a network are of interest in many fields, including systems neuroscience. We use an idealized, dynamical model of the spread of neuronal network activity with refractoriness to explore this relationship. We start with the three broad network classes of scale-free, random, and stochastic-block networks, and alter connectivity in each class by, respectively, removing highest-connected hubs, increasing connection probability, or adding inter-block connections. We track the activity of each network by observing the number and the lengths of the stable periodic sequences of activity (the coding space). We find that in each network class there is narrow range of "optimal" connectivity where the coding space has the largest repertoire of available stable activity patterns. A detailed examination of the underlying structure of "optimally-diverse" networks reveals that most network-structure characteristics differ from one network class to the next. However, in all of them, the size of the largest strongly connected component is the best predictor of the coding properties.

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PP100

Inferring Dynamical Systems through Active Queries

Inferring the parameters of networked dynamical systems is currently a popular research topic. In a typical setting, model parameters are estimated from passive observations over which the user has no control. Here, we consider the problem of determining the local functions of a dynamical system by actively interacting with the system. The user submits queries to the system and infers the model from the outputs. We develop tight bounds on the number of queries needed, complexity results for producing optimal query sets and efficient algorithms that produce near-optimal query sets for several classes of deterministic and stochastic dynamical systems.

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PP100

Modeling the Evolution of Discriminatory Biomarkers in the Immune Response to Infection with Transcriptomics Data

We present our work in identification of minimal sets of discriminatory biomarkers of a gene network constructed from a human challenge influenza transcriptomics dataset which model the time course of the infection. We compare how pre-existing pathways and an undirected search on the transcriptome can smoothly model the dynamics in the body across all data in a low dimensional fashion, transitioning from the healthy, to infected, back to a modified healthy state modeled as a network evolving in time. Tools to reduce the network of approximately twelve thousand genes will be investigated, including hierarchical clustering analysis and various centrality measures on the network.

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PP100

Action-Based Model for Network Data with Errors

The majority of network data available to researchers can be thought of as being acquired from noisy measurements of the true structure, but this aspect is rarely considered in various network analysis and modeling techniques. Recent efforts have focused on using simple network models for estimating network structure and properties from these unreliable measurements with limited success. In this work, we develop action-based models for reconstructing the true network, given multiple and single edge measurements having uniform error rates. The action-based model represents a portfolio of link prediction algorithms for each node such that the posterior probability of the true network is maximized. To parameterize the model, we use the expectation-maximization algorithm and consequently the probability distribution of the true network structure. The proposed approach shows promising results for network reconstruction and possesses the additional capability of naturally extracting link creation preferences of nodes in a network.

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PP100

Inhibitory Synapses Are Central to Structural Balance in *C. Elegans* Neuronal Network

The functionality of real world networks is often due to the balance they achieve in the presence of competing relationships. The harmony in networks of people, societies and countries has been investigated using the notion of 'structural balance' and this abstract concept could also be meaningfully applied in other networked systems. In brain networks, neurons interact with each other to control behavior of the organism. The neuronal network of *C. elegans*, comprises of 277 neurons interconnected with 2105 excitatory or inhibitory synapses. We divided this graph to study topological properties of the excitatory (positive) and inhibitory (negative) subgraphs. We found that, while the negative subgraph is akin to a random network, the positive component has higher clustering, closer to the original network. In this study we propose quantification of structural balance to enumerate the 'frustration' in a network with the balance index BI, which quantifies the extent of balance in the network. We observe that *C. elegans* neuronal network has higher BI than its Erdős-Rényi and degree distribution preserved control. Given the relevance of structural balance in the presence of conflicting relationships, our results suggest importance of excitatory synapses vis-à-vis inhibitory synapses in this neuronal system.

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PP100

On the Statistical Detection of Clusters in Directed Networks

We propose a new statistical likelihood objective function for use in clustering directed networks and compare the performance of this objective function against directed modularity. Likelihood is shown to outperform directed modularity on a range of simulated benchmark networks. We also develop and demonstrate a parameter updating algorithm for the likelihood objective function that reduces its time-to-solution under heuristic optimization to a fraction of that required by modularity.

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PP100

Robustness and Vulnerability of Coupled Interdependent Networks: Mathematical Optimization Aspects

Coupled interdependent networks arise in a wide variety of application domains, for instance, those related to infrastructure systems. Such networked systems are often vulnerable to *cascading failures*, which typically initiate from a small fraction of "seed" nodes and then dynamically propagate to a large portion of a network via interdependent links. The task of identifying such subsets of nodes whose initial disruptions/failures are most "critical" for large-scale cascading failure processes is often addressed via simulation-based rather than exact optimization-based approaches. In this work, we propose *exact* mathematical optimization techniques for identifying "critical" nodes in coupled interdependent networks via mixed integer programming. The presented results are based on our group's recent papers and current work.

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PP100

Analytical Formulation of the Block-Constrained Configuration Model

We provide a novel family of generative block-models for random graphs that naturally incorporates degree distributions: the block-constrained configuration model. Block-constrained configuration models build on the generalised hypergeometric ensemble of random graphs and extend the well-known configuration model by enforcing block-constraints on the edge generating process. The resulting models are analytically tractable and practical to fit to large networks. These models provide a new, flexible tool for the study of community structure and for network science in general, where modelling networks with heterogeneous degree distributions is of central importance.

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PP100

Competition Graph Variants for Characterizing Coordinated Automation in Social Networks

Increased use of and reliance on social media has led to a responsive rise in the creation of automated accounts on such platforms. Recent approaches to identification of automated accounts has relied on machine learning methods utilizing features drawn predominantly from text content and profile metadata. In this work we explore a novel use of graph theoretic based measures, specifically competition graphs and their variants, to identify and characterize automated online accounts in social media. In addition, we develop edge weight variants of fuzzy and fuzzy $p-$competition graphs to further characterize coordination of automated accounts within subnetworks of social media ecosystems.

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PP100

Non-Random Teleportation in Random Walk Based Network Sampling

Many heterogeneous networks employ random walks to capture the neighborhood of nodes and further use models such as skip-gram for the generation of node embeddings to

be used as features for tasks such as node classification and clustering. In particular, researchers have developed multiple embedding techniques to learn deep latent representations of nodes within a network such as node2vec , DeepWalk , and metapath2vec. While these techniques outperformed state of the art methods, the random walk sampling approach does not consider factors such as node attributes but instead relies on the concept of homophily. By not utilizing elements such as node attributes during random walks, the developed node embedding from embedding-based methods such as Skip-Gram, Wide & Deep, and neural factorization machines may be limited in how well they can truly represent the relationships between similar nodes in a network. In our approach, we extend the node context to include similar nodes that may not be in the same local neighborhood as the source node. We develop the non-random teleportation approach in random walk based network sampling and use this technique to get a reliable representation of node embeddings that would improve evaluation results.

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PP100

Demos of Software for Local Graph Clustering - In lieu of a poster, this presentation will be a demo presented in Cottonwood C&D

In lieu of a poster, this presentation will be a demo presented in Cottonwood C&D from 3:50 PM - 4:25 PM. The goal of this demo is to provide a brief introduction to local graph clustering, focusing on the advantages compared to global graph clustering and community detection as well as our software to work with multiple local graph clustering algorithms. This will enable us to combine algorithms from multiple perspectives in the literature easily to understand the structure of large networks easily.

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PP100

Spanning Tree Modulus for Secure Broadcast Games

We present a connection between a secure broadcast game, wherein a broadcaster attempts to send a message to all other nodes of a communications network while evading an eavesdropper on an unknown edge, and the modulus of spanning trees on a graph. Broadly speaking, p-modulus provides a general framework for quantifying the richness of a family of objects on a graph; modulus will be large for families containing many objects with small pairwise intersections. When applied to the family of spanning trees, p-modulus has an interesting probabilistic interpretation. This can be made more precise through the minimum expected overlap formulation of modulus, where the goal is to choose random spanning trees that share as few edges as possible on average. This goal is remarkably similar to that of the broadcaster in the game. We establish relationships between the solution of the modulus problem on spanning trees and solutions to the broadcast game.

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PP100

A Dynamical Systems Approach to Threshold Models of Social Influence

With concepts like virality and polarization on social networks in the forefront of the public consciousness, it is increasingly crucial to model the spread of ideas on networks. Many studies of cascades on these networks have considered threshold models of binary decisions, such as the Watts threshold model, where each actor in the network switches from an inactive to an active state if a threshold fraction of its neighbours is active. We look at the problem of idea spreading using dynamical systems: each node on the network is governed by a differential equation driven by the state of its neighbours. Considering extremely fast dynamics, approximated by each node moving to its steady state in a single 'step', recovers the Watts threshold model. For more general time scales we can study the spatiotemporal dynamics of cascades. On Newman–Watts small-world networks, we present an expression for the proportion of active nodes against time that matches the 'S-shaped' curves found widely in the literature. It is of logistic form, as in the Bass model for the adoption of innovations. We find that on Newman–Watts networks, increasing the number of connections can reduce the mean path length and in turn speed up cascades. Conversely, on networks with already short mean path lengths (e.g. Erdős–Rényi $G(n, p)$ networks with $p \gg n-1$), adding more connections can slow down a cascade.

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PP100

Topologies That Favor Synchronization in Second Order Kuramoto Oscillator Networks

An evolutionary optimization technique is used to generate network topologies that present a small number of edges and favors frequency synchronization as the dynamics of the nodes are given by a second order Kuramoto oscillator. These topologies would be of great interest when building power grids duo to the costs involved in the construction of transmission lines.

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PP100

Dynamic Behaviour of Distributed Generation DC Network and Stabilization with Passivity-Based Control

An off-grid distributed DC power network is introduced with multiple renewable DC sources connected in a ring formulation and coupled together with dissipation. The DC the network employs DC/DC power converters to convert the input voltage, obtained from the DC sources into a more desirable value. In this network, each converter unit represents a node and the dissipation is analogous to the link. The aim of this paper is to formulate a method of control focusing on the energy as well as the physical characteristics of the network. First, the network is modeled with Port Controlled Hamiltonian Modelling (PCHM), which classifies the network into well-defined interconnection, dissipation and input matrices, regardless of the number of nodes in the ring. Passivity-based Control is a technique that brings the system to a desired equilibrium by manipulating the energy characteristics of the system. Energy shaping implies the introduction of a new energy function with a minimum at the desired equilibrium. This energy function can be tailored to have multiple equilibria depending on the natural characteristics of the system. It was shown that a DC power network with a ring configuration was stabilized by manipulating the energy characteristics of the network to suit the natural behaviour of the DC/DC converter-solar array system. The response of all the nodes of the network and the asymptotic behaviour was observed pertaining to the flow of energy between the them.

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PP100

Community Detection, the No Free Lunch Theorem, and Attack Games

A no free lunch (NFL) theorem was recently proven for community detection. We liken the no free lunch theorem to attack games, which explains the theorem and an inexact variant as analogues of perfect and semantic security, opening up a rich conceptual toolkit for community detection and its measures.

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PP100

Graph Comparison via the Non-Backtracking Spectrum

The comparison of graphs is a vitally important, yet difficult task which arises across a number of diverse research areas including biological and social networks. There have been a number of approaches to define graph distance however often these are not metrics (rendering standard datamining techniques infeasible), or are computationally infeasible for large graphs. In this work we define a new pseudometric based on the spectrum of the non-backtracking graph operator and show that it can not only be used to compare graphs generated through different mechanisms, but can reliably compare graphs of varying size. We observe that the family of Watts-Strogatz graphs lie on a manifold in the non-backtracking spectral embedding and show how this metric can be used in a standard classification problem of empirical graphs.

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PP100

GeoNet: A Framework for Intrinsic Geospatial Anomaly Detection

The dynamics of a geographic environment are defined by the movements of people, cars, vehicles, and other objects across a region, captured using location acquisition systems and are well-modeled by a dynamic network. A neglected use-case for the analysis of this data is in wide-area geospatial anomaly detection — the discovery of unexpected shifts in movement patterns across a region. We introduce a novel dynamic network analysis framework, called GeoNet, to enable this use case. The ubiquitous nature of location acquisition systems enables the collection of data at scale and may be modeled as a dynamic network, where vertices represent meaningful or relevant points of interest (PoIs), as extracted by an intrinsic point of interest discovery algorithm [M. Piekenbrock & D. Doran, Intrinsic Point of Interest Discovery from Trajectory Data, 2017], and directed edges correspond to movement from one PoI to another. The dynamics of the geographic region are modeled using a seasonally dynamic stochastic blockmodel (SDSBM) [J. Robinson & D. Doran, A Seasonal Dynamic Stochastic Blockmodel, 2018] to facilitate anomaly detection. Visualization is supported through a native web-based application featuring PoI visualization and dynamics exploration with integrated anomaly detection via the SDSBM log-likelihood values. GeoNet applies recent contributions in the field of geospatial anomaly detection to present a framework for wide-area geospatial anomaly detection.

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PP100

Structural Balance Dynamics and Community Structure

Structural balance theory asserts that, for a signed network, stable triads are characterized by a positive product of ties. This behavior implies that a network will typically divide into two antagonistic factions with only positive intra-faction ties and negative inter-faction ties. This outcome has been demonstrated using the dynamical system $\frac{dX}{dt} = X^2$ where X is the signed adjacency matrix. We investigate structural balance dynamics in the presence

of initial community structure as generated using a two-community stochastic block model. Specifically, we consider how the dynamically-evolved network relates to the initial communities as gauged by the assortativity metric. We vary the “bias’ parameter, which controls the probability of positive initial ties within communities and negative ties between them, and the network density. Simulation results show a sharp transition from a non-assortative final network to a highly assortative one as the bias is increased. This transition stems from the eigenvalue spectrum of the initial network and is related to threshold for the detection of community structure. An analytical formula for the transition is in good agreement with simulation. Our results shed light on the dynamics of cooperation and conflict in social systems that possess community structure due to, for example, ethnic, religious, or ideological differences.

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PP100

Topology Identification in Conservative Distribution Networks

A distribution network is defined as the connected network in which a commodity flows from sources to sinks and flows are conserved. It may be a water distribution network, a power distribution network, a biological network and so on. The topology of such a network can be represented using a graph. Under conservation of flows, we show that the graph of such a network can be identified from the steady state flow measurements alone and propose a methodology to do so. Firstly, Principal Component Analysis (PCA) is applied on a matrix of steady state flow measurements to identify a linear model which describes the relations between the flow variables [S.Narasimhan.et.al. ”Desconstructing Principal Component Analysis using a data reconciliation perspective”, 2015]. Since many possible linear models exist, the obtained model is transformed such that it can be graphically interpreted. We show that an f-cutset matrix of the network graph can be obtained through a specific transformation. The graph can then be realised from f-cutset matrix using an existing graph realization algorithm. In general, graph realization is possible only upto 2-isomorphism while we show that for a network with a single source and no loops, the exact graph can be identified. This methodology can be extended to noisy data using certain variants of PCA. Simulation studies are performed on randomly generated networks to show that the method is robust to even noisy measurements.

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Idealized Models of Insect Olfaction

When a locust detects an odor, the stimulus triggers a specific sequence of network dynamics of the neurons in its antennal lobe, characterized by synchronous oscillations, followed by a short quiescent period, with a transition to slow patterning of the neuronal firing rates, before the system finally returns to a background level of activity. We model this behavior using an integrate-and-fire neuronal network, composed of excitatory and inhibitory neurons, each of which has fast-excitatory, and fast- and slow-inhibitory conductance responses. We further derive a firing rate model for the excitatory and inhibitory neuronal populations, which allows for more detailed analysis of and insight into the plausible olfaction mechanisms seen in experiments, prior models, and our numerical model. We formulate two mathematical models to describe the possible underlying mechanisms by which insects detect and identify odors using a coarse-grained approach. The resulting firing rate model incorporates the slow and fast conductance timescales believed to play a vital role in the network behavior of the locust antennal lobe. The fast dynamics arise as an attracting limit cycle, followed by a pause in activity due to the slow variable, before a much slower oscillatory pattern reemerges.

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Estimation in the Popularity Adjusted Stochastic Blockmodel

Consider a network with its adjacency matrix $A_{ij} \sim \mathrm{Ber}(P_{ij})$. We estimate the probability matrix P. Our estimation technique involves the penalized optimization procedure. We estimate the matrix of the probability of connection between nodes by minimizing the squared differences between the blocks of the matrix A to its best rank one approximation over the set of all possible clustering matrix. We use the oracle inequality to find the upper bound of the estimation error.

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On the Bottleneck Structure of Positive Linear Programming

It is well-known that many traditional network problemse.g., max-flow, max-min or network utility maximizationcan be solved using general linear programming (LP) algorithms. In this essay, we show that the reverse is also true for all positive LP problems. For this class of problems, each variable can be interpreted as a flow while each inequality constraint corresponds to a bottleneck link in the corresponding network. This approach reveals new insights on the bottleneck structure of the optimization problem that general approaches such as the Simplex or interior-point methods are not able to capture, which can be exploited to design fast algorithms

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Modeling Graphs with Vertex Replacement Grammars

Graph models aim to capture the building blocks of real world networks in order to encode various physical and natural phenomena. Recent work at the intersection of formal language theory and graph theory has explored the use of graph grammars for graph modelling. But existing graph grammar formalisms, like Hyperedge Replacement Grammars, can only operate on small tree-like graphs. The present work relaxes these restrictions by revising a different graph grammar formalism called Vertex Replacement Grammars (VRGs). We show that many a VRG can be efficiently extracted from many hierarchical clusterings of a graph. The lossless VRG encoding of a graph, mirroring the seminal eNCE vertex replacement grammar formalism, is a faithful but overly complex model. Instead, we show that a lossy version of the VRG model is succinct yet faithfully preserves the structure of the original graph. In experiments on large real-world graphs, we show that graphs generated from the lossy VRG model exhibit a diverse range of properties that are similar to those found in the original networks.

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Degree-Targeting Triggers Global Extinction Cascades in Modular Networks

It is well known that degree-heterogeneous networks are "robust yet fragile" with respect to node removal; the largest connected component survives a long time upon removing nodes uniformly at random, but is broken up almost immediately upon removal of the highest-degree nodes. One might naturally ask whether this dichotomy extends to other properties of degree-heterogeneous networks, such as the dynamics of cascading failures on them. Building on work of Gleeson, we present an analytical framework that lets us understand the effect of degree targeting for a broad class of binary-state irreversible dynamics on networks, including percolation, determination of k-core sizes, and the Watts threshold model. Taking inspiration from species extinction in mutualistic ecological networks, we apply our results to the Watts threshold model on a modular network. We find that degree heterogeneity hinders global cascades when seed nodes are selected uniformly at random, while facilitating global cascades when seed nodes are selected according to degree.

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Opinion Model for Distributed Anomaly Detection on Smart Grids

Today, an electricity disruption such as a blackout can have a domino effect -a series of failures that can affect banking, communications, traffic, and security. A smarter grid will add resiliency to the electric power system and make it better prepared to address emergencies. Smart grids are fitted with sensors that gather and transmit data, and they can be subject to external attacks and susceptible to failure due to anomalous patterns of demand. These networks allow the possibility to include a distributed anomaly detection algorithm in order to detect irregularities in the flow of energy inside them. However, we can divide this system in two simpler processes that co-evolve at the same time. On the one hand, we have the diffusion process that carries the energy across the network and, on the other hand, the opinion spreading process among the nodes in the network. We can tune the interplay of these two processes using one parameter to characterize each process. We analyze the transitions of the threat awareness in analogy with the classical percolation model. We show that key parameters of the spreading process, such as the extent of diffusion bias towards the target, have similar effects as an external field applied at the percolation phase transition. The analogy of our awareness-spreading model with a magnetic field in a spin system can be used to guide possible ways of tuning the extent to which information can be shared.

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Motif Signatures of Social Networks are Function of Hierarchy and Homophily

Configurations of small number of actors and the ties between them are fundamental to many social network theories. In this paper we investigate how the presence of two basic social forces: homophily (similarity) and hierarchy (popularity) influences the statistics of motifs observed in social networks. First, we demonstrate that the motif occurrence varies across social networks of different genre, suggesting connection to diverse functions of those systems. Next, we use hyperbolic embedding of graphs as a decomposition method, allowing for estimation of the effects of similarity and popularity on network formation. We show that the occurrence of motifs associated by social theory to hierarchy correlates with global measures of popularity quantified by the radial coordinates of nodes in the hyperbolic space. Finally, we classify social networks based on identified balance between homophilic and hierarchical tendencies.

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Neuronal Network Reconstruction of the Cerebral Cortex

The extent of the relation between architectural and functional connectivity in the cerebral cortex is a question which has attracted much attention in recent years. Neuroscientists frequently use the functional connectivity of neurons, i.e. the measures of causality or correlations between the neuronal activities of certain parts of a network, to infer the architectural connectivity of the network, which indicates the locations of underlying synaptic connections between neurons. Architectural connectivity can be used in the modeling of neuronal processing and in the forming of conjectures about the nature of the neural code. We begin by reconstructing the entire network using time-delayed spike-train correlation, and we determine the time required before an adequate reconstruction becomes possible and compare this to time spans employed by experimentalists. We then sample the matrix randomly and use the tool of matrix completion to fill-in the rest of the network. To be more experimentally valid, we next examine a small slice or submatrix of the network and determine how much information we can deduce about the whole network from this small piece. An examination of the spectral properties of connectivity matrices forms a major part of this analysis.

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Cascade Dynamics on Multiplex Networks

The dynamic spread of influence in networks has been studied using the linear threshold model (LTM) on monoplex networks. In the LTM any node in the network becomes active when a sufficiently large fraction of its neighbors is active. A monoplex network is a single layer of nodal interconnections that are treated identically. In reality, nodes may be interconnected through multiple sensing, communication, or physical modalities. For example, a node may have one set of neighbors that it can see and another set of neighbors that it can hear. To explore what can happen when spreading protocols distinguish these modalities, we define the LTM on multiplex networks, which have multiple layers and a fixed number of nodes. Each layer in the multiplex network represents the interconnections among the nodes for a different modality, and the spreading protocol combines signals from the different layers. For example, in the OR protocol, a node becomes active if a large enough set of its visible neighbors or a large enough set of its audible neighbors is active; whereas in the AND protocol, the node becomes active only if both active sets are sufficiently large. We design an algorithm to compute nodal cascade centrality, which measures a node's influence on the cascade dynamics. The results show how different protocols model groups with different traits, e.g., with responsive or conservative tendencies. We discuss extensions to continuous-time dynamics and further possibilities.

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