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IP1

Mathematics in the Age of AI: Discovery, Verification, and the Future of Proof

Mathematics is entering a period of unusual promise and unease. Large language models, formal proof assistants, and AI-assisted reasoning suggest new modes of discovery, while raising concerns about rigor, attribution, and the future role of mathematicians. Through my own transition from number theorist to Founding Mathematician at Axiom Math, I will describe the emerging landscape of AI-assisted mathematics and offer examples of how these tools can support and augment research. I will also discuss what this shift may mean for mathematical practice, collaboration, and the ways new ideas are checked and communicated.

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IP2

Sampling on Graphs

Is it possible to compute the average value of a function on a graph by knowing the function values at a small set of vertices? If so, how small can this subset be and how does one find it? What sorts of functions can we average? In this talk I will introduce Graphical Designs which allow us to answer these questions. The story draws on a range of mathematics from analysis to geometry to discrete math. When the graph has special structure, its designs become highly structured, connecting them to well-known and classical objects in mathematics and computer science. For instance, Graphical Designs in graphs of hypercubes are orthogonal arrays which are related to linear codes. Joint work with Catherine Babecki, Zawad Chowdhury and Stefan Steinerberger

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IP3

Unintended Consequences of Artificial Intelligence in Financial Markets

Artificial intelligence (AI) is increasingly used in financial markets. AI-based systems can process large amounts of data and act quickly, leading to the expectation that markets will become more competitive and more informative. However, AI can also create new and unexpected risks that affect market fairness and financial stability. Collusion. Algorithms may learn to coordinate their actions, even if they are not programmed to cooperate. Collusion delivers outcomes that are not competitive, which lead to higher profits at the expense of others. Market manipulation and spoofing. AI trading algorithms can learn to manipulate prices. For example, they may place orders in electronic exchanges (e.g., Nasdaq, LSE) with no intention of trading; instead, the objective is to influence how other traders behave. This can distort prices and undermine fair market functioning. Market making and reduced competition. In exchanges, when multiple AI algorithms interact, they may learn to behave in ways that resemble cooperation. This reduces competition, allowing them to earn higher profits at the expense of others. Competition and blocking new entrants. AI algorithms can learn to coordinate and deter new competitors from entering the market. Bubbles. AI agents can participate in speculative bubbles and exploit the bounded rationality of human traders. They are more likely to join a bubble if they infer that they are early in its formation.

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IP4

Mathematical Modeling and Optimization for Vertical Farming: From Engineered Substrates to Dynamic Microclimate Control

Vertical farming is often advertised as sustainable, yet key decisions, such as substrate choice and climate control, are still guided by heuristics. This lecture shows how mathematical modeling and optimization can replace trial-and-error with predictive, scalable design tools. Two complementary frameworks are presented, illustrating how multiphysics simulation and PDE-constrained optimization enable quantitatively grounded, sustainability-oriented design of controlled-environment agriculture. The first addresses soilless cultivation by designing innovative porous growing media as periodic lattice scaffolds. Their macroscopic mechanical support and permeability properties are governed by the micro-geometry, computed through coupled elasticity-flow topology optimization procedures. Thus, a 3D inverse-homogenization, density-based SIMP formulation, enhanced with anisotropic mesh adaptation, yields robust, manufacturable architectures, exported as STL lattices for root-growth simulations and 3D-printed prototypes. The second framework moves beyond static climate recipes by modeling the growth chamber as a co-evolving plantmicroclimate system. Coupled 3D CFD and crop growth/transpiration update canopy resistances and source terms over time; after validation, surrogate-based multi-objective optimization yields growth-stage-dependent set-points and air-supply designs that boost biomass while lowering energy under canopy microclimate constraints.

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IP5

From Polynomials to Nonlinear Special Functions

Special functions are like the number π, found everywhere but hard to describe because they are transcendental. In this talk, I will provide an overview beginning with the questions of Kepler and Newton and leading to the construction of special functions now central in mathematics. As far back as 1893, Felix Klein said It is well known that the central problem of the whole of modern mathematics is the study of the transcendental functions defined by differential equations. The most interesting transcendental functions of modern times are the ones defined by nonlinear difference equations, but many remain enigmatic. At the end of the talk, I hope to briefly describe recent results on discrete versions of the Riemann-Hilbert method for solving such difference equations.

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IP6

Cutting Through the Noise: Denoising and Data Completion Using Low-Rank Tensor Optimization

Experimental data is noisy, whether this data is collected from an exploration seismic experiment (length scale of km) or from an electron microscope (nm). Low resolution data can result from limited xray photon dosage to prevent sample damage or environmental factors such as trucks driving over nearby roadways or limited aperture recording equipment in a seismic experiment. Recovering the underlying image from noisy or incomplete data is a fundamental math problem. Additionally, when noisy data is used to train AI/ML models, this corruption can lead to incorrect predictions. Traditional denoising and data completion techniques include basic ideas such as interpolation and regularization. Recently the focus has shifted to AI/ML for deblurring/denoising. In this presentation I will discuss advances in both the application and use of some denoising ideas. One such tool exploits the redundancy in related images by storing them in a higher-order tensor. This redundancy implies the tensor is naturally low-rank. Noise and missing data increase the rank of the tensor, so low-rank tensor minimization can help to remove this corruption. Hybrid methods that combine mathematics with AI/ML show additional promise over each individual method. I will also discuss a number of different application problems ranging from time-lapse seismology to improving data quality in state-of-the-art electron microscopy images collected using the world's fastest cameras.

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IP7

Discontinuous Solutions for Partial Differential Equations in Fluid Mechanics

The compressible Euler equation can lead to the emergence of shock discontinuities in finite time, notably observed behind supersonic planes. A very natural way to justify these singularities involves studying solutions as inviscid limits of Navier-Stokes solutions with evanescent viscosities. The mathematical study of this problem is however very difficult because of the destabilization effects of the viscosities. Bianchini and Bressan proved the inviscid limit to small BV solutions using the so-called artificial viscosities in 2004. However, until very recently, achieving this limit with physical viscosities remained an open question. In this presentation, we will provide the basic ideas of classical mathematical theories to compressible fluid mechanics and introduce the recent method of a-contraction with shifts. This method is employed to describe the physical inviscid limit in the context of the barotropic Euler equation, and to solve the Bianchini and Bressan conjecture in this special case. This is a joint work with Geng Chen and Moon-Jin Kang.

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IP8

Scalable Methods for Large-Scale Bayesian Inverse Problems Under Model Uncertainty

Mathematical models are fundamental tools in the sciences, enabling researchers to simulate, analyze, and predict the behavior of complex systems. In practice, however, these models often depend on uncertain inputs or parameters due to the inability to measure them (e.g., phenomenological parameters), limitations in observations (data), and measurement noise. In addition, modeling errors arise from simplifying assumptions and idealizations that may not fully capture real-world behavior, due to additional unknown parameters or sources of uncertainty, and/or from replacing the accurate model with a surrogate model. When such models are used for prediction and decision-making, it becomes imperative to improve both the accuracy of the input parameters and account for model errors. Inferring unknown parameters from observational data leads to a severely ill-posed inverse problem that is challenging to solve. Bayesian inversion combined with optimal experimental design facilitates the integration of data with models to quantify and reduce uncertainties in predictions. The algorithmic developments in this context face key challenges, including high-dimensional parameter spaces, expensive model evaluations, and model uncertainty additional to the uncertainty in inversion parameters. In this talk, we focus on scalable methods for inverse problems governed by differential equationbased models that exploit problem structure and are robust to model uncertainty.

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IP9

Is It Noise, Or Is It Superconvergence?

Noise is everywhere. In datasets, signal communication, images, audio, etc. Noise appears in different forms as random disturbances, or according to a probability density function. Noise can hinder effective data analysis, application of AI techniques, or diagnosing of illnesses. Noise can be a nuisance. An alternative perspective is to view noise through the lens of numerical approximations. In this context, the most common types of noise are Gibbs oscillations (from a Fourier approximation to a discontinuous function) or from aliasing (where the sampling rate is too low). However, for piecewise polynomial approximations, noise is embedded in the errors. For these approximations, the notion of superconvergence exists, in which, at special points, the convergence rate is faster than that predicted through Taylor series expansion. The property of superconvergence allows for extracting extra accuracy through convolutional filtering. This can enable a reduction in the amount of data necessary to gain meaningful insights. Moreover, for temporal evolution equations, the filtering can often be performed at the final time. In this presentation, we explore the relationship between noise and superconvergence in piecewise polynomial approximations as well as the potential to unlock more information from datasets.

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IP10

Nonlinear Algebra Meets Tensors in Quantum In-

formation

Tensors represent quantum states, the core of quantum information (QI). Entanglement is the resource that drives the capabilities of quantum algorithms and the capacities of quantum channels. Two key problems guide our work: classify and separate distinct entanglement types and determine the states that have the most entanglement. Singular value decomposition (SVD) governs entanglement classification in the bipartite situation, and higher order singular value decomposition (HOSVD) plays a similar role for generic multi-partite states. In recent work [SIAGA 2025] with Ian Tan (Charles U., Prague) we extend HOSVD [De Lathauwer et al., SIMAX 2000] and provide algorithms for separating entanglement types for generic multi-qubit systems, generalizing work of Kraus [Phys Rev Let 2010] and others. Classical invariant theory tells us that polynomial tensor invariants vanish on separable states, so the states that maximize invariants can be considered maximally entangled. Constrained optimization is the right tool to find these critical states, however, since tensor spaces grow exponentially, one also needs a toolkit that scales similarly. In another recent work [J. Physics A 2025] with Tan, we combine Vinberg theory for dimension reduction and homotopy continuation, which scales favorably with parallel computing, to solve this optimization problem. This method finds, in certain situations, all previously known entanglement maximizers.

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SP1

SIAM Industry Prize Lecture: Topological Data Analysis for Machine Learning-Based Network Intrusion Detection

Many cyberattacks persist in networks undetected for extended periods of time, while exploiting the security and privacy of large volumes of packet data. Intrusion detection systems (IDS) exist as a security mechanism to autonomously monitor network traffic for unauthorized activities of various types (e.g., distributed denial of service, policy violations). Machine learning-based IDS can enhance network resilience, by scanning networks for anomalous activities or unknown cyberattacks for which there are no signatures. However, these types of IDS are susceptible to errors (e.g., false positive and negative rates). In this talk, I explore how topological data analysis (TDA) approaches combined with machine learning algorithms can deepen our understanding of patterns in network traffic. To this end, I show how topological measures (e.g., persistence diagrams, Betti numbers) from TDA can support data preprocessing for anomaly and machine learning-based IDS, providing methods for feature extraction, and thereby improving IDS effectiveness.

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SP2

W. T. and Idalia Reid Prize Lecture: Rattlebacks, Spinning Tops, and Snakeboards: The Mathematics of Nonholonomic Mechanics and Control

Mechanical systems can exhibit all sorts of unexpected and fascinating dynamical behavior. Examples of such systems include the rattleback top or Celtic stone, the Chaplygin sleigh or shopping cart, the snakeboard (a variation of the skateboard), falling cats, and ice skaters. In this talk I will describe some of the mathematics behind such systems. I will also discuss their important role in control theory. The mathematics includes Lagrangian and Hamiltonian mechanics, variational (or non-variational) principles, nonholonomic mechanics, and nonlinear control theory. Lagrangian and Hamiltonian systems are foundational in mechanics. Nonholonomic systems, which are systems with velocity constraints, are generalizations of such systems, and the theory of nonholonomic mechanics is key to understanding many of the examples mentioned here. Nonholonomic systems are not variational, and their analysis leads to interesting generalizations of some of the basic theorems in mechanics. For example, Noether's theorem relating symmetries to conservation laws needs to be generalized to a theorem involving a momentum equation. Phase space volume need not be conserved even in the absence of external dissipation or forces. I will show that the theory of nonholonomic systems is also closely related to nonlinear control theory. I will show also how these systems are used in engineering and control applications including the control of wheeled vehicles, satellite control and stabilization, and legged robot locomotion. Finally, I will also describe some of the challenges involved in learning the dynamics of such systems from data.

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SP3

AWM-SIAM Sonia Kovalevsky Lecture: Spectral Problems in Inverse Scattering

Inverse scattering is a central theme in applied mathematics, with rich mathematical structure and a wide range of applications. The problem is inherently nonlinear and ill-posed, giving rise to fundamental challenges in uniqueness, stability, and algorithmic reconstruction. A paradigm shift in this area has emerged through the study of the relative scattering operator, which maps incoming to outgoing waves. This framework yields mathematically justified and computationally efficient reconstruction methods that exploit properties of the linear scattering operator to recover nonlinear information about the scattering object. In the frequency domain, this approach leads to interior eigenvalue problems posed on the support of the scatterer. These eigenvalues correspond to parameter values for which there exist nontrivial incident waves that generate no scattered field and are determined solely from scattering data. A prominent example for the inhomogeneous media is the transmission eigenvalue problem, a non-self-adjoint spectral problem with a perplexing mathematical structure. This presentation surveys the significance of such spectral problems in uniqueness and reconstruction and highlights many open theoretical and computational questions.

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SP4

John Von Neumann Prize: Epidemics, Erdos numbers, and the Internet: Graphs and Networks in

the Real World

There is a long tradition of the study of graphs and networks in mathematics and adjacent fields, but recent years have witnessed a major shift with the new availability of large-scale data on real-world networked systems, including computer networks, information networks, social networks, and biological networks. Many of these, it turns out, have surprising structural properties that are both important for their function and inspire new theories of network topology, formation, and behavior. This talk will give an introduction to this area of study, its methods and models, and discuss some of the intriguing mathematical questions that arise.

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SP5

Julian Cole Lectureship: A Nonlinear Plancherel Theorem, Dispersive Equations and the Inverse Problem of Caldern

We consider a nonlinear Fourier transform in two dimensions for which a proof of the Plancherel theorem had been a long-standing open problem. The first part of the talk will explain the background, main ideas and novel harmonic analysis bounds involved in the solution of this problem. The second part of the talk will describe the role of this transform in our solution of two other challenging open problems: global well-posedness in the mass critical case for the defocusing DaveyStewartson II and the modified Novikov-Veselov systems. These are integrable nonlinear dispersive partial differential equations emerging through asymptotic expansions of the incompressible Euler equations in distinct physical regimes. In the third part of the talk, we will show how the same nonlinear Fourier transform yields a constructive solution of the Caldern inverse boundary value problem for a class of unbounded conductivities. All these results are from collaborations with Peter Perry, Idan Regev and Daniel Tataru.

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SP6

AMS Invited Address: Computer-Assisted Proofs of 3D Euler Singularity and Nonuniqueness of LerayHopf Solutions for the Unforced 3D Navier-Stokes Equations

Whether the 3D incompressible Euler equations can develop a finite-time singularity from smooth initial data remains one of the central open problems in nonlinear PDEs. In this talk, I will present recent joint work with Dr. Jiajie Chen, in which we rigorously prove finite-time blowup for the 2D Boussinesq equations and the 3D axisymmetric Euler equations with smooth initial data and smooth boundary. Our approach uses a dynamically rescaled formulation that reduces singularity formation to the long-time stability of an approximate self-similar blowup profile. A key difficulty is proving the linear stability of a numerically constructed profile. To address this, we decompose the solution operator into a leading-order part, which admits sharp stability estimates, and a finite-rank perturbation, which is controlled by a computer-assisted proof. I will also discuss recent joint work with Yixuan Wang and Changhe Yang on nonuniqueness of LerayHopf solutions to the unforced 3D incompressible NavierStokes equations. In this setting, the viscous term introduces several new ingredients but also greatly simplifies the analysis: standard H^1 estimates suffice, without the singular weights needed in the inviscid case. A central step is to establish the existence of a self-similar LerayHopf solution and then prove the existence of a second solution by analyzing the stability of the linearized operator around this profile and showing that it admits an unstable mode. These results highlight the fruitful interplay among analysis, computation, and rigorous validation in nonlinear PDEs.

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SP7

I.E. Block Community Lecture: Modeling for Life with a Little Help from Our Friends

Modeling human biology is complex. We are composed of around 31013 human cells and similar numbers of bacterial cells and viral particles that all interact and form hierarchies of functional structures. Cells form tissues, that form organs, that organize into organ complexes, that make up individuals, that make up populations. Different biological entities share similarities, but some features are species specific or even specific for an individual. In biomedical research and drug discovery different model systems are used to try to understand human biology, traditionally human cell lines and animal models. But a cell line is a simplified model and for example a mouse model, although sharing some biological features of a human model, have properties that are specific to mice. Over the last years new models have taken stage, like complex human ex-vivo systems, sometimes patient-derived; in silico mathematical models; and a growing pool of high resolution multimodal human data from real life settings. Integrative and holistic analyses, using all available models, hold the potential to transform biomedicine, drug discovery and ultimately health care. Mathematical and computational modeling, leveraging the Human-Machine Partnership for multidisciplinary and collaborative data exploration, will propel the transformation and will give us a new understanding of Life.

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SP8

Learning with AI: A Framework for Students, Instructors, and Universities

Join Mac Hyman (former SIAM president) for an overview of Learning with AI: A Framework for Students, Instructors, and Universities, a forthcoming SIAM book on teaching and learning in a world where AI tools are part of ordinary academic life. Topics will include the conflict students face between earning grades, demonstrating understanding, and being honest about AI use; approaches to verify that learning is internalized; and practical frameworks for assignment design, grading, and assessment in AI-aware courses. This session is relevant for faculty, administrators, students, and anyone interested in how mathematical and scientific reasoning is changing in the AI era. Attendees will have the chance to share feedback to help shape the book before publication and review a draft at the SIAM bookstore.

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SP9

Siam Publications Update AI, SIALS, and Accessibility

Join Tamara G. Kolda, SIAM Vice President for Publications, Kivmars Bowling, SIAM Publications Director, and Jonathan Rubin, SIAM Journal on Life Sciences (SIALS) Editor-in-Chief, for an update on new developments across journals, books, and proceedings. Topics will include AI and research integrity; the recently launched SIALS; and the new Joint Math Society Author Guidelines on Accessibility. This session is relevant for anyone who engages with SIAM Publications, whether as a reader, author, editor and/or instructor. Attendees will have the chance to ask questions as well as share feedback and ideas regarding the SIAM Publications program.

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JP1

Joint Plenary Speaker with 2026 SIAM Conference on the Life Sciences: When More Isnt Better: A Lesson from Rethinking Scale in Single-Cell Foundation Models

The success of transformer-based foundation models on natural language and images has motivated their use in single-cell transcriptomics. In this talk, we will assess how pre-training dataset size and diversity affect the performance of single-cell foundation models. Using a corpus of 22.2 million cells, we pre-trained 400 models and evaluated over 6,400 experiments. Our results show that current methods tend to plateau in performance with pre-training datasets that are only a fraction of the size, challenging the assumption that ever-larger datasets are required for optimal generalization. This will lead us to the second half of the talk where we evaluate training data composition on model performance. Focusing on human hematopoiesis, we train and analyze deep generative models with a variety of training datasets, including cells from adult and developing tissues, disease states, and perturbation atlases. Here, we observe that (1) deep generative models generalize poorly to unseen cell types and (2) addition of malignant or perturbed cells to healthy corpora does not consistently improve modeling of novel states. These findings highlight the nuanced roles of dataset size and heterogeneity, suggesting that strategic curation, rather than indiscriminate scaling, is key for optimizing single-cell foundation models.

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JP2

Joint Plenary with SIAM Conference on Mathematics of Planet Earth: Grid to Grid: A Vision for Coupling Earth Systems Models to Energy Networks

Producing accurate, actionable Earth system forecasts that include information relevant about impacts upon the water cycle, energy infrastructure, and other related and interconnected targets is as important as ever. However, the Earth and its component system models are complex, multiscale, and interconnected, especially at the regional and local spatial and time scales where smart coupling to equally complex and multimodal Energy models is needed. This talk presents a vision and strategy to apply more powerful and flexible models to diagnose and predict a diverse suite of impactful events. This is especially important as we welcome learning-based models in Earth and energy system prediction. The community requires coordinated and specialized interactions of model and experimental output that are designed to be used by multiple infrastructure model types, spatial and time scales, data structures and volumes, software, security protocols, and scientific cultures. This talk presents considerations in planning, executing, and optimizing multidomain coupling, workflows and communication strategies along with several illustrative examples. The role of verification and validation to quantify the effects of algorithmic and statistical choices in improving and coupling models is also discussed. The expansion of best practices, community benchmarks, key stakeholder needs will enable multifaceted, actionable, and flexible forecasts that will save lives, mitigate damage, and lead us to a more prosperous future.

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JP3

Joint Plenary with SIAM Conference on Applied Mathematics Education: Ooh, Ooh, Ooh What a Little Course Can Do: Personal and Institutional Transformation Through 1-credit ADAPT Courses

To meet the needs of rapid technological changes and a data-driven world, we need to rethink education. Attention spans are short. People learn best by doing things they care about. Those of us who can be flexible learners and willing to evolve our work practices will be best equipped to help our students do the same. We are tired in so many ways, but we cannot give up. As applied mathematicians, mathematical and statistical modelers and data and AI practitioners, we are well-positioned to lead. My education-related experiences in K-12, industry, higher education, non-profit, and government led me to become the inaugural Executive Director of the NC State University Data Science and AI Academy, which is celebrating its 5th birthday right around the time of the 2026 SIAM Annual Meeting. In this short time, the academy has developed interdisciplinary capacity to engage data and AI across the 12 colleges of the largest public university in North Carolina, reaching students in over 175 programs of study, building data and AI literacy and fluency for students, faculty, staff, and community partners. The key to this success has been a common pedagogical approach: the All-Campus (or perhaps all-learner) Data Science and AI Project-Based Teaching and Learning Model. I look forward to sharing how this approach has infused data science and AI across our campus and beyond.

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CP1

A Priori and A Posteriori Error Analysis of a Nitsche Method for the StokesPoissonBoltzmann Equations with Mixed Boundary Conditions

We study the StokesPoissonBoltzmann equations with mixed Dirichlet and Navier boundary conditions. The system consists of the incompressible Stokes equations coupled with a nonlinear PoissonBoltzmann equation through electrostatic forcing and convective transport effects. To handle the mixed boundary conditions in a unified framework, we employ Nitsches method for their weak imposition within a conforming finite element setting. We derive a consistent and stable discrete formulation and establish well-posedness of the resulting problem. By carefully choosing the penalty parameters, the bilinear form is shown to be coercive and continuous. A priori error estimates are proved in the natural energy norms, yielding optimal-order convergence under suitable regularity assumptions. Furthermore, we develop residual-based a posteriori error estimators that incorporate element residuals, inter-element jump terms, and boundary contributions arising from the Nitsche formulation. The estimators are shown to be reliable and locally efficient, providing a rigorous basis for adaptive mesh refinement. Numerical experiments confirm the theoretical results and demonstrate the robustness and accuracy of the proposed method for the StokesPoisson-Boltzmann system.

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CP1

Design of High-Order Fractional-Step RungeKutta Methods with Low-Order Subintegrators

When employing operator splitting methods, like the LieTrotter method and the second-order Strang method, the substeps are often integrated using standard RungeKutta (RK) methods or variations thereof. Recently, Spiteri and Wei introduced a formalism for writing the composition of RK methods within a fractional-step method as a larger RK method, herein referred to as an FSRK method and representable as an additive RungeKutta (ARK) method. This formalism allows the sophisticated tools developed for the analysis of RK methods to be applied to FSRK methods as well, enabling a deeper understanding and improvement of their stability and accuracy properties. In general, the order of an FSRK method is limited by the minimum of the local order of accuracy of the substep integrators and that of the underlying operator splitting method. It is therefore natural to ask whether, through a careful choice of substep integrators, error cancellation can be deliberately introduced so that the overall order of the FSRK method exceeds the order of some of its component parts. We show that it is indeed possible to construct FSRK methods whose overall order of accuracy is higher than that of the individual substep integrators. We present new families of such methods and endow them with desirable properties such as L-stability, strong stability preservation, and symplecticity. Numerical experiments are also provided to illustrate the behavior of the newly constructed methods.

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CP1

Weighted Upwinding in a Vector Kinetic Lattice Boltzmann Framework for Hyperbolic Systems

The Vector Kinetic Lattice Boltzmann (VKLB) framework discretizes a Boltzmann-type equation and recovers macroscopic hyperbolic systems via discrete moments and tailored equilibrium distribution functions. These methods have been shown to effectively capture shocks, discontinuities, and unresolved steep gradients. This presentation describes a weighted upwinded VKLB technique for equilibrium distributions constructed with a flux decomposition suitable for general hyperbolic systems. We identify instabilities that can arise in a full upwinded VKLB technique in regions where eigenvalues of the flux decomposition transition through zero. [LeVeque, Finite Volume Methods for Hyperbolic Problems, Cambridge University Press, 2002]. To mitigate these instabilities, we propose a weighted upwinding VKLB scheme that weights eigenvectors of corresponding eigenvalues, allowing for a smooth transition between an upwinding and centered flux VKLB framework. We evaluate this proposed method on challenging prototype problems from the shallow water, Euler, and ideal magnetohydrodynamics (MHD) systems. Initial results show improved stability in transonic and discontinuous flows, comparable or improved error norms, and sharper shock resolution, demonstrating the robustness of the weighted upwinding method on complex hyperbolic problems.

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CP1

A Parallel, Pseudo-Fast Marching Method

The Fast Marching Method has long been the gold standard for solutions to the Eikonal equation and has been widely used in the level-set community to perform reinitialization. The method itself is an inherently serial process to ensure consistency of the solution. Modifications to the original algorithm for parallel architectures such as Fast Iterative Method or domain decomposition methods potentially require that points are updated multiple times as information from other domains propagates. In this work we propose a Pseudo-Fast Marching Method that can be trivially onto parallel architectures. The key innovation is the relaxation of the strict up-winding requirement of the

Fast Marching Method, allowing for points to be updated out-of-order as compared to the original method. A novel discretization of the Eikonal equation is also introduced, resulting in a higher order of convergence when the method is applied to the reinialization of a level-set field.

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CP1

Convergence of a Residual-Based Adaptive Finite Element Scheme for Dynamic Phase-Field Fracture

Phase-field models of dynamic fracture lead to a complex coupled system involving a hyperbolic equation for elastodynamics and a parabolic (or elliptic) variational inequality for the damage evolution. The multiscale nature of crack propagationwhere the process zone is orders of magnitude smaller than the structural domainrenders uniform mesh refinement computationally prohibitive. In this talk, we present a convergent adaptive finite element method (AFEM) for the AmbrosioTortorelli approximation of dynamic brittle fracture. We formulate the irreversibility of crack growth as a strict variational inequality constraint within a staggered time-stepping scheme. A key contribution of this work is the derivation of a residual-based a posteriori error estimator that reliably drives local mesh refinement near the propagating crack tip. We provide a rigorous analysis showing that the sequence of discrete solutions generated by our adaptive algorithm converges to a critical point of the dynamic energy functional. Numerical benchmarks on 2D geometries confirm that the method efficiently resolves crack branching and instability phenomena with optimal degrees of freedom. This work is supported by the National Science Foundation under Grant No. 2316905.

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CP1

A Hybrid Isogeometric and Finite Element Method: Nurbs-Enhanced Finite Element Method for Hexahedral Meshes (nefem-Hex)

In this talk, we introduce a NURBS-enhanced finite element method that integrates the NURBS-based boundary representation of a geometric domain into a standard finite element framework for hexahedral meshes. We decompose an open, bounded, convex three-dimensional domain with a NURBS boundary into two parts, define NURBS-enhanced finite elements over the boundary layer, and use piecewise-linear Lagrange finite elements in the interior region. We introduce a special quadrature rule and a stable interpolation operator for the NURBS-enhanced elements. We discuss how the h-refinement in finite element analysis and the knot insertion in isogeometric analysis can be utilized in the refinement of the NURBS-enhanced elements. To illustrate an application of our methodology, we utilize a generic weak formulation of a second-order linear elliptic boundary value problem and derive a priori error estimates in the H^1 norm. In addition, we use the Poisson problem as a model problem and provide numerical results that support the theoretical results. The proposed methodology combines the efficiency of finite element analysis with the geometric precision of NURBS, and may enable more accurate and efficient simulations over complex geometries.

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CP2

Mathematical Modeling of Tertiary Lymphoid Structure Development and Stage Progression in Chronic Kidney Disease

Tertiary lymphoid structures (TLSs) are inducible ectopic lymphoid structures that emerge under chronic inflammatory conditions, including in the kidneys of patients with autoimmune diseases, and are closely associated with poor renal outcomes. Recent studies have classified TLS development into three stages correlated with chronic kidney disease severity. However, the mechanisms governing TLS initiation and stage transitions in the kidney remain unclear. To address this, we developed an interdisciplinary approach combining mathematical modeling with *in vivo* experimental data from a mouse model of kidney injury to capture immune cell interactions during TLS formation. We constructed a mathematical model that tracks the dynamics of injured proximal tubular cells, lymphocytes, proinflammatory fibroblasts, follicular dendritic cells, and other key cell types. Using this model, we found that T cell recruitment appears to be mediated by distinct mechanisms at different stages of TLS development: primarily initiated by signals from injured tissue in the early phase, and later sustained by components within the developing TLS structure itself during advanced stages. Furthermore, our *in silico* experiments using sensitivity analysis revealed stage-specific key regulators that may serve as potential therapeutic targets. Our findings offer new insights into TLS development and provide a theoretical framework for future experimental and clinical investigations.

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CP2

A Delayed, Stochastic Model of Prion Diseases with Interconnectome Protein Transport

Prion diseases are rapidly fatal neurodegenerative disorders characterized by the misfolding of the endogenous Cellular Prion Protein ($\mathrm{PrP^C}$) into a toxic variant known as Scrapie Prion Protein ($\mathrm{PrP^{Sc}}$). These toxic proteins spread throughout the brain, converting $\mathrm{PrP^C}$ into more $\mathrm{PrP^{Sc}}$. In this presentation, we build a model starting with heterodimer protein kinetics and incorporate three key biological elements: (i) stochasticity, to account for randomness and uncertainty in prion clearance; (ii) the Unfolded Protein Response (UPR), a cellular defense mechanism that halts protein translation after a delay; and (iii) the capacity for toxic proteins to spread between different brain connectomes. Through an asymptotic limit, we establish a nonlinear, delayed, stochastic ordinary differential system that tracks the concentration of PrP^{Sc} within one or multiple brain regions. We demonstrate the global existence and positivity of solutions and explore qualitative outcomes, including conditions for disease persistence or extinction, as well as the emergence of Hopf bifurcations.

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CP2

Adaptive Cancer Therapy Modeling

The evolutionary and ecological dynamics of tumors under immune responses and therapeutic interventions pose major challenges to long-term treatment success. A major problem in cancer treatment is the emergence of resistance. Although treatment may initially achieve short-term disease control, resistant cancer cell subpopulations often arise leading to relapse with more aggressive and treatment-resistant forms of the disease. Here, we develop and analyze mathematical models describing the interactions among effector immune cells, effector-sensitive tumor cells, and effector-resistant tumor cells under distinct immune-evasion strategies. The models incorporate ecological and evolutionary processes, including competition and cooperation between resistant and sensitive tumor subpopulations. We identify threshold conditions governing tumor persistence, elimination, and phenotype dominance under varying therapeutic intensities. These findings provide a theoretical framework for designing targeted and combination therapies and offer insights into strategies for mitigating the treatment resistance.

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CP2

A Mathematical Model of Chemotherapy-Induced Cancer Cell Senescence

Damage caused by chemotherapy administered to a tumour cell can result in different outcomes, the most common being recovery or cell death. A lesser-studied outcome is treatment-induced senescence. Senescence is a state in which cells stop replicating but do not die; rather, they release signals called senescent-associated secretory phenotype (SASP) which encourage the rapid growth of cells in the area. To combat senescent cells, researchers are currently developing senolytics (anti-senescent drugs). Here we ask the question: when should senolytics be introduced to achieve the best patient outcome? To answer this, we present a mathematical model of the tumour microenvironment with considerations for the chemo-induced senescent cancer cell population and the immune system. In this model, we introduce a probabilistic chance that a senescent cell can resume replicating. We find that giving a senolytic to fast-growing tumours during primary treatment will, at best, have little effect on the tumour's lethality, and at worst, increase it. This is because clearing senescent cells from the system with a senolytic also removes the boost to anti-tumour immune effectors the SASP provides. The hotter the tumour, i.e. the greater the immune response, the more detrimental a senolytic can be. However, for slower-growing tumours or tumours that have been essentially cleared of proliferating cells, introducing a senolytic reduces the risk of relapse, suggesting a strong use case.

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CP2

A Reaction-Advection-Diffusion Model for Alzheimer's Disease with Differential Susceptibility

Alzheimers disease is characterized by the accumulation and spread of amyloid-β (Aβ) aggregates. We present a reaction-advection-diffusion PDE model that describes the spatiotemporal dynamics of Aβ and its impact on neuronal health. Monomer dynamics incorporate production, age-dependent clearance, aggregation, diffusion, and advective transport. We account for fibrils accumulating through Aβ aggregation. Differential susceptibility is incorporated to reflect region-specific vulnerability, allowing comparison of progression patterns across distinct brain regions.

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CP3

A Bayesian Framework for Symmetry Inference in Chaotic Attractors

When data emerge as trajectories of dynamical systems, symmetries encode structural properties of the dynamics that enable model reduction, principled comparison across conditions, and detection of regime changes. While recent optimal transport methods provide practical tools for data-driven symmetry detection in this setting, they rely on deterministic thresholds and lack uncertainty quantification, limiting robustness to noise and ability to resolve hierarchical symmetry structures. We present a Bayesian framework that formulates symmetry detection as probabilistic model selection over a lattice of candidate subgroups, using a Gibbs posterior constructed from Wasserstein distances between observed data and group-transformed copies. We establish three theoretical guarantees: (i) a Bayesian Occam's razor favoring minimal symmetry consistent with data, (ii) conjugation equivariance ensuring frame-independence, and (iii) stability bounds under perturbations for robustness to noise. Posterior inference is performed via Metropolis-Hastings sampling and numerical experiments on equivariant dynamical systems and synthetic point clouds demonstrate accurate symmetry recovery under high noise and small sample sizes. An application to human gait dynamics reveals symmetry degradation induced by mechanical constraints, demonstrating the framework's utility for statistical inference in biomechanical and dynamical systems.

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CP3

Unusual Stability Domains in Families of Free-Parameter Multistep Methods

A stability domain, also known as a region of absolute stability, is a plot in the complex plane showing for which values of $z = \lambda h$ a particular numerical method will give stable results when implemented with stepsize h for the linearized ODE $y = \lambda y$. Typically a stability domain either contains no area (e.g., a portion of the imaginary axis) or consists of one connected region. All boundaries of stability domains for stable methods go through the origin vertically. In this talk, I discuss a novel brute force method for generating a stability domain and compare it to the more traditional root locus method for generating stability domains. With this new method, we have been able to observe some atypical stability domains for multistep methods, to include stability domains with two disconnected pieces and stability domains that do not go through the origin. In this talk, we present our investigation of several different families of free-parameter multistep methods with intriguing stability domains for some values of the free parameters. We show our full analysis of general one-step and two-step predictor-corrector methods with one and two free parameters respectively; we also demonstrate some unusual behavior in stability domains of some non-predictor-corrector methods.

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CP3

Multi-Symplectic Modeling and Neural Surrogate Analysis of Modulational Instability in Hirota-Type Systems

Modulational instability and soliton dynamics are key phenomena in nonlinear dispersive wave systems and appear in reduced models of plasma wave interactions relevant to high-temperature fusion environments, including magnetic confinement devices such as ITER. Hirota-type nonlinear wave equations provide a unified framework encompassing the nonlinear Schrdinger and complex modified Kortewegde Vries equations, capturing essential dispersive and nonlinear effects. We study modulational instability for a generalized class of Hirota-type systems using a structure-preserving multi-symplectic finite difference formulation that enables stable long-time simulations while preserving the Hamiltonian structure. Linear stability analysis yields classical modulational instability conditions under generalized dispersion relations, which are verified numerically. To facilitate the exploration of parameter regimes in nonlinear plasma wave models, we incorporate a neural surrogate that learns smooth relationships between dispersion-based features, numerical invariants, and instability growth trends obtained from multi-symplectic simulations. The surrogate is used as an auxiliary tool to assist numerical investigation and provide indicative trends, reducing reliance on exhaustive computations.

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CP4

From STLS to Projection-Based Dictionary Selection in Sparse Regression for System Identification

Sparse regression methods for nonlinear dynamical systems, including SINDy, are widely used to infer governing equations directly from time series data. Sequential Threshold Least Squares (STLS) is an algorithm for solving the ℓ^0 sparse least squares problem, and its performance depends strongly on the choice of dictionary and thresholding strategy. In this work, we revisit STLS and introduce a score guided dictionary selection approach, where for each candidate subset of dictionary terms a score is defined as the discrepancy between the orthogonal projections of the regression target onto the full dictionary and onto the subspace spanned by the selected terms. We begin with an analysis of the dictionary selection mechanism in STLS and compare it with the proposed score guided strategy. We then present numerical experiments on ordinary and partial differential equations illustrating how score guided dictionary selection improves accuracy and interpretability in system identification.

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CP4

Rational Approximation Using Greedy Continued Fractions

Rational functions are typically more efficient for approximation than polynomials, particularly for functions with singularities on or near the domain. Interpolation by a rational function in the form of a continued fraction (CF) was introduced by Thiele in 1909. Application of his formula, however, was limited by numerical instability until 2024, when Salazar Celis showed that a greedy node selection algorithm produces stable results. It has an $O(n^3)$ complexity, compared to $O(n^4)$ for the popular AAA method for rational interpolation, and requires only simple arithmetic, making it easy to use with extended precision. We present some refinements of Salazar Celis' CF idea and its implementation in open-source software for Julia and Python.

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CP4

New Algorithms to Solve Non-Linear Least Square Problems

Non-linearity often leads to slow or unstable convergence in iterative solvers for nonlinear least-squares problems. In this work, we introduce a family of accelerated algorithms that leverage a periodically restarted variant of the Generalized Minimum Residual (GMRES) method to address these challenges. The restarting strategy keeps the computational cost under control and makes the method more reliable when dealing with nonlinear problems. To further improve efficiency, our approach integrates sketching and subspace-projection mechanisms, enabling substantial reductions in computational cost while maintaining high solution accuracy. We derive an explicit perturbation bound that quantifies how inaccuracies in the reduced subspace influence the stability of the computed solution. Extensive numerical experiments confirm that the resulting algorithms deliver accurate reconstructions with markedly improved computational performance compared to classical gradient-based techniques.

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CP4

Fractional Relaxation with Time-Varying Memory: Kernel Approximation and Numerical Simulation

Many dynamical systems exhibit relaxation behavior with memory effects that evolve over time, as occurs in materials whose internal response gradually changes. In this talk, fractional relaxation models will be considered in which time-dependent memory is represented through convolution kernels defined in the Laplace domain. Since the associated time-domain kernels are generally not available in closed form, explicit approximations will be presented, obtained through asymptotic expansions in the Laplace domain and achieving quadratic accuracy in the modulation amplitude. These approximations will be combined with numerical inverse Laplace transform techniques to compute solutions of scalar and coupled linear relaxation systems. Numerical results will illustrate how different temporal memory profiles influence decay rates and transient behavior, and how classical fractional relaxation is recovered as the modulation diminishes.

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CP5

Maximum Likelihood Estimator of Markov Processes with Censored Data for the LotkaVolterra Predatorprey Model and Beyond

In this paper, we study estimation of the infinitesimal generator Q of a finite-state continuous-time Markov jump process $X(t)$ when only the endpoints $X(0)$ and $X(T)$ are observed. Under this extreme censoring, the classical MLE fails to exist. We introduce a regularized likelihood functional and prove the existence of a maximizer. The method is illustrated for BirthDeath processes (including LotkaVolterra predatorprey dynamics) and for taxi movement data in Manhattan. To enforce locality in the directed graph structure, we impose sparsity by restricting Q to transitions supported on the vertexedge complex, encoded via the graph Dirac operator. Using the regularized estimator, we reconstruct unobserved trajectories through a Doob h-transform and embed this within an expectationmaximization framework. Numerical examples demonstrate recovery of hidden distributions and scalability to larger sparse graphs.

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CP5

Learning Dynamics of the Influencer's Game in Resource Landscapes

This work develops a mathematical framework for influencer games, a class of games in which players compete for spatially distributed resources through relative influence. Interactions are mediated by influence kernels that model

spatial decay of control, capturing settings from species home-range competition to social media engagement. We establish foundational equilibrium results for this class of games. Existence of Nash equilibria follows from Renys theorem for compact, quasi-concave games, and uniqueness of the symmetric Nash equilibrium is shown for symmetric log-concave influencer games. Stability conditions are derived via Jacobian analysis exploiting the systems block-symmetric structure. In one-dimensional games with Gaussian influence kernels, we obtain closed-form results showing that the symmetric equilibrium coincides with the mean of the resource distribution. Stability is governed by a threshold relating the kernel reach parameter σ to the resource variance. Crossing this threshold yields rich dynamics, including bifurcations, limit cycles, and multiple equilibria as the number of players grows or influence becomes more localized. These results extend to higher-dimensional strategy spaces and alternative kernel families, including multivariate Gaussian and Dirichlet distributions, providing a unified framework for spatial competition driven by relative influence.

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CP5

Finite-Domain Persistence for An Integro-Difference Equation with Strong Allee Effects and Overcompensation

Integro-difference equations (IDEs) are discrete-time, continuous-space population models that accommodate a wider range of growth and dispersal behaviors than reactiondiffusion formulations. The finite-domain problem for IDEs concerns persistence when favorable habitat is spatially limited. For monotone growth or overcompensatory growth without an Allee effect, this problem is well understood. In contrast, results are much more limited when strong Allee effects are combined with overcompensation. In this work, we establish the existence of equilibria via the associated ODE in the case of Laplace dispersal and show that these equilibria can be linearly stable in certain parameter regimes. We further extend the analysis numerically to other dispersal kernels and investigate bifurcations with respect to domain size.

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CP5

Stochastic Stability and Control of Competitive Exclusion in a Managed PredatorPrey System

We analyze a three-species predatorprey competitive system in which one predator is competitively dominant, leading under classical dynamics to exclusion of the weaker species. We introduce state-dependent management controlsincluding asymmetric subsidy to the weaker predator, shared subsidy with leakage to the dominant predator, and active suppression of the dominant predatorand show that varying intervention parameters can induce regime shifts between exclusion and coexistence, with regions of bistability and tristability organized by saddle manifolds. To incorporate implementation uncertainty, we model the maximum deliverable subsidy as a stochastic, piecewise-constant process, thereby coupling ecological dynamics with fluctuating control capacity. In the stochastic regime, the system exhibits metastability and noise-driven transitions between long-lived states. Policy performance is explored using distribution-based metrics, including high-percentile population levels and the probability of falling below critical viability thresholds, allowing us to investigate how management interacts with stochastic forcing to influence basin structure and transition dynamics.

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CP5

Network-Based Stochastic Modeling of Prion Disease Progression on the Mouse Brain Connectome

Neurodegenerative diseases (NDs) are characterized by the progressive spread of toxic protein species throughout the brain. In NDs, the normal cellular prion protein ,produced primarily by neurons, misfolds into the pathogenic scrapie isoform. Misfolded prion proteins propagate between anatomically connected brain regions, inducing cellular stress and progressive neurodegeneration. Although extracellular mechanisms of prion conversion have been extensively studied, how local misfolding dynamics interact with brain-wide anatomical connectivity to shape disease progression remains poorly understood. In this work, we develop a stochastic network-based model that couples extracellular prion conversion dynamics with interregional transport over the mesoscale structural connectome of the mouse brain. Brain connectivity is informed by the Allen Mouse Brain Connectivity Atlas reported by Oh et al.(2014) providing a weighted, directed representation of axonal projections between anatomical regions. At each brain region, the model describes nonlinear interactions between healthy and misfolded prion protein concentrations, with time-delayed feedback representing unfolded protein response (UPR)-mediated regulation of protein production. Analysis of the resulting delayed stochastic network system identifies parameter regimes associated with prion clearance, persistence, and connectivity-driven propagation, offering quantitative insight into network-mediated prion disease progression.

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CP6

A Scalable Variational Quantum Framework for ReactionDiffusion Systems with Extrapolated Exponential Time Differencing.

Variational quantum algorithms offer a promising paradigm for the simulation of time-dependent partial differential equations on near-term quantum devices.

Here, we propose a variational quantum approach for solving reactiondiffusion systems based on an extrapolated exponential time differencing scheme, which admits natural extensions to higher-order time-stepping formulations. Each time step is formulated as a variational optimization problem, enabling quantum-assisted implicit time integration in one-, two-, and three-dimensional domains. As spatial resolution increases, the required qubit counts for global formulations grow rapidly and limit trainability. To address this challenge, we introduce local operator decomposition strategy that replaces a single high-dimensional optimization with a sequence of lower-dimensional variational quantum subproblems. Through statevector simulations in one-, two-, and three-dimensional settings, we demonstrate stable time evolution and consistent numerical accuracy. The framework extends to multi-component reactiondiffusion systems and provides a decomposition-based formulation for quantum-assisted simulation of nonlinear evolution equations.

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CP6

Numerics-Informed Neural Networks for Parabolic Partial Differential Equations

We study Numerics-Informed Neural Networks (NINNs) for solving parabolic partial differential equations, combining classical finite difference discretization with neural network–based time-stepping. The NINN formulation studied here embeds a fixed 5-point Laplacian stencil within a lightweight U-Net that learns step-to-step updates by minimizing discrete residuals. Dirichlet boundary conditions are enforced exactly through boundary lifting, eliminating penalty weight tuning and ensuring exact boundary satisfaction. We apply NINNs with backward Euler time discretization to the 2D heat equation and provide a systematic convergence analysis for parabolic NINNs. Numerical experiments across nineteen manufactured solutions demonstrate improved pre-asymptotic convergence behavior, ranging from second-order to superconvergent rates (up to 11th order) depending on solution smoothness, with polynomial and trigonometric cases achieving the strongest performance. In the most favorable cases and at fine resolutions, NINNs can achieve up to 66× lower L^2 error than standard finite differences. We establish discrete error bounds linking residual minimization to solution accuracy and show that partial training schedules can retain accuracy while reducing computational cost. This work bridges numerical analysis and machine learning by preserving the structure and interpretability of finite difference methods while using neural networks to learn solution-dependent corrections.

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CP6

On the Qualitative Study of An Abstract Fractional Functional Differential Equation Via the Ψ-Hilfer Derivative

We investigate the existence, uniqueness, Ulam-Hyers and generalized Ulam-Hyers stability of the fractional functional differential equation: ${}^{H}D_{0}^{\alpha,\beta;\Psi}(u(t)+g(t,u(t))) = Au(t) + f(t,u(t)), t \in [0,T]$, with initial condition $I_{0^+}^{1-\gamma;\Psi}u(0) = u_0$,where ${}^{H}D^{\alpha,\beta;\Psi}$ is the Ψ-Hilfer operator. We first establish a variation of constants formula, and then use the Banach fixed point principle and the Krasnoselskii's fixed point theorem to achieve our existence and uniqueness results. We also explore the stability of this equation under some appropriate conditions. Our results generalize some recent ones on the subject. We finally give an example to illustrate our main result.

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CP6

Finite Element Eigenfunction Networks for PDEs on Complex Geometries

Neural operators learn mappings between infinite-dimensional function spaces, but their performance often deteriorates on complex geometries due to geometry-agnostic representations. We propose the Finite Element Eigenfunction Network (FEENet), a hybrid framework grounded in the eigenfunction theory of elliptic operators. For a fixed domain Ω, FEENet computes a geometry-adapted basis by solving $\mathcal{L}\psi_k = \lambda_k\psi_k$ with homogeneous boundary conditions using the finite element method. PDE solutions are represented in this basis, and learning reduces to predicting the associated spectral coefficients. Experiments on Poisson, heat, and biharmonic equations over irregular two- and three-dimensional domains demonstrate relative errors one to two orders of magnitude smaller than standard neural operator baselines, with fewer parameters and reduced training time. By embedding an analytic spectral scaling layer λ_k^{-s}, a single trained FEENet model generalizes zero-shot to the spectral fractional Laplacian $(-\Delta)^s u = f$ at arbitrary fractional orders $s \in (0,1)$ without retraining—a capability unavailable to purely data-driven approaches. The framework further enables resolution-independent inference, and is robust to coarse meshes used in the offline eigenbasis computation. We envision that FEENet motivates further work in the broad space at the intersection of classical numerical analysis and modern machine learning.

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CP6

A Natural Primal-Dual Gradient Method for Adversarial Neural Network Training on Solving Partial Differential Equations

We propose a scalable deep learningbased algorithm for solving PDEs that integrates preconditioned gradient methods with adversarial training. By multiplying the PDE with a test function, we reformulate the problem as an infsup saddle-point problem and apply the Primal-Dual Hybrid Gradient algorithm. To enhance efficiency and stability, we introduce appropriate preconditioning operators into the proximal steps of the PDHG algorithm, yielding a natural gradient ascentdescent scheme for updating neural network parameters. The resulting natural gradients are evaluated efficiently using the Krylov subspace method (MINRES) involving iterative matrixvector products. Convergence guarantees are established for time-continuous algorithms when applied to linear equations, particularly elliptic PDEs in divergence form. We validate the method on a wide range of linear and nonlinear PDEs with dimensions ranging from 1 to 50. Numerical results demonstrate that our approach achieves more stable convergence and higher accuracy than several widely adopted deep learningbased approaches, particularly in high-dimensional settings.

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CP7

What We Still Cannot Formalize About Learning Systems

Modern learning systems achieve remarkable performance when objectives are clearly defined and measurable. Learning, in this context, is primarily driven by statistical optimization over large datasets. However, current formalisms still lack a clear treatment of memory as an active component tied to decision justification over time. Memory is generally modeled as storage or state, but rarely as an explicit, interpretable object that accumulates and contextualizes past errors. This talk does not refer to error as instantaneous loss – this is well-formalized. Instead, it points to error as a persistent, contextual signal that shapes future decisions and their justification over time. This distinction remains largely implicit in existing frameworks. The goal is not to propose a new model, but to highlight a conceptual gap that appears across many learning formalisms: the absence of memory as a first-class object tied to responsibility, explanation, and temporal coherence. This talk deliberately stays upstream of formalization, but speaks to communities working on dynamical systems, online learning, control theory, and temporal reasoning. The aim is to clarify what needs to be formalized before choosing how.

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CP7

Toward Robotic Consciousness

This talk is speculation about what robot consciousness might be like as an extension of human consciousness. Human consciousness can be significantly described by the 48-element binary octahedron group and its related subgroups or near subgroups. For example basic robotic motions can be defined by 4-dimensional quaternions of the 24-elements of the symmetric group S4. The more complicated 48-element group can add colors and sounds. Extending to 96 elements in 8-dimensional-space can add metallics such as silver and gold as it may be supposed it will be important for robots to distinguis

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CP7

Machine Learning Methods for Pricing Financial Derivatives

Stochastic differential equation (SDE) models form the foundation of modern option pricing and hedging. Traditional SDE-based models rely on parametric specifications of drift and volatility, which can limit their ability to capture complex market dynamics observed in practice. In this talk, we study a machine-learning-based approach in which the drift and volatility functions of an SDE are represented by neural networks and calibrated directly to option market data. We focus on the empirical performance of neural SDE models when applied to real option surfaces, with particular emphasis on single-stock options. Model calibration is performed using stochastic gradient-based optimization combined with Monte Carlo simulation of the underlying asset dynamics. We evaluate pricing accuracy both in-sample and out-of-sample across strikes, maturities, and calendar time, and compare the neural SDE approach against standard benchmarks including BlackScholes, local volatility, and stochastic volatility models. Beyond static pricing accuracy, we examine the stability of the learned models under repeated recalibration, which is important for practical deployment. Numerical results show that neural SDE models achieve improved out-of-sample pricing performance while maintaining stable behavior over time. These results illustrate how machine learning can be combined with classical stochastic modeling to construct flexible pricing frameworks for financial derivatives.

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CP7

Diffusion-Based Representation Learning of Chaotic Attractors in Nonlinear Pdes

Recent work by Finn et al., Representation Learning with Unconditional Denoising Diffusion Models for Dynamical Systems (2024), shows that unconditional denoising diffusion models can learn useful representations of chaotic attractors in low-dimensional ODE systems from state samples alone. Motivated by this result, this project investigates how these ideas extend to chaotic dissipative PDEs, where the state is high-dimensional and spatially structured. As a primary testbed, we consider the Kuramoto-Sivashinsky equation, a canonical nonlinear PDE exhibiting spatiotemporal chaos. The aim is to train unconditional diffusion models to generate long-time PDE states on physical grids, treating the model as a learner of attractor structure and state statistics rather than as a forecaster. This approach avoids spectral truncation and keeps the learned representation tied to the underlying spatial dynamics. Ongoing work focuses on: (i) identifying architectural and training choices that enable diffusion models to represent chaotic PDE state distributions; (ii) evaluating generated samples using distributional metrics computed in learned low-dimensional feature spaces to address the curse of dimensionality; and (iii) exploring how learned representations may be reused for downstream tasks such as surrogate modeling. The broader goal is to clarify the role of diffusion models as representation learners for nonlinear PDE-driven dynamical systems.

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CP7

Inference Asymmetry and Counterfactual Failure Modes in Generative Language Models

Large generative language models are trained to approximate conditional distributions of the form $p(y \mid x)$ by maximizing expected log-likelihood under observed data. While effective for forward prediction, this objective induces a structural asymmetry in inference: the model is optimized to affirm consequents given antecedents, but is not penalized for invalid inversions, negations, or counterfactual conditionals that lie outside the support of the training distribution. We formalize this asymmetry by distinguishing forward inference operators from counterfactual evaluation, showing that likelihood-based objectives implicitly collapse these modes. Using a minimal probabilistic construction, we demonstrate that common logical failure modes—such as affirmation under denied antecedents or unsupported causal reversals—are unavoidable under standard autoregressive training. We then introduce a dual-inference formulation in which likelihood maximization is augmented by explicit counter-evidence constraints that suppress infeasible conditional mappings. This decomposition clarifies the mathematical origin of counterfactual failures in generative models and suggests principled directions for inference-aware training objectives.

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CP8

Entropy Stable Closures Derived from the Boltzmann Equation Via the Variational Multiscale Method

In this presentation, we discuss using the Variational Multiscale Method[1] as a framework for systematically deriving a closed system of conservation equations for rarefied gas dynamics from the Boltzmann equation. The framework is general enough to subsume the Chapman-Enskog expansion[2] while opening doors to new possibilities. It also incorporates an analysis of the evolution of the entropy of a resulting system of conservation equations in a natural way. Results related to closures derived through the framework that extend the Navier-Stokes-Fourier equations beyond the continuum flow regime will also be presented.
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CP8

A Dominant Balance Series Solution to the Rayleigh Collapse

For the classic Rayleigh Collapse problem for a single spherical vacuum in an infinite fluid, the exact analytic solution to the nonlinear ordinary differential equation that governs the bubble radius during the collapse is first obtained via a very slowly converging direct power series, and this includes a derivation of the formula of the series coefficients in general. Two different asymptotically motivated factorizations are both considered including one previously discussed in the literature, and in both cases, this leads to an acceleration of the convergence of the series. To achieve machine precision, it is shown that the prior methods require an impractical number of terms varying from just over 80.9 million to just over 1.09×10^{37} series terms. Next, a dominant balance series solution, which is an exact analytic series solution as a function of a gauge variable that removes the singular behavior, was found as well, and a comparison of the estimated numerical errors of the different solution methods was considered. The error analysis shows that the dominant balance series achieves optimum computational efficiency by reaching machine precision with only 35 series terms. Other issues are considered too such as an alternative gauge variable series and applying the dominant balance series method to a two-bubble model extension. Finally, singularities in complex plane domains are discussed in the context of the radius of convergence for a given series method.

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CP8

A Domain Hemivariational Inequality for 2D and 3D convective Brinkman-Forchheimer extended Darcy equations

This paper studies hemivariational inequality problems associated with the non-stationary two- and three-dimensional convective Brinkman-Forchheimer extended Darcy (CBFeD) equations, which model the flow of viscous incompressible fluids through saturated porous media in bounded domains. These equations can be viewed as generalized Navier-Stokes equations that incorporate both damping and pumping effects. For all admissible values of the absorption exponent $r \geq 1$ and effective viscosity $\mu > 0$, the existence of weak solutions to the non-stationary 2D and 3D CBFeD equations with hemivariational inequalities is established by means of a regularized Galerkin approximation scheme based on the regularization of the Clarke subdifferential. A notable contribution of this work is that the obtained existence results also apply to the three-dimensional non-stationary Navier-Stokes equations. In addition, for $r \geq 1$ in 2D and $r \geq 3$ in 3D, with the additional condition $2\beta\mu > 1$ when $r = 3$, the solution is proven to be unique.

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CP8

Mckean-Vlasov Equations for Particle Systems with Dynamic Edges

Classical Mckean-Vlasov theory concerns high-dimensional particle systems for which the effect of one particle on another is instantaneous. However in many applications, particularly neuroscience, the effect of one particle on another is not instantaneous but delayed. For biophysically-accurate neuroscientific models, for each $j \mapsto k$ one can introduce an additional stochastic process that describes the propagation of the signal from j to k. This process is also noisy, since the vesicle opening / closing in the synaptic cleft is random. In this talk I determine a self-consistent autonomous SDE that describe the high-dimensional limit of such neural networks. In doing this, we generalize the classical Mckean-Vlasov Theory to networks with dynamics edges. The results are replied to a one-dimensional ring model of the visual cortex in the mammalian brain. The network is random and sparse, with the probability of a connection depending on the positions of the neurons. Through introducing excitatory and inhibitory neurons with different synaptic timescales, we determine Turing and Hopf Bifurcations that are induced by the delayed interactions.

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CP8

Consequences of Pressure Elimination for Fluid-Structure Interaction Models

In this talk we present applications of our new technique for eliminating and recovering the pressure for a fluid-structure interaction model that is valid in general bounded Lipschitz domains, without additional geometric conditions such as convexity of wedge angles. The specific fluid-structure interaction (FSI) that we consider is a well-known model of coupled Stokes flow with linear elasticity. The coupling between these two distinct PDE dynamics occurs across a boundary interface, with each of the components evolving on its own distinct geometry, and with the boundary interface being Lipschitz. We consider both linear and nonlinear versions of this FSI system (i.e., Stokes and Navier-Stokes flow), where the new pressure elimination technique leads to a proof of well-posedness of the continuous PDE in the explicit semigroup sense, that now holds in general geometries. For the nonlinear case with Navier-Stokes flow and associated boundary nonlinearities, we adopt an approximating nonlinear semigroup formulation of a certain truncated problem. We illustrate some other consequences of our pressure-elimination technique, such as numerical approximations, where it provides FEM convergence estimates over polygonal domains. We illustrate the advantages of our method in a FEM for solutions of the static PDE where the approximating fluid subspace does not require the divergence-free condition.

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CP8

Symmetric and Asymmetric Floating Drops

A drop of liquid rests on a supporting bath of a different liquid, and the entire configuration is contained in a vertical tube. Symmetric and asymmetric configurations are numerically computed, and the resulting potential energies are compared. We present a variety of parameter studies that show examples where the symmetric configuration has lower energy, and also where it does not.

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CP9

Investigating the Location and Service Efficiency of Charlotte Fire Stations Using Optimal Transport

This project examines how effectively Charlottes fire stations serve the citys population and emergency needs. Using recent data on fire station locations and incident reports from 2021 to 2025, we looked for trends in coverage and developed a measure of service efficiency. Our analysis uses modern mathematical tools, the optimal transport and shuffled regression, to compare station locations with patterns of demand, helping to highlight where resources are well-placed and where improvements could be considered. The results show that this approach can uncover insights not easily seen with traditional methods, offering valuable information for urban planning and emergency response.

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CP9

A Gradient-Based Optimization Scheme for PDE-Constrained Inverse Problems with Disconnected Box Constraints

We propose a gradient-based optimization scheme for large-scale PDE-constrained inverse problems with disconnected box constraints on the parameter space. Each parameter component is restricted to a finite union of intervals, resulting in a separable admissible set. Such constraints arise naturally in inverse problems such as full waveform inversion, where physical parameters are known a priori to lie within distinct admissible ranges. We reformulate the constrained optimization problem into a regularized form and construct a sequence of approximate problems. Under mild assumptions, we establish an asymptotic convergence result showing that solutions of the approximate problems converge to a solution of the original problem. Motivated by this result, we develop a heuristic sequential optimization scheme that solves the approximate problems successively. Each subproblem can be efficiently solved using a proximal gradient method. Numerical experiments on synthetic examples and full waveform inversion demonstrate the practical effectiveness of the proposed approach.

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CP9

PDE-Constrained Optimisation for Multiphysics Problems with Gridap.jl

Many problems in science and engineering involve determining unknown parameters that affect system behaviour through physical laws, and are naturally formulated as PDE-constrained optimisation problems. Even with gradient-based methods, PDE-constrained optimisation remains challenging for multiphysics problems, owing to the computational cost of repeated large scale simulations and the complexities of developing problem specific code, especially for computation of the gradient. In many existing approaches, gradients are derived analytically, which is often challenging for multiphysics problems, or rely on finite-differencing when derivatives become complicated. To address these challenges, we develop a PDE-constrained optimisation framework designed to support multiphysics problems with minimal problem-specific effort and with efficiency and scalability as core design objectives. The framework is built on the Julia finite-element library Gridap.jl [Badia and Verdugo, Gridap: An extensible Finite Element toolbox in Julia, 2020]. In alignment with the design principles of Gridap.jl, we provide a syntax to specify arbitrary state equations and objective functions that is near one-to-one with the mathematical notation and implement automatic differentiation tools to eliminate the requirement for user defined gradients. We demonstrate the approach on representative multiphysics problems.

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CP9

Fast Relax-and-Round Unit Commitment with Sub-hourly Mechanical and Ramp Constraints

We propose a novel computational method for unit commitment (UC), which does not require linearized approximation and provides several orders of magnitude performance improvement over current state-of-the-art. The performance improvement is achieved by introducing a heuristic tailored for UC problems. The method can be implemented using existing continuous optimization solvers and adapted for different applications. UC is a mixed integer program which typically requires solvers whose computation time scales exponentially in the number of generators (the problem size). If forced to converge more quickly, the quality of results deteriorates. Our solver's runtime scales sub-quadratically while maintaining the quality of the solution perfectly. We expect that the capability demonstrated in this paper will be critical to address emerging power systems challenges with more volatile large loads, such as data centers, and generation that is composed of larger number of smaller units, including significant behind-the-meter generation. We first use our formulation to solve a single period UC with fast ramping generators and compare the results to a mixed integer solver. The mixed-integer solver is very slow and scales poorly, so we omit it in the next steps. We then test our new solver in a multi period problem with constraints that can require generators to run, or disallow them from running. Finally, we add ramping constraints which limit a generator's production power based on its previous production power and generation state. Our method maintains accuracy perfectly and can solve UC with almost 15,000 generators in less than a minute.

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CP10

Bayesian Inference for a Seaird Model: A Retrospective Analysis of Covid-19 Infection and Mortality in U.S. States

We present a retrospective study of COVID 19 transmission and mortality patterns across the US using a flexible SEAIRD compartmental modeling framework. The model distinguishes between symptomatic and asymptomatic infections and allows key processes such as transmission, reporting, and mortality to vary over time, reflecting changes in mobility, public behavior, testing capacity, and clinical response during the pandemic. State level mobility data and testing information are directly incorporated to connect observed social activity and surveillance intensity with epidemic dynamics. Model parameters are estimated within a Bayesian hierarchical framework, allowing uncertainty to be quantified while borrowing strength across states. This approach provides state specific estimates of infection trajectories, effective reproduction numbers, and reporting dynamics. To further understand heterogeneity across regions, we apply robust clustering methods to group states with similar epidemic characteristics. The results reveal substantial variation in transmission intensity and outcomes across the country, emphasizing the importance of adaptive, region specific public health strategies.

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CP10

Role of Relapse and Multiple Time Delays in Shaping Nipah Virus Epidemic Dynamics: a Mathematical Modeling Study

Nipah virus (NiV) is a sporadic but highly lethal zoonotic pathogen with high case fatality rates. Prolonged incubation, documented relapse, and delayed-onset encephalitis following apparent recovery suggest that NiV dynamics are shaped by complex temporal processes. However, the mechanistic contributions of these processes to epidemic persistence remain poorly understood. We develop a delay differential equation model for NiV transmission that explicitly incorporates these mechanisms. We compute the basic reproduction number (R_0) characterize equilibria, and analyze their stability including delay-induced Hopf bifurcations. We show that relapse sustains an endemic equilibrium when $R_0 < 1$, reflecting a relapse-driven shift in the effective persistence threshold rather than a backward bifurcation. We fit the model to NiV incidence data from Bangladesh (2001-2024). Scenario analyses show that relapse and encephalitis-related delays affect post-peak dynamics, whereas incubation delay modulates the timing and magnitude of the outbreak peak. We also introduce a relapse-driven replenishment fraction to quantify relapse contributions to infectious-state replenishment, demonstrating its increasing importance after the primary outbreak peak. Our study identifies relapse as a key mechanism for epidemic persistence and underscores the importance of incorporating relapse and time delays into epidemiological models.

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CP10

Qualitative Analysis of a Caputo Fractional-Order System Arising from Within-Host Virus Dynamics

We investigate a class of autonomous fractional-order nonlinear dynamical systems motivated by an in-host HIV infection model incorporating three structural mechanisms: logistic proliferation of healthy target cells, two transmission pathways–virus-to-cell infection and cell-to-cell transmission through virological synapses–and Caputo fractional-order derivatives accounting for memory effects. A threshold parameter, formulated as the basic reproduction number R_0, is derived and shown to govern the global dynamics. Specifically, the infection-free equilibrium is globally asymptotically stable when $R_0 < 1$, whereas uniform persistence is established when $R_0 > 1$. The local stability of the endemic equilibrium is further examined, and parameter regimes associated with a transition from steady-state convergence to oscillatory dynamics are identified. Due to intrinsic properties of autonomous fractional-order systems, exact periodic solutions and classical Hopf bifurcations are not expected. Instead, the observed oscillatory behavior corresponds to Hopf-type instability manifested through long-lasting transient or quasi-periodic dynamics. Although the fractional order does not modify the threshold structure determined by R_0, it significantly influences convergence rates and qualitative asymptotic behavior, highlighting fundamental dynamical distinctions between integer-order and fractional-order systems.

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CP10

Stochastic Modeling of Viral Release Strategies with Innate, Cellular, and Adaptive Immunity

Stochastic immune responses can critically reshape the fate of viral infections, yet their interaction with viral release strategies such as budding and bursting remains poorly quantified. Building on a previously developed framework for viral dynamics without immunity, we extend a basic viruscell model with four cell compartments to include innate, cellular, and adaptive immune components, both individually and in combination, for viruses that either burst or bud from infected cells. Each immune configuration is formulated as a reaction network and analysed at the stochastic level using diffusion-type approximations, including jumpdiffusion SDEs for bursting and modified EulerMaruyama schemes for budding. We estimate virus and cell extinction probabilities, conditional mean extinction times, and regime structure (recovery, chronic infection, recoveryreinfection, and host cell death) as functions of burst size and immune parameters. The results show that innate, cellular, and adaptive responses each expand the parameter region where viral extinction is likely, with combined immune mechanisms acting synergistically to shorten infection duration and isolate trajectories from host-death states, while preserving qualitative differences between budding and bursting strategies.

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CP10

Forecasting West Nile Virus (wnv) in the Southwest Desert Using Mathematical and Statistical Modeling Approach

West Nile Virus (WNV) diseases present a significant public health challenge, with effective prevention requiring accurate forecasting of mosquito populations and associated disease prevalence. Using a 10-year time series of weekly mosquito abundance and WNV prevalence data collected in Maricopa County, we investigated how local climate variations influence mosquito population dynamics and disease transmission. We developed a mechanistic model of WNV dynamics driven by daily temperature and precipitation to predict mosquito populations and WNV prevalence. To achieve this, we applied the Ensemble Kalman Filter (EnKF) method to estimate model parameters. We forecasted these time-varying parameters on a two-week basis, incorporating precipitation and temperature as covariates. These forecasts were used as inputs for a mechanistic ordinary differential equation (ODE) model, which predicted mosquito abundance and WNV prevalence while capturing associated uncertainties. Our iterative framework was applied over a 46-week period, successfully capturing seasonal variations in mosquito populations and WNV prevalence throughout the datasets. Our findings underscore the importance of integrating climate data with adaptive filtering techniques to address forecasting challenges and enable effective responses to emerging or re-emerging mosquito-borne pathogens, which, driven by human behavior and

environmental changes, may potentially escalate to pandemic levels.

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CP11

Time-Varying Risk-Premium PCA for Asset Pricing

We ask a simple question: why do different assets earn different returns? Factor models argue that a small set of systematic forces explains the cross-section and that assets earn more when they load on risks that command premia. But exposures change as firms, industries, and economic conditions evolve. Time-Varying Risk-Premium PCA (TVRPPCA) addresses this by extracting factors disciplined by risk premia while allowing exposures to drift smoothly through time. Our result is a scalable, economically grounded representation of how characteristics map into priced risk and how that mapping evolves. Empirically, TVRPPCA delivers stable and improved pricing of average returns, directly targeting the core motive of expected-return differences.

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CP11

On the Valuation of European Asian Option

European Asian options depend on time averages of the underlying asset price, leading to path-dependent payoffs that generally preclude closed-form valuation. In this paper, we develop two distinct analytic approximation methods for pricing European Asian options under a continuous-time diffusion framework. The first approach employs a systematic reduction technique that leverages the closed-form solution of the geometric-average Asian option, while the second is based on an alternative analytic approximation for the time-integrated diffusion process. Both methods exploit structural properties of stochastic integrals to obtain tractable pricing formulas without resorting to full Monte Carlo simulation. We assess the accuracy and efficiency of the proposed approximations through systematic comparisons with Monte Carlo benchmarks across a range of maturities, volatilities, and moneyness levels. Numerical results demonstrate that both methods provide accurate and computationally efficient approximations.

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CP11

The Cross Section of Stock Price Adjustments to Signal and Its Signaling Feedback to Stock Returns

This paper develops a methodology to estimate heterogeneous effect of a macroeconomic signal to the cross-section of stock prices. To establish causal interpretation among noisy signals, I first build an estimation framework guided by the theoretical asset pricing model of Pastor and Veronesi (2012), then combine it with a modified synthetic control (SC) approach from machine learning literature. Empirical analysis supports the new framework well as the estimated speeds of price adjustments predict returns in the cross-section of equities up to 48 months horizon. The proposed framework thus provides a novel understanding of price discovery mechanisms at the individual stock level.

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CP11

Threshold Structure in Stochastic Impulse Control with Fixed Costs

We investigate a stochastic impulse control problem with fixed intervention costs. The objective is to characterize the structure of optimal policies. The problem is formulated via a quasi-variational inequality arising from the dynamic programming principle. We establish existence of an optimal intervention strategy and show that the optimal policy is characterized by a pair of threshold levels defining continuation and intervention regions. Necessary optimality conditions are derived to identify the optimal trigger and post-intervention levels. The analysis provides a complete structural characterization of optimal impulse control policies with fixed costs and contributes to the theory of stochastic impulse control.

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CP11

A Geometric Instability Diagnostic for Compact-Interior Short-Maturity Heston Pricing Near the Variance Boundary

We present a geometry-based instability diagnostic for the Heston diffusion near the degenerate variance boundary $v \to 0$. On the interior $v > 0$, the principal symbol induces the Riemannian metric $g = a^{-1}$. The scalar curvature and curvature-gradient invariant are explicit: $R(v) = -\sigma_v^2/v$ and $J_g(v) = \|\nabla^g R\|_g = \sigma_v^3 v^{-3/2}$. Although ρ enters the metric tensor and geodesic distance, it cancels from R and J_g, so the blow-up law is ρ-invariant. With $\lambda_{\mathrm{loc}}(v) = \sigma_v/(2\sqrt{v})$, this gives the exact interior identity $J_g(v) = 8\lambda_{\mathrm{loc}}(v)^3$. Using short-time heat-kernel/Varadhan asymptotics, we construct a geodesic parametrix proxy C_{geo} for a fixed mollified payoff and benchmark it against a finite-difference PDE price C_{PDE}. On compact interior analysis sets $K \subset \{v_0 \geq \epsilon_K\}$, with x_0 near $\log S_0$, the normalized theorem-facing diagnostic and compact-set log-price envelope remain small at short maturities and show near first-order scaling in T over the reported fit window. This provides conservative evidence for a geometry-informed short-time trust region, not a global boundary pricing theorem. Reliability maps and sensitivity diagnostics are reported as supplementary checks.

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CP11

A Scientific Machine Learning Approach to Liquid-

ity Optimization Via Pinn-Based PDE Solvers

Decentralized exchanges create new quantitative problems where stochastic dynamics, optimization, and market microstructure interact in fully algorithmic settings. In Uniswap v3, concentrated liquidity lets providers allocate capital over chosen price ranges, creating a trade-off between higher fees and inactive liquidity risk. We study the range-selection problem as a PDE-constrained optimization task. The market state follows stochastic differential equations, while the expected utility of a liquidity position is represented, through the FeynmanKac formula, by the solution of a backward parabolic PDE. To approximate this value function efficiently, we use Physics-Informed Neural Networks (PINNs), embedding the differential operator and boundary conditions into the loss function to obtain a mesh-free surrogate solver. This shifts most computation to an offline training stage, allowing fast online pricing and real-time optimization. Numerical tests under BlackScholes and Heston models show accurate approximations and competitive results versus standard liquidity strategies, highlighting the value of SciML for stochastic control in modern financial markets. Acknowledgments: This work is partially supported by the project: FLINT - Prog. n.: F/380134/01-03/X77 - MIMIT This work is partially supported by the project: TUAI: Towards an Understanding of Artificial Intelligence via a transparent, open and explainable perspective, Marie Curie Doctoral Network, ID: 101168344

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CP12

Analytical and Numerical Modeling of Diffusion-Controlled Wax Growth in Pipelines

Wax deposition is a major flow assurance challenge in crude oil pipelines, where solid wax crystals form and grow on the pipe wall, reducing flow capacity and increasing operational risk. This work presents an analytical and numerical study of diffusion-controlled wax growth inside pipelines, with emphasis on the dominant role of molecular diffusion during the early and intermediate stages of deposition. The problem is formulated as a coupled diffusion-growth system. The wax concentration in the fluid phase satisfies a convectiondiffusion equation, while the deposit thickness evolves through a Stefan-type moving boundary condition. By exploiting the small radial length scale and the dominance of diffusive transport near the pipe wall, an asymptotic reduction is derived, leading to a simplified analytical description of the growth rate. The reduced model is solved analytically for limiting cases and numerically for general parameter regimes. The results reveal clear scaling laws linking wax layer growth to the diffusion coefficient, flow conditions, and concentration gradients. Comparisons between analytical predictions and numerical simulations show excellent agreement and provide physical insight into the mechanisms governing wax accumulation. The proposed framework provides a rigorous and efficient approach for predicting wax deposition in pipelines and can be extended to account for thermal and shear-induced effects.

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CP12

A New Stabilized Finite Element Approach for Fluid Flow

This work studies a new time relaxation model that incorporates stabilization terms into the time dependent Navier-Stokes equations to address oscillations and effects from small scales in fluid flows. To resolve these small scales, we implement spatial filtering and approximate deconvolution operators. This model acts as a sequel to a Dunca and Neda (2014) model by omitting fluctuation on the test function in the stabilization term, which previously made the model impossible to be implemented in the Crank-Nicolson algorithm. We explore numerical stability, convergence, and computational simulations.

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CP12

A Numerical Study of Singularity Formation in An Euler Model of Shallow Water Wave Propagation: the Case of An Illposed Boussinesq Equation

We numerically study the issue of finite-time existence of solutions associated with the initial value problem of an ill-posed Boussinesq equation subject to small-amplitude sinusoidal initial disturbances over a 2π periodic domain. A spectral method in combination with the fourth-order RungeKutta method is used to perform numerical experiments using several time steps, several precision arithmetic and filters with several cut-off levels. The calculations indicate that the solution blows up in a very short time t_c at $x = 3\pi/2$, independent of the parameter e. It also appears that the profile of the solution at the location of the singularity is parabolic, of the form $?(x, t; \epsilon) = ?_0(t; \epsilon) + c_1(t; \epsilon)(x - 3\pi/2)^2$ as the singularity forms, where t_c $1/\epsilon^p, p$ 0.28. The functions $?_0(t; \epsilon)$ and $c_1(t; \epsilon)$ are determined numerically and discussed. From numerical calculations, we find that $c_1(t; \epsilon) \sim (t_c - t)^{-\delta(\epsilon)}$ as $t \to t_c$ where ϵ-dependent δ is the rate of singularity formation. We obtain the following estimates for δ : $\delta = 2.46$ for $\epsilon = 0.10$ and $\delta = 2.67$ for $\epsilon = 0.025$. Reference: A Numerical Study of Singularity Formation in an Euler model of shallow water wave propagation: The case of Illposed Boussinesq Equation, R. Soc. Open Sci. 13: 251726, 2026; https://doi.org/10.1098/rsos.251726

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CP12

Quantum-Classical Hybrid Algorithms for Darcy Flow Based on Weak Galerkin Finite Element Methods

While quantum computing is intended to address computational bottlenecks in large-scale tasks, e.g., simulations of Darcy flow in highly anisotropic and heterogenous media, preservation of physical properties, e.g., local mass conservation, should not be overlooked. This talk presents our preliminary results on development of quantum-classical hybrid algorithms for Darcy flow based on the weak Galerkin finite element methods. We will present numerical results on noisy intermediate-scale quantum (NISQ) computers (utilizing Qiskit libraries).

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CP12

Explicit Adaptive Dispersive Water Wave Modeling with Hyperbolic Systems

The shallow water equations are widely used to model free-surface flows in geophysical hazard assessment. However, their non-dispersive character limits their ability to accurately capture shorter-wavelength phenomena, which can lead to imprecise predictions of coastal run-up. In contrast, dispersive wave models account for dispersion effects but typically do not permit shock formation, an important mechanism for representing physical wave breaking. Moreover, these models often involve high-order spatial derivatives, mixed spacetime terms, or elliptic constraints without explicit temporal evolution, which complicates the development of efficient large-scale numerical solvers due to the need for implicit operator inversions. Recent advances in hyperbolic reformulations of dispersive wave models offer an alternative framework that preserves dispersive effects while enabling shock-capturing techniques. In this work, we develop a hybrid numerical solver that dynamically transitions between hyperbolic approximations of the SerreGreenNaghdi equations and the shallow water equations, depending on the flow regime. The explicit structure of the discretization naturally supports patch-based adaptive mesh refinement, allowing efficient resolution of solution features across a wide range of spatial scales. The proposed methodology is validated through comparisons with benchmark laboratory experiments and idealized tsunami simulations

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CP12

Data-Driven Mesh Motion for Multiphysics Ale Methods

In problems of high energy-density physics, such as inertial confinement fusion, radiation energy and momentum densities can strongly influence the fluid dynamics. To accurately model the energy exchange between radiation and the fluid, it is necessary to solve the equations of radiation hydrodynamics. Traditional methods typically use either a purely Eulerian approach or an arbitrary LagrangianEulerian (ALE) approach, which involves a Lagrange+remap phase to maintain mesh regularity. In this work, we propose a new Direct-ALE method that utilizes the Eulerian fluid description while allowing the mesh to move arbitrarily. Historically, the mesh velocity has been determined using hand-tuned monitor functions that aim to capture features such as shocks by identifying regions of steep gradients and high curvature. However, their performance depends on heuristic, problem-specific tuning of monitor functions coefficients. We explore a data driven approach to guide mesh placement based on local solution features, thereby replacing the need for hand tuning. This approach enables the incorporation of AI/ML techniques to determine optimal mesh distributions without modifying the underlying hydrodynamic or radiation solvers, thus preserving solver fidelity. We demonstrate the effectiveness of the Direct-ALE method using a set of hydrodynamic, radiative transfer, and radiation hydrodynamics problems.

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CP13

From Chain Kinetics to Printability: A Transient Network Model for Bioink Rheology

The rheological behavior of bioinks plays a central role in extrusion-based bioprinting, governing both print fidelity and the mechanical environment experienced by embedded cells, yet many commonly used constitutive models rely on empirical fits that obscure underlying molecular mechanisms and limit predictive capability. In this talk, we present a physically grounded transient network model that links polymer chain attachmentdetachment kinetics to small-amplitude oscillatory shear (SAOS) moduli. By resolving chain populations across a continuous spectrum of detachment rates, the model naturally captures the power-law scaling of storage and loss moduli observed in alginate and carboxymethyl cellulose hydrogels over experimentally relevant frequency ranges. Unlike multimode Maxwell or fractional viscoelastic models, each relaxation mode in our framework has a direct kinetic interpretation, allowing molecular processes to be connected to macroscopic rheological response. The model fits SAOS data with high fidelity, accurately reproducing both storage and loss moduli while yielding physically interpretable parameters such as chain stiffness, characteristic relaxation times, and reattachment rates. These results provide a foundation for predictive bioink design, enabling rational formulation strategies that link molecular network dynamics to flow behavior and cell-scale mechanical environments in bioprinting applications.

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CP13

RHR-NMF: A Framework for Multi-Dimensional

Immune Discovery

Modern biological datasets contain high-dimensional feature sets across several axessuch as genes, cells, experimental stimuli, etc. While these datasets capture complex biological interactions, standard matrix factorization methods often flatten multi-dimensional data, discarding the inherent coupled relationships across the axes. Furthermore, we show that traditional tensor methods like CANDECOMP/PARAFAC (CP) decomposition frequently split biological patterns into redundant, overlapping components. This loss of structural integrity obscures interpretable relationships and limits the discovery of biological modules. Here we introduce Row-Hierarchical Regularized NMF (RHR-NMF), a tensor-aware framework, which preserves multi-dimensional structure by performing a two-stage decomposition that conserves modules in separate components. By applying RHR-NMF to the Immune Dictionarya single-cell atlas of mouse lymph node responses that captures gene expression across 17 immune cell types in response to 86 cytokines we reveal that immune responses are are composed of hierarchical submodules, where each cell-type response is associated with unique combinations of gene and cytokine modules. Practically, RHR-NMF enables researchers to prioritize biologically meaningful sub-modules, providing a systematic framework for identifying latent immune programs in high-dimensional biological datasets.

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CP13

AI, Machine Learning, and Medical Statistics

AI and classical statistics each offer distinct strengths for medical data analysis. This presentation surveys principled ways to combine them: using LLMs for unstructured clinical text and risk prediction, integrating ML models with statistical inference for calibrated effect estimates, and hybrid pipelines that preserve interpretability while leveraging representational power. Through worked examples, we show complementary workflows where AI handles complex feature extraction and statistics provides formal uncertainty quantification and causal checks. Pedagogical insights and practical recommendations for clinical deployment are provided.

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CP14

Average Kernel Sizes - Computable Sharp Accuracy Bounds for Inverse Problems

The reconstruction of an unknown quantity from measurements is a mathematical problem relevant in applied sciences, e.g. in medical imaging or astronomy. This is often an ill-posed inverse problem. To tackle such problems, there exist a myriad of methods to design approximate inverse maps, ranging from optimization-based approaches, e.g. compressed sensing, over Bayesian approaches, to data-driven techniques e.g. deep learning. For stable approximate inverse maps, there are accuracy limits that are larger than zero for ill-posed inverse problems, due to the accuracy-stability tradeoff [Gottschling et al., SIAM Review, 67.1 (2025)] and [Colbrook et al., PNAS, 119.12 (2022)]. The variety of methods for solving such problems begs for a unifying approach to help scientists choose approximate inverse maps that obtain this optimum. There do not exist computable accuracy bounds to this optimum. We provide computable sharp accuracy bounds to the reconstruction error of solution methods to inverse problems. The bounds are method-independent and depend on the dataset, forward model of the inverse problem, and noise model. We provide an algorithmic framework and an accompanying software library to compute these accuracy bounds. We demonstrate the validity of the algorithms on two inverse problems: fluorescence localization microscopy and super-resolution of multi-spectral satellite data. Computing the accuracy bounds for a problem before solving it, enables optimizing datasets.

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CP14

Computational Methods for Electrical Impedance Tomography

Electrical Impedance Tomography (EIT) is a portable, inexpensive, noninvasive imaging system that does not use ionizing radiation. Due to these properties, EIT has been of great interest for many different medical applications. In practice, electrodes are attached to a patient's body where current is applied, and the resulting voltage is measured to reconstruct internal electrical properties. However, the EIT inverse problem is severely ill-posed due to the limited number of measurements from the partial boundary data, and aggressive changes in the electrical properties inside the body cause regularization difficulties. In this work, we will compare both traditional and machine learning methods, to improve image reconstructions for full array and reduced array electrode models. These methods will be compared using both simulated data and test data collected in a lab, with anomalies placed in varying locations.

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CP14

Chemistry Reduction and Acceleration Based on Neural Network Surrogate

Reducing pollutant emissions, mitigating climate impact and improving the overall ecological footprint of the space sector is becoming a major concern for European manufacturers. Current industrial efforts, particularly for liquid propulsion using LOx/hydrocarbon-based fuel, face a major tradeoff: these fuels give an operational advantage for manufacturers over LH_2. However, they lead to the formation of hydrocarbon-rich byproducts and soot. Since soot particles have a much higher radiative forcing potential than CO_2 and H_2O when released in upper atmosphere, their prediction is crucial for assessing the environmental impact of the launch phase, and more broadly the whole life cycle of a launcher. The present work proposes an innovative data-driven reduction method based on replacing chemical source terms integration in CFD solvers by neural networks. The proposed approach involves training a network on data generated from a detailed mechanism. The training database stores the full thermochemical state of the system at each timestep at time t and $t + dt$. The reduction method consists in applying a transformation to the database to group multiple chemical species into a fictitious one. Thus, the chemistry network is trained to capture the temporal evolution of the reduced thermochemical state. The proposed method was tested and validated on autoignition simulations in pseudo zero-dimensional reactors where it accurately reproduced soot precursor evolution.

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CP14

Generalized Eigenvalues of a Third Order Quaternion Tensor and Multilinear Discriminant Analysis Under Qt-Product

This work investigates a structured approach to multimodal dimensionality reduction using quaternion tensor algebra. Our study focuses on extending the multilinear discriminant analysis (MLDA) to the quaternion domain, following a systematic logical progression. First, we establish a theoretical foundation by defining the generalized eigenvalue problem for quaternion tensors within the Qt-product framework. We provide a spectral characterization of these operators, focusing on the specific algebraic properties induced by the non-commutative nature of quaternions. Building upon this theoretical basis, we develop the Quaternion Multilinear Discriminant Analysis model based on Qt-product. By encoding multiple correlated modalities into the components of a single quaternion tensor, we define quaternion-valued within-class and between-class scatter operators. This formulation seeks to preserve intrinsic cross-modal interactions through the Qt-product structure, which are often neglected in real-valued tensor methods. Finally, we explore the potential application of this framework in multimodal classification tasks. Our preliminary analysis investigates the feasibility of solving the resulting optimization problem and evaluates how this unified representation facilitates more compact feature extraction. This study aims to provide a theoretical stepping stone for advancing discriminant analysis in high-dimensional, multisource data settings.

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CP14

Channel Crosstalk Induced by Detection-Array Symmetry in Orbital Angular Momentum Multiplexing Systems

Orbital angular momentum (OAM) multiplexing can increase the throughput of line-of-sight millimeter-wave links, but practical receivers sample incoming fields with sparse antenna arrays, inducing two-dimensional aliasing and inter-mode crosstalk. We study how the point-group symmetry of sampling locations influences the observed LaguerreGaussian (LG) modal content. Using a group-theoretic classification of arrays (cyclic point groups with vertical mirror planes, C_{nv}) and first-order degenerate perturbation theory, we predict that sampling-induced distortions lead to modes of the same irreducible representation coupling most strongly. We validate the model via coherent field sampling of an approximate first-order LG beam (with a carrier frequency near 84.75 GHz) over a cross-section that is perpendicular to the propagation axis. The beam is generated using a spiral phase plate, and the receiver array is synthesized by rastering a phase-coherent detector over the transverse detection plane. For different sampling geometries (including C_{2v}, C_{3v}, C_{4v}, and C_{6v}) and multiple sampling densities, modal decompositions confirm that symmetry-induced crosstalk decreases with sampling density and indicate that the influence of overall pattern symmetry can dominate that of lattice symmetry. These results provide guidance for OAM receiver design by enabling symmetry- and mode-selection choices that reduce crosstalk and improve link margin.

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CP15

Aligned by Design: How Cross-System Math Alignment Can Improve Students Pathways from High School to College

Too often, discussions about mathematics education focus on constraints rather than possibilities. This session invites higher education mathematics educators to imagine whats possible by exploring insights from Aligned by Design, a new report from Just Equations. Building on research and interviews with K12 and higher education leaders across five states, the report identifies promising strategies for aligning math policies and pathways to support equitable student success. Participants will examine how collaboration across systemsthrough course co-design, transparent expectations, readiness courses, dual enrollment, and aligned admissionscan strengthen students transitions from high school to college. The session treats alignment not as a technical reform but as equity infrastructure: coherent expectations reduce barriers that disproportionately affect students from under-resourced schools. By making mathematics relevant, empowering, and connected to students real-world decision-making, educators can expand opportunity and foster persistence. Attendees will leave with practical strategies and policy insights to advance cross-system partnerships that make math more meaningful and accessible for all learners.

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CP15

Collaborative Use of Interactive Applets in Trigonometry Learning

This study examines the effects of collaborative learning using interactive applets on students ability to find exact values of trigonometric functions for angles in different quadrants and to solve contextual problems involving trigonometric functions. Prior research has highlighted student difficulties in identifying exact trigonometric values beyond the first quadrant and in applying identities such as sum-and-difference and double-angle formulas. These challenges often limit students success in application-based tasks. To address these challenges, the study evaluates the instructional effectiveness of incorporating interactive applets within a structured, pair-based collaborative learning environment. One group of students participated in collaborative classroom activities using interactive applets, while a comparison group received traditional instruction without the use of interactive applets. Students written responses on classroom exams were analyzed to assess their ability to determine exact values of trigonometric functions across different quadrants and to solve contextual problems involving trigonometric functions. The findings indicate that students who participated in collaborative activities with interactive applets demonstrated greater improvement than those receiving traditional instruction. The results suggest that collaborative use of interactive applets can effectively strengthen students understanding and application of trigonometry.

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CP15

Inverse Problems in a Linear Algebra Course

In this talk, I will introduce how to incorporate an inverse eigenvalue problem in linear algebra and how it could lead to undergraduate research projects.

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CP15

Explain the Truth of the Pythagorean Theorem in Two-Dimensional Space Through Various Proof Methods

The Pythagorean Theorem, which comes from ancient Greece, is one of the most important rules in geometry, and later it is also used in many areas like architecture, engineering and computer graphics. The theorem explains that if you take a right triangle, then the square of the two legs added together will be the same as the square of the hypotenuse, written as a + b = c. The theorem also inspired Pythagoras' Tree Fractal, a self-similar geometric structure formed by recursively adding squares to the legs of a right triangle. Plenty of research has been conducted on this theorem; however, these studies are limited to Euclidean geometry, lacking a visual exploration of fractal structures in hyperbolic geometry. This makes it abstract and over-theoretical for middle school students in China. This paper, for the first time, employs a visualization-based approach using GeoGebra, a common mathematical software in middle school, to construct a simplified Pythagoras tree in the Poincar disk model, examining the difference between curved branches and Euclidean tree straight-line branching. The results show very clearly that in hyperbolic geometry, the negative curvature changes the fractal structure and also the angle shapes. Because of this special curvature, the straight line in Euclidean geometry is no longer straight, but it becomes an arc, so the whole fractal looks very different in structure and in appearance from the Euclidean one.

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CP16

A Unified Framework for Estimating Both Constant and Time-Varying Parameters in Epidemiological Systems

Parameter estimation in dynamical systems is typically formulated under the assumption that model parameters are either constant or time-varying , with most existing methods designed to handle only one of these cases. In this work, we present a unified parameter estimation framework that enables the recovery of both constant and time-varying parameters within a single methodology, and using partial observations given by functions of the state variables. The approach is formulated as a data assimilationbased optimization framework, allowing parameters to be estimated locally in time while reconstructing their evolution over the full observation horizon. The method is first demonstrated on a SusceptibleInfectedSusceptible (SIS) system with a time-dependent transmission rate. It is then applied to a SusceptibleInfectedVaccinatedRecovered-Deceased (SIVRD) influenza model using CDC incidence data, illustrating its applicability to real-world epidemiological settings. The results demonstrate stable parameter reconstructions that are robust to observational noise, highlighting the effectiveness of the proposed framework for inverse problems in nonlinear dynamical systems.

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CP16

Edge & HPC Systems for Rapid, Privacy-Preserving Clinical Genomics

We describe an integrated edge HPC workflow tailored for clinical genomics in resource-constrained healthcare settings. The edge tier performs compressed-index alignment, lightweight variant calling, and Sci-LLM-based prioritization while keeping raw reads local; enriched variant summaries are then optionally sent to HPC for deeper annotation and population-level analyses. We present latency, energy, and privacy benchmarks from a field pilot and discuss system tradeoffs (model complexity vs. on-device latency) and governance for clinical use. The pipeline emphasizes pragmatic constraints: limited connectivity, regulatory considerations, and quality-of-care timelines.

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CP16

Analysis of the Nowak Model for Prion Production with the Unfolded Protein Response

Prion diseases are neurodegenerative disorders characterized by the dynamical spread of toxic proteins throughout the brain. In this talk, we develop a mathematical model that accounts for the interaction, aggregation, and degradation of proteins, while also incorporating a cellular defense mechanism that introduces a time delay affecting protein translation. This formulation leads to a system of nonlinear delayed differential equations, a generalization of the Nowak model for prion production. Our first objective is to establish the existence of positive and bounded solutions to the model. Subsequently, we analyze the asymptotic behaviour of the system by deriving conditions on the parameters that govern its dynamics. Additionally, we derive conditions on the time delay under which the system exhibits a Hopf bifurcation.

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CP16

Microbial Dynamics in a Plug-Flow Reactor with a Variable Dilution Rate Induced by Biofilm Growth

Bioclogging — typically driven by microbial overgrowth — plays a key role in a wide range of pathological and engineered settings where blockage develops inside confined channels. Motivated by this common geometry, we study clogging dynamics in plug-flow reactors (PFRs) by coupling spatial transport with wall-associated growth. We propose a modeling framework that captures microbial colonization and surface accumulation under volume (cross-sectional) constraints, thereby linking biofilm buildup to effective dilution. Using this framework, we characterize dynamical regimes and long-term persistence of microbial populations. Our analysis provides mechanistic insight into how channel narrowing reshapes reactor performance and clarifies mechanisms that drive clogging and biofouling.

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CP16

Learning Reaction Rates from Product Formation-Time Data in Multiscale Stochastic Reaction Networks.

We study parameter inference in multiscale stochastic reaction networks when only product formation times are observed. Classical inference methods require full state trajectories and therefore cannot be applied in this setting. Using scaling limits and stochastic averaging, we reduce high-dimensional MichaelisMenten systems to effective one-dimensional dynamics. A weakly interacting particle system construction and propagation of chaos yield asymptotically independent event times and a tractable likelihood. This framework enables both frequentist and Bayesian estimation directly from event-time data, connecting multiscale stochastic analysis with statistical inference.

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CP17

Memory-Driven First Passage Time Analysis of Deformable Fiber Transport in Perforated Media

Transport of deformable fibers in heterogeneous porous media often exhibits long-time correlations that cannot be captured by classical Markovian diffusion models. We formulate an upscaled description based on a Continuous Time Random Walk framework with non-exponential waiting-time distributions, leading to a FokkerPlanck equation with temporal memory. Applying a Laplace transform reduces the governing equation to a modified Helmholtz problem in a perforated domain with a frequency-dependent parameter determined by the memory kernel. Semi-analytical solutions are constructed using FourierBessel expansions and matrix systems derived via Grafs addition theorem. From these solutions, first passage time and mean first passage time statistics are obtained explicitly, revealing how memory kernels control delay, localization, and anomalous scaling. In the exponential limit, the model recovers classical diffusion, providing a unified framework for both Markovian and non-Markovian transport.

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CP17

Statistical Inference for Fractional Brownian Bridges Via Independence Transformations

Fractional Brownian bridges are Gaussian processes with boundary constraints and long-range dependence, which complicates statistical inference. We introduce a transformation that converts dependent-bridge observations into independent variables, thereby removing dependence on the unobservable terminal value. This representation enables the use of classical inference methods and reveals an exponential family structure with sufficient and complete statistics. As a consequence, optimal estimators, including uniformly minimum variance unbiased estimators, can be constructed. These results provide a new theoretical and statistical framework for inference in fractional Brownian bridge models with Hurst parameter H=1/2.

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CP17

Data-Driven Rate Recovery and Sensitivity Analysis for Discrete Stochastic Chemical Reaction Systems

Identifying governing parameters of discrete stochastic reaction networks from trajectory data is a core challenge in computational science, since direct inversion of the chemical master equation is typically intractable. We present a data-driven mass-action framework based on extended dynamic mode decomposition. From stochastic simulation algorithm trajectories, we construct snapshot pairs in an observable dictionary matched to mass-action propensities, estimate a finite-dimensional Koopman operator, recover a continuous-time generator through a matrix logarithm, and extract reaction rates algebraically from the species rows of the recovered generator. The observable-space dynamics are represented as $\frac{d}{dt}\langle\psi(x)\rangle = \mathcal{A}\langle\psi(x)\rangle$, which avoids assembly of the full probability-space operator. To quantify robustness, we perform Fréchet-derivative sensitivity analysis of the logarithm map. Using a block-matrix identity, we compute $D\log(K)[E]$ efficiently without eigendecomposition and obtain first-order error propagation formulas for individual reaction channels. This yields a condition metric κ that identifies when spectral clustering amplifies rate uncertainty, especially in oscillatory regimes. Experiments on Lotka-Volterra, Michaelis-Menten, and Brusselator models show accurate rate recovery together with interpretable sensitivity trends.

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CP17

Harmonic-Measure Distribution Functions in Various Geometries

Consider releasing a Brownian particle from a basepoint z_0 in a planar domain Ω. What is the chance, denoted $h_{\Omega,z_0}(r)$, that the particles first exit from Ω occurs within a fixed distance $r > 0$ of z_0? The function $h_{\Omega,z_0}(r)$: $[0,\infty) \to [0,1]$ is called the harmonic-measure distribution function, or h-function, of Ω with respect to z_0. It can also be formulated in terms of a Dirichlet problem on Ω with suitable boundary values. For simply connected domains Ω, the theory of h-functions is now quite well-developed, and in particular the h-function can often be explicitly computed, making use of the Riemann mapping theorem. However, until recently, for multiply connected domains the theory of h-functions has been almost entirely out of reach. In this talk, it will be shown how to construct explicit formulae for h-functions of symmetric multiply connected slit domains whose boundaries consist of an even number of colinear slits, and how these formulae can be generalized to compute h-functions for multiply connected slit domains on a spherical surface. Special function theory and conformal mapping are judiciously combined to this end.

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CP17

The Stress Dependent Random Walk

Our stress levels change constantly and our behavior with it. It is plausible that market participants should behave the same. We propose to order daily returns by stress levels rather than chronological. A log-normal random walk with parameters that are functions of market stress naturally accounts for volatility clustering and fat-tailed return distributions. Fitting this model to a stock and a bond index we find no evidence of significant misspecification even though the model has no adjustable parameters. This model can be interpreted as a stochastic volatility model without latent variables. We obtain a closed-form expression for the Value at Risk (VaR) that accommodates returns of any magnitude and discuss several other applications.

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CP17

Sanctions As Perturbations of Entropic Optimal Transport: Explicit Sensitivity and Diversion Certificates

We study entropic-regularized optimal transport: for full-support $a \in \Delta^m$, $b \in \Delta^n$ and cost $C \in \mathbb{R}^{m\times n}$, minimize $\langle C, P\rangle + \varepsilon\sum_{i,j} P_{ij}(\log P_{ij} - 1)$ over $P \geq 0$ with $P\mathbf{1} = a$, $P^\mathsf{T}\mathbf{1} = b$. The unique optimizer $P = P_\varepsilon(C)$ satisfies $P_{ij} = \exp((\alpha_i + \beta_j - C_{ij})/\varepsilon)$. We show $C \mapsto P_\varepsilon(C)$ is Fréchet differentiable on the quotient by row/column gauges and derive an explicit sensitivity map. For a perturbation H, fix gauge $b^\mathsf{T}\delta\beta = 0$ and solve $\mathrm{Diag}(a)\delta\alpha + P\delta\beta = (P \odot H)\mathbf{1}$, $P^\mathsf{T}\delta\alpha + \mathrm{Diag}(b)\delta\beta = (P \odot H)^\mathsf{T}\mathbf{1}$ with $P = P_\varepsilon(C)$. Then $\mathrm{D}P_\varepsilon(C)[H] = \varepsilon^{-1}P \odot (\delta\alpha\,\mathbf{1}^\mathsf{T} + \mathbf{1}\delta\beta^\mathsf{T} - H)$. This yields first-order counterfactuals for targeted sanctions $H = \lambda E_{ij}$ and a Lipschitz bound $\|P_\varepsilon(C+H) - P_\varepsilon(C)\|_1 \leq \kappa\|H\|_\infty$, where κ is controlled by the smallest nonzero eigenvalue of the Schur complement $\mathrm{Diag}(a) - P\,\mathrm{Diag}(b)^{-1}P^\mathsf{T}$ on $\mathbf{1}^\perp$. The same implicit-function argument extends to convex penalties modeling soft capacities or bans, yielding influence functions for diversion (primal) and incidence (dual potentials), fast to evaluate.

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CP18

Physics-Informed Neural Networks for Inverse Parameter Estimation in the Gray-Scott Reaction-Diffusion System

We address the inverse problem of estimating the feed rate F and kill rate K from observed concentration fields in the 2D Gray-Scott system. Two physics-informed neural network (PINN) strategies are compared: (i) a *pure* time-dependent PINN that treats F and K as learnable parameters via automatic differentiation, and (ii) a *parametric* CNN encoder mapping fields to parameter estimates. Both are benchmarked against data-driven baselines (CNN and Bi-LSTM). The pure PINN achieves sub-2% relative errors across diverse Turing patterns, outperforming baselines, while the parametric encoder attains competitive accuracy with inference speedups above three orders of magnitude. The proposed training strategy - combining data-only warmup, gradual PDE ramp-up, and separate optimizers -is essential for robust convergence. Results show that embedding the PDE structure as a soft constraint provides an inductive bias that compensates for data scarcity, establishing PINNs as an effective framework for inverse parameter identification in reaction-diffusion systems. This work is partially supported by the project: FLINT - Prog. n.: F/380134/01-03/X77 - MIMIT This work is partially supported by the project: TUAI: Towards an Understanding of Artificial Intelligence via a transparent, open and explainable perspective, Marie Curie Doctoral Network, ID: 101168344

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CP18

Model Synthesis and Identifiability Analysis of Stiff Chemical Reaction Systems with Invaert Networks.

The computational cost of integrating stiff chemical reaction systems motivates neural network-based acceleration. Complementary to this, is the task of amortized inference, estimating reaction rate parameters from full or partial concentration data without the need to retrain the network. Structural non-identifiability, i.e., multiple parameter sets producing nearly identical concentration profiles make this task especially challenging. Our work demonstrates the effectiveness of InVAErt networks, a data-driven framework, in providing a unified apparatus for forward emulation, density estimation and inverse parameter recovery for stiff dynamical systems, where the problem is formulated under uniformly distributed priors, and validated using established benchmarks such as the ROBER and POLLU systems. To ensure robust performance across transient and slow-varying regimes, we implement a solution-adapted resampling approach during data generation. The framework employs data-driven emulators based on ResNet and LSTM architectures, and a conditional VAE-based encoder decoder setup for model inversion. This approach circumvents the need for repeated numerical integration, while simultaneously providing almost instantaneous parameter retrieval without retraining.

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CP18

Dynamic-Time-Warping-Based Trajectory Clustering Analysis Identifies High-Risk and Previously Overlooked Chronic Kidney Disease Patients

Background: Many chronic kidney disease (CKD) patients remain undiagnosed, and their characteristics are unclear. Conventional analyses have difficulty capturing their clinical courses. This study aimed to identify overlooked CKD groups at high risk of dialysis or death. Methods: We applied a newly developed AI algorithm—time-series K-means with dynamic time warping—to classify 3,129 patients using 34 time-series variables, including background, laboratory data, and medications. Barycenter transition analysis was used to visualize group trajectories. Results: The mean age and eGFR were 62.0 years and 50.6 mL/min. Seven clinically interpretable groups were identified. One group had low urinary protein, no hypertension, and no clear CKD cause; although considered low risk and not specifically treated, their outcomes were worse than those of treated hypertensive patients (hazard ratio 2.82; 95% CI 1.58–5.09; $p < 0.0001$). While groups initially showed distinct courses, their trajectories gradually converged into a final common pathway. Conclusion: AI-based trajectory clustering revealed a previously overlooked CKD group with poor outcomes despite benign initial findings. This approach is useful for detecting unmet clinical needs in large datasets.

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CP18

Geometric Structure and Loss Landscape of Relu Networks on Sequentially Linearly Separable Data

In this project, we investigate the geometric structure of deep ReLU neural networks trained on sequentially linearly separable (SLS) data, building upon the frameworks developed in [Munoz Ewald, Explicit ReLU Classifiers for Non-Separable Data, 2025]. We generate synthetic datasets designed to be SLS using explicit hyperplanes and cone constructions. A feedforward ReLU network is then trained via stochastic gradient descent to classify these datasets. After training, we extract the cumulative weight matrices and bias vectors across layers to recover the linear maps implemented by the network. Using these parameters, we construct truncation maps and their polyhedral cones, compute each cones base point and edge vectors, and visualize how the data is transformed layer by layer through PCA projections. Through this pipeline, we show that cone-like structures emerge during training and that they visualize learned decision geometry. Subsequently, we construct explicit weights and biases implementing separating hyperplanes of the synthetic data, yielding zero-loss global minima. We then perturb these parameters, run gradient descent from these perturbed initializations, and analyze how training converges to study the local loss landscape around these minima. Finally, we construct suboptimal

local minima by selectively disabling truncation maps to study their stability and energy efficiency as replacement initializations through local perturbation-based loss landscape analysis.

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CP18

Computing the Basis Functions for Multiscale Problems Using Physical Informed Neural Network

The major problem in multiscale simulations is to obtain an accurate description of a flow behavior, in spite of the intrinsic heterogeneity of the medium. Numerical solution of these equations requires a very fine computational mesh, something that is infeasible to consider even with our modern supercomputers. To overcome this problem, one uses asymptotic analysis as a tool to produce homogenized equation that approximate the solutions of the original equation. This procedure of replacing the original systems is called homogenization. In this context, computing the cell-problems and the related basis functions for first-order approximation can be computationally demanding by traditional means and many efforts in the literature have been dedicated to minimize this cost. In this talk, I will present a way to compute using Machine Learning (ML), where the data used to start the training of the network is generated by an analytical approximation of the cell-problem (in $L^2(\Omega)$), then the final solution (in $H^1(\Omega)$) is produced when the underlying physics into ML is introduced and the minimization of the error between the data and the original PDE, through Physics Informed Neural Network (PINN) is achieved. I will present results showing how this approach compares to standards numerical approaches and with the ML for solving the cell-problem without this proposed initialization data.

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CP18

Hypernetwork-Based Approach for Grid-Independent Functional Data Clustering

Clustering functional data is sensitive to discretization: most methods implicitly operate on sampled grids, causing cluster assignments to depend on resolution and preprocessing. This is problematic for scientific applications, where each observation represents functions and discretization approximates an underlying infinite-dimensional object. We propose a resolution-independent framework that maps functions to a fixed-dimensional representation. Our auto-encoding architecture encapsulates the information of each function into a compact representation — a key requirement in computational and engineering applications where data is scarce. The encoder is a hypernetwork that maps observations of a function at arbitrary resolution to the weight-space of an implicit neural representation (INR), which serves as the decoder. As INRs are well-known for accurately representing individual functions with very few parameters, this design yields low-dimensional representations that are decoupled from the sampling grid, while the hypernetwork learns to map previously unseen functions to the weights of an INR capable of approximating them. Clustering is performed in this latent space, allowing direct application of existing finite-dimensional clustering algorithms. Through synthetic and real-world examples in high-dimensional settings, we demonstrate that our approach achieves competitive clustering performance while uniquely exhibiting robustness to change in sampling resolution.

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CP19

Mathematical Modeling of Complex Systems with Applications to Fisheries

This study aims to deepen the understanding and optimize fishing activity in Morocco by holistically integrating biological and economic aspects. On the biological front, we examine the rivalry between three marine species: Sardine, Mackerel, and Tuna, and the need to preserve the balance of their biomass. On the economic side, we focus on maximizing fishermens profits. We develop a biological equilibrium model for fishermen operating in the Atlantic region, where the three species coexist. These competing species exhibit their natural growth represented by logistic curves. We propose a mathematical model that takes into account the density and competition between species to explain population dynamics. Integrating human intervention adds a realistic dimension to our modeling. Fishermen specifically target all three species, thereby influencing population dynamics based on their fishing activities. This approach allows us to explore the effects of human-nature interaction on the biological equilibrium of sardine equilibrium of sardine, mackerel, and tuna populations

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CP19

Machine LearningEnhanced Reduced Order Modeling for Fast Parametric Simulation of Seismic Wave Propagation

High-fidelity numerical simulation of parameter-dependent wave equations is a central problem in scientific computing, as repeated large-scale solves are highly expensive for many-query and real-time settings. Building on recent advances in Proper Orthogonal Decomposition (POD) and machine-learning-assisted reduced order modeling, this project aims to develop efficient reduced-order and data-driven methodologies for the fast and accurate approxi-

mation of parametric seismic wave propagation. The focus will be on the construction of low-dimensional reduced spaces and on the integration of machine learning techniques to learn the parametric dependence and time evolution of the reduced systems, enabling rapid prediction at previously unseen parameter values. The proposed methods will be validated against high-fidelity finite-element discretizations of the seismic wave equations, viewed as a challenging benchmark for large-scale, time-dependent parametric PDEs. This work results in the development of robust ROMML methodologies for the efficient and accurate approximation of parametric seismic wave propagation

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CP19

Bayesian Emulators on Planet Formation Condition

Exploring the full parameter space of planet formation conditions and processes is computationally impractical as each simulation can take weeks to complete, and the parameter space remains vast. In this work, we propose a framework to infer planet formation conditions while reducing computational costs. Our approach accounts for intrinsic variations in conditions and the stochastic nature of outcomes within a given set of conditions. We employ statistical emulators to model the relationship between planet formation parameters - such as solid normalization, radial distribution of solids, and gas disk depletion - and key observables, including period ratio, transit multiplicity, transit ratio, and hill spacing. Since these observables are inherently stochastic and represented by probability distributions, we first map the stochastic outputs to a reduced-dimensional space. We then use Gaussian processes (GP) to model the relationships within this reduced space. Once the emulators are trained on existing simulation data, we apply a Bayesian modular approach to infer the underlying parameters. Fast GP predictions within the likelihood ensure computationally feasible inference.

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CP19

A Spatio-Temporal Cp Decomposition Analysis of New England Region in the Us

Spatio temporal data consist of measurement for one or more raster fields such as weather, traffic volume, crime rate, or disease incidents. Advances in modern technology have increased the number of available information for this type of data hence the rise of multidimensional data. We will be using the NCAR Climate Data Gateway website which provides data discovery and access services for global and regional climate model data. The daily values of total precipitation (prec), maximum (tmax), and minimum (tmin) temperature are combined to create a multidimensional data called tensor (a multidimensional array). In this talk, I will present our method using a spatio temporal principal component analysis to initialize CP decomposition component. We take full advantage of the spatial and temporal structure of the data in the initialization step for cp component analysis. The performance of our method is tested via comparison with most popular initialization methods. We also run a clustering analysis to further show the performance of our analysis.

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CP20

Topological Photonics: A Methematical Perspective

In the field of light matter interactions, current technologies allow the design of optical media (photonic lattices, photonic crystals, metamaterials) so that novel states of light are created. As such, topological photonics refers to features of such states of light that are characterized by a topological (quantized) property, leading to for example robust propagation properties. This talk will introduce the audience to the field as well as highlight current developments.

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CP20

Interpretable Network Structure Using Topological Data Analysis

Topological Data Analysis (TDA) is an emerging tool in the field of network analysis. Our groups previous work has applied persistent homology, a TDA method, to neural, quantum, and machine learning data with a focus on Betti numbers and birthdeath diagrams to characterize higher-order organization in network systems. However, other TDA approaches such as Mapper [Madukpe, Ugoala, and Zulkepli, A Comprehensive Review of the Mapper Algorithm] and sheaf cohomology [Curry, Sheaves, Cosheaves and Applications] have the potential to provide additional insight into the structure of data in network models. In this work, we applied Mapper to analyze neural, machine learning, and quantum network data to discover underlying structural relations in the data. Through mathematical analysis and application, we determine how Mapper lens functions reveal interpretable topological structures - such as cycles, voids, and hubs - and their relation to network dynamics and organization across neural, machine learning, and quantum systems.

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CP20

Topology Optimization for Iso-Complaint 3D Printable Prosthetic Foot

Prosthetics are assistive devices designed to replace missing limbs and restore mobility and functionality to amputated individuals. The mechanical performance of a prosthetic foot must satisfy strength, durability, and compliance requirements while remaining lightweight and comfortable for the patient. In this work, we present a computational framework to streamline the topology design of prosthetic feet. We begin by constructing a reference domain derived from the patients anatomical scan. Boundary conditions are then applied in accordance with relevant ISO standards, scaled to the patients body weight, to accurately represent physiological loading scenarios. Material properties are defined to initiate the 2D topology optimization procedure. The optimization is then performed by iteratively updating the material density distribution within the design domain to achieve minimal compliance with constraints on material volume fraction. Then design is post-processed using spline-based smoothing algorithms to eliminate rough boundaries for maximum compatibility with 3D printing and reduced stress. The entire framework is implemented using open-source computational tools, including FEniTop and DOLFINx, which provide robust finite element analysis and optimization capabilities. The results demonstrate that the proposed automated framework enables rapid, reliable, and consistent prosthetic foot designs, offering a scalable approach for patient-specific prosthetic development.

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CP20

Discrepancy Minimization and Mean Curvature Flow

The level-set formulation of motion by mean curvature is a degenerate parabolic partial differential equation, known as the mean curvature flow (MCF) equation. We show that when the initial hypersurface is the hypercube in $\mathbb{R}^m$, the solution of the MCF equation can be characterized as the value function of an existing combinatorial discrepancy problem, the so-called online Komlos problem. More precisely, we specify a sequence of discrete-time online Komlos problems whose value functions converge in the continuous-time limit to the solution of the MCF equation. This is another instance of a mean curvature flow arising from a two-person game, following Kohn, Serfaty (CPAM 2006).

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CP21

Eigenvalue Bound Preservation: Numerical Experiments on the 2D Q-Tensor Flow

We study the evolution of nematic liquid crystals in two dimensions using the Q-tensor model, a continuum framework that describes the orientational order of rod-like molecules via symmetric, traceless matrices. Focusing on the Landau-de Gennes energy and its associated gradient flow, we consider a reduced two-dimensional formulation in which the Q-tensor is fully described by two scalar functions. This reduction simplifies the system to a nonlinear, coupled PDE for the scalars, while preserving essential physical features. A key question is whether the eigenvalues of the Q-tensor remain within the physically admissible range under this flow. Building on a theoretical result that establishes eigenvalue preservation for smooth solutions, we perform numerical simulations to verify this behavior. Our results confirm the robustness of the eigenvalue constraint across various initial configurations, providing computational support for the physical consistency of the model.

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CP21

Stability and Dispersion Analysis of Spectral Finite Element Methods for Linear Dispersive Metamaterials

Electromagnetic metamaterials are artificial media designed to control wave propagation in ways not observed in natural materials. Their behavior is often modeled using dispersive constitutive laws, such as the Drude and Lorentz models, which lead to frequency-dependent material parameters. Reliable numerical simulation of these media requires methods that can accurately predict wave speeds while remaining stable over long time intervals. In this talk, we present a study of the dispersion and stability analysis of time-dependent Maxwells equations in linear dispersive metamaterials using a high-order mass-lumped finite element method. The dispersive effects are incorporated through auxiliary differential equation formulations. From the semi-discrete system, we derive the numerical dispersion relation and compare it with the continuous model to understand phase errors and anisotropy. We further investigate the stability of the method using a von Neumann analysis and determine the conditions under which spurious modes may appear. Numerical results verify the theoretical predictions for anisotropy, demonstrate the expected convergence rates of the dispersion error, and illustrate the stability behavior of the method. These findings provide insight into the performance of high-order methods for simulating wave propagation in complex electromagnetic materials.

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CP21

Asymptotic Analysis of Switching Diffusion Processes with Periodic Coefficients

We study homogenization for a class of switching diffusion processes (also called diffusion-transmutation processes) whose drift and diffusion coefficients, and jump intensities are smooth, spatially periodic functions; we assume full coupling between the continuous and discrete components of the state. Assuming uniform ellipticity of the diffusion matrices and irreducibility of the matrix of switching intensities, we explore the large-scale long-time behavior of the process under a diffusive scaling. Our main result characterizes the limiting fluctuations of the rescaled continuous component about a constant velocity drift by an effective Brownian motion with explicitly computable covariance matrix. The main quantitative finding is the computation of an extra contribution to the limiting diffusivity stemming from the switching.

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CP21

A Higher Order Polytopal Method for Contact Mechanics with Tresca Friction

In this work, we design and analyze a Discrete de Rham (DDR) scheme for a contact mechanics problem involving fractures along which a model of Tresca friction is considered. Our approach is based on a mixed formulation involving a displacement field and a Lagrange multiplier, enforcing the contact conditions, representing tractions at fractures. The approximation space for the displacement is made of vectors values attached to each vertex, edge, face, and element, while the Lagrange multiplier space is approximated by piecewise constant vectors on each fracture face. The displacement degrees of freedom allow reconstruct piecewise quadratic approximations of this field. We prove a discrete Korn inequality that account for the fractures, as well as an inf-sup condition (in a non-standard $H^{-1/2}$-norm) between the discrete Lagrange multiplier space and the discrete displacement space. We provide an in-depth error analysis of the scheme and show that, contrary to usual low-order nodal-based schemes, our method is robust in the quasi-incompressible limit for the primal variable (displacement). An extensive set of numerical experiments confirms the theoretical analysis and demonstrate the practical accuracy and robustness of the scheme.

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CP21

Steady Vibration Problems in the Coupled Theory of Thermoporoelasticity under Moore-Gibson-Thompson Heat Conduction

In the present work, the linear theory of Moore-Gibson-Thompson thermoporoelasticity is considered, and the 3D basic boundary value problems (BVPs) of steady vibrations of this theory are investigated. Namely, the fundamental solution of the governing system of steady vibration equations is constructed explicitly. Green's formulas are obtained and the uniqueness theorems for classical solutions of the BVPs are proved. The BVPs are reduced to the always solvable singular integral equations for which Noether's theorems are valid. The existence theorems for classical solutions of the BVPs of steady vibrations are proved by using the boundary integral equations method and the modern theory of the singular integral equations. Acknowledgements: This work was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG) [Grant # FR-23-4905].

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CP22

Multi-Fidelity Particle Flow Filter

This work proposes a new Multi-Fidelity Particle Flow Filter (MF-PFF) based on a linear control variate framework and multilevel Monte Carlo methods. Conventional particle filters often suffer from weight collapse and degeneracy in high-dimensional spaces. Particle flow filters address this by smoothly transporting prior particles toward the posterior distribution using a homotopy-based advection-diffusion law, thereby avoiding the need for resampling. We explore, in this study, a two-fidelity data assimilation framework utilizing both stochastic (Gromov) and deterministic (Exact) flows, applied to the Korteweg-De Vries (KdV) and Quasi-Geostrophic (QG) test problems. To reduce computational cost, we augment a small ensemble of expensive full-order model runs with a large ensemble of inexpensive reduced-order surrogates, constructed via intrusive Galerkin projection. These surrogates act as control variates to enhance the statistical estimate of the full-order posterior. Numerical experiments demonstrate that the proposed MF-PFF achieves accuracy comparable to high-fidelity simulations while significantly reducing computational expense.

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CP22

Data Assimilation for Chemical Reaction Networks and Population Models

Chemical Reaction Networks (CRNs) modeling biochemical and industrial processes may exhibit complex nonlinear dynamics, including multi-stability, oscillations and chaos, making the real-time estimation of unmeasured species concentrations a significant challenge. Our work presents a linear algebraic framework for the design of observers for CRNs that guarantee exponential convergence of the observer error for a certain class of CRNs. This class includes systems that are oscillatory or even chaotic. Moreover, our method is applicable not only to CRNs, but other population models that appear in epidemiology and ecology which share a common structure with CRNs. Our observer design process relies on identifying a so-called critical stoichiometric subspace and introducing an associated decomposition of the state space into the direct sum of certain subspaces. We provide a sufficient condition for the exponential stability of the error dynamics, which reduces the complex nonlinear estimation problem to the verification of the Hurwitz property of a derived system submatrix. We also provide an analysis of the performance of our observer when the observations are assumed to be corrupted by noise. The efficacy of this observer is explicitly demonstrated through its application to some real world CRN examples. These examples highlight the capability of this proposed observer to robustly reconstruct hidden trajectories even in chaotic cases.

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CP22

Second-Order Flows for Variational Minimization Via the Sav-E Approach

Second-order flows represent an emerging paradigm for non-convex variational minimization, characterized by damped hyperbolic partial differential equations. In this work, we develop a novel scalar auxiliary variable method (SAV-E) tailored for this class of flows, yielding a scheme that is linear and unconditionally energy-stable. We rigorously prove the unconditional energy stability in terms of a modified energy. Furthermore, we conduct an in-depth analysis of the subsequential convergence to a stationary point. We identify a critical theoretical bottleneck regarding the uniform boundedness of the numerical solution in the infinite-dimensional setting, which poses a significant challenge for establishing strong convergence without additional assumptions. Extensive numerical experiments validate the unconditional stability and demonstrate the superior robustness and efficiency of the proposed method compared to state-of-the-art baselines, showcasing its practical convergence despite the identified theoretical open questions.

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CP22

Structure-aware Coefficient Estimation in Polynomial Chaos Methods

In uncertainty quantification, polynomial chaos is a non-sampling technique that can be used to approximate the solution of a partial differential equation (PDE) with stochastic parameters. The PDE solution is expressed as a countably infinite polynomial expansion that is truncated via an M bound for the sake of approximation. The approach is then to derive a resulting system of deterministic (often coupled) PDEs, called an M system, with Galerkin projection and solve the M system for the expansion coefficients with standard numeric techniques. One challenge in this approach is that there is no flexibility around choosing which expansion coefficients in an M system are more advantageous to estimate accurately. In this talk, we examine common structural features of M systems that emerge when solving stochastic PDEs with polynomial chaos. We then consider how to design an algorithm that can take advantage of this shared structure to judiciously prioritize the expansion coefficients whose estimates have greater influence on the final solution.

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CP22

Worst-Case Optimal Fourier Multipliers for Bounded Frequency Extrapolation

Recovering fine-scale image details from coarse measurements is a classical problem in image processing, closely related to deconvolution and super-resolution. A common formulation views this task as frequency extrapolation: estimating high-frequency components of a Fourier transform from known low-frequency data. When the target high-frequency region is unbounded, the problem becomes severely ill-posed. One way to mitigate this difficulty is to restrict extrapolation to a bounded high-frequency region. Under this restriction, the problem can be simplified, focusing on the design of a convolution filter, or Fourier multiplier, that minimizes an approximation error metric over a known class of images. In this talk, we show that, under suitable conditions, a worst-caseoptimal multiplier exists for the entire class and that all such optimal multipliers share a common canonical structure. For finite image collections, we further show that the set of worst-caseoptimal multipliers can be parameterized by a positive definite matrix, which leads to a practical fixed-point iteration for computing an optimal multiplier. Numerical experiments illustrate the effectiveness of the proposed approach.

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MS1

Computationally Efficient Techniques for Bayesian UQ on Parametric Image Reconstruction

Quantifying uncertainty in the solution to imaging inverse problems remains a significant computational challenge. In the cases where target objects are assumed to be piecewise constant (such as tumor boundaries in medical imaging) and measured data are limited and noisy, traditional pixel-level inversion methods may not be feasible. This work explores novel approaches to efficient uncertainty quantification in this setting by introducing parametric image representations that incorporate hierarchical Bayesian inference techniques. Numerical results demonstrate the effectiveness of our approach in UQ for image reconstruction on several computed examples.

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MS1

Efficient Low Rank Nodal DG Methods Accelerated Via Sketching-Based Summation of Tucker Tensors

In this talk, we present advances in a hybrid computational method combining Nodal Discontinuous Galerkin (NDG) discretization with low-rank tensor approximations for solving the BGK kinetic equation. Our approach addresses the curse of dimensionality inherent in kinetic simulations by employing nodal DG for physical space variables and low-rank Tucker tensor decomposition with accelerated sketching-based summation for velocity space discretization. This combination reduces computational costs and memory requirements while maintaining accuracy. We demonstrate the method's performance through numerical experiments, highlighting both its advantages and current limitations of our solver.

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MS1

Learning Locally Mass Conservative Solutions of Darcy Flows

Due to the popularity of AI, there is an increased interest in applying machine learning algorithms to model physical phenomena in science and engineering. However, purely data driven methods fail to capture accurate solutions for problems that rely on physical conservation laws; these problems are characterized by coupled and nonlinear partial differential equations. The field of scientific machine learning (SciML) addresses the drawbacks of purely data driven machine learning by constraining the learned solution to physical laws. In this talk, we formulate a SciML method that learns a finite-dimensional representation of the true solution of the PDE. Our numerics informed neural network (NINN) method is mesh aware and utilizes knowledge from classical numerical methods for PDEs. Small convolutional neural networks are trained in an unsupervised manner to predict solutions of PDEs that lie in the space of discontinuous piecewise polynomials. The loss function is inspired from the discontinuous Galerkin method. We show convergence of the NINN method as the mesh size tends to zero under the assumption of a controlled optimization error. Various numerical examples confirm the theoretical error bounds.

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MS1

Structure-Preserving Reduced-Order Modeling for Advection Dominant Equation Via Optimal Transport

Efficient simulation of parameterized differential equations is critical for optimal design, control, and inversion in science and engineering. Many queries for high-fidelity solutions are computationally expensive, necessitating reduced-order modeling to construct efficient surrogate solvers. This work focuses on advection dominant equation such as a time-dependent Fokker-Planck equation and its model reduction strategy. We leverage optimal transport to transform the original solution space into the Wasserstein tangent space to address the convection-dominant feature, and apply skeleton decomposition to select basis directly from the feature matrix so that it preserves the optimal transport structure in the tangent space. Because of the intrinsic structure of their solutions, the model requires the design of structure-preserving (e.g., positivity) reduction strategies.

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MS2

Rank Geometry for Real $2 \times 2 \times 2$ Tensors: Singularities, Best Low-Rank Approximations, and Visualization

Even small, real valued tensors of size $2 \times 2 \times 2$ are sufficient to demonstrate interesting phenomena like rank-jumping sequences and ill-posed low-rank approximation problems, which do not plague matrices of any size. We highlight and review the geometric and algebraic complexities that distinguish tensors from matrices, showing how tensors violate many well-known matrix properties. For example: matrices have a single typical rank, but $2 \times 2 \times 2$ tensors can be rank 2 or 3 with positive probability; matrices always have a best rank-r approximation, but no rank-3 tensor of size $2 \times 2 \times 2$ has a best rank-2 approximation. We unify the analysis of the matrix and tensor cases using tools from algebraic geometry and optimization, in some cases providing new direct proofs which better leverage geometric intuition. Many seemingly counterintuitive facts are shown to arise from the geometry of the singular locus of the hyperdeterminant, a connection we make clear. Throughout we confirm and build geometric intuition using new interactive visualizations for sets of fixed and bounded rank.

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MS2

Morse Inequalities for Stratified Semi-Algebraic Sets and Applications

We extend the classic Morse inequalities to polynomial Morse functions on Whitney stratified semi-algebraic subsets of R^n.

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MS2

Stiefel Optimization Is Np-Hard

We show that linearly constrained linear optimization over a Stiefel or Grassmann manifold is NP-hard in general. We show that the same is true for unconstrained quadratic optimization over a Stiefel manifold. We will show that unless $\mathrm{P} = \mathrm{NP}$, these optimization problems over a Stiefel manifold do not have FPTAS. As an aside we extend our results to flag manifolds. Combined with earlier findings, this shows that manifold optimization is a difficult endeavor even the simplest problems like LP and unconstrained QP are already NP-hard on the most common manifolds.

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MS2

Lagrange Multiplier Expressions and Tightness in Matrix Polynomial Optimization

Matrix polynomial optimization (MPO) arises in control, quantum information, and signal processing, but is computationally challenging due to noncommutativity and the size of semidefinite relaxations. In this talk, we study first-order optimality conditions for MPO and derive explicit formulas for the associated Lagrange multiplier matrices under standard nondegeneracy assumptions. Using these expressions, we develop a strengthened MomentSOS hierarchy. We show that this hierarchy is tight in the sense that it achieves finite convergence under general conditions, thereby closing the gap between relaxation and global optimality. We also present practical criteria for detecting tightness and extracting optimizers, supported by numerical experiments demonstrating significant efficiency gains over standard SOS methods.

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MS3

Boundaries of logarithmic Voronoi Cells Can be Transcendental

Logarithmic Voronoi cells partition the probability simplex according to which point of a statistical model best explains the data in the maximum-likelihood sense. I will present two examples showing that, even for very simple algebraic statistical models, these cells need not have algebraic boundaries. The examples are one-dimensional models in the probability simplex: a union of two lines and a cuspidal curve.

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MS3

Identifiability of Level-2 Phylogenetic Networks Under the Jukes-Cantor Model

In statistical evolutionary biology a common research question is whether we can infer past evolutionary events from observable genetic data. Usually this means fitting a tree-based probability model to our data which describes some set of evolutionary events. These models can tell us how species evolved together and how long ago they split off from common ancestors. Phylogenetic networks extend tree-based models to allow for hybridization, horizontal gene transfer (the movement of DNA between organisms that dont share a parent-offspring relationship) and other non-treelike processes. However, the space of such models is huge, and in many cases different topologies can give the same probabilities of observing our data, making the true model unidentifiable. We prove generic identifiability for a class of networks under the Jukes-Cantor model using tools from computational algebraic geometry and combinatorics.

In this talk I will show how the network topology is recoverable with any number of leaves, so long as we only allow up to two hybrid events per biconnected component, and we dont allow three-cycles or hybrid events that lead directly into another hybrid event. These results clarify when it is possible to reconstruct complex evolutionary histories from genetic data.

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MS3

Identifiability of Species Relationships from Quintet Concordance Factors

Phylogenomics attempts to infer evolutionary relationships between taxa, depicted as a tree or a network, from sequence data for many genes. The Multispecies Coalescent Model describing how gene trees arise from the species network, provides a framework for studying what network features can be inferred from summaries of unrooted topological gene trees. Identifiability of level-1 network features from quartet concordance factors has been well-studied, giving a theoretical basis for practical inference methods, despite the non-identifiability of network roots and 2-cycles from them. Since quintet concordance factors identify the root location of a species tree by [Allman2011] we began a preliminary investigation of quintet CFs in a network setting. We give several distinguishability results, indicating that quintet CFs indeed contain information on 2-cycles and network rooting. We also develop software to calculate concordance factors symbolically.

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MS3

Finding Input-Output Equations for Linear Compartmental Models with Prescribed Orders

Linear compartmental models are linear systems of ODEs that are determined by a graphical structure G. A common question that arises when performing parameter estimation is whether the parameters in our model can be recovered uniquely from perfect input-output data (i.e. data from variables we can measure). One way to assess this is by studying the coefficients of input-output equations, which are usually obtained via differential elimination. In this talk, we discuss a linear algebra-based algorithm that allows us to compute ”nice” sets of input-output equations that have prescribed orders for the derivatives that appear in the equations.

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MS4

Learning Pseudo-Differential Operators

Pseudo-differential operators (PDOs) are a broad and fundamental class of operators in analysis and partial differential equations, with wide-ranging connections to inverse problems. In this talk, I will present recent work on learning elliptic PDOs from noisy data. Within a wavelet-Galerkin framework, we formulate this task as a structured infinite-dimensional regression problem with multiscale sparsity. Building on this structure, we propose a sparse, data- and computation-efficient estimator, which leverages a novel matrix compression scheme tailored to the learning task and a nested-support strategy to balance approximation and estimation errors. In addition to establishing convergence rates for the estimator, time permitting, I will also discuss how the learned operator can be used to construct an efficient and stable Galerkin solver whose numerical error matches its statistical accuracy.

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MS4

GAIA: Geometry-Adaptive Operator Learning for Forward and Inverse Problems

Operator learning for partial differential equations (PDEs) on arbitrary geometries builds fast neural surrogates for large-scale simulation. Although recent geometry-adaptive neural operators have made substantial progress, they are mainly designed for forward problems in which inputs and outputs share the same spatial domain. This limits their applicability for boundary value problems (BVPs) and inverse problems, where inputs and outputs may live on different domains. We introduce the Geometry-Adaptive Integral Autoencoder (GAIA), an operator learning model that encodes the domain boundary and the interior field distribution into geometry tokens, and conditions integral transform layers on these tokens via cross-attention, allowing the kernel to adapt locally to geometric features. This yields a single architecture for forward (including BVPs) and inverse problems on arbitrary domains in one pass, without retraining, iterative optimization, or graph construction. We evaluate GAIA on seven 2D and 3D benchmarks, four of which are new or substantially extended benchmarks for inverse problems and BVP: electrical impedance tomography, optical tomography, 3D Darcy flow on varying geometries, and a modified setting of Poisson BVP on mechanical components benchmark (MCB). GAIA sets new state-of-the-art results on every inverse and BVP task, reducing median relative L^2 error by 64% on airfoil flow reconstruction and 27% on EIT relative to the next best amortized method, and outperforming all baselines on every shape category of MCB. On other forward problems, GAIA is competitive with specialized solvers while maintaining stable accuracy across point resolutions on which transformer-based baselines degrade.

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MS4

Reduced Order Model for Inverse Problems in Kinetic Models

Kinetic equations are high-dimensional and often involve nonlinear collision operators. As a result, numerical solvers are computationally expensive, especially when computing the steady-state solutions, which typically require many iterations for an iterative scheme to converge. This challenge becomes even more pronounced when repeated solver calls are needed, such as in inverse problems or parameter estimation. In this talk, I will present a reduced-order modeling framework that reformulates the kinetic equation as a low-dimensional constrained optimization problem. This approach significantly accelerates the computation while maintaining accuracy and preserving key physical properties of the solution. The framework is further applied to inverse problems for recovering parameters in the collision operator. I will demonstrate the performance of the method through numerical examples based on the kinetic BGK equation and the Boltzmann equation.

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MS5

Phase Retrieval under One-Bit Quantization

We study the sample complexity and develop efficient algorithms for 1-bit phase retrieval, i.e., the recovery of a signal $x \in \mathbb{R}^n$ from m phaseless bits $\{sign(|a_i^\top x| - \tau)\}_{i=1}^m$ with standard Gaussian a_i. By investigating a phaseless version of random hyperplane tessellation, we show that (constrained) hamming distance minimization uniformly recovers all unstructured signals with Euclidean norm bounded away from zero and infinity to the error $O(\frac{n}{m}\log(\frac{m}{n}))$, and $O(\frac{k}{m}\log(\frac{mn}{k^2}))$ when restricting to k-sparse signals. We also develop efficient and near-optimal algorithms for 1-bit (sparse) phase retrieval. Specifically, we prove that (thresholded) gradient descent with respect to the one-sided ℓ_1-loss, when initialized via spectral methods, converges linearly and attains the near-optimal reconstruction error, with sample complexity $O(n)$ for unstructured signals and $O(k^2\log(n)\log^2(\frac{m}{k}))$ for k-sparse signals. Our proof is based upon the observation that a certain local approximate invertibility condition is respected by Gaussian measurements. Our results establish the major findings of (memoryless) 1-bit compressed sensing in a phaseless setting.

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MS5

On Dynamical Sampling of 3D Tensor Signals

We consider a dynamical sampling problem for three-dimensional tensor signals, where an unknown initial tensor evolves under a fixed tensor operator defined via the t-product and is observed through partial measurements over time. We establish necessary and sufficient conditions for exact recovery and derive stability bounds ensuring robustness to noise. Numerical simulations validate the theoretical results and illustrate the effects of spatial and temporal sampling on reconstruction performance.

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MS5

Learn to Evolve: Self-Supervised Neural JKO Operator for Wasserstein Gradient Flow

The Jordan-Kinderlehrer-Otto (JKO) scheme provides a stable variational framework for computing Wasserstein gradient flows, but its practical use is often limited by the high computational cost of repeatedly solving the JKO subproblems. We propose a self-supervised approach for learning a JKO solution operator without requiring numerical solutions of any JKO trajectories. The learned operator maps an input density directly to the minimizer of the corresponding JKO subproblem, and can be iteratively applied to efficiently generate the gradient-flow evolution. A key challenge is that only a number of initial densities are typically available for training. To address this, we introduce a Learn-to-Evolve algorithm that jointly learns the JKO operator and its induced trajectories by alternating between trajectory generation and operator updates. As training progresses, the generated data increasingly approximates true JKO trajectories. Meanwhile, this Learn-to-Evolve strategy serves as a natural form of data augmentation, significantly enhancing the generalization ability of the learned operator. Numerical experiments demonstrate the accuracy, stability, and robustness of the proposed method across various choices of energies and initial conditions.

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MS5

Randomized Subspace Embeddings for Tensor Data with Applications

The emergence of big data has led to a need for versatile tools to represent higher-order data with multiple aspects and high dimensionality. Data in the form of multidimensional arrays, known as tensors, arise in a variety of applications such as physics, neuroimaging, biometrics and hyperspectral imaging. In this talk, a brief review of tensor concepts and a common tensor decomposition, CPD, as a natural extension of SVD to multidimensional data, are presented. A modewise Johnson-Lindenstrauss (JL) approach is discussed for compressing tensors. Theoretical guarantees for the norm and inner product approximation errors as well as theoretical bounds on the embedding dimension are presented for data with low CP rank, and the corresponding effects of assumptions on basis coherence are addressed. Experiments are performed on synthesized, neuroimaging, and Hamiltonian data using various choices of embedding matrices. Two applications of the modewise JL method are discussed. (i) Approximate solutions to least squares problems as a computationally efficient way of fitting tensor decompositions, and (ii) Many-Body Perturbation Theory problems involving energy calculations where the mode sizes of tensors can grow exponentially, rendering the direct calculation of perturbative correction terms challenging.

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MS6

A Two-Fold Randomization Framework for Impulse Control Problems

We propose and analyze a randomization scheme for a general class of impulse control problems. The solution to this randomized problem is characterized as the fixed point of a compound operator which consists of a regularized nonlocal operator and a regularized stopping operator. This approach allows us to derive a semi-linear Hamilton-Jacobi-Bellman (HJB) equation. Through an equivalent randomization scheme with a Poisson compound measure, we establish a verification theorem that implies the uniqueness of the solution. Via an iterative approach, we prove the existence of the solution. The existence–and–uniqueness result ensures the randomized problem is well-defined. We then demonstrate that our randomized impulse control problem converges to its classical counterpart as the randomization parameter $\boldsymbol{\lambda}$ vanishes. This convergence, combined with the value function's $\mathcal{C}^{2,\alpha}_{loc}$ regularity, confirms our framework provides a robust approximation and a foundation for developing learning algorithms. Under this framework, we propose an offline reinforcement learning (RL) algorithm. Its policy improvement step is naturally derived from the iterative approach from the existence proof, which enjoys a geometric convergence rate. We numerically demonstrate the effectiveness of our algorithm using a widely-studied example. The results show that our RL algorithm can learn the randomized solution, which accurately approximates its classical counterpart. A sensitivity analysis with respect to the volatility parameter σ in the state process effectively demonstrates the exploration–exploitation tradeoff.

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MS6

Market Factor Structure and Relative Arbitrage: A PDE Approach via Eigenvalue Bounds

We present a new formulation of the relative arbitrage problem from stochastic portfolio theory that identifies a time horizon beyond which arbitrage relative to the market exists in all sufficiently volatile markets. We interpret sufficiently volatile as a lower bound on an ordered eigenvalue of the instantaneous covariation matrixa quantity central to the empirical factor structure of large markets. Through stochastic optimal control, we characterize the time horizon as the unique viscosity solution of a fully nonlinear partial differential equation. Finally, we discuss the implications of these eigenvalue bounds for factor models in high-dimensional systems.

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MS6

Exponential Stability of Stochastic Filters Without Global Mixing

One of the most important properties of a stochastic filter is its stability: i.e., the property that the distance between two filters started from different initial distributions (i.e., different priors) vanishes as the time horizon increases (i.e., as we collect more observations). In many classical models, the filter enjoys exponential stability: i.e., the aforementioned distance decays exponentially fast. All previously established proofs of such exponential stability either rely on (a version of) global mixing property of the signal, or work only in special/restrictive classes of models. In particular, the exponential stability has remained an open question for general partially observed diffusion models (observed continuously or at discrete times) set up in unbounded domains (e.g., in $\mathbb{R}^d$). In this talk, I will describe a new method for proving the exponential stability of stochastic filters, which does not require the global mixing property and which succeeds for general diffusion models in unbounded domains, provided that the signal is ergodic and has a non-degenerate diffusion component. This approach is based on a combination of techniques from the ergodic theory of Markov processes and the martingale theory, as well as coupling methods for McKean-Vlasov equations (since the evolution of a filter is governed by one of such equations). Joint work with D. Noelck.

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MS6

Analytical Approach to Continuous-Time Causal Optimal Transport

We study causal optimal transport problems with Markovian costs and prescribed Markovian marginals. We show that the associated value function solves a fully nonlinear parabolic partial differential equation (PDE), for which we establish a comparison principle and, consequently, uniqueness of its viscosity solution. This PDE characterization allows us to identify the value with that of a constrained version of the control problem for the KushnerStratonovich equation. We further derive a third, equivalent formulation as an optimal control problem with a state constraint, which is particularly useful, as it leads to implementable numerical schemes for causal optimal transport. This is joint work with Julio Backhoff-Veraguas, Erhan Bayraktar, and Ibrahim Ekren.

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MS7

Product Formulas for Basic Hypergeometric Series by Evaluations of Askey-Wilson Polynomials

Ismail and Wilson derived a generating function for Askey–Wilson polynomials which is given by a product of q-Gauss (Heine) nonterminating basic hypergeometric functions. We provide a generalization of that generating function which contains an extra parameter. A special case gives a closed form summation formula for a quadruple basic hypergeometric sum. We further present two new terminating balanced ${}_4\phi_3$ summations that give rise to quadratic special values for Askey–Wilson polynomials. We also present three new terminating 2-balanced ${}_4\phi_3$ summations and two new terminating 3-balanced ${}_4\phi_3$ summations. Using the Ismail–Wilson generating function combined with explicit summations for terminating balanced basic hypergeometric ${}_4\phi_3$ series, we compute new basic hypergeometric product transformations for nonterminating basic hypergeometric series and provide corresponding integral representations.

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MS7

Exponentially-Improved Asymptotics for q-Difference Equations

Divergent power series in which the coefficients grow like a factorial arise in the asymptotic analysis of differential or difference equations. Surprisingly, in the q-world the growth of the nth coefficient is much stronger, growing typically like $q^{-n(n-1)/2}$, in which $q \in (0, 1)$ is fixed. To make sense of these formal series, we have to introduce alternative Borel and Laplace transforms. In this talk, I describe joint work with Adri Olde Daalhuis, where we considered exponentially-improved asymptotics for the basic hypergeometric function ${}_2\phi_0$ and for solutions of the q-difference first Painlev equation qPI.

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MS7

From the Riemann Hypothesis to Bose-Einstein Condensation: Mathematical and Physical Applications of the Riemann Zeta Function

Although most of us are familiar with the still unproved conjecture about the non-trivial zeros of the Riemann zeta function lying on a specific critical line, the zeta functions important physical applications, especially connections to problems in quantum field theory, are less well-known by those outside the field. This talk, which will provide a broader view of the functions applications, is motivated by a desire to receive feedback on strengthening and expanding the mathematical and physical application sections in the NIST Digital Library of Mathematical Functions (DLMF). The intent is also to expand the number of chapters with sidebars linking to notes on mathematical and physical applications, as seen on the title page of DLMF, Chapter 9 Airy and Related Functions.

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MS7

Eigenvalue Equations for Sieved Polynomials or Proving Askey Right Again

The sieved Jacobi polynomials have been introduced by Askey. These can be obtained from conveniently taking q to be a root of unity in the Askey–Wilson polynomials. The question of determining if they are eigenfunctions of some operator has been lingering for a long time. Askey impressed on us his conviction that it had an affirmative answer. It is shown that he was right and that this operator is of Dunkl type with cyclic reflections corresponding to the powers of q.

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MS8

Generalized Dek-Type Orthogonal Polynomials

It is well known that for a family of orthogonal polynomials with respect to a measure , one can multiply the measure by a polynomial to obtain a new sequence of orthogonal polynomials via the Christoffel transformation. However, in some nonstandard situations, the Christoffel transformation cannot be directly applied. One of such situations is when the family of polynomials is a sequence of exceptional orthogonal polynomials. It has already been shown how to modify the Christoffel transformation so it can be applied to one of the first known examples of exceptional orthogonal polynomials introduced by Dubov, Eleonskii, and Kulagin, thus, we extend this transformation to a larger class of non-classically orthogonal polynomials. We then explore properties of these polynomials and show their similarities with biothogonal polynomials and exceptional orthogonal polynomials.

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MS8

Ramanujan's Mock Theta Functions: a Unifying Theory and New Results

Asymptotic analysis, and in particular resurgence theory, has enabled us to develop a unified framework for Ramanujan's mock theta functions (Mfs) and, in principle, to extend their computation to arbitrary order, well beyond the order 13 investigated by Zagier, Chen, and others. We show that there is a unique continuation through the natural boundary $|q| = 1$, with preservation of the relations they satisfy. This continuation singles out a distinguished Mf vector in each group (for example, in the third-order case, the pair (f, ω) crosses the boundary correctly, whereas for the remaining ones the relations break down). Such "privileged" vectors had been observed empirically by Zagier, Chen, and collaborators, but without a structural framework valid uniformly across orders. Up to order 10 all selections agree. At order 11 the continuation selects Zagier's choice but not Chen's, while at order 13 the situation is reversed. Fully rigorous proofs are established up to order 5, and a complete treatment for higher orders is in progress.

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MS8

Parabolic Cylinder Functions Revisited Using Borel-Laplace Techniques

We gather and extend classical results for parabolic cylinder functions, namely solutions of the Weber differential equations, using a systematic approach by Borel–Laplace methods. We revisit the definition and construction of the standard solutions U, V of the Weber differential equation

$$w'(z) - \left(\frac{z^2}{4} + a\right) w(z) = 0$$

and provide representations by Laplace integrals extended to include all values of the complex parameter a; we find an integral integral representation for the function V; none was previously available. For the Weber equation in the form

$$u'(x) + \left(\frac{x^2}{4} - a\right) u(x) = 0,$$

we define a new fundamental system $E_\pm$ which is analytic in $a \in \mathbb{C}$, based on asymptotic behavior; they appropriately extend and modify the classical solutions E, E^* of the real Weber equation to the complex domain. The techniques used are general and we include details and motivations for the approach. Work in collaboration with Giorgos Mavrogiannis.

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MS8

Asymptotic Evidence for Ferromagnetism in Non-

abelian Spin Models

Acknowledgments: Based on joint work with A. Abdesselam (University of Virginia) and G. Uraltsev (University of Arkansas). Just over a century ago, the now-famous Ising model emerged as a powerful and mathematically rigorous emulation of ferromagnets and their phase transitions. The Ising model, which consists of a large lattice of coupled ±1-valued spins, is the simplest example of a *spin model*. In the latter, the spins may be valued in some other compact space (such as a circle, sphere, flag manifold, etc), and the symmetry group of that space plays a definitive role in the analysis of the model. In fact, only a few spin models (such as the Ising model and the XY model) are fully understood in the thermodynamic limit, and those examples all have abelian symmetry groups. Crucially, the existence of the thermodynamic limit for a spin model is contingent on a Griffiths-Kelly-Sherman (GKS) inequality, whose proof remains elusive in the non-abelian cases. In this talk we will describe our recent work on general spin models with arbitrary (compact Lie, not necessarily abelian) symmetry groups. Specifically, we will present a new asymptotic formula that, thanks to a remarkable property of Kirchhoff polynomials, supports Abdesselams conjecture that the GKS inequalities are satisfied by a surprisingly wide class of spin models.

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MS9

Mathematical Analysis of Many-Body Quantum Simulation with Coulomb Potentials

Efficient simulation of many-body quantum dynamics is central to advances in physics, chemistry, and quantum computing. A fundamental question is whether the simulation cost can scale polynomially with system size in the presence of realistic interactions. In this talk, we focus on many-body quantum systems with Coulomb interactions, which play a central role in electronic and molecular dynamics. We prove that first-order Trotterization for such unbounded Hamiltonians admits a polynomial dependence on the number of particles in the continuum limit, with a convergence rate of order 1/4in contrast to prior Trotter analyses for bounded operators, which diverge in this limit. The result holds for all initial wavefunctions in the domain of the Hamiltonian. This 1/4-order rate is optimal, as previous work shows that it can be saturated by the ground state of the hydrogen atom. Moreover, higher-order Trotter formulas do not improve the worst-case scaling. We also discuss additional regularity conditions on the initial state under which the original Trotter convergence rate can be recovered. The main analytical challenges arise from the many-body structure and the singular nature of the Coulomb potential.

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MS9

A Static Quantum Embedding Scheme Based on Coupled Cluster Theory

We provide a systematic evaluation of the sample-based quantum diagonalization (SQD) method for electronic structure based on the W4-11 thermochemistry dataset, comprising 124 total atomization, 83 bond dissociation, 20 isomerization, 505 heavy-atom transfer, and 13 nucleophilic substitution processes, covering diverse bonding situations and reaction mechanisms. This is the largest study assessing the accuracy and precision of a quantum-hybrid algorithm on a digital quantum device across a variety of molecular systems and chemical reactions, using 16.85 hours on the superconducting quantum processor ibm_rensselaer and 724.22 node hours on the supercomputer AiMOS. To ensure a fair comparison, our study employs commensurate resource allocation for both classical and quantum simulations. Although SQD exhibits large statistical deviations from ground-state reference energies, energy extrapolations yield CCSD-level accuracy. While bond-breaking reactions show a systematic improvement as computational resources increase, nucleophilic substitution or heavy atom transfer reactions do not. The limitations quantified in this manuscript indicate opportunities for improvement in SQD-based algorithms. This work provides a benchmark and community resource for exploring new quantum algorithms and devices, supported by an online benchmark challenge and an open-source Python library for direct comparison.

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MS9

Fault-Tolerant Block Encoding for Second-Quantized Hamiltonians

Block encoding is a central technique used in quantum simulation to provide information about physical systems of interest. We would like to begin with recent developments in block encoding for quantum many-body system Hamiltonians, as well as block encoding of expansions. We will then discuss a key subroutine of block encoding, state preparation, and its recent progress. Finally, we would like to discuss current developments in fault-tolerant block encoding.

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MS9

A Quantum-Classical Neural Network for Long-Term Time Series Forecasting

Quantum machine learning (QML) is a promising direction for exploring practical quantum advantage. One of the main components of QML, quantum kernels, is believed to provide rich representations of classical data by embedding it into high-dimensional Hilbert spaces. However, not every dataset is expected to benefit from quantum kernels, as shown by Huang et al. in Power of data in quantum machine learning where the authors proposed a kernel testing framework for classification tasks. In this work, we adapt their method to assess the potential advantage of quantum kernels on regression tasks, with a focus on multivariate time series forecasting. With the results from prescreening, we then implement two hardware-efficient hybrid quantum-classical machine learning models. The first model uses a data-reuploading circuit to construct a quantum feature map for datasets with strong autoregressive structure. For datasets that require nontrivial cross-feature correlations, we replace the self-attention mechanism in TimeXer, one of the state-of-the-art models for time series forecasting, with quantum counterparts. Our results show good agreement between the prescreening and model evaluations, suggesting that quantum kernel analysis can help identify datasets where quantum components are more likely to be useful. They also demonstrate the feasibility of hybrid machine learning models for multivariate time series problems.

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MS10

Co-Designing Performance-Portable Solvers for Multiscale Materials Modeling

Multiscale modeling of structural materials seeks to establish quantitative links between microstructure (e.g., precipitates, interfaces, defects) and macroscopic mechanical performance. For materials design and deployment, thousands of simulations must be performed across microstructural states and loading conditions, while resolving fine-scale features that govern failure and rare events. Traditional approaches combine efficient solvers with semi-analytical or data-driven homogenization to reduce computational cost. Although effective, these approximations introduce information loss, limit experimental validation, and increase predictive uncertainty. To overcome these limitations, a DOE SciDAC collaboration between Nuclear Energy and Advanced Scientific Computing is developing next-generation FFT-based micromechanical solvers designed for performance portability and scalability. We present the current state of algorithms and implementations, identify key bottlenecks in large-scale FFT-based mechanics codes, and introduce a new architecture that separates mathematical specification from hardware-specific optimization. Leveraging SPIRAL to generate platform-tuned kernels, the framework enables efficient execution on distributed-memory systems and multi-GPU architectures. This work demonstrates how close collaboration between domain scientists and computing experts enables modernization of high-value materials codes, balancing portability, performance, and scientific fidelity for next-generation multiscale simulations.

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MS10

Need For Speed: FFT-Based Material Science Kernels

A number of partial differential equations (PDEs) used in material science applications related to nuclear engineering (molten salt simulation or plasma simulation) can be efficiently done via (pseudo-)spectral solvers that center on the fast Fourier transform. However, efficiently solving these problems requires "across-the-stack' understanding of the problem, its symmetries and degrees of freedom, and how to map them to modern hardware, including AI/ML accelerators without FP64 support. In this talk we discuss the "across-the-stack' challenges and how we bring together a team of researchers from the various abstraction layers to convene a community interested in advancing the state-of-the-art. The talk serves as setup for the minisymposium and update on recent advances in the FFTX/SpectralPack work.

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MS10

Tiles, Bricks, and Layouts to Reduce Data Movement in Structured Grid Computations

Data movement is the dominant execution and energy cost across the application workloads in data centers and supercomputers. Programming at the tile level has become a popular strategy for optimizing data movement for both deep learning and general structured grids, using Triton, cuTile, bricks, and fine-grained data blocks. Expressing hierarchical data and thread layouts, mostly designed with matrix processors in mind, facilitates automatic code generation that further raises the level of abstraction in such code. In this talk, we will describe prior work on BrickLib supporting fine-grained data blocks and active research on HashBrick for sparse structured grids. We will connect these concepts with emerging hardware features and future demands on programming systems to reduce data movement in optimizing structured grids.

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MS10

Semantics Lifting for Performance Portability

Modernizing legacy scientific application code for emerging architectures requires both performance portability and maintaining correctness as implementations evolve across platforms and optimization layers. Many high-value scientific kernels encode complex numerical behavior and domain-specific assumptions that become difficult to recover once expressed in low-level optimized implementations. As a result, modernization efforts often risk obscuring algorithmic intent and introducing subtle correctness issues. This talk presents a stepwise semantics lifting approach for recovering high-level structure from legacy scientific kernels. Using an extended SPIRAL framework, the method combines symbolic execution and theorem proving to statically derive high-level semantics from low-level implementations. The resulting lifting process provides a structured path for verifying correctness while extracting algorithmic structure that can guide transformations and retargeting across architectures.

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MS11

Time-Evolving Subspaces with Dynamical Matrix and Tensor Low-Rank Approximations for Fluid Flows

Dynamical low-rank approximation based on time-dependent bases (TDB) is an emerging dimension reduction and reduced-order modeling framework that enables solving high-dimensional dynamical systems on manifolds of low-rank matrices and tensors. Recent applications of TDB underscore its potential in addressing a wide spectrum of fluid mechanics challenges, ranging from flow stability analysis and uncertainty propagation in unsteady flows to simulations of turbulent flows and combustion. A defining characteristic of TDB is that the subspaces evolve with the flow, capturing highly transient dynamics while achieving a significant reduction in dimension. Another distinguishing feature is the ability to derive the evolution equations for TDB directly from the model, bypassing the need for data generation. In this talk, we cover several example applications of TDB for unsteady flows, including new developments based on adaptive interpolation methods for cost-effective solution of TDBevolution equations.

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MS11

Transient Growth and Nonlinear Breakdown of Optimal Wavelet-Based Resolvent Modes in Turbulent Channel Flow

Transient amplification plays a central role in wall-bounded turbulence, yet most resolvent analyses rely on Fourier modes that obscure time-local dynamics. Here, I present a time-localised resolvent framework that directly captures transient growth events in turbulent flow. Using a windowed, wavelet-based formulation of the resolvent operator (Ballouz et al., J. Fluid Mech., 2024), we compute principal forcing modes that are localized in time and optimally amplified by the linearised NavierStokes equations. These modes are injected into a turbulent minimal flow unit to examine how transient linear amplification interacts with nonlinear turbulence. For the dominant spatial wavenumbers, the optimal forcing takes the form of streamwise rolls that generate streaks exhibiting transient growth and decay. At early times and near the wall, the turbulent response closely follows the predicted resolvent response mode. However, nonlinear interactions limit growth and induce premature decay, with stronger forcing leading to faster energy dissipation. Despite this, the principal forcing mode amplifies near-wall streaks far more effectively than random forcing or suboptimal modes. By quantifying nonlinear energy transfer during breakdown, we show that energy is consistently redirected into spanwise-oscillatory secondary structures, revealing a robust pathway through which transiently amplified streaks are reabsorbed into the turbulence.

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MS11

Gradient-Based Model Reduction for Transient Nonlinear Dynamics

Reduced-order models (ROMs) can fail when they group together full-order states that produce different outputs. Any choice of reduced variables induces fibers — sets of full-order states indistinguishable in the reduced coordinates and therefore treated as identical by the ROM. Identifying appropriate fibers is essential for modeling transient dynamics near, but not confined to, low-dimensional manifolds. These fibers are difficult to identify using data-driven methods, especially when dynamically important directions exhibit small variance due to fast dynamics or nonnormal sensitivity. Instead, gradients of future outputs with respect to the current state, computed using automatic differentiation or adjoint equations, reveal directions relevant for prediction. Motivated by this observation, we introduce Covariance Balancing Reduction using Adjoint Snapshots (CoBRAS), a class of methods uniting balanced truncation and active subspaces, to identify reduced-order modeling variables and oblique projections that minimize output variance along the resulting fibers. We describe applications of CoBRAS to forecasting, extreme event prediction, and extensions to reduced-order optimal control, with demonstrations on several challenging spatiotemporal partial differential equations.

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MS11

Parametric Analysis of Locally Optimal Subspaces on the Grassmann Manifold for Fluid Flow Modeling and Prediction

The dynamics of fluid flows are described by partial differential equations, including NavierStokes equations, implying that the trajectory of a fluid-flow state evolves in a very high-dimensional space. On the other hand, we have long expected that the dominant behavior of fluid flows can be captured by a significantly lower-dimensional subspace. Modal analysis has revealed that the dominant modes can be extracted from a large-scale dataset obtained by high-fidelity numerical simulations or experiments, motivating the development of reduced-order models (ROMs). A major challenge of ROMs is that they often fail to reproduce flow fields at parameter values (e.g. Reynolds number) different from those used for extracting dominant modes because the extracted modes are valid only at the flow parameter associated with the training data. In this study, we consider a parametric mode representation on the Grassmann manifold where the subspace at a specific parameter is treated as an element of the manifold. The representation of the subspace variation as a curve on the Grassmann manifold provides not only a framework for parametric ROMs but also a geometric perspective for analyzing the relationship between flow dynamics at different parameter values and the variation of dominant flow features during transient processes. We discuss the sensitivity of the subspace with respect to flow parameters and the applicability of the parametric ROM based on the Grassmann manifold.

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MS12

Well-Posedness and Transmission Eigenvalues for Penetrable Biharmonic Scattering

We study biharmonic wave scattering by a penetrable obstacle in an infinite two-dimensional KirchhoffLove plate, assuming the plate thickness is small relative to the incident wavelength. In the frequency domain, the problem is governed by the biharmonic wave equation. Using an operator factorization approach, the direct scattering problem is reformulated as a coupled boundary value problem for the Helmholtz and modified Helmholtz equations, leading to well-posedness and reciprocity results. We further analyze the associated transmission eigenvalue problem for biharmonic scattering, proving the existence and discreteness of transmission eigenvalues and establishing the monotonicity of the first transmission eigenvalue with respect to the refractive index. Numerical experiments illustrate and validate the theoretical findings.

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MS12

Low-Rank Generalized Tensor-on-Tensor Regression and Applications

We introduce the Generalized Tensor-on-Tensor Regression model (GToTR), a novel modeling framework that extends the Generalized Linear Model (GLM) and Tensor-on-Tensor Regression (ToTR) for regression problems involving tensor data, i.e., multidimensional arrays. As with GLMs, GToTR allow a linear model to relate expected responses to covariates via a link function, providing flexibility in solving problems beyond typical identity link/Gaussian-response regression. Similarly, as in ToTR, GToTRs allow for tensor covariates and responses by leveraging their tensor structure that is often discarded when the data is vectorized and modeled entry-wise using scalar-response GLMs. GToTR combines both approaches, thus making parameter inference possible in situations where a large sample size would otherwise be necessary for a well-posed inference problem. Instead, we impose low-rank tensor structure on the GToTR parameter tensor, thus requiring fewer samples, and leading to a well-posed inference problem. Here, we extend GLM and ToTR to GToTR, introduce an algorithmic framework for solving the GToTR inference problem when the Canonical Polyadic (CP) low-rank structure is imposed on the GToTR parameter tensor, and illustrate multiple uses of GToTRs on simulated and real-world application data.

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MS12

A Proximal Point Galerkin Method for Manifold Constrained Optimization: Application to the Isometry Constraint

Following the seminal work of Friesecke–James–Muller, certain nonlinear plate models can be recast as energy minimization problems under an isometry constraint (the first fundamental form of the surface has to be the identity matrix). Bartels and subsequent authors have proposed to approximate the minimizers of such constrained problems by using a gradient flow with a tangent space update, which creates two issues. First, a preprocessing step is needed in order to satisfy the boundary conditions and produce an initial guess "close enough" to being an isometry. Second, each step of the gradient flow gives an update that a little bit further away from being an isometry. In this paper, we propose a different approach based on the Proximal Point algorithm as they have recently been used for convex constraints by Keith et al. This method leverages available knowledge about the Stiefel manifold and Riemannian geometry in order to have a much more efficient method. First, no preprocessing step is needed, which saves a lot of computational time. Second, we show that at each step of our computation, the method produces an update that is exactly an isometry at the barycentre of each cell. Finally, we demonstrate on several standard numerical examples that the method requires less iterations and provides a much smaller isometry defect when compared to previous methods.

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MS12

Nuclear Security: The Intersection of Diagnostics and Analysis

The Department of Energy employs scientists, mathematicians, and engineers to work on problems ranging from renewable energy resources to global climate change. However, unbeknownst to many people is the fact that the Department of Energy is also the nations overseer of our nuclear weapons program, nuclear non-proliferation, nuclear emergency response, and nuclear power for the U.S. Navy. In this presentation, some of the scientific research interests of the Department of Energy will be highlighted, with a focus on measurement diagnostics and analysis for subcritical experiments in support of the Stockpile Stewardship Program at the Nevada National Security Site: the nations premier explosives laboratory.

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MS14

New Frontiers of Bayesian Inverse Problem

Data science techniques like dictionary learning and matrix factorizations are computationally efficient alternatives to machine learning and neural network-based approaches for taking advantage of prior and model-based information in problems with forward models too complex to be used in traditional optimization settings. Furthermore, hierarchical Bayesian methods can be very effective for promoting, e.g., sparsity of the dictionary representation, to incorporate desired properties in dictionaries, or for designing factorization techniques with factor matrices with desired characteristics. The effectiveness of combining data science and hierarchical Bayesian models will be illustrated with computed examples.

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MS14

Variational Sequential Optimal Experimental Design

We present variational sequential optimal experimental design (vsOED), a framework for constructing optimal finite sequences of experiments under a Bayesian decision-theoretic formulation with information-based utilities. The method introduces a one-point reward representation combined with variational posterior approximations, yielding a tractable lower bound on the expected information gain. To solve for the optimal design policy, we develop numerical algorithms based on an actor-critic architecture, including explicit derivations of policy and variational gradients for joint optimization of the design strategy and posterior approximation. Flexible density representations such as Gaussian mixtures and normalizing flows enable accurate posterior approximation. The framework naturally accommodates nuisance parameters, implicit likelihoods, and multiple competing models, and it supports different design objectives, including parameter estimation, model discrimination, and goal-oriented prediction, as well as weighted combinations of these criteria. We illustrate vsOED on a range of test problems, demonstrating improved sample efficiency relative to existing sequential design strategies. This is joint work with Wanggang Shen and Jiayuan Dong.

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MS14

Recent Advances in Optimal Experimental Design

Modern advances in scientific machine learning have had significant impact on the development of optimal experimental design (OED). This talk surveys recent progress in the field of OED, at the interface of Bayesian inverse problems and uncertainty quantification. We will highlight the key theoretical and computational advances as well as emerging challenges in the field.

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MS15

Mixed Precision Algorithms for Imaging and Inverse Problems

In recent years a substantial amount of work has been done on developing mixed-precision algorithms for linear systems, methods that can exploit capabilities of modern GPU architectures. However, very little work has been done for ill-conditioned problems that arise from large-scale inverse problems. Special considerations, which normally do not arise when solving well-conditioned problems, such as incorporating regularization into the developed methods, need to be considered. In this talk we consider the use of low-precision, regularized preconditioners in Krylov subspace methods.

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MS15

A Unified Perspective on Microlocal Artifacts in Limited Data Tomography and Inverse Problems

We use microlocal analysis to provide a unified framework for understanding how and why artifacts arise in filtered backprojection-type reconstruction methods for limited data tomography. We assume the forward operator, F, is a Fourier integral operator. Our results are valid for a broad range of tomography problems, including X-ray CT, sonar, radar, seismic imaging, and Compton tomography. We provide a paradigm that depends on the properties of F and its canonical relation to describe each type of microlocal artifact that can appear. We will provide sample reconstructions illustrating our results.

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MS15

Spotlight Inversion, a Projection Method for Model Reduction in Imaging

It is a common situation in imaging applications that the imaging data depend on parameters of secondary interest which may have a strong effect on the reconstruction of the image of interest. As an example, in local tomography, the image of primary interest may be a small region of interest, or spotlight, while the attenuation data depend on the absorption coefficient in the whole imaging region. In this talk, a purely linear algebraic approach for filtering out the nuisance parameters is represented, and its connections to Bayesian image analysis are discussed. Of particular interest is also the connection to a more general question of modeling errors in the forward map that often propagate as significant artifacts in the reconstructed image. Computed examples include X-ray tomography and non-linear electrical impedance tomography (EIT). The talk is based on collaborative work with Daniela Calvetti, Nuutti Hyvnen, and Ville Kolehmainen.

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MS16

Fractional Mean Field Games of Controls

Mean field games model competition in a large population of rational agents. In this setting, each individual minimizes a cost based on the probability distribution of player states. A mean field game of controls is a particular class where the cost for each agent depends not only on the distribution of states, but also of optimal strategies. In this talk I will focus on a mean field game of controls with a nonlocal diffusion, which models a game where the state of players can jump. By deriving a priori estimates on solutions and applying them with the Leray-Schauder fixed point theorem, I will establish existence of solutions to the system.

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MS16

Modelling Crime Response to Deterrence: Existence of Solutions, Optimal Policies, and Fairness

In this talk, we will discuss a recent work investigating how rational agents decide whether or not to commit a crime in response to potential punishment, and the social ramifications of the punishment details. The agents' decisions are based on a utility calculation, influenced by a judge who sets a society-wide threshold corresponding to the likelihood of an individual being found guilty and a legislator who sets a society-wide punishment level. We study how the overall crime rate is influenced by the judges threshold and the legislators punishment level, propose an objective function for the judge and legislator to minimise, and study the optimal threshold and punishment levels for this objective. We then consider the case in which the overall society is subdivided into multiple social "groups" with varying characteristics, introducing a constraint on fairness in treatment between the groups. We study how an optimal threshold and punishment level might be chosen under this fairness constraint, what ramifications the constraints have on outcomes for individuals, and under what circumstances the constrained optimum agrees with the unconstrained optimum.

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MS16

Economic Agglomeration and Spatial Solow Models with Labor Migration

Solow models with spatial features such as labor migration and wealth distribution provide a natural mathematical framework for studying economic agglomeration – the uneven geographic concentration of economic activity driven by mobility, interaction, and local production. In this talk, I present recent advances in spatial Solow models where agglomeration appears as spatially concentrated patterns. Using tools from bifurcation theory and perturbation analysis, we show how migration intensity, wealth mobility, and the structure of the production function determine the onset and shape of these patterns. These results offer a mathematical explanation of how local economic interactions can lead to large-scale concentration.

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MS17

Performance Comparison of Weak Form and Classical Methods for ODE System Inference

Parameter inference and state estimation for dynamical systems governed by Ordinary Differential Equations (ODE) remains a fundamental problem of interest across scientific and engineering disciplines. The performance of any given method for inference can depend strongly on the underlying problem characteristics, including system stiffness, measurement noise, and data sparsity. We compare weak form scientific machine learning methods against other traditional and modern approaches across a suite of canonical dynamical systems. By evaluating these methods under varying conditions of stiffness, noise, and sampling density, we provide practical guidance on method selection for real-world applications.

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MS17

Occupation Kernel Hilbert Spaces for Learning Nonlinear Systems

This talk gives a theoretical framework for a new Hilbert space of functions, the so called occupation kernel Hilbert space (OKHS), that operates on collections of signals rather than real or complex numbers. To support this new definition, an explicit class of OKHSs is given through the consideration of a reproducing kernel Hilbert space (RKHS). This space enables the definition of nonlocal operators, such as fractional order Liouville operators, as well as spectral decomposition methods for corresponding fractional order dynamical systems. In this manuscript, a fractional order DMD routine is presented, and the details of the finite rank representations are given. Significantly, despite the added theoretical content through the OKHS formulation, the resultant computations only differ slightly from that of occupation kernel DMD methods for integer order systems posed over RKHSs.

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MS17

A Statistical Weak Form Approach to Parameter Estimation and Inference

The Weak-form Estimation of Non-linear Dynamics (WENDy) framework is a recently developed approach for parameter estimation of systems of ordinary differential equations (ODEs). Prior work demonstrated WENDy to be robust, computationally efficient, and accurate. In 2025, we extended our algorithm to accommodate ODEs that are nonlinear-in-parameters and to more general noise distributions. In 2026, we developed new techniques that make our estimators consistent. Furthermore, we developed a Bayesian framework tofacilitate the use of priors for the parameters. This work includes automatically defining so-called objective priors.Bayesian WENDy (BENDy) isa much-needed extension to the existingweak form parameter estimation and inference algorithms.

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MS17

Streaming Compression of Scientific Data Through Surrogate Modeling

The production of scientific data, either via simulation or experiments, is undergoing a stage of exponential growth, which makes data compression important and often necessary for storing and utilizing large scientific data sets. As opposed to classical offline compression algorithms that perform compression on a readily available data set, streaming compression algorithms compress data online while the data generated from simulation or experiments is still flowing through the system. This feature makes streaming compression algorithms well suited for scientific data compression, where storing the full data set offline is often infeasible. In this talk, we will discuss a new streaming compression algorithm, streaming weak-SINDy, which takes advantage of the underlying data characteristics during compression. Time permitting, we will also explore other weak-form approaches to the streaming compression problem.

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MS18

Truncated Kernel Windowed Fourier Projection: A Fast Algorithm for the 3D Free-Space Wave Equation

We present a spectrally accurate fast algorithm for evaluating the solution to the scalar wave equation in free space driven by a large collection of point sources in a bounded domain. With M sources temporally discretized by N_t time steps of size Δt, a naive potential evaluation at M targets on the same time grid requires $O(M^2 N_t)$ work. Our scheme requires $O((M + N^3 \log N)N_t)$ work, where N scales as $O(1/\Delta t)$, i.e., the maximum signal frequency. This is achieved by using the recently-proposed windowed Fourier projection (WFP) method to split the potential into a local part, evaluated directly, plus a smooth history part approximated by an N^3-point equispaced discretization of the Fourier transform, where each Fourier coefficient obeys a simple recursion relation. The growing oscillations in the spectral representation (which would be present with a naive use of the Fourier transform) are controlled by spatially truncating the hyperbolic Green's function itself. Thus, the method avoids the need for absorbing boundary conditions. We demonstrate the performance of our algorithm with up to a million sources and targets at 6-digit accuracy. We believe it can serve as a key component in addressing time-domain wave equation scattering problems.

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MS18

Adaptive Mesh and Algorithm Refinement: A Case Study

Traditionally, Adaptive Mesh Refinement (AMR) has been used as a technique to adapt the resolution of a simulation within a domain while solving the same equations at different levels of refinement. More recent work has extended the concept of AMR to allow different representations of the physics at different levels. As an example, we consider the dynamics of random walkers under the influence of an external potential, which can be described by a stochastic partial differential equation (SPDE) known as the Dean-Kawasaki equation. However, the SPDE description breaks down when the local number density is sufficiently small. We can construct a hybrid algorithm that solves the SPDE when the number density is large but dynamically switches to a particle description when the number density is small. In this talk we will describe the algorithm with a focus on the coupling between the different models using traditional AMR methodology and present some numerical examples illustrating the behavior of the algorithm.

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MS18

On Corrections for Mixed Precision Runge-Kutta Methods

Performing computations in low precision can yield speedups of 4x or greater, though this often comes at the cost of reduced accuracy. To address this tradeoff, we analyze mixed precision additive Runge Kutta (MP ARK) methods. These methods reduce the computational burden of expensive implicit stages by utilizing cheaper, low precision arithmetic. The explicit stages are then executed using high precision, which provides a necessary correction to the implicit stages and helps recover overall accuracy. While additional explicit corrections in high precision may be used to improve the accuracy even further, they can have an impact on numerical stability. We propose various stable correction strategies and present numerical experiments to validate our findings.

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MS18

Validation of a Grid-free Framework for Numerically Simulating Flow Through Permeable Boundaries

Intravenous drug delivery, migrating cells, and wastewater filtration all rely on the dynamics of partial fluid passage through a permeable membrane at the microscopic scale. We describe a grid-free approach that uses regularized forces and regularized source/sink pairs to model permeability. We present model validation and convergence analysis for flow through permeable membranes in various scenarios, including channel flow in two and three dimensions and permeable spheres under tension. Recent work focuses on calibration of numerical parameters and validation of the framework using the exact solution for flow through permeable infinite channels.

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MS20

Structural Identifiability in Gaussian Graphical Models

Gaussian graphical models are a key area of research in Algebraic Statistics where the dependence structure between jointly normal random variables is determined by a graph. In this talk, I will present the problem of structural identifiability in Gaussian DAG models. I will show how imposing symmetry conditions on the model parameters can guarantee identifiability. Building on prior work by Peters and Bhlmann and by Wu and Drton, we establish structural identifiability under homogeneous structural coefficients, as well as for a broader class of models with partially homogeneous structural coefficients called BPEC-DAGs. In the end, I will present an analogue of the GES algorithm for learning BPEC-DAGs and evaluate its performance on real datasets.

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MS20

Causal Discovery Under Mean Independence and Linearity

Causal discovery methods such as LiNGAM identify causal structure from observational data by assuming mutually independent disturbances. This assumption is fragile: shared volatility, common scale effects, or other forms of dependence can cause the methods to recover the wrong causal order, even with infinite data. We introduce the Linear Mean-Independent Acyclic Model (LiMIAM), which replaces full independence with weaker one-sided mean-independence restrictions on the disturbances. Under finite-order consequences of these restrictions, source nodes are generically identifiable, and hence a compatible causal order can be recovered recursively. Our proof is constructive and leads to DirectLiMIAM, a sequential residual-based algorithm for causal discovery under dependent noise. In simulations with mean-independent but dependent disturbances, DirectLiMIAM outperforms LiNGAM methods. A large-scale empirical application to the oil market highlights the implausibility of the independence assumption and the ability of DirectLiMIAM to recover a realistic causal ordering, from policy to production and prices to inflation.

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MS20

Identifiability and Dimension of Polynomial Neural Networks

Modern AI systems are often built around trained neural network models. Mathematically, these define highly overparameterized families of functions. A central question in understanding such models is identifiability: when does a models observable inputoutput behavior uniquely determine its parameters, up to inherent symmetries? This talk presents several identifiability results for polynomial neural networks. Parts of this talk are joint work with Bella Finkel, Chenxi Wu and Thomas Yahl, as well as Kevin Dao.

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MS20

Algebraic Identifiability in Independent Component Analysis Mixture Models

We discuss *Independent Component Analysis mixture models*, which are non-parametric extensions of the celebrated family of Gaussian mixtures. We show when the mixing coefficients, linear transformations, and source moments (up to order d) can be recovered, up to a finite class, from the moments of the observed distribution. In particular, when the mixing coefficients are known, the maximum number of mixture components one can hope for while retaining algebraic identifiability is asymptotic to cn^{d-2} for some positive constant c. For $d \geq 3$, we prove algebraic identifiability for up to Γ_d mixture components, where Γ_d is asymptotic to cn^{d-2} when $d = 3$ and $d \geq 5$, and Γ_d is asymptotic to $\frac{1}{2}cn^{d-2}$ when $d = 4$.

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MS21

Using Spectral Structure of the Forward Problem to Regularize and Accelerate the Inverse Problem

In this work, we show an effective strategy for solving inverse problems when the corresponding (linear) forward map from unknowns to measurements has a spectral gap. This spectral structure typically implies a well-defined signal space defined by the underlying physics or measurement data. The key point is to analyze the structure and estimate the dimension of the signal space from the forward model. Then, one can invert the corresponding linearized problem efficiently in the signal space using random algorithms. This means that one can implement Newton's methods efficiently for the original nonlinear inverse problem with physics or measurement based regularization. This strategy can improve stability, accelerate convergence, and reduce computational cost significantly compared to first order methods, such as gradient decent or adjoint methods. Inverse scattering problems will be used to demonstrate our strategy.

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MS21

Bayesian Inference for Latent Gaussian Models Governed by PDEs

Latent Gaussian Models describe a wide range of problems in which an observed variable depends on an unknown parameter with a Gaussian prior and on some additional hyperparameters. Bayesian inference methods have been developed that marginalize out the dependence on the hyperparameters in a fast and accurate way when the dependence of the data on the parameter is governed by a simple operator. PDE governed inverse problems pose additional challenges, since existing methods do not account for problems for which evaluating the forward model is the most computationally expensive step. In this talk we will present a method for marginalizing hyperparameters efficiently for linear PDE governed problems using low-rank approximation of the prior-to-posterior precision update.

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MS21

Parametric Hyperbolic Conservation Laws: A Unified Framework for Conservation, Entropy Stability, and Hyperbolicity

In this talk, we will discuss a parametric hyperbolic conservation law (SymCLaw) for learning hyperbolic systems directly from data while ensuring conservation, entropy stability, and hyperbolicity by design. Unlike existing approaches that typically enforce only conservation or rely on prior knowledge of the governing equations, our method parameterizes the flux functions in a form that guarantees real eigenvalues and complete eigenvectors of the flux Jacobian, thereby preserving hyperbolicity. At the same time, we embed entropy-stable design principles by jointly learning a convex entropy function and its associated flux potential, ensuring entropy dissipation and the selection of physically admissible weak solutions. A corresponding entropy-stable numerical flux scheme provides compatibility with standard discretizations, allowing seamless integration into classical solvers. We will present numerical experiments on a range of benchmark problems to demonstrate the accuracy, stability, and physical consistency of the proposed framework.

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MS21

Inverse Problem of Photoacoustic Imaging with Multi-Photon Absorption

We study forward and inverse problems for a semilinear radiative transport model where the absorption coefficient depends on the angular average of the transport solution. Our first result is the well-posedness theory for the transport model with general boundary data, which significantly improves previous theories for small boundary data. For the inverse problem of reconstructing the nonlinear absorption coefficient from internal data, we develop stability results for the reconstructions and unify an L^1 stability theory for both the diffusion and transport regimes by introducing a weighted norm that penalizes the contribution from the boundary region. The problems studied here are motivated by applications such as photoacoustic imaging of multi-photon absorption of heterogeneous media.

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MS22

Quantitative Propagation of Chaos and Universality for Asymmetric Langevin Spin Glass Dynamics

We obtain quantitative estimates on quenched propagation of chaos for Langevin spin glass dynamics with i.i.d. disorder. Prior work in the case of Gaussian disorder established the qualitative convergence of the law of a single spin to a deterministic McKean-Vlasov limit. We prove convergence rates in expected Wasserstein distance and quantitative concentration rates for Lipschitz observables under the assumption that the disorder satisfies the T2 inequality. The proof uses a coupling argument, together with techniques from concentration of measure, filtering theory, and Malliavin calculus

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MS22

Asymptotic Behavior of the Intermediate Order Statistics of Large Mean-Field Systems and Statistical Estimations

We study the asymptotic behavior of the intermediate order statistics of a system of N real-valued diffusive particles with mean-field interaction in the drift. Our focus is on the intermediate order statistics with ranks $k(N)$, $2k(N)$, and $4k(N)$ for $k(N) \to +\infty$ with $k(N)/N \to 0$ as $N \to +\infty$. We show that under reasonable assumptions, the $N \to +\infty$ weak limit of the appropriately normalized intermediate order statistics is the same for both the interacting particles and for N independent copies of a solution to the corresponding McKean-Vlasov equation (propagation of chaos). This asymptotic behavior enables us to show weak consistency and asymptotic normality of the Pickands estimator with interacting particles. This allows us to estimate the extreme value index when we only observe the system of interacting particles.

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MS22

Universal Basic Income in a Financial Equilibrium

Universal basic income (UBI) is a tax scheme that uniformly redistributes aggregate income amongst the entire population of an economy. In this talk, I will discuss the existence of an equilibrium in a model that implements UBI. The economic agents choose the proportion of their time to work and earn wages that can be used towards consumption and investment in a financial market with a traded stock and annuity. A proportion of the earned wages is uniformly distributed amongst all agents, leading to interconnectedness of the agents decision problems, which are already dependent on one another through the financial market. The decision problems are further entangled by Nash perceptions of labor; the agents respond to the labor choices of others and act upon their perceived income in their decision problems. The effects of a UBI policy are analyzed with respect tolabor market participation, the stock market, and welfare

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MS23

Cycle Index Polynomials and Graph Zeta Functions in Quantum Information Theory

Cycle index polynomials of the symmetric group arise naturally in quantum information theory whenever one studies properties of a density matrix through its moments. In my work, these polynomials appear as the exact analytical form of acceptance probabilities for quantum separability and mixedness tests, providing a direct connection between symmetric group combinatorics and entanglement detection. I will explain how this structure extends further through the introduction of a graph zeta function associated to a density matrix, whose coefficients generate the corresponding cycle index polynomials and encode spectral invariants of the state. This perspective provides a unifying framework linking moment-based entanglement criteria, separability tests associated with the PPT condition, and recent symmetry-based approaches to quantum error correction. The talk will focus on the mathematical role of symmetric functions, Newton identities, and determinant-based generating functions, illustrating how tools from algebraic combinatorics and special function theory naturally organize quantum information quantities. The goal is to highlight a recurring mathematical theme: cycle index polynomials and zeta-function constructions provide a common language for describing entanglement, spectral structure, and symmetry in quantum systems.

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MS23

Transition Asymptotics for the Real Solutions of the Sinh-Gordon Painlev III

We consider solutions of the sinh-Gordon Painlev III equation

$$u_{xx} + \frac{1}{x}u_x = \sinh u$$

that are real on $(0, \infty)$. They are parametrized by the monodromy parameter $p \in \overline{\mathbb{C}}$, $|p| > 1$, and an additional real parameter $s^{\mathbb{R}}$ when $p = \infty$. We describe the transition between singular solutions ($|p| < \infty$) and smooth solutions ($p = \infty$), as $x \to +\infty$ and $p \to \infty$ given that $2\Im(p) = -s^{\mathbb{R}}$. This talk is based on joint work with Maxim Yattselev.

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MS23

On Hypergeometric-type Solutions of Linear Differential Equations

A key feature of many classical linear differential equations is that their series solutions' coefficients are generated by two-term recurrence relations, which ensures their solvability and allows for closed-form expressions. What structural properties should such differential equations possess? Which other differential equations exhibit these characteristics? What are closed-form solutions to these 'other' equations? In this talk, we address these questions and further investigate the structural features of linear differential equations whose series solutions admit three-term recurrence relations. This analysis provides some insights into, for example, the quasi-exact solvability of linear differential equations. The question of exploring similar characteristics of second-order linear difference equations is also addressed.

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MS24

Orthogonal Polynomials, Matrix Models, and Map Enumeration

The interplay between combinatorics of maps, matrix models, and orthogonal polynomials has an almost 50 year history. The main link is that the free energy (log of the partition function) has an asymptotic expansion whose coefficients acts as generating functions for the number of maps of a given genus (with prescribed degree sequence). By studying critical phenomena (i.e., studying the places where this asymptotic expansion breaks down), one can probe the large-vertex asymptotics of these graphs, and obtain results along the lines of Bender, Gao, and Richmond (2008), which characterize these asymptotics in terms of a special Painlevé I transcendent. An important generalization of the unitary invariant ensembles is the 2-matrix model, which arose in the physics literature in the mid-80s. The combinatorial interest in this model arises from the fact that the free energy of this model now enumerates 2-colored maps, in a certain sense. This links this model to the study of the Ising model on random maps. In this talk, I will try to explain the connection of the 2-matrix model to problems in combinatorics of 2-colored maps. I will also present some preliminary results (joint work with Maurice Duits and Seung-Yeop Lee) on a special critical phenomena in the 2-matrix model, which physically corresponds to the Ising phase transition on random maps, and gives rise to a special higher-order Painlevé transcendent.

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MS24

Asymptotic Analysis of Some Multiple Orthogonal Polynomials Arising in the Six-vertex Model

I will discuss the analysis of some mixed-type multiple orthogonal polynomials arising in applications. These polynomials have the following property which may be of independent interest: the odd part of the polynomial times a weight satisfies its own orthogonality condition.

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MS24

Q-Deformation of the Marchenko-Pastur Law

This talk explores the rich interplay between q-orthogonal polynomials and combinatorics. Our primary goal is to compute the asymptotic distribution of the roots of q-Laguerre orthogonal polynomials. A key feature of this model is that the density of states undergoes a phase transition governed by a parameter λ. Below a critical threshold λ_c, the density of states is supported on a compact interval within $(0, 1)$. Above this threshold, a saturated region emerges where the density of states matches the upper constraint $\frac{1}{\lambda x}$. We compute this density across both regimes, utilising two complementary approaches:

1. The Moment Method: We explicitly calculate the moments of the limiting density by introducing the novel concept of *Laguerre histories*.

2. Large Deviation Principle (LDP): We establish that the sequence of empirical measures satisfies an LDP, explicitly characterise the underlying rate function, and compute its minimiser.

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MS25

Recent Developments and Applications of a Quantum Algorithm for Nonlinear Partial Differential Equations

We review recent work done with collaborators related to a quantum algorithm for solving nonlinear partial differential equations (QPDE). We briefly describe the QPDE algorithm, highlighting its hybrid classical-quantum nature. We then discuss quantum circuits that implement the three quantum oracles appearing in the QPDE algorithm so that it is now fully specified using quantum circuits. We also discuss a recent version of the QPDE algorithm that implements an implicit time development scheme which is needed for applications in radiation hydrodynamics. Finally we present two recent applications of the QPDE algorithm: (1) single and multi-soliton solutions of the Korteweg-deVries PDE in 1, 2, and 3 spatial dimensions; and (2) incorporating finite volume, high accuracy, shock stabilization methods into Euler equation solutions with and without shocks.

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MS25

Time-parallel Multiple-Shooting for Optimal Control of Quantum Dynamics

Optimal control of quantum systems is a central task in quantum computing, where carefully shaped control pulses steer qubits to implement desired operations. Mathematically, this leads to nonlinear optimal control problems constrained by time-dependent Schrdinger dynamics. Even for systems of only a few qubits, simulations involve long time horizons and stiff dynamics, making conventional sequential optimization slow and computationally costly. I will present a time-parallel multiple-shooting approach for quantum control based on multiple-shooting. By partitioning the time horizon into shorter segments, the method enables independent propagations to be computed concurrently while enforcing consistency through matching conditions. I will show how this approach reduces time-to-solution, its scalability on high-performance computing platforms, and its potential to enable the design of faster and more accurate multi-qubit operations.

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MS25

Quantum Stochastic Collocation - A Provably Convergent Summation-by-parts Quantum Algorithm for Uncertainty Quantification

We present a quantum algorithm for uncertainty quantification leveraging stochastic collocation (SC), where time integration of the semi-discrete form is accomplished using the linear combination of Hamiltonian simulations (LCHS) approach. The resulting algorithm enables the solution of parameterized random partial differential equations by encoding the collocation nodes and weights directly into quantum evolution operators. The spatial discretization is constructed using summation-by-parts (SBP) operators to approximate spatial derivatives, and simultaneous approximation terms (SATs) to weakly impose boundary conditions and inter-element coupling. The combination of SBP-SAT results in provably stable semi-discrete forms. Practical implementation of the LCHS algorithm requires approximating the matrix exponential; here we consider the Chebyshev expansion method and first prove that coupling this time integrator with the SBP-SAT semi discrete form results in a convergent fully discrete algorithm. Next, we prove that we can leverage these components to construct a convergent LCHS algorithm. We present an implementation of our algorithm as an explicit quantum circuit and provide rigorous complexity estimates. To verify the proposed approach, we classically simulate the quantum algorithm to perform convergence studies and analyze the impact of our approximations on the numerical error. This work establishes a pathway for performing uncertainty quantification on fault tolerant quantum computers with asymptotic speedup when compared to classical approaches.

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MS25

Practical Block Encodings of Matrix Polynomials That Can Also Be Trivially Controlled

Quantum circuits naturally implement unitary operations on input quantum states. However, non-unitary operations can also be implemented through block encodings, where additional ancilla qubits are introduced and later measured. While block encoding has a number of well-established theoretical applications, its practical implementation has been prohibitively expensive for current quantum hardware. In this paper, we present practical and explicit block encoding circuits implementing matrix polynomial transformations of a target matrix. With standard approaches, block-encoding a degree-d matrix polynomial requires a circuit depth scaling as d times the depth for block-encoding the original matrix alone. By leveraging the recently introduced Fast One-Qubit Controlled Select LCU (FOQCS-LCU) framework, we show that the additional circuit-depth overhead required for encoding matrix polynomials can be reduced to scale linearly in d with no dependence on system size or the cost of block encoding the original matrix. Moreover, we demonstrate that the FOQCS-LCU circuits and their associated matrix polynomial transformations can be controlled with negligible overhead, enabling efficient applications such as Hadamard tests. Finally, we provide explicit circuits for representative spin models, together with detailed non-asymptotic gate counts and circuit depths.

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MS26

FFTX and GX A Case Study in Performance

Portability in a Fusion Application Code

GX is a GPU-native code for modeling gyrokinetic turbulence in tokamaks and other fusion reactors. As a part of its spectral discretization, a convolution using Fast Fourier Transforms (FFTs) is an important part of GXs algorithmic and performance footprint. While GX developers have depended on vendor library FFTs for performance, this presents portability challenges which strain the already-stretched resources available to a scientific community code, while also providing potentially sub-optimal performance relative to a fully customized integrated algorithm. The FFTX framework provides a set of mathematical abstractions that allow it to function as a domain-specific language (DSL) for FFTs and spectral discretizations more broadly, while using a code-generation capability provided by Spiral to support performance portability and tuning. We present a case study of the use of FFTX as a mathematically-informed DSL to implement the entire convolution operation in GX as a single integrated algorithm, enabling improved throughput and portability relative to vendor-library implementations, with consequent increases in developer productivity through the automation of performance portability and tuning. We present results which demonstrate the effectiveness of our approach, and discuss lessons learned which may be useful in the broader context of scientific computing applications.

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MS26

MathDx: NVIDIA Device Extension Libraries

The MathDx package is a comprehensive collection of NVIDIA device extension libraries that empower CUDA developers to run advanced mathematical operations directly inside their GPU kernels, leveraging kernel fusion for maximum efficiency and flexibility. These libraries are crafted to work seamlessly together, providing a unified solution for high-performance computations, data processing, and random number generation all without unnecessary host-device data transfers. MathDx delivers performance portability across hardware generations, abstracting low-level GPU architecture details so developers can focus on algorithms rather than hardware-specific tuning.

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MS26

Performance-Portable Abstractions in Julia and Python

The "two-language problem' remains a challenge for post-exascale computing era: high productivity languages like Python and Julia traditionally sacrifice performance compared to C++, Fortran, and low-level models such as Kokkos or OpenMP. This talk highlights emerging solutions that narrow this gap. We present two frameworks for heterogeneous architectures:

- Mojit: A Python abstraction built on the Mojo ecosystem.
- JACC $JuliaforACCelerators$: A unified interface for executing Julia kernels across diverse hardware backends.

Our evaluation shows that while hand-tuned C++ or Fortran still holds a slight edge, the gap is increasingly negligible for many scientific workloads. JACC and Mojit deliver strong productivity-to-performance ratios, offering practical alternatives to traditional low-level approaches. By adopting these portable abstractions, developers can maintain expressivity while operating near peak hardware performance.

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MS27

Limit Cycle Induced Phase Autoencoder for Synchronization Dynamics in Transient Flows

Understanding the phase dynamics of high dimensional fluid flows is crucial for flow control and synchronization. We present a physics informed phase autoencoder that maps complex flow fields to a low dimensional latent space governed by the normal form of the Stuart-Landau equation. Unlike approaches that assume linear latent evolution, our architecture constrains trajectories to a supercritical Hopf bifurcation, explicitly learning the topological parameters of the limit cycle. This structure allows us to extract the asymptotic phase and Phase Sensitivity Function (PSF) directly from the data via both automatic differentiation and analytical derivations from the learned ODE parameters, bypassing computationally expensive adjoint solvers. We validate this method on the vortex shedding dynamics of flow over a backward-facing step. The model accurately captures the limit cycle and the phase dynamics of the flow while also maintaining the ability to accurately reconstruct the spatial data. These results demonstrate a robust, data-driven framework for characterizing synchronization properties in transient fluid flows.

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MS27

Transient Causal Modal Analysis of Aerodynamic Flows with Information-Theoretic Convolutional Learning

Aerodynamicists have aimed to capture dominating features of flow fields to understand complex unsteady flow and aerodynamic phenomena. Indeed, our eyeballs have persistently sought the causal relationship between vortical structures and aerodynamic forces. To grasp such an aerodynamic causal relationship in an interpretable manner, we propose information-theoretic convolutional learning that provides a time-varying modal structure causally related to the future aerodynamic response. The current convolutional neural network-based approach provides spatially continuous modes, which has been challenging to achieve with conventional techniques. Furthermore, a low-order submanifold representing informative vortical structures and the aerodynamic coefficient is identified. The proposed technique is applied to a range of aerodynamic flow examples, including extreme vortex-gust airfoil interaction, experimental measurements of transverse jet-wing interaction, and a turbulent separated wake. We reveal the causal relationship between vortical structures and the lift dynamics relying only on flow data and information metrics. This work may contribute not only to a deeper understanding of unsteady aerodynamics but also to offering causal insights into modeling and controlling fluid flows.

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MS27

Optimal perturbations in extreme gust-airfoil encounters

Small vehicles flying in extreme environments can encounter large gusts, leading to massive lift fluctuations and flow separation. Flight in these conditions is challenging as the gust ratio (a ratio of the gust to flight velocity) approaches O(1). Unfortunately, there are few studies at high gust ratios. Here, we bridge this gap by investigating the stability of gust encounters around NACA0012 airfoils. Stability is typically investigated by considering the asymptotic behavior of the equations linearized about a steady flow. We can not take this approach due to the unsteady nature of gust-airfoil encounters. Instead, we study the *transient growth* of perturbations about the gust-airfoil encounters using nonmodal stability analysis. In this analysis, we consider the transient growth of three-dimensional perturbations to two-dimensional laminar flows. We perform a spanwise Fourier decomposition and compute optimal perturbations (i.e., the largest growing perturbations) at each wavenumber. Low-wavenumber perturbations to gust-airfoil encounters grow orders of magnitude larger than perturbations to an airfoil or a gust alone (at Reynolds numbers greater than 300). This dramatic increase in perturbation size occurs due to strong amplification in the vortex dipole that appears after the gust impinges on the leading-edge of the airfoil surface. Finally, we add the optimal perturbation to the nonlinear simulation, which dramatically decreases the lift fluctuations.

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MS27

Cluster-Based Latent Control of Unsteady Fluid Flows

We present a data-driven framework for low-order analysis and control of transient fluid flows. A variational autoencoder (VAE) is used to learn a low-dimensional, interpretable manifold that captures nonlinear transient dynamics in high-dimensional flow fields. Unsupervised clustering in the latent space identifies dynamically meaningful anchor states corresponding to coherent flow regimes. The control objective is formulated as steering the system from arbitrary initial conditions to a prescribed target cluster state. Discrete control actions are associated with transitions between clusters, and Bayesian optimization determines energetically efficient control sequences that drive the system toward the desired state. Demonstrations on canonical flows, including low Reynolds number cylinder and airfoil wake configurations, show that the framework reliably reaches specified cluster states while minimizing actuation energy. Preliminary results on aeroelastic flows suggest that steering toward stable clusters can modulate transient instability growth.

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MS28

Numerical Methods for High-Frequency Waves and Eikonal Equations in Forward and Inverse Problems

High-frequency waves arise in seismic imaging, optics, and tomography, where strong oscillations and multiscale behavior create significant computational challenges. In this talk, I will begin with a brief introduction to the mathematical foundations of high-frequency wave propagation, geometric optics, and eikonal equations. I will then present recent advances in numerical methods for forward wave equations, including Hadamard integrators for efficient time- and frequency-domain propagation, as well as computational approaches for eikonal problems on complex geometries. Finally, I will discuss how these developments connect naturally to inverse problems and wave-based imaging.

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MS28

Butterfly Algorithms for Compressing Tensors in High-frequency Wave Problems

Butterfly algorithms, in their original matrix forms, have been successful in handling large-scale integral and differential operators for solve high-frequency wave equations. For example, the discretization of Green's function on a n^d spatial grid leads to an operator matrix of size $n^d \times n^d$, which can be compressed and manipulated by butterfly algorithms in $O(n^d \log n)$ complexity. That said, matrix algorithms do not fully exploit the redundancy in degree of freedoms in the higher-dimensional space and tensor algorithms can be considered. In this talk, I will discuss our recent work in P. M. Kielstra et al., Multiscale Model. Simul., 2025, which can be considered as the extension of butterfly algorithms from matrix to tensor. The tensor butterfly algorithm relies on Tucker decomposition of judiciously selected subtensors and nested construction of the factor matrices in each Tucker decomposition. It can achieve $O(n^d)$ complexity with significantly smaller prefactors than matrix butterfly algorithms. In contrast, other existing tensor algorithms such as hierarchical Tucker, CP, Tensor-train will lead to superlinear complexities. This is a joint work with P Michael Kielstra, Tianyi Shi, Hengrui Luo, and Jianliang Qian.

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MS28

Approximately Kinematic Waveform Inversion Methods

High-frequency asymptotics of waves connects kinematic (transit time) and dynamic (waveform) aspects of wave propagation. Inverse problems for both aspects of wave propagation are important in seismology and other scientific fields in which waves play a central role. The commonest formulations of kinematic and dynamic inverse wave problems, via nonlinear least squares and variants, appear unrelated and exhibit quite different numerical behaviour. In particular, mean square transit time error has a priori nothing to do with data frequency content, whereas mean square waveform error depends strongly on frequency, so that low-to-high frequency continuation has become a routine element of practical waveform inversion algorithms. However, other objective functions for dynamic inversion do measure travel-time error in the high frequency limit - that is, they are approximately kinematic. For example, Adaptive Waveform Inversion (AWI), produces an objective function asymptotic to the mean-square transit time error, in some circumstances. In other circumstances (multiple ray paths) this relation fails, and the AWI objective appears to be as strongly frequency dependent as mean square waveform error. A formulation based on synthetic antenna data, on the other hand, is asymptotic to a non-standard kinematic objective (so is approximately kinematic) even when multiple wavefronts, related to multiple ray paths, appear in the data.

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MS28

High Order Absolutely Convergent Fast Sweeping Methods with Multi-resolution WENO Local Solvers for Eikonal and Factored Eikonal Equations

In this paper we develop high order fast sweeping methods with multi-resolution WENO local solvers for solving Eikonal equations, an important class of static Hamilton-Jacobi equations. Based on such kind of multi-resolution WENO local solvers with unequal-sized sub-stencils, iteration residues of the designed high order fast sweeping methods can settle down to round-off errors and achieve the absolute convergence. In order to obtain high order accuracy for problems with singular source-point, we apply the factored Eikonal approach developed in the literature and solve the resulting factored Eikonal equations by the new high order WENO fast sweeping methods. Extensive numerical experiments are performed to show the accuracy, computational efficiency, and advantages of the new high order fast sweeping schemes for solving static Hamilton-Jacobi equations.

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MS29

Neuroscience Models for Neuromorphic Computing

Mathematical modeling of neuroscience data has been instrumental in advancing our understanding of how fundamental aspects of brain function, including neural dynamics and animal behavior, emerge from the biophysical properties of individual neurons. In this talk, I will explore how such models are being used not only to deepen neuroscience understanding but also to guide the development of neuromorphic emulations of key biological computations. Historically, neuromorphic computing has been motivated by the relatively low power requirements of biological brains. By abstracting detailed biological data into compact descriptions of biological computation, mathematical neuroscience models play a crucial role in achieving energy-efficient large-scale computations.

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MS29

Pattern Formation in a Non-Reciprocal Cahn-Hilliard Equation

We consider a non-reciprocally coupled Cahn-Hilliard (NRCH) equation recently proposed by Brauns and Marchetti in 2024 as a minimal model for mass-conserving non-reciprocal dynamics. Focusing on the sharp interface limit, we derive a Mullins-Sekerka type reduction which describes the time evolution of the interface between two different states. In contrast to gradient dynamics, like the classical Cahn-Hilliard equation, the NRCH can exhibit rich dynamic solutions such as traveling wave-trains and with straight or undulating interfaces. We illustrate how the sharp interface asymptotics can be used to provide detailed descriptions of these solutions as well as their linear stability.

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MS29

Mathematical Modeling for Insects and Vector-Borne Diseases

Mosquito populations are highly dependent on environmental factors such as temperature and precipitation, but the relationships between these populations and their environment vary by species and location. We developed a mathematical and statistical modeling framework for mosquito population dynamics that enables us to understand the conditions which lead to historical mosquito population dynamics. This data-driven and process-based mathematical model for mosquito populations is a hybridization of an integral projection model and a partial differential equations model, which allows us to capture the detailed mosquito lifecycle behavior while retaining the ability for fast computation. Our model results effectively capture seasonal population dynamics for Culex mosquitoes in Toronto, Canada and San Diego, California, USA two distinct geographical locations. We also explore extensions of this model to other insect pests affecting livestock and crops.

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MS30

A Doubly Stochastic Model of Government Interventions to Preserve Ecosystems Services in the Context of Large-scale Industrial Agriculture

Deforestation, driven by industrial agriculture and cattle farming, has significantly impacted communities and ecosystems across the globe. In this paper, we develop a discrete-time Markov model to evaluate the effectiveness of market-based interventions, such as Payment for Ecosystem Services (PES) and taxes, in addressing forest loss within the context of large-scale agriculture. Specifically, we focus on how commodity price variability influences deforestation decisions. To model these price fluctuations, we represent agricultural prices as Geometric Brownian Motion (GBM). By linking commodity price dynamics to land use transitions, our model aims to provide insight into how financial mechanisms can slow or stop deforestation. We find that the structure of the implemented policies have a large effect even if the total dollar amount across different structures were to remain constant. Therefore, decision makers should carefully choose the structure of their policies depending on their objectives with regards to poverty alleviation, deforestation prevention, and reforestation incentives.

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MS30

Alternatives to the Laplacian for Scalable Spectral Clustering with Group Fairness Constraints

Recent research has focused on mitigating algorithmic bias in clustering by incorporating fairness constraints into algorithmic design. Among these, group fairness (balance) ensures that each protected group is proportionally represented within every cluster. However, incorporating balance as a metric of fairness into spectral clustering algorithms has led to computational times that can be improved. Our work was able to enhance the efficiency of spectral clustering algorithms by reformulating the constrained optimization problem using a new formulation derived from the Lagrangian method and the Sherman-Morrison-Woodbury (SMW) identity, resulting in the Fair-SMW algorithm. Fair-SMW employs three alternatives to the Laplacian matrix achieving clustering solutions with comparable balance to existing algorithms while offering improved runtime performance. Achieving an improvement in computation time that is twice as fast as the state-of-the-art, and also flexible enough to achieve twice as much balance.

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MS30

Spectral Fusion for Identifying Early State Exclusion in Symmetric Quantum Spin Chains

Perfect state transfer (PST) in one-dimensional quantum spin chains provides a natural setting in which quantum information transport can be analyzed using spectral methods. In the single-excitation subspace, the dynamics of a chain with nearest-neighbor interactions are governed by a Jacobi matrix, allowing questions of state transfer to be formulated in terms of eigenvalue distributions and sym- metry properties of eigenvectors. In this work, we investigate the phenomenon of early state exclusion (ESE), whereby the overlap of the time-evolved state with the initial state vanishes at a time strictly earlier than the first occurrence of per- fect state transfer. Building on earlier constructions of Hamiltonians exhibiting PST with and without ESE, we provide explicit Jacobi matrix realizations for arbitrary odd-length chains and establish general conditions under which ESE occurs or does not occur. We propose the process of spectral fusion (SF) to build infinite families of such Hamiltonians. These results broaden the known class of spin chains displaying early state exclusion and further clarify the role of spectral structure of the Hamiltonians.

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MS30

Guerrero Presentation TBA

To Come

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MS31

Edge-Promoting Sequential Bayesian Experimental Design

This work considers sequential edge-promoting Bayesian optimal experimental design for X-ray imaging. The process of computing a total variation type reconstruction for the absorption inside the imaged body via lagged diffusivity iteration is interpreted in the Bayesian framework. Assuming a Gaussian additive noise model, this leads to an approximate Gaussian posterior with a covariance structure that contains information on the location of edges in the posterior mean. The next projection geometry is then chosen through A- or D-optimal Bayesian experimental design, which corresponds to minimizing the trace or the determinant of the updated posterior covariance that accounts for the new projection. The method is tested via numerical experiments based on simulated measurements.

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MS31

Optimal Kernel Learning for Gaussian Process Models with High-Dimensional Input

Gaussian process (GP) regression is a popular surrogate modeling tool for computer simulations in engineering and scientific domains. However, it often struggles with high computational costs and low prediction accuracy when the simulation involves too many input variables. For some simulation models, the outputs may only be significantly influenced by a small subset of the input variables, referred to as the "active variables'. We propose an optimal kernel learning approach to identify these active variables, thereby overcoming GP model limitations and enhancing system understanding. Our method approximates the original GP model's covariance function through a convex combination of kernel functions, each utilizing low-dimensional subsets of input variables. Inspired by the Fedorov-Wynn algorithm from optimal design literature, we develop an optimal kernel learning algorithm to determine this approximation. We incorporate the effect heredity principle, a concept borrowed from the field of "design and analysis of experiments', to ensure sparsity in active variable selection. Through several examples, we demonstrate that the proposed method outperforms alternative approaches in correctly identifying active input variables and improving prediction accuracy. It is an effective solution for interpreting the surrogate GP regression and simplifying the complex underlying system.

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MS32

Diffeomorphic Image Registration: Variational and Deep Learning Approaches

In this talk, we study the problem of enforcing diffeomorphic constraints in image registration, with the aim of providing rigorous guarantees of diffeomorphism for deformation fields predicted by deep learning models. We begin by reviewing classical variational formulations, in which diffeomorphic mappings are ensured through analytically well-posed constraints on velocity fields or transformation parameterizations. We then analyze the fundamental difficulties that arise when such constraints are transferred to data-driven models, highlighting the gap between constraint-satisfying training objectives and the potential loss of diffeomorphic structure at prediction time. To address this issue, we propose a novel transformation framework that enforces diffeomorphism at the mathematical level, independent of network approximation errors. This framework naturally integrates with generative diffusion equations, enabling stable training in the small-data regime. We conclude by providing comparative results that demonstrate the effectiveness of the proposed approach in delivering provable diffeomorphic guarantees relative to existing variational and learning-based methods.

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MS32

Optical Fourier Transform-Based Preconditioning for Large-Scale Inverse Problems

FFT-based preconditioners are well established for large-scale inverse problems, where they are used to efficiently approximate inverse operators. Optical Fourier transforms, the analog counterpart to digital Fourier transforms, exploit light propagation through optical systems and offer the potential for greater throughput and energy efficiency than conventional FFT implementations. However, practical optical systems are inherently imperfect and introduce a variety of physical perturbations and measurement errors. As a result, optical Fourier transforms can only provide approximations to their digital counterparts, and the implications of these inexact transforms for iterative solvers remain largely unexplored. This work investigates the use of optical Fourier transforms as replacements for digital FFTs within preconditioners for regularized least-squares problems. We simulate optical Fourier transforms by incorporating optical imperfections and examine how these errors affect preconditioner quality and convergence behavior.

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MS32

Hyperspectral Band Selection Via Matrix and Ten-

sor Low Rankness

Hyperspectral band selection is crucial for reducing data dimensionality while preserving essential information. However, many existing methods face challenges such as high memory usage and difficulty maintaining inherent spatial-spectral relationships. In this talk, we present band selection approaches that integrate graph regularization or 3D total variation with matrix/tensor low-rank modeling. Using the Alternating Direction Method of Multipliers (ADMM), we develop efficient algorithms that apply matrix/tensor CUR decompositions to enhance computational efficiency. Experiments on benchmark datasets show that our methods outperform state-of-the-art alternatives.

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MS32

Enhanced Diffusion-Based Image Super-Resolution with Perceptual Loss

Diffusion-based image super-resolution (SR) generates high-resolution (HR) image by starting from noise and denoising step by step, guided by a low-resolution (LR) input. It has wide applications in medical imaging, remote sensing, and other settings where higher resolution is needed. Most diffusion-based SR methods are trained mainly with pixel-wise reconstruction losses. However, pixel-wise losses do not always match human perception, so diffusion-based SR can miss perceptually important details such as sharp edges and realistic textures. In this work, we enhance diffusion-based SR by adding a perceptual loss. We use a pretrained VGG network as a feature extractor and define the perceptual loss as the difference between VGG features of the ground-truth HR image and the reconstructed image. Compared to pixel-only loss, this feature-based loss improves edge sharpness, texture quality, and leads to faster convergence. The method can be incorporated into existing diffusion SR frameworks with small changes. Visual results and quantitative evaluation against representative pixel-only loss baselines support the effectiveness of our approach. This is joint work with Min Wang (University of Houston), Jing Qin (University of Kentucky), Max Van Fleet (UNC Chapel Hill), Weihong Guo (Case Western Reserve University), Ying Liang (Duke University), Yifei Lou (UNC Chapel Hill), Pavithra Venkatachalapathy (Texas Tech University).

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MS33

Spatial Pattern Formation and the Evolution of Cooperative Behavior

Social dilemmas featuring tension between the individual incentive to cheat and a collective goal to maintain cooperative behavior arise across a range of natural and social systems, from the origins of multicellular life to the sustainable manage of shared natural resources. Evolutionary game theory provides a helpful analytical framework for describing this conflict between individual and collective interests, exploring mechanisms that can help the emergence of cooperative behaviors. In this talk, we discuss several PDE models for evolutionary games featuring diffusion of individuals and directed motion towards either increasing payoff or improved environmental quality. We show that biased motion of cooperators can promote the formation of spatial patterns featuring regions with greater population density and increased average payoffs and environmental quality in regions in which cooperators have aggregated. However, by measuring the average payoff of the population or the average level of environmental quality across the population, we see that these pattern-forming mechanisms can actually decrease the overall success of the population, relative to the equilibrium outcome in the absence of spatial motion. This suggests that payoff-driven and environmental-driven motion can produce a kind of spatial social dilemma, in which biased motions towards more beneficial regions can produce emergent patterns featuring a worse overall environment for the population.

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MS33

Multiscale Modeling and Simulation of Urban Crime Dynamics

We present a multiscale framework for modeling and simulation of urban crime dynamics that integrates agent-based models with continuum partial differential equation (PDE) descriptions obtained through mean-field limits. The baseline system captures the coupled evolution of environmental attractiveness and criminal density, reproducing the emergence and persistence of crime hotspots through nonlinear feedback mechanisms. We further extend the modeling framework to incorporate additional response and interaction mechanisms that influence criminal activity across spatial and temporal scales. Using both agent-based and PDE simulations, we investigate how these mechanisms affect hotspot formation, stability, and spatial redistribution in heterogeneous urban environments. The framework supports realistic geometries and spatial variability, including simulations on the city of Chicago. Together, these results demonstrate how integrated multiscale modeling and simulation provide a flexible computational platform for studying complex urban crime dynamics and for enabling future data-driven calibration and predictive analysis.

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MS33

Stochastic Control Methods for Optimization

In this talk, we investigate a stochastic control framework for global optimization over both finite-dimensional Euclidean spaces and the Wasserstein space of probability measures. In the Euclidean setting, the original minimization problem is approximated by a family of regularized stochastic control problems; using dynamic programming, we analyze the associated Hamilton–Jacobi–Bellman equations and obtain tractable representations via the Cole–Hopf transform and the Feynman–Kac formula. For optimization over probability measures, we formulate a regularized mean-field control problem characterized by a master equation, and further approximate it by controlled -particle systems. We establish that, as the regularization parameter tends to zero (and as the particle number tends to infinity for the optimization over probability measures), the value of the control problem converges to the global minimum of the original objective. Building on the resulting probabilistic representations, Monte Carlo-based numerical schemes are proposed and numerical experiments are reported to illustrate the practical perspective.

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MS34

Bias, Coverage, and Pre-Smoothing in the WENDy-IRLS Algorithm

The Weak-form Estimation of Nonlinear Dynamics (WENDy) method is a recently proposed class of parameter estimation algorithms that exhibit notable noise robustness and computational efficiency. We first examine the bias and coverage properties of the WENDy-IRLS algorithm across five benchmark systems Logistic, Lotka-Volterra, FitzHugh-Nagumo, Hindmarsh-Rose, and a Protein Transduction Benchmark under four noise distributions and noise levels well beyond those previously tested. This analysis reveals systematic estimator bias that motivates the second part of this work: improving WENDy estimator bias through pre-smoothing. Focusing on the Logistic, Lotka-Volterra, and FitzHugh-Nagumo systems, we investigate how smoothing window size and data resolution affect parameter error under varying noise levels, with and without padding. We further extend WENDy-IRLS's existing covariance correction framework to the pre-smoothing and investigate its effect on parameter error.

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MS34

Data Assimilation for Weak SINDy Surrogate Models

We construct weak SINDy surrogate models to compress streaming scientific data and explore the utility of additional sparsely sampled data for reconstructing streaming scientific data. We use continuous data assimilation as a tool to combine information from the weak SINDy surrogate model and sparsely sampled data in the data reconstruction process. We investigate the relation between weak SINDy surrogates and data sampling strategies and discuss how the choice of sampling strategies leads to different compression performance.

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MS34

Data-Driven MPC via WSINDy for Plasma, Drone Control, and Chaotic Systems

In science and engineering, strong nonlinearities, noise, and computational constraints often challenge traditional control approaches. Thanks to recent advances in data-driven system identification methods, which have been shown as powerful techniques that provide fast, interpretable, parsimonious models, many model predictive control (MPC) applications have flourished. In this work, we present the WSINDy with actuation inputs (WSINDYc) within a MPC framework, which enables a more robust identification of the equations of motion, particularly when data is under high noise levels, compared to baseline methods. As a result, it leads to more efficient control. We assess the capabilities of the WSINDY-MPC framework in different dynamical systems, including fusion data, drone tracking, and the Lorenz system. The results show that the proposed framework achieves superior performance in different metrics, such as noise presence, prediction horizon, and state tracking error.

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MS34

Ensemble Wsindy for Data Driven Discovery of Governing Equations from Laser-Based Full-Field Measurements

This talk covers recent work that leverages laser vibrometry and the weak form of the sparse identification of nonlinear dynamics (WSINDy) for partial differential equations(PDEs) to learn macroscale governing equations from full-field experimental data. In the experiments, two beam-like specimens, one aluminum and one particulate composite, are subjected to shear wave excitation in the low frequency regime and the response is measured in the form of particle velocity on the specimen surface. The WSINDy for PDEs algorithm is applied to the resulting spatio-temporal data to discover the effective dynamics of the specimens from a family of potential PDEs. The discovered PDEs are of the recognizable Euler-Bernoulli beam model form, from which the Young's modulus is recovered for both materials. An ensemble version of the WSINDy algorithm is also used, which provides estimates of the uncertainty in the PDE coefficients and resulting Young's moduli. Finally, the discovered PDEs are solved with a finite element code to compare against the experimental data with reasonable accuracy. Using full-field experimental data and WSINDy together is a powerful non-destructive approach for learning unknown governing equations and gaining insights about mechanical systems in the dynamic regime.

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MS36

Recovering Parameters on Exceptional Sets

The field of numerical algebraic geometry consists of algorithms for numerically solving systems of polynomial equations. When the system is exact, such as having integer or rational coefficients, the solution set is well-defined. When solving parameterized polynomial systems with parameter values that are not exact due to imprecision in measurement or prior computations, the structure of the solution set can change. This talk will describe methods to robustly recover nearby parameters corresponding to the desired structure for solutions at infinity, positive dimensional components, multiplicity, and irreducible components. These methods will be demonstrated through illustrative examples and problems arising from the kinematics of mechanisms and robots.

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MS36

Lagrangian Dual Sections

This talk discusses joint work with Venkat Chandrasekaran, Jose Israel Rodriguez, and Kevin Shu, where we initiate the study of Lagrangian dual sections. This theory gives rise to sufficient conditions for the "hidden convexity" of certain nonconvex optimization problems. Notable examples include spectral inverse problems and certain unbalanced Procrustes problems. As an additional bonus, when the constraint set is a compact Riemannian manifold, the Lagrangian formulation allows us to solve these problems using a numerical continuation algorithm based on Riemannian gradient descent.

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MS36

Computing Complements of Real Hypersurfaces using Pseudo-Witness sets

Many hypersurfaces in algebraic geometry, such as the discriminants of a parametrized polynomial system, arise as a projection of another variety. The existing methods of computing the real complements of these hypersurfaces use the defining equation of the projection. Accessing this equation is often computationally prohibitive. In this talk, we describe a method to compute the chambers of the real complement of a hypersurface given by the projection of a variety, by using pseudowitness sets. We conclude by demonstrating the efficiency of our method on several interesting examples.

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MS36

Equilibrium Configurations in the Planar n-Vortex Problem Using Numerical Algebraic Geometry

The n-vortex problem, a classical topic linking fluid dynamics and celestial mechanics, examines the motion and equilibrium of point vortices in an ideal fluid. This project focuses on relative equilibria where vortices rotate uniformly while preserving their configuration. Previous work has been done to find all possible configurations for n ¿= 4. To confirm and expand these results, homotopy continuation methods within numerical algebraic geometry can be applied to these nonlinear systems. This talk will give examples for the 3- and 4-vortex cases, as well as new results. This is joint work with Gareth Roberts and Nicholas Cesario.

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MS37

Finding Equilibria of Small Networks of Linear Springs

We use tools from nonlinear algebra to study the equilibria of small linear spring networks. We describe two constructions for a system of polynomials from a given spring network. We use the techniques of homotopy continuation, monodromy, and parameter homotopy (a.k.a. cheater homotopy) to solve these systems of polynomials and compute the equilibria of all rigid linear spring networks with 5 nodes or fewer.
We describe a method of implementing parameter homotopy that arises naturally from the physical structure of the system. We give precise total degree bounds for general planar spring networks on the maximum number of solutions and compare the computation efficiency of each of these techniques against a baseline of Newton's method for spring networks of various sizes.

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MS37

Integrating Plasticity into Bioinspired Neural Networks Leads to Interpretable and Safe Learning Systems

The core approach underlying recent advances in artificial intelligence is training black-box models called artificial neural networks (ANNs). Using nonlinear activation functions, large ANNs can approximate complex functions. However, biological neurons can do something more. The XOR operation, which can only be achieved by a two-layer ANN, can be performed in a single biological neuron. Capturing key features of neural computation may lead to more powerful ANN models. We have previously shown that Synthetic Nervous Systems (SNSs), a bioinspired ANN, can be used to design sparse networks. However, the design relied mainly on analytical methods, limiting its application. In this study, we aim to incorporate plasticity into SNSs, enabling them to perform learning tasks. We have discretized the SNS equations and expressed the dynamics as recurrent neural networks. We then modelled SNSs in machine learning libraries so that they can be trained using supervised and reinforcement learning algorithms. To show the advantages of using SNSs in learning and control, we trained SNS policies for robotic manipulation tasks. Combined with bio-inspired architecture and network pruning, we can train highly interpretable SNS controllers in simulation and transfer them to real robots with little tuning. Moreover, we showed that SNS dynamics can alleviate the impact of sensory noise. These results suggest that SNSs with plasticity are a strong candidate for interpretable, safe machine learning.

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MS37

Constructing Continuous Manifold Dynamics in Spiking Neural Networks

Low-dimensional manifolds embedded in high-dimensional neural dynamics provide a unifying framework for understanding computation in biological and artificial neural systems. We present a class of spiking neural networks that enables the systematic construction of continuous manifolds supporting heteroclinic channels, limit cycles, and discrete state transitions within a single dynamical architecture. These systems can be designed to realize targeted flows on manifolds, bridging attractor networks, winner-take-all circuits, and state-machine-like dynamics in a common mathematical framework. We demonstrate this approach in the context of motor control by constructing a network that generates traveling waves of activity resembling those observed in spinal locomotor circuits. When coupled to a biomechanical simulation of rat hindlimb locomotion, the resulting dynamics produce stable, coordinated gait patterns and support smooth modulation of speed and phase relationships. The same underlying architecture admits reduced descriptions that recover classical half-center oscillator behavior as a limiting case, clarifying the relationship between continuous and discrete models of rhythmic control. Finally, we discuss implementation on neuromorphic hardware, where spiking realizations of these networks enable low-power simulation of high-dimensional systems of coupled differential equations. This framework connects dynamical systems theory, neural modeling, and neuromorphic computation, providing constructive tools for designing neural circuits with prescribed manifold dynamics and scalable hardware realizations.

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MS37

An Overview of Recent Advances in Collaborative Navigation

The equations that govern the measurement models in collaborative multi-vehicle navigation can have multiple local maxima for the likelihood of vehicle states (i.e. positions and orientations). It is generally desirable to find the best global solution, but it may also be necessary to track multiple hypotheses. This work explores the challenges associated with multi-vehicle state estimation by comparing traditional nonlinear optimization approaches based on Newtons method to nonlinear algebraic approaches based on homotopy continuation and monodromy. The effects of various state representations will also be discussed.

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MS38

Recent Advances in the Stability and Uniqueness of Solutions to Systems of Conservation Laws

In this talk, we will discuss recent developments in the stability and uniqueness of solutions to 2×2 conservation laws in 1-d. We will begin with a Hölder-L^2 estimate of the form

$$||u(\cdot,\tau) - v(\cdot,\tau)||_{L^2} < K||u(\cdot,0) - v(\cdot,0)||_{L^2}^{1/2},$$

where v is a small-BV solution and u is a bounded entropic solution that has a regularity *weaker than BV*. Two classes of weak solutions that possess this regularity property are the small L^∞ solutions constructed by Glimm and Lax and Hölder continuous solutions constructed by convex integration. The latter are considered due to a recent construction of Chen, Vasseur, and Yu which produces non-unique continuous (but not Hölder continuous) solutions to a class of 2×2 conservation laws. Using the Hölder-L^2 estimate, we deduce the uniqueness for the construction of Glimm and Lax starting from Sobolev initial data. We also have uniqueness of C^α solutions to 2×2 conservation laws, provided that $\alpha > \frac{1}{2}$. These results are joint works with Geng Chen, Jeffrey Cheng, and Sam G. Krupa.

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MS38

Are L^∞ Solutions to Hyperbolic Systems of Conservation Laws Unique?

For hyperbolic systems of conservation laws in 1-D, fundamental questions about uniqueness and blow up of weak solutions still remain even for the apparently simple systems of two conserved quantities such as isentropic Euler and the p-system. Similarly, in the multi-dimensional case, a longstanding open question has been the uniqueness of weak solutions with initial data corresponding to the compressible vortex sheet. We address all of these questions by using the lens of convex integration, a general method of constructing highly irregular and non-unique solutions to PDEs. Our proofs involve computer-assistance. This talk is based on joint work with Lszl Szkelyhidi, Jr.

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MS38

Conditional Liouville Theorem for the Stationary Navier-Stokes Equations

We present a novel approach to the Liouville problem for the stationary Navier-Stokes equations. Under assumptions on the growth rate of the antiderivative of the velocity, we prove that there exists no nontrivial solution to the three-dimensional stationary Navier-Stokes equation.

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MS38

Instantaneous Blowup of Incompressible Flow with Passive Tracer

We construct a family of solutions (u, b) of the incompressible flow with a passive tracer for which both $\|u(t)\|_{L^\infty}$ and $\|b(t)\|_{L^\infty}$ blow up at time T_*. Away from T_*, the solutions remain smooth in both space and time. The argument adapts the inverse cascade mechanism from [CDP25] to the presence of an advected scalar, but the passive component creates a new compatibility constraint: the iteration must propagate the tracer while preserving the same principal velocity profiles from one stage to the next. We resolve it by introducing a simultaneous decomposition lemma for a symmetric tensor and a vector field. We also show the existence of an infinitely family of instantaneous blowup solutions to the 2D MHD system, with critical blowup rate for the velocity component according to the scaling of the system. Moreover, the non-uniqueness is sharp in the sense that it occurs in spaces borderline to $L^2_t L^\infty_x$, the endpoint space of the Ladyzhenskaya–Prodi–Serrin type where uniqueness is known.

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MS39

Deterministic Policy Gradient Learning in Continuous Time Mean Field Control

Continuous-time mean field control aims to learn deterministic feedback policies that depend on both an agents state and the population distribution. However, most existing continuous-time RL methods use stochastic policies, which increase variance, slow learning, and complicate deploymentespecially under mean-field coupling. In this paper, we extend deterministic policy gradients to continuous-time mean field control. We derive a clean continuous-time deterministic policy gradient expressed via a mean-field advantage rate. This concise formulation allows deterministic policy gradients to be estimated far more efficiently than usual stochastic policy gradients. Building on this theory, we propose MF-CT-DDPG, a model-free actor-critic algorithm that allows stable learning in mean-field control. Experiments show improved stability and faster convergence across tasks with varying discretizations and noise levels.

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MS39

Mean Field Generalization and Optimal Control

In this talk we will consider the problem of learning optimal controls from a fixed set of training data. We will particularly consider the situation where controls are parameterized by an overparameterized neural network (which we analyse using the mean-field formalism), but we wish to control overlearning and the expected out-of-sample performance. We will see that generalization error estimates allow us to find algorithms yielding good performance, and see how this works on some practical problems.

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MS39

Implicit Regularization of Early Stopping for Gradient Descent: a Mean Field Control Formulation

It is widely observed that overparameterized neural networksoften with more parameters than training samplescan interpolate the training data while still generalizing well. One theoretical approach to this phenomenon studies the dynamics of gradient-based training. Empirically and in several settings theoretically, gradient descent is seen to converge to particular simpler solutions among many minimizers, a bias commonly referred to as implicit regularization. Early stopping during the training process can further reduce effective model complexity and often improves generalization. We adopt the mean-field formulation on wide neural networks, representing the network by a probability measure over parameters and viewing training as a gradient flow on Wasserstein space. Building on this viewpoint, we introduce a mean-field control formulation of the training dynamics. This control perspective, together with dynamic programming principle, leads to a mean-field analogue of the Wasserstein-2 distance and provides a framework for analyzing early stopping and implicit regularization.

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MS40

Matrix Model for Mixed Multiple Orthogonal Polynomials

We present a Gaussian Hermitian matrix model whose eigenvalue density provides a mixed multiple orthogonal polynomial (MOP) ensemble. This gives a concrete matrix integral for mixed-MOP determinantal processes describing non-intersecting Brownian motions with general multi-start/multi-end boundary data. We outline how this viewpoint can be used for asymptotic analysis, linking Riemann–Hilbert steepest descent for mixed MOPs with standard large-n matrix-model tools, and suggesting new routes to critical regimes.

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MS40

Orthogonal Polynomials and Mutually Unbiased Bases

Two interesting phenomena for the construction of quantum states are that of mutually unbiased bases and that of balanced states. We explore a recently developed approach to each phenomenon using orthogonal polynomials on the unit circle. In the case of mutually unbiased bases, we provide a negative result. In the case of balanced states, we provide examples of pairs of orthonormal bases and states that are balanced with respect to them and extensions to the infinite dimensional setting. This is based on joint work with Graeme Reinhart.

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MS40

Some Inequalities About the Norms of Wick Products with Respect to the Poisson Probability Measure

We review first the definition of Poisson Wick product in terms of the Charlier polynomials. Then we provide a formula for the Poisson Wick product involving series. We find next sharp inequalities concerning the L^1 and L^2 norms of the Poisson Wick product. Finally, we interpolate to find (not sharp) inequalities about the other L^p norms of the Poisson Wick product. This is a joint work with Alberto Lanconelli from the University of Bologna.

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MS41

Quantum Linear Algebra for Classical Convex Optimization

We present computational advances in quantum linear algebra for optimization, with a focus on the first numerical demonstrations of Quantum Interior Point Methods (QIPMs) realized through an open-source software stack and evaluated both in classical simulation and on real quantum hardware. The central approach employs Quantum Linear Systems Algorithms (QLSAs) to solve the Newton systems arising at each iteration of a classical interior point method, offering favorable polylogarithmic scaling in problem dimension. Our experiments address key practical challenges in this integration, including inexactness inherent to quantum subroutines, sensitivity to ill-conditioning, and measurement bottlenecks associated with extracting useful classical information from quantum states. We report empirical scaling behavior across problem instances and hardware configurations, situating these results within a rigorous complexity-theoretic comparison between classical and quantum IPMs and identifying practical conditions under which quantum acceleration in conic optimization may be achievable.

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MS41

Super-polynomial Quantum Advantage for Optimization via Continuous Relaxation

Combinatorial optimization is a major target for quantum algorithms, yet most existing approaches work directly in the discrete search space and rely on specific problem structures to achieve provable speedups. In this talk, we discuss how continuous quantum optimization algorithms can be used to provide computational advantage for combinatorial optimization by relaxing binary variables to continuous ones. For a cardinality-constrained variant of QUBO, we formulate a penalty-based continuous relaxation problem and analyze a hybrid algorithm that combines Quantum Hamiltonian Descent (QHD) for generating warm-started guesses and classical gradient descent for fast local refinement. We show that the proposed algorithm can find the global minimum of the continuously relaxed problem in a sub-exponential time, which is super-polynomially faster than known algorithms in this regime. Our analysis leverages the Fundamental Gap Theorem for continuous-variable quantum Hamiltonians, offering a new framework for establishing practical quantum advantage.

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MS41

Quantum-Inspired Hamiltonian Descent for LLM Sparsification

Large language model (LLM) inference incurs substantial computational cost, driven primarily by dense matrix multiplications. Model sparsification aims to reduce this cost by reconstructing model behavior using sparse weight matrices. Building on SparseGPT, the sparsification process can be formulated as a set of mixed-integer quadratic programming (MIQP) problems. However, the scale and volume of these optimization tasks make conventional CPU-based solvers impractical. To address this challenge, we employ a GPU-native metaheuristic optimization method, quantum-inspired Hamiltonian descent (QIHD). QIHD produces near-optimal sparse reconstructions with significantly lower deviation from the original dense models than existing approaches, reducing up to 60% of deviation of layer outputs compared to conventional methods in practice. For small-scale LLMs, QIHD completes post-training sparsification within fully parallelable 100 GPU hours, demonstrating its practicality for accurate and scalable model pruning. For intermediate-scale LLMs, proper integration of QIHD and conventional heuristics significantly improves the model performance with minimal computational overheads in optimization solving.

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MS41

Continuous-Variable Quantum Algorithms for Dissipative Dynamics: From Pdes to Optimization

Simulating nonlinear differential equations on quantum computers typically requires Carleman linearization and fault-tolerant digital hardware. We present an alternative analog approach using continuous-variable quantum systems, where classical fields are encoded into coherent states of bosonic modes. Leveraging the Koopman-von Neumann formalism, nonlinear dynamics are lifted to linear evolution implementable with logarithmic circuit depth. We then explore preliminary extensions to optimization, where engineered Lindblad dissipation can drive the system toward solutions of least-squares problems.

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MS42

Stability and accuracy effects of filtering on RungeKutta discontinuous Galerkin methods: Fourier analysis for the second-order case

In this work, we study the stability and accuracy effects of filtering on the Runge–Kutta (RK) discontinuous Galerkin (DG) methods for scalar hyperbolic conservation laws. Both the standard RKDG method and its variant, the RKDG method with compact stencils (cRKDG), will be considered. We focus on the second-order schemes and apply the modal filters after the DG operators at each RK stage. Using a Fourier-type analysis, we quantitatively assess the time step constraints for stability and accuracy of multiple filtered schemes. We show that the application of filters can significantly improve the CourantFriedrichsLewy numbers while maintaining the optimal convergence rate. However, for problems containing sonic points, the convergence order of some filtered schemes may degrade. To address this issue, we apply filters only away from the sonic points and adopt a local time-stepping strategy for the cRKDG method to take advantage of the larger time steps enabled by the filters in these regions.

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MS42

Stability and Convergence Analysis of Multirate Methods for Coupled Free Flow with Porous Media Flow

The coupled Stokes/Darcy model describes the interaction of two fluid models with widely varying flow rates, i.e, a relatively fast moving free fluid coupled with a slow porous media flow. Solving the fully coupled problem with a time step dictated by the fast changing solution of the free fluid results in unnecessary computational effort updating the slow changing porous flow solution. Multirate methods are ideal in this scenario because they allow for the use of two different time steps that depend on the flow rates in each subdomain. In this talk we discuss the stability and convergence of finite element based multirate schemes for Stokes/Darcy problem. In addition, we present numerical results verifying predicted theoretical convergence rates.

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MS42

SUNDIALS Adaptive Timestepping Methods in Magnetic Confinement Fusion Simulation Codes GENE-X and SOLPS-ITER

Timestepping schemes are crucial components of direct numerical simulations for magnetic confinement fusion (MCF) experiments. With an accurate and efficient timestepping scheme, we can verify and improve fusion device design rapidly, and generate a large amount of useful data for physicists to build actual devices, and for computer scientists to build Machine Learning models about those devices. In this talk, we present adaptive timestepping schemes implemented in GENE-X and SOLPS-ITER, using SUNDIALS. These adaptive schemes control the temporal integration error, and find the suitable timestep sizes automatically throughout the simulations. We demonstrate overall performance improvement via TCV-X21 tokamak benchmarks. Simulations are performed on the NERSC Perlmutter HPC cluster. The GENE-X code solves the full-f gyrokinetic equation that models plasmas in tokamak and stellarator designs from core to edge. It is capable of CPU parallel and GPU parallel simulations. The SOLPS-ITER code solves the Braginski equation, coupled with the kinetic Monte Carlo neutral solution. It excels at modeling the scrape-off layer in MCF. The SUNDIALS code is a numerical integration framework that provides a variety of state-of-the-art methods. Its flexible APIs allow streamlined integration with GENE-X and SOLPS-ITER, and brings advanced numerical integration methods into those codes.

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MS42

Adaptive Timestep Control for Coupled Multimodel Simulations

Coupled multiscale and multiphysics simulations are becoming an increasingly common part of engineering and science simulation workflows. In addition to coupling traditional numerical models, recent advances include coupling models across multiple levels of fidelities include AI/ML based surrogate models. The Parallel Coupler for Multimodel Simulations (PCMS) has been developed to address many of these needs. However, the determination of coupling timesteps with suitable accuracy and stability remains a manual process. This talk provides an overview of recent advances in PCMS for performing conservative field transfer operations and recent work to integrate PCMS with SUNDIALS to achieve automatic, stable timestep selection. Developments will be demonstrated in the context of coupled simulations to support fusion pilot plant design.

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MS43

Multi-Fidelity Concensus Based Optimization

Consensus-based optimization (CBO) has recently emerged as a robust, gradient-free framework for solving high-dimensional and nonconvex optimization problems using interacting particle dynamics. In many scientific and engineering applications, however, optimization is constrained by expensive PDE-based forward models, making repeated high-fidelity evaluations prohibitive. In this talk, we develop a multi-fidelity CBO framework for PDE-constrained optimization, where low-fidelity surrogate models are used to guide global exploration and high-fidelity solvers are invoked selectively to refine the consensus. In addition, we introduce an adaptive entropy-controlled weighting strategy that mitigates overconfidence and prevents premature convergence to suboptimal consensus states. We test the proposed approach on benchmark optimization problems, including the thermal block example and a Hohlraum radiation transport problem.

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MS43

A Structure-Preserving Explicit-Implicit-Null Penalization Method with Low-Rank Extension for the Single-Species Rosenbluth-Fokker-Planck Equation

In this talk, I will discuss a structure-preserving penalization scheme for the stiff, single-species Rosenbluth-Fokker-Planck (RFP) equation. The scheme features three novel components: 1) a novel generalization of the well-known ChangCooper discretization for the RFP equation that is equilibrium-preserving and enables positivity while preserving mass, momentum, and energy; 2) an easy-to-invert isotropic variable-coefficient penalization operator to deal with the temporal stiffness without resorting to a fully implicit scheme, borrowing ideas from explicit-implicit-null (EIN) methods, and 3) an adaptive time stepping strategy that preserves the positivity of the full penalized scheme. The resulting scheme conserves mass, momentum, and energy strictly, is unconditionally stable, and robustly positivity preserving. To address the computational challenges associated with the high dimensionality of the RFP equation, I will also present a low-rank extension of the scheme, in which the nonlinear RFP operator is evaluated via cross approximation and the resulting discretized equation takes the form of a generalized Sylvester equation, solved using a previously developed Krylov-based adaptive-rank algorithm [1]. [1] H. El Kahza, J.-M. Qiu, L. Chacn, and W. Taitano, Sylvester-preconditioned adaptive-rank implicit

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MS43

Accelerating Hohlraum Design Optimization Via Weak-Form Reduced-Order Modeling

Solving large-scale optimization problems constrained by high-dimensional, time-dependent partial differential equations (PDEs) is computationally challenging, as it requires repeated solution of the governing equations. The Latent Space Dynamics Identification (LaSDI) framework, a data-driven, projection-based reduced order modeling method, addresses this challenge by enabling efficient surrogate-based simulation within optimization loops. When paired with the weak formulation, the LaSDI framework gains improved accuracy and robustness to noise in training data. In this work, we employ weak-form LaSDI to accelerate PDE-constrained optimization and derive adjoint-based sensitivities for scalable gradient evaluation. We demonstrate the proposed framework on thermal radiative transfer equations for an idealized Hohlraum problem, where WLaSDI enables efficient simulation and design optimization with over four orders of magnitude reduction in computational cost relative to full-order models.

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MS43

Multi-Fidelity Bayesian Optimization for Electrostatic Collisional Hybrid Models

Recent ignition events have brought the scientific community to the realization that the real-time control of plasmas and the optimal design of plasma experiments are amongst the greatest challenges of the 21st century. Indeed, achieving ignition required a painstaking effort to tweak the experimental setup to increase the probability for success. This relied on computational and data-driven models to explore the design space and provide guidance to experimenters. Further advances will need to leverage higher-fidelity computational models, but the highest fidelity, and most predictive, simulations require tremendous computational resources for even a single evaluation. In this presentation, we discuss multi-fidelity Bayesian optimization approach where the acquisition function selects the optimal fidelity (or fidelities) to evaluate and incorporates multi-fidelity gradient information. We demonstrate this multi-fidelity optimization methods on simplified problems to build intuition, as well as an electrostatic collisional hybrid model for the Vlasov-Fokker-Planck model of a Hohlraum.

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MS44

Geodesic-Based Numerical Integrators on Manifolds with Applications to Wavefront Propagation

We introduce two new explicit numerical integrators, Manifold-TVDRK (MTVDRK) and Manifold Taylor Series (MTS) methods, designed for solving differential equations on embedded manifolds, with a focus on applications to $\mathbb{S}^n$ and the special orthogonal group $\mathrm{SO}(n)$. Unlike many existing methods, our integrators do not require extending the vector field off the manifold or projecting back onto it; instead, they evolve solutions along geodesics while respecting the underlying geometric structure, making them both natural and straightforward to implement. We first demonstrate convergence and accuracy using Hamiltonian flow and benchmark our methods against existing integrators. As an application, we compute high-order multivalued solutions to wavefront propagation problems by solving the ray tracing equations of the surface eikonal equation on the unit sphere using the MTVDRK method. We then develop an efficient adaptive framework to maintain resolution of the wavefront throughout the computation.

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MS44

Gluing High Frequency Resolvent Formulas

For many scattering problems it is desirable to decouple analysis near the scatterer from analysis near infinity. We achieve this by writing the resolvent of the corresponding Helmholtz equation as a series, in terms of models near infinity and near the scatterer. We prove rapid convergence of the series using propagation of singularities estimates, for high frequencies and when trapping is mild. Examples include inhomogeneous media, possibly combined with complex scaling or complex absorbing barriers. This talk is based on joint work with Andras Vasy, and with Shingyu

Leung, Jianliang Qian, and Yuxiao We.

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MS44

A Computational Method for Inverse Mean-Field Games

We study inverse problems for mean-field game (MFG) models, where unknown parameters are inferred from partial and noisy observations of population dynamics. The forward problem is solved using an iterative algorithm, which becomes expensive to differentiate through when used inside gradient-based optimization. To address this, we use a Jacobian-free backpropagation approach within automatic differentiation to compute gradients through the iterative solver without storing all intermediate iterates. This significantly reduces memory costs while avoiding explicit Jacobian construction, and allows the inverse problem to be solved at scale using standard optimization methods. We illustrate the approach with inverse problems arising in mean-field games.

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MS44

Hadamard Integrators for Wave Equations: An Overview

Hadamard integrators are based on Hadamard's seminal ansatz for wave equations, which provides a local parametrix for wave equations. In combination with the Kirchhoff-Huygens principle, such an ansatz allows us to obtain a global parametrix for wave equations so that caustics can be implicitly handled naturally. Computationally, we can develop low-rank separable representations of Hadamard's ingredients such as eikonal and amplitude coefficients so that the global parametrix can be made available rapidly, resulting in efficient Hadamard integrators for wave equations. We will review our recent progress on developing Hadamard integrators in different settings and for different applications.

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MS45

In Search of An Efficient Model Reduction Strategy for Parameterized, Incompressible Mixed-Convection Flow Regimes

Herein we present an investigation into data-driven compression and parameterization strategies for developing reduced-order models (ROMs) of incompressible mixed convection problems. Given the high degree of nonlinear coupling between velocity, pressure, and temperature fields, the construction of accurate surrogate models for practical flow regimes presents significant challenges in terms of both computational efficiency and model fidelity. Our initial exploration of parameterized Dynamic Mode Decomposition (pDMD) revealed fundamental limitations: the complex dynamics of our target system require prohibitively high modal retention. This observation motivates a broader investigation into alternative compression and parameterization frameworks suitable for building digital twins of complex fluid-thermal systems. We examine this challenge through the lens of a 2D pipe flow problem over obstructions with independently heated or cooled surfaces, exploring candidate methodologies that balance model complexity, computational tractability, and predictive accuracy. This work aims to identify viable pathways for constructing comprehensive digital twins when traditional modal decomposition approaches prove insufficient for capturing the full parametric richness of the underlying physics.

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MS45

Recent Advances in Quasi-Trefftz Methods

Quasi-Trefftz methods are high-order Discontinuous Galerkin (DG) schemes whose discrete spaces are locally tailored to the partial differential equation (PDE) under consideration. Developed over the last decade, they extend classical Trefftz methods, which employ exact local solutions of the PDE as trial and test functions. Classical Trefftz methods have been extensively studied for linear, homogeneous wave propagation problems with piecewise-constant coefficients. In quasi-Trefftz approaches, exact local solutions are replaced by approximate ones, enabling the treatment of PDEs with variable coefficients, as occur in wave propagation through inhomogeneous media. These methods can achieve high accuracy with reduced computational cost compared to classical finite element or standard DG approaches. In this talk, I focus on Taylor-based polynomial quasi-Trefftz methods, with discrete spaces of polynomials in the kernel of a quasi-Trefftz operator obtained by composing the differential operator with a Taylor truncation. After a brief overview of the framework, I present recent theoretical results and new insights extending quasi-Trefftz methods to complex vector-valued PDEs, including the time-harmonic Maxwell equations. Particular attention is devoted to the approximation properties of quasi-Trefftz spaces and to an efficient algorithm for constructing quasi-Trefftz polynomial bases.

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MS45

Mobility Restrictions as a Disease Control Strategy

We present recent findings on the dynamics of infectious diseases under conditions where movement of one subpopulation is completely restricted to limit disease transmission. This work is motivated by public health interventions, such as quarantine and lockdown measures, that constrain population mobility. We investigate two distinct scenarios: (i) restriction of susceptible individuals movement, and (ii) absence of movement among infected individuals. In both cases, our results reveal a novel and significant interplay among total population size, transmission risk, and the saturated incidence function in shaping disease persistence, extinction, and spatial distribution.

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MS47

One-Photon Localization in a Discrete Model of Quantum Optics

We consider a discrete model for the propagation of a single photon in a random medium of two-level atoms. The system describes light-matter coupling on a lattice with spatial disorder in the atomic density, and is modeled by a random quantum optical Hamiltonian. We prove that in an energy band centered at the atomic resonance frequency, the spectrum is almost surely pure point; an effect known as Anderson Localization. Moreover, increasing the fieldmatter coupling enlarges the set of energies for which this localization occurs. We will also discuss some work towards the multi-photon analog of this model.

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MS47

Reducible Fermi Surface for Multi-layer Quantum Graphs Including Stacked Graphene

Reducibility of the Fermi surface allows for the construction of local defects that engender bound states at energies embedded in the radiation continuum. We construct two types of multi-layer quantum graphs (Schrödinger operators on metric graphs) for which the dispersion function of wave vector and energy is proved to be a polynomial in the dispersion function of the single layer. This leads to the reducibility of the algebraic Fermi surface, at any energy, into several components. Each component contributes a set of bands to the spectrum of the graph operator. When the layers are graphene, AA-, AB-, and ABC-stacking are allowed within the same multi-layer structure. One of the tools we introduce is a surgery-type calculus for obtaining the dispersion function for a periodic quantum graph by joining two graphs together.

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MS47

Theoretical and Computational Studies on Inverse Random Source Problems

In the field of inverse problems, the estimation of an unknown source term from indirect observations is a fundamental challenge. Inverse source problems play a significant role in various fields, including antenna synthesis, seismology, and medical imaging. Stochastic inverse problems emerge when uncertainties within the model need to be considered, and the introduction of random sources further amplifies the complexity due to their inherent ill-posedness and uncertainties. This talk covers both theoretical and computational investigations into the inverse random source problems. In our theoretical findings, we establish a unified framework for stability estimates of inverse source problems governed by the stochastic acoustic, biharmonic, and elastic wave equations driven by white noise. Our computational exploration focuses on a data-assisted approach that utilizes boundary measurement data to reconstruct the statistical properties of the random source. This method requires fewer realizations compared to traditional methods. We will also highlight potential directions for future research involving stochastic inverse scattering problems.

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MS48

Efficient Hyperparameter Estimation in Large-Scale Bayesian Inverse Problems

In Bayesian inverse problems, there are several hyperparameters that define the prior and the noise model and must be estimated from the data. For linear inverse problems with additive Gaussian noise and Gaussian priors defined using Matern covariance models, we estimate the hyperparameters using the maximum a posteriori estimate of the marginalized posterior distribution. However, this is a computationally intensive task since it involves computing log determinants. To address this challenge, we consider a stochastic average approximation (SAA) of the objective function and use preconditioned Lanczos methods to efficiently approximate the objective function and the gradient.

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MS48

Regularization for Landslide Thickness Estimation Via Finite Element Methods

This talk addresses the estimation of landslide thickness from remote sensing data by formulating the problem as a linear inverse problem based on mass conservation principles. We develop a finite element discretization using Raviart-Thomas basis functions for the velocity field and Lagrange basis for the thickness, ensuring proper treatment of the divergence operator. To handle the severe ill-conditioning arising from noisy measurements, we introduce a distributed Tikhonov regularization approach where regularization parameters can vary spatially across the landslide domain. An iterative algorithm based on hierarchical Bayesian modeling computes both the maximum a posteriori estimate of the scaled thickness and the spatially distributed regularization parameters. Numerical results on synthetic data and real-world applications demonstrate the methods effectiveness in recovering landslide geometry while adapting regularization strength to local data quality and velocity field heterogeneity.

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MS48

Bayesian Optimization on Networks with Application in Inverse Problems

This talk studies Bayesian optimization on networks modeled as metric graphs, with applications in inverse problems. Motivated by settings where the objective function is expensive to evaluate or only available as a black box, we develop Bayesian optimization algorithms that sequentially update a Gaussian process surrogate model to guide the acquisition of query points. To ensure that the surrogates are tailored to the network's geometry, we adopt Whittle–Matérn Gaussian process prior models defined via stochastic partial differential equations on metric graphs. In addition to establishing regret bounds for optimizing sufficiently smooth objective functions, we analyze the practical case in which the smoothness of the objective is unknown and the Whittle–Matérn prior is represented using finite elements. Numerical results demonstrate the effectiveness of our algorithms for Bayesian inversion via *maximum a posteriori* estimation within a Bayesian formulation of a point–source identification inverse problem on a telecommunication network, as well as for optimizing benchmark objective functions on a synthetic metric graph.

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MS48

Projection Methods, Intersections, and Feasibility: From Nonlinear Inverse Problems to Weakly Supervised Learning

While geophysical inverse problems traditionally leverage projection methods to handle multiple constraints, the rise of deep generative priors has fundamentally shifted the optimization landscape. This evolution raises a critical question: do feasibility and intersection methods still offer value in a deep learning-dominated world? We demonstrate that these classical approaches are suited for certain types of weakly supervised learning, where multiple constraint sets arise naturally from the problem structure. By porting existing optimization ideas into deep learning frameworks, we provide methodology illustrated through image segmentation and diverse geospatial applications.

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MS49

Non-Linear Stochastic Networks

Despite the popularity of linear stochastic networks, they are not well understood in the context of non-linear constraints between the variables of the graph. Due to the non-linearity, it is difficult to quantify the statistics of the graph analytically, thus leaving computational methods as the only viable option. In this talk, concepts from uncertainty quantification for partial differential equations and numerical analysis are introduced in the context of efficient evaluation of high-dimensional stochastic Newton iterates with applications to non-linear networks. In particular, complex analytic regularity theory is developed for the solution with respect to the random variables. This justifies the application of stochastic collocation with sparse grids for the computation of statistical quantities. Convergence rates are derived and shown to be sub-exponential or algebraic with respect to the number of realizations of random perturbations. Furthermore, due to the accuracy of the method, sparse grids are also well-suited for computing low probability events with high confidence. This approach is tested on the non-linear power flow equations for electric networks. Numerical experiments on the 39-bus New England power system model with large stochastic loads are consistent with the theoretical convergence rates. Moreover, compared to the Monte Carlo method, our approach is at least 100,000,000,000 times faster for the same accuracy.

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MS49

Complex Analyticity and Sparse-Grid UQ for Stochastic Nonlinear PoissonBoltzmann Equation

Uncertainty quantification for nonlinear PoissonBoltzmann models depends crucially on establishing sufficient regularity of the parameter-to-solution map to justify structure-exploiting surrogates beyond Monte Carlo sampling. In this talk, I establish complex-analytic regularity of the parameter-to-solution map for a stochastic nonlinear PoissonBoltzmann equation, providing the key hypothesis behind fast UQ methods such as sparse-grid collocation. Since real-variable convex/variational arguments do not extend to the complex field, we prove existence and uniqueness of strong solutions under explicit smallness conditions by combining compactness with a topological fixed-point argument posed in an appropriate Sobolev space. We then prove holomorphic parameter-dependence by establishing a Bernsteinpolyellipse extension in parameter space. As a consequence, isotropic Smolyak sparse-grid collocation achieves sub-exponential convergence for moments of quantities of interest, in contrast with the one-over-square-root sampling rate of Monte Carlo. Numerical experiments in biomolecular electrostatics, including controlled stochastic rigid motions, illustrate the predicted rapid error decay, and I briefly comment on extensions to interface formulations with random domains.

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MS49

A General Regularity Analysis for Parametric El-

liptic Partial Differential Equations Using Absolutely Monitonic Functions

We investigate second-order linear elliptic partial differential equations with homogeneous essential boundary conditions, where the diffusion coefficient may depend on a high-dimensional parameter. While numerous techniques exist for analyzing parametric regularity, they often require a case-by-case approach tailored to specific models, such as affine or periodic parametrizations. This paper proposes a novel, unified technique, so called alternative-to-factorial technique, that establishes a general theory for parametric regularity, thus eliminating the need for model-specific analysis. This unified framework not only simplifies theoretical analysis but also has significant practical implications, providing a powerful tool for proving the convergence of numerical methods, including the Gauss family quadrature and Quasi-Monte Carlo integration.

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MS49

Structure-Preserving Stochastic Galerkin Formulations and Energy-Stable Schemes for the Parametric Shallow Water Equations

The shallow water equations (SWE) are an important set of equations describing fluid flow in a simplified "shallow water" setting. These equations are a system of time-dependent, nonlinear hyperbolic balance laws. In practice, the environment or initial conditions may be imprecisely known due to incomplete information, or uncertain due to a stochastic model. One effective strategy for uncertainty quantification for the SWE is the stochastic Galerkin method via polynomial Chaos. One challenge with numerical methods is that the model may lose important physical structure of the solution, such as hyperbolicity and/or positivity. We present novel advances in stochastic Galerkin methods for the SWE system. We show that a known elegant connection in the deterministic case between water height positivity and hyperbolicity of the equations can be extended to the stochastic/uncertain case. We leverage this theoretical connection to develop structure-preserving numerical methods for these equations: Our algorithms ensure positivity of the water height, hyperbolicity of the stochastic Galerkin formulation, and obey the well-balanced property, ensuring stable simulation of certain steady-state solutions. We demonstrate the effectiveness of the algorithm for simulations in one and two spatial dimensions, and describe high order energy conservative and energy stable schemes that are derived from entropy-entropy flux pairs.

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MS50
Dimension Reduction for Graphon Dynamical Systems

Dynamical systems on networks are high-dimensional, complicating analysis in fields like biology, neuroscience, engineering, and social systems. Many problems involve a large-network limit described by a graphon, resulting in a mean-field equation that aggregates interactions via an integral. The infinite dimension and complex coupling pose mathematical challenges. We explore dimension reduction techniques to simplify these systems, reduce computational costs, and improve analysis. Motivated by prior work developing reduction approaches that map high-dimensional dynamics into a lower dimensional space, we use a weighted-observable reduction for dynamics on networks. We discuss theoretical foundations such as wellposedness, including existence and uniqueness of solutions for the graphon dynamical system, and extend the GaoBarzelBarabasi (GBB) approach to the graphon setting. The key idea of the GBB reduction is to replace the full state with a single observable defined as a graphon-weighted average of the state, where weights are determined by each nodes degree. For numerical simulations, we employ six dynamical models and assess the accuracy of the GBB reduction across six graphons. For the power-law and uniform graphons, accuracy increases with effective coupling strength; for the uniform graphon, the approximation error is nearly zero. Overall, for most dynamical-systemgraph pairs we have assessed, the graphon GBB reduction gives reasonably accurate approximations.

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MS50
Mathematical Assessment of the Impact of the R21/Matrix-M Vaccine on the Control of Malaria in Children

Malaria, a parasitic disease spread to humans via an effective bite by an infectious adult female Anopheles mosquito, continues to exude a major burden in endemic areas (causing in excess of 600,000 deaths annually, mostly in children under the age of five). Much progress was made over the last two or three decades in the fight against malaria, largely due to the heavy and large-scale use of chemical insecticides (particularly in the form of long-lasting insecticidal nets and indoor residual spraying) to kill the malaria mosquito, promoting a renewed quest for malaria eradication. Unfortunately, such heady use has also resulted in widespread Anopheles resistance to all the main chemical insecticides used in vector control, posing challenges to the eradication objective. New anti-malaria vaccines have been approved recently and are being deployed in a number of countries in sub-Saharan Africa. In this talk, I will present a new mathematical model, in the form of a system of delayed-differential equations, for assessing the population-level impact of one of the approved vaccines in curtailing the disease burden in the targeted (vaccinated) population.

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MS50

Interpretable Brain Tumor Classification from High-Dimensional Microarray Data via Feature Selection and Network Analysis

Microarray gene-expression datasets for brain tumor studies are typically high-dimensional, with tens of thousands of genes measured on relatively few samples, which can lead to multicollinearity and overfitting in predictive modeling. This talk presents a reproducible machine-learning workflow for brain tumor classification using the public microarray dataset GSE50161 (130 samples across five classes). The approach combines regularized and tree-based feature selection with dimensionality reduction to obtain compact, informative gene sets and low-dimensional representations for visualization. We compare several supervised classifiers, including support vector machines, ensemble methods, and probabilistic baselines, using cross-validation with preprocessing performed within training folds to mitigate information leakage. In addition to predictive performance, we construct an interaction network from selected genes and apply modularity-based community detection to identify gene modules that support biological interpretation and potential biomarker discovery. The results illustrate how careful validation and integrated feature selectionclassification can yield accurate and interpretable tumor subtype prediction from high-dimensional transcriptomic measurements.

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MS50

Dynamics of a Two-Stage Epidemiological Model with Post-Infection Mortality and Transmission Heterogeneity

Many diseases naturally progress from an initial mild infectious phase to a more severe stage (e.g., Influenza and COVID-19). This motivates us to formulate a two-stage epidemiological model that incorporates key post-infection features, including reinfection and post-infection mortality (PIM). The model emphasizes the role of transmission heterogeneity in shaping disease dynamics, influencing both endemic levels and oscillatory behaviors. Numerical simulations show that late-stage hyper-infectivity leads to higher endemic infection levels with long-period oscillations, while early-stage hyper-infectivity results in lower infection levels with shorter-period oscillations.

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MS51

Fourier Test Function Selection for Robust Weak-form Sparse Model Identification

We introduce Fourier Weak SINDy, a minimal noise-robust and interpretable derivative-free equation learning method that combines weak-form sparse equation learning with spectral density estimation for data-driven test function selection. By using orthogonal sinusoidal test functions inspired by their prevalence in Modulating Function-based system identification, the weak-form sparse regression problem reduces to a regression over Fourier coefficients. Dominant frequencies are then selected via multitaper estimation of the frequency spectrum of the data. This formulation unifies weak-form learning and spectral estimation within a compact and flexible framework. We illustrate the effectiveness of this approach in numerical experiments across multiple chaotic and hyperchaotic ODE benchmarks.

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MS51

Self-test Loss Functions for Learning Weak-form Operators and Gradient Flows

A central challenge in data-driven modeling with weak-form operators is the principled selection of test functions. We introduce self-test loss functions, where test functions depend on the unknown parameters, designed for operators linear in the unknowns. The construction conserves energy for gradient flows, coincides with the expected log-likelihood ratio for SDEs, and is quadratic enabling rigorous identifiability and well-posedness analysis. It supports efficient parametric and nonparametric regression, requires only low-order or no derivatives, and is robust to noisy and discrete data.

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MS51

Tensors and Neural Network Architectures for Weak-Form Model Discovery

In recent years, weak-form methods have made significant advances in data-driven discovery of dynamical systems. However, in high-dimensional settings, current techniques can prove punitive in both computation and memory costs. In this work, we present TT-WSINDy, which adapts the weak-form sparse identification of nonlinear dynamics (WSINDy) algorithm, implementing all requisite computations in the tensor-train (TT) format. We demonstrate that this method is able to search an exponentially-growing space of candidate functions – performing weak-form transformation, regression, and sparsification – without suffering from the curse of dimensionality.

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MS51

Energetic Variational Approach in Learning Irreversible Generalized Diffusions

We present a data-driven framework that combines variational structures with neural networks to learn the drift decomposition of non-potential Fokker-Planck equations. These equations describe irreversible generalized diffusions and capture key non-equilibrium thermodynamic phenomena, including entropy production, circulation, and non-equilibrium steady states. Numerical results involving noisy data and rough potentials are presented to demonstrate the robustness and effectiveness of the proposed method.

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MS53

Counting Lines in a Symmetric Quintic Threefold Surface Under the Action of S_5

A symmetric quintic threefold is a 3-dimensional surface of degree 5 in 4-dimensional complex projective space. These surfaces are important examples in algebraic and differential geometry since non-singular quintic threefolds are Calabi-Yau manifolds. It is a classic result that a generic quintic threefold contians exactly 2875 distinct lines. On the other hand, example such as the Fermat quintic threefold contain infinitely many lines. When a quintic threefold is symmetric, one can count the orbits under the action of the group of pemutations S_5. Prior to our work, Thomas Brazelton had shown that the 27 lines on the Fermat cubic lie on three S_4-orbits of sizes 12, 12, and 3. In this talk, we will give a brief introduction to the broad area of equivariant enumerative geometry. We will then show how to compute the S_5-orbits and the corresponding isotropy subgroups for the 2875 lines on a particular symmetric quintic threefold. We will finish our talk with some facts and conjectures about the lines on symmetric quintic threefolds.

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MS53

Routing Functions, Real Numerical Algebraic Geometry, and Collision-Free Robot Paths

Nonlinear polynomial equations naturally arise throughout mathematics, science, and engineering with their solutions describing various phenomena including the motion of a mechanical linkage such as a robotic arm. Since the physically-meaningful solutions in most applications are real, this talk will highlight recent developments using routing functions for numerical computing and representing real solutions to systems of polynomial equations, collectively called real numerical algebraic geometry, along with demonstrating them on constructing collision-free robot paths.

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MS53

Dietmaier Optimization: Tips and Tricks

At the end of the twentieth century, Dietmaier developed a local optimization procedure which searches the parameter space of a parameterized polynomial system to find points which maximize the number of real solutions, which he used to find a Stewart-Gough platform with 40 real postures. Since then, this method has been employed elsewhere in the literature, to varying degrees of success. Our work unifies these different implementations by providing a framework for the method as well as several auxiliary techniques devised with the intention of improving the performance of Dietmaier's optimization algorithm. These include new sampling strategies, as well as descriptions of the contexts in which these strategies may succeed in maximizing real solution counts.

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MS53

Common Real Secants of a Pair of Twisted Cubic Curves

Over the complex numbers, a general pair of twisted cubic curves in space has ten common secant lines. We investigate the novel problem of determining the possible collections of ten common secant lines to a pair of real twisted cubic curves. This includes determining the distribution between real and nonreal common secant lines and, for the real ones, classifying as totally real, partially real, or minimally real. Using a mix of combinatorics and computational algebraic geometry, we show that for each n = 0, ... ,10, there exists a pair of real twisted cubic curves with exactly n common totally real secant lines.

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MS54

Decision and Control of Worm-Like Robots - When Is Linearity Enough in Soft Robots?

Controlling a robot with many DOF requires coordination, but how precise does that coordination need to be? One might think that soft robots relax the requirements on precision for control. However, while the softness helps in generating large contact, it can limit progress. How much does shifting from linearization to more precise geometry help the robot move? And more abstractly, how much can nonlinear models of complex environments and behaviors improve our understanding of these systems? At decision-making levels, can linear tuning of parameters assist in developing nonlinear dynamics that are stable. The decision-making models are general and can be represented by saddles rather than stable points in state space.

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MS54

Discriminant Analysis for Small Spring Networks

Many problems in kinematics, robotics, and navigation require repeatedly solving parameterized polynomial systems for varying parameter values. Parameter homotopy is an effective technique for this task, combining homotopy continuation with differential path tracking to efficiently compute solutions across parameter space. However, as the number of parameter instances increases, difficulties arise in reliably tracking and organizing solutions. We introduce a topologically informed parameter homotopy algorithm that improves the retention and identification of solutions across repeated solves. In addition, we propose a novel method for approximating the projection of the discriminant variety of a polynomial system without explicitly computing the discriminant. The algorithm is tested on the two-vehicle system, a parameterized polynomial collaborative navigation model, to illustrate the effectiveness of this method.

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MS54

Frequency-Domain Analysis of Neural Systems for Proprioception at Multiple Scales

Studying animal nervous system dynamics can advance the frontiers of neuroscience, and directly inform and improve engineered control systems, particularly the filtering of noisy oscillatory signals. Biological experimentation confirms that interneurons and gap junctions effectively filter noisy sensory neuron voltages, a concept critical for control. Our work first derived the governing equations of such neural networks, applying traditional engineering methods for frequency analysis and signal processing. We then applied these equations and tools to systematically compare how different proprioceptive inputs (e.g., muscle spindle fibers and Golgi tendon organs) become the primary drivers of control at various organism scales. Organism scale is a crucial factor because the dominant forces resisting limb actuationsuch as inertia, elasticity, gravity, and viscositychange significantly with animal size and speed. As such, the dominant methods of proprioception may also change with scale. The findings provide a simplified, analytically tractable platform for developing signal processors within biologically-inspired robotic systems of different sizes. The findings also advance our understanding of sensorimotor transformation.

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MS54

Polynomial Approximation of Spring Systems in Autonomous Navigation Without GPS

Proper estimations of position are critical in autonomous navigation and without GPS. These estimations are often based on measurements such as bearing and range, and often become complex nonlinear systems with multiple locally optimal minima. To find such minima, we model such problems as spring systems, which are further translated into systems of polynomial equations. Using numerical methods such as homotopy continuation, we can then identify our desired solutions. However, certain relationships, notably bearing measurements and the corresponding torsional springs, cannot be easily represented as polynomials. In this presentation, we will first overview the spring system model and the corresponding polynomials before going into the challenges of creating and solving those polynomials.

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MS55

Large-Amplitude Vortex-Carry Solitary Gravity Waves

We consider two-dimensional steady gravity waves in finite-depth water. We prove that, for any supercritical Froude number, there exists a continuous one-parameter family of solitary waves in equilibrium with a submerged point vortex. This family bifurcates from an irrotational uniform flow, and, at least for large Froude numbers, extends up to the development of a surface singularity. These are the first rigorously constructed gravity wave-borne point vortices without surface tension. Notably our formulation allows the free surface to be overhanging, and we provide numerical evidence that strongly suggests that some of these waves indeed overturn.

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MS55

Vortex Atmospheres: 2D Dipoles Versus 3D Rings

We consider traveling solutions in the incompressible Euler equations in the vorticity form in two or three dimensions. The support of such a traveling solution is called the core of the vortex. The vortex atmosphere is an envelope of the core, which is traveling together with the core. In this presentation, we offer a concise survey of vortex atmosphere configurations. By rigorous analysis, we contrast the planar atmospheres from 2D vortex dipoles with the axisymmetric atmospheres from 3D vortex rings, highlighting their topological differences.

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MS55

Weak-Small Bv Stability for Euler with Boundaries

Dafermos and DiPerna have introduced the Weak-Strong Principle for the stability of Lipschitz solutions to conservation laws. The a-contraction theory is a recently developed energy-based method, which extends this principle to the stability of small BV solutions to the Euler equations. In this talk, we will explain how stability results, originally obtained in the whole-space setting, can be extended to boundary value problems. More precisely, we prove Weak-BV stability for Euler weak solutions satisfying the strong trace property in all subsonic boundary configurations: impermeable, inflow, and outflow. In addition, we establish Inviscid limits-BV stability from barotropic Navier-Stokes to Euler for the impermeable and outflow cases. The Weak-BV stability result is joint work with Moon-Jin Kang, HyeonSeop Oh, and Alexis Vasseur, and the Inviscid-BV stability result is joint with Alexis Vasseur.

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MS55

Vanishing Viscosity Limit of Two Interacting Shocks for Compressible Navier-Stokes Equations

The talk is concerned with our recent progress on the vanishing viscosity limit of two interacting shocks (from both different families and the same family) for compressible isentropic Navier-Stokes equations and full Navier-Stokes-Fourier equations. Moreover, the decay rate with respect to the viscosity can also be obtained. Based on the joint works with Lin-an Li from Beijing Normal University, China and Dehua Wang from University of Pittsburgh, USA.

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MS56

Computational Advances in Weak Form Scientific Machine Learning

Recent advances in Weak form-based Scientific Machine Learning (WSciML) allow for the creation and inference of interpretable models directly from data via advanced numerical functional analysis, computational statistics, and numerical linear algebra techniques. This class of methods completely bypasses the need for forward-solve numerical discretizations and yields both parsimonious mathematical models and efficient parameter estimates. These methods are orders of magnitude faster and more accurate than traditional approaches and far more robust to the high noise levels. The combination of these features in a single framework provides a compelling alternative to both traditional modeling approaches as well as modern black-box neural networks. In this talk, I will present our WSciML framework as well as recent computational advances concerning test function construction and parameter inference for systems with unobserved variables

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MS56

Resolvent Compactification Methods for Spectral Approximation of Koopman Operators

We present data-driven techniques for spectral approximation of Koopman and transfer operators of measure-preserving ergodic flows that are based on operators with compact resolvent. Our approach performs a bounded transformation of the Koopman generator, followed by smoothing by a Markov semigroup of kernel integral operators. This results in a skew-adjoint, compact operator with compact resolvent whose eigendecomposition is expressible as a variational generalized eigenvalue problem amenable to approximation using Galerkin methods. A key aspect of these methods is that they are physics-informed, in the sense of making direct use of dynamical vector field information through automatic differentiation of kernel functions. Solutions of the associated eigenvalue problem reconstruct evolution operators that preserve unitarity of the underlying Koopman group while spectrally converging to it in a suitable limit. In addition, the computed eigenfunctions have representatives in a reproducing kernel Hilbert space, enabling out-of-sample evaluation of learned dynamical features. We illustrate this method with numerical experiments on quasiperiodic and chaotic systems.

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MS56

Generalized Moving Least-Squares Methods for Solving Vector-Valued Pdes on Unknown Manifolds

In this paper, we extend the Generalized Moving Least-Squares (GMLS) method in two different ways to solve the vector-valued PDEs on unknown smooth 2D manifolds without boundaries embedded in $\mathbb{R}^3$, identified with randomly sampled point cloud data. The two approaches are referred to as the intrinsic method and the extrinsic method. For the intrinsic method which relies on local approximations of metric tensors, we simplify the formula of Laplacians and covariant derivatives acting on vector fields at the base point by calculating them in a local Monge coordinate system. On the other hand, the extrinsic method formulates tangential derivatives on a submanifold as the projection of the directional derivative in the ambient Euclidean space onto the tangent space of the submanifold. One challenge of this method is that the discretization of vector Laplacians yields a matrix whose size relies on the ambient dimension. To overcome this issue, we reduce the dimension of vector Laplacian matrices by employing an appropriate projection. The complexity of both methods scales well with the dimension of manifolds rather than the ambient dimension. We also present supporting numerical examples, including eigenvalue problems, linear Poisson equations, and nonlinear Burgers' equations, to examine the numerical accuracy of proposed methods on various smooth manifolds.

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MS56

Generative Artificial Intelligence Methods for Particle-Based Kinetic Computations in Bounded Domains

Simulating stochastic differential equations (SDEs) in bounded domains, presents significant computational challenges due to particle exit phenomena, which requires accurate modeling of interior stochastic dynamics and boundary interactions. Despite the success of machine learning-based methods in learning SDEs, existing learning methods are not applicable to SDEs in bounded domains because they cannot accurately capture the particle exit dynamics. We present a unified hybrid data-driven approach that combines a conditional diffusion model with an exit prediction neural network to capture both interior stochastic dynamics and boundary exit phenomena. Our ML model consists of two major components: a neural network that learns exit probabilities using binary cross-entropy loss with rigorous convergence guarantees, and a training-free diffusion model that generates state transitions for non-exiting particles using closed-form score functions. The two components are integrated through a probabilistic sampling algorithm that determines particle exit at each time step and generates appropriate state transitions. The performance of the proposed approach is demonstrated via three test cases: a one-dimensional simplified problem for theoretical verification, a two-dimensional advection-diffusion problem in a bounded domain, and a three-dimensional problem of interest to magnetically confined fusion plasmas.

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MS57

Predictable Forward Performance Processes under Periodic Re-Evaluation

Predictable Forward Performance Processes (PFPPs) provide a stochastic control framework for agents who manage a randomly evolving system while specifying its dynamics only over a short horizon ahead. I present a new extension of PFPPs for an investor who periodically re-evaluates her short-term consumption and investment objectives and adapts her long-term performance criterion accordingly, thereby preserving time consistency across successive re-evaluation periods. The construction reduces to a sequence of inverse optimal investment problems in which the initial value function is prescribed and the corresponding terminal utility function must be determined. Existence and uniqueness of solutions are established through the analysis of an associated integral equation, and the results are illustrated with numerical examples.

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MS57

Simple Policies for Long Horizons: Reinforcement Learning in Finite-Horizon LQ Control

Finite-horizon LQ control problems typically require time-varying policies, which are computationally and statistically expensive to learn. We propose a “simple-agent’ perspective, restricting learning to stationary policies to leverage simpler policy classes and lower-variance gradient estimates. We prove this restriction is asymptotically cost-free in long-horizon tasks, as the performance gap vanishes as the horizon grows. We establish that stationary-policy gradient methods converge to near-optimal controllers in both fully known model and reinforcement learning settings. Numerical experiments confirm the theory and illustrate the practical efficiency gains from learning stationary controllers in long-horizon tasks.

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MS57

Neural Dynamic Portfolio Control with Provable Learning Guarantees

Deep learning offers a scalable approach to high-dimensional dynamic portfolio optimization, but typically rely on parametric return models or prespecified Markovian state representations and are largely supported by empirical evidence rather than comprehensive performance guarantees. We develop a provable learning framework for discrete-time, finite-horizon portfolio control that takes a step toward closing these gaps. We parameterize the investor’s decision at each rebalancing time as a monetary allocation that depends directly on the realized return path, rather than as portfolio weights modeled as functions of Markovian states. This formulation is operationally natural, avoids explicit dynamics modeling, and accommodates return processes with general temporal dependence. Under self-financing dynamics and concave terminal utility, the resulting objective is convex with respect to the policy function. Exploiting this geometry, we model each periods policy using a wide two-layer neural network and, via a mean-field analysis, establish global convergence guarantees for noisy gradient descent with weight decay. In particular, the geometric convergence rate is independent of the planning horizon. We further derive finite-sample bounds that control both generalization error and regularization bias. Numerical experiments show that these theoretical guarantees come with empirical competitive performance relative to standard baselines across representative return environments.

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MS58

Combinatorics of Even Valent Graphs on Riemann Surfaces

Let $N_g(m,j)$ denote the number of connected labeled m-valent graphs with j vertices that can be embedded in a compact Riemann surface of minimal genus g. For example, $N_0(4,1) = 2$ and $N_1(4,1) = 1$, which can be verified by drawing connected labeled 4-valent graphs with a single vertex on the sphere and on the torus. The problem of determining $N_g(m,j)$ arose in models of two-dimensional quantum gravity and has since inspired a rich body of work, involving both combinatorial methods and techniques from random matrix theory. In this talk, I will present recent joint work with Tomas Lasic Latimer (University of Sydney) on the enumeration of regular even-valent graphs embedded in a compact genus-g Riemann surface, giving explicit formulae in which both the number of vertices j and the (uniform) even valence m are treated as variables. Our results extend to higher genus the enumerative formulae obtained by Ercolani - McLaughlin - Pierce (2008) in genus 0 and by Ercolani - Lega - Tippings (2023) in genus 1.

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MS58

Random Determinants and Quasimodular Forms

Let $G(z)$ be an arbitrary analytic function on the unit disc, let $u_1, \ldots, u_N$ be iid uniformly random points on the unit circle, and consider the random analytic function defined by $G_N(z) = \det[G(zu_i\overline{u}_j]_{i,j=1}^N$. I will present a formula for the expected value of $G_N(z)$ and show that whenever the input $G(z)$ is a hypergeometric function the $N \to \infty$ scaling limit of this expectation is Eulers generating function $E(z) = \prod_{n=1}^{\infty}(1-z^n)^{-1}$ for integer partitions. Moreover, I will show that subleading corrections to this limit are quasimodular forms.

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MS58

Special Functions for Structured Random Permutation Statistics

We study a family of structured random permutations of size $N = 2^n$, arising naturally from Gaussian elimination with partial pivoting on structured random matrices, which we call butterfly permutations. Their recursive structure leads to exact distributional descriptions for several statistics and to nonclassical limiting laws. In particular, certain generating functions exhibit real-rootedness and zero interlacing, yielding Gaussian limits and suggesting limiting zero distributions. I will discuss how orthogonal polynomial techniques provide analytic access to limiting objects that are otherwise defined only implicitly by functional equations.

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MS59

Quantum Linear Algebra for PDE-Constrained Optimization

Quantum linear algebra provides new quantum tools that can accelerate the computation of certain problems, including optimization and scientific computing applications. One major challenge, however, is that the input/output overhead can be considerably large. In this talk, we show that PDE-constrained optimization is an application where quantum linear algebra can achieve an exponential speedup with respect to the number of state variables. We explore two strategies. The first is a classical discretize-then-optimize approach, where a quantum linear system solver is used as a subroutine. The second is a Schrdingerize-then-optimize approach, in which Schrdingerization is employed as the PDE solver.

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MS59

Beyond LXEB: On Test Statistics for Random Circuit Sampling and Certified Randomness

Random Circuit Sampling (RCS) serves as both the leading paradigm for demonstrating quantum advantage and the core hardware primitive for certified randomness protocols. In any such protocol, the verifier must evaluate the ideal output probability of each sampled bitstring, a task whose classical cost scales exponentially in the number of qubits and dominates the overall resource budget. Maximizing the statistical information extracted per verified sample is therefore essential. Existing certification pipelines rely almost exclusively on the Linear Cross-Entropy Benchmark (Linear XEB), which, while unbiased, is far from statistically efficient. This work develops a likelihood-based inference framework for noisy RCS, grounded in a principled probabilistic model of the output distribution. Within this framework, a family of test statistics is systematically constructed and analyzed, and their statistical properties are characterized. The resulting estimators attain tighter confidence intervals on the fidelity at matched soundness guarantees, translating directly into reduced verification cost for certified randomness protocols. Connections to existing certified randomness protocols are discussed, along with preliminary numerical validation.

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MS59

Toward Resource-Aware End-to-End Quantum Algorithms for Scientific Computing

This talk presents quantum algorithmic approaches and resource estimations for scientific applications in quantum chemistry, linear systems, and differential equations. In quantum chemistry, we discuss hybrid methods that replace constrained variational optimization with generalized eigenvalue formulations over adaptive non-orthogonal bases. For linear systems, we examine how precision, matrix properties, and fault-tolerant resource costs shape performance, showing that lower-precision settings can retain solution quality while reducing circuit cost. For differential equations, I present a hybrid oscillator-qubit formulation that reduces qubit overhead and circuit cost while maintaining accurate solutions. Together, these results motivate resource-aware evaluation of quantum algorithms for scientific computing from NISQ and error correction perspective.

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MS60

Embedded Implicit-Explicit Strong Stability Preserving RungeKutta Methods

Strong Stability Preserving (SSP) Runge-Kutta methods are time integration schemes designed to preserve monotonicity and nonlinear stability properties of spatial discretization methods when solving time-dependent differential equations. In recent times, new classes of problems have emerged which can be modeled by time-dependent equations that involve both stiff and non-stiff terms, where the non-stiff terms are solved explicitly and stiff terms are treated implicitly. This has motivated the development of Implicit-Explicit (ImEx) SSP methods designed for fixed time stepping. However, this may not be ideal for problems with rapidly changing dynamics. To address this limitation, we introduce a new class of ImEx SSP methods that employ adaptive time stepping to adjust step sizes while preserving stability properties. Numerical experiments are conducted to analyze the efficiency and robustness of these new methods.

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MS60

Implicit-Explicit Runge-Kutta for Radiation Hydrodynamics with Multifrequency High-Order-Low-Order Transport

We present a high-order-in-time, moment-accelerated algorithm for non-relativistic radiation-hydrodynamics with multigroup thermal radiative transfer (TRT). Building on the linearly implicit-explicit (LIMEX) and additive LIMEX framework developed for gray diffusion, this work couples LIMEX RungeKutta time integrators to a high-order/low-order (HOLO) moment acceleration strategy for the multifrequency thermal radiative transfer equation. Key contributions include (i) a partitioning of the rad-hydro system that separates explicit hydrodynamics from stiff absorptionemission physics while retaining high-order stage consistency; (ii) a practical formulation for evaluating the HO-LO consistency terms γ in terms of RungeKutta stage solutions, including discrete time-derivative expressions appropriate for IMEX stages; and (iii) two time-integration approaches for HOLO TRT a natural extension of commonly used semi-implicit scheme, and an implicit-explicit "one-sweep" formulation that breaks the temperature dependence via auxiliary variables to require only a single transport sweep per implicit stage. We demonstrate stability, accuracy, and computational advantages on three challenging rad-hydro test problems, showing that the proposed schemes preserve asymptotic limits (streaming and diffusion) while substantially reducing sweep counts in optically thick regimes. The methods are suitable for large-scale multifrequency rad-hydro simulations where memory and sweep cost dominate.

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MS60

Exponential Nystrm Methods

For the time integration of second-order differential equations, classical Runge-Kutta-Nystrm integrators and their extended variants have been widely used. While effective for small or non-stiff problems, these methods often suffer from stability issues and inefficiency when applied to large, stiff or highly oscillatory systems. To overcome these limitations, we develop and analyze a new class of time integration methods, called exponential Nystrm (expN) methods. These methods allow significantly larger time steps without sacrificing accuracy. We establish convergence results up to fifth-order accuracy within the framework of strongly continuous semigroups, with error bounds independent of the stiffness or high frequencies of the system. Our numerical experiments demonstrate that the proposed expN methods outperform existing Nystrm-type integrators in both efficiency and accuracy.

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MS61

An Implicit, Conservative, Asymptotic-Preserving Electrostatic Particle-in-Cell Algorithm for Arbitrary Magnetic Fields

We propose a new electrostatic particle-in-cell algorithm able to use large timesteps compared to particle gyroperiod in non-uniform external magnetic fields. The algorithm extends earlier electrostatic fully implicit PIC implementations with a new asymptotic- preserving (AP) particle-push scheme that allows timesteps much larger than particle gyroperiods. In the large-timestep limit, the AP integrator preserves all the averaged particle drifts, while recovering particle full orbits with small timesteps. The scheme allows for a seamless, efficient treatment of particles in coexisting magnetized and unmagnetized regions, conserves energy and charge exactly, and does not spoil implicit solver performance. Non-uniform magnetic fields require modifications to the standard Crank-Nicolson orbit integrator to capture all first-order drifts for timesteps much larger than the gyrofrequency. We demonstrate by numerical experiment that significant speedups are possible vs. the standard fully implicit electrostatic PIC algorithm without sacrificing solution quality and while preserving strict charge and energy conservation.

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MS61

Learning Interpretable Closures for Thermal Radiation Transport in Optically Thin Media Using Wsindy

We introduce an equation learning framework to identify a closed set of equations for moment quantities in 1D thermal radiation transport (TRT) in optically thin media. While optically thick media admits a well-known diffusive closure, the utility of moment closures in providing accurate low-dimensional surrogates for TRT in optically thin media is unclear, as the mean-free path of photons is large and the radiation flux is far from its Fickean limit. Here, we demonstrate the viability of using weak-form equation learning to close the system of equations for the energy density, radiation flux, and temperature in optically thin TRT. We show that the WSINDy algorithm (Weak-form Sparse Identification of Nonlinear Dynamics), together with an advantageous change of variables and an auxiliary equation for the radiation-energy-weighted opacity, enables robust and efficient identification of closures that preserve many desired physical properties from the high fidelity system, including hyperbolicity, rotational symmetry, black-body equilibria, and linear stability of black-body equilibria, all of which manifest as library constraints or convex constraints on the closure coefficients. Crucially, the weak form enables closures to be learned from simulation data with ray effects and particle noise, which then do not appear in simulations of the resulting closed moment system. Finally, we demonstrate that our closure models can be extrapolated in the key system parameters of drive temperature and scalar opacity, and this extrapolation is to an extent quantifiable by a Knudsen-like dimensionless parameter.

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MS61

An Explicit, Energy-Conserving Particle-in-Cell Method for the Relativistic Vlasov-Maxwell System

The particle-in-cell (PIC) algorithm has been a standard numerical method for the Vlasov equation and its relatives for over 50 years. It combines a Lagrangian representation of the distribution function with an Eulerian representation of the electromagnetic fields to mitigate the curse of dimensionality. However, PIC has long suffered from so-called grid heating, in which the energy in the system grows secularly when certain (potentially irrelevant) physical scales are under-resolved. This problem has been solved in the context of implicit PIC methods over the last 15 years, but implicit methods come with additional costs. We present an explicit PIC method that eliminates grid heating by enforcing exact energy conservation and report its extension to include relativistic effects. The schemes relationship to the structure-preserving Higuera-Cary time integrator for relativistic charged particle motion is discussed, and its compatibility with popular discretizations of Maxwells equations is shown. The method is verified on standard test problems from the literature, with dramatic improvements in energy conservation observed.

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MS61

A Deterministic Particle Method for the Relativistic Landau Equation

We propose a deterministic particle method for the spatially homogeneous relativistic Landau equation, based on a gradient-flow variational formulation with a regularized collision operator. This method preserves conservation laws and entropy decay, and achieves second-order accuracy. Comparison against theoretical equilibria, as well as the transition to the non-relativistic Landau case, confirms its accuracy and consistency, especially for low-speed particles, highlighting its potential for high-order time integration schemes in plasma simulations.

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MS62

Using Spatial Pattern to Distinguish Among Drivers of Ecological Fluctuations

Ecological oscillations can be driven by noise or by deterministic nonlinear feedbacks (such as density dependence) that are intrinsic to the system. Since all natural systems are subjected to noise, even intrinsic oscillations appear somewhat irregular, and distinguishing noise-induced from intrinsic oscillations is a long standing challenge. By studying the transition from spatial disorder to spatial synchrony in networks of both noise-induced and intrinsic oscillators, we find that the onset of synchrony is distinct in these two situations. Specifically, we show how the impact of stochasticity causes the transition to synchrony diverge from the deterministic bifurcation point. Our work illustrates that spatial patterns contain information about what is driving the underlying temporal dynamics.

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MS62

Forecasting phase shifts in a population with noisy 2-cycle dynamics

Forecasting changes in a population requires contending with complex interactions between the environment and various density-dependent processes underlying the populations dynamics. In concept, forecasting should be straightforward for populations whose dynamics follow repeating patterns like cycles, but in practice, the sensitivity of population cycles to environmental stochasticity and the ways in which perturbations can break these repeating patterns are not well resolved. We use a general resource-budget model, shown previously to produce regular overcompensatory cycles, to investigate how stochasticity in different traits affects the predictability of the dynamics. Inspired by statistical physics, we define two possible phases of oscillation population peaks in odd or in even years and characterize the occurrence of phase shifts, at which the repeating cycle breaks and the population unexpectedly increases or decreases twice in a row. We show that phase shifts are caused by two distinct mechanisms, and that their frequency depends strongly on which traits are sensitive to environmental stochasticity. By understanding the mechanisms, phase shifts would be fully predictable if we had perfect knowledge of how the stochastic traits vary through time, though of course we would not have this knowledge in the real world. We therefore conclude our study by evaluating several imperfect but observable quantities for their ability to forecast an impending phase shift.

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MS62

Spatial Synchrony of Oscillating Ecological Populations and Models from Statistical Physics

The study of spatial synchrony, the dynamics of the phase of coupled ecological systems, is an important way to gain insight into what is responsible for the dynamics of ecological populations. Ecological systems are notoriously noisy with stochasticity affecting both dynamics and observations, so inferences from observations can be difficult. Just as proceeding from observations of equilibrium behavior to observations of oscillations of single populations has provided much insight, going the next step to spatiotemporal dynamics provides much more insight. The simplest, and also quite common, ecological oscillators are 2-cycles in discrete time which then have two phases that can be identified with the two states used in the standard models of statistical physics. I will demonstrate the correspondence between standard ecological models with two cycles and noise on a lattice and the Ising model of statistical physics. I will also provide insights into a more specific model describing the dynamics of trees that bear heavy crops every other year, and describe how these ideas play a role in understanding spatio-temporal ecological dynamics. This work will show the power of using ideas from statistical physics and suggest new questions.

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MS62

The Ising Model and Synchronization in Metapopulations with 2-Cycle Behavior

The Ising model, originally developed to understand magnetism, is a simple model in statistical physics that provides a paradigmatic example of a critical phase transition. The Ising model has been shown to capture many features of the synchronization transition of noisy, coupled, 2-cycle ecological oscillators. The surprising correspondence between the Ising model and 2-cycle metapopulation models is an example of universalitythe phenomena that a large class of systems display the same features at a phase transition independent of model details. In this talk we discuss universality and then introduce two generalizations of the Ising model motivated by ecological considerations. The first of these generalizations adds memory to Ising dynamics to mimic the stability of 2-cycle ecological oscillators in the absence of noise. The Ising model with memory remains in the two-dimensional Ising universality class but memory slows the dynamics of the system and tends to stabilize the synchronized phase against noise. The second generalization adds long range couplings representing long range dispersal. Here we find that even a small concentration of long-range couplings yields mean field behavior, which is a distinct universality class from that of the two-dimensional Ising model.

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MS64

Flexural-gravity Wave Scattering on Ice: Forward and Inverse Problems

In this talk we will discuss fast and accurate numerical algorithms for simulating the propagation of linear flexural-gravity waves through ice sheets. We will illustrate the effectiveness of the proposed approach through several numerical examples and discuss extensions to more general wave phenomena. In the second portion of this talk we will discuss recent work on the corresponding inverse problems.

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MS64

Localization of Phonon and Schrdinger Operators Above the Upper Band Edge in Periodic Graphs

We study defectinduced eigenmodes above the upper spectral band edge for Schrdinger operators with weighted, non-periodically perturbed graph Laplacians on periodic graphs. The connection of this model to the existence of phonons on the same underlying graph structure is established. Sufficient and necessary criteria on the perturbation for the existence of eigenmodes in dimensions 2 and 3 are presented.

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MS64

Quantum State Transfer

Recent years have witnessed substantial mathematical progress in understanding state transfer fidelity in ideal quantum systems. Of particular interest are nearest-neighbor quantum spin chains, motivated by their deep connections to orthogonal polynomials. Building on Kays characterization of chains that permit perfect state transfer (PST), in which an excitation propagates between the endpoints with unit fidelity, we examined whether the initial state can be excluded prior to the time of PSTa phenomenon known as early state exclusion (ESE). In this talk, we discuss how spectral properties of Hamiltonians relate to the ESE phenomenon.

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MS64

Sampling and Reconstruction of Discrete-Valued Images Via the Dft

This talk explores minimal sampling strategies for the discrete Fourier transform of integer-valued images. Using lattice methods, we develop efficient reconstruction algorithms that reduce redundancy and enable fast, exact recovery.

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MS65

Tv-Regularized Reconstruction for Synthetic-Wavelength Holographic Imaging in Scattering Media

Inverse problems in computational imaging are often severely ill-posed due to phase loss, speckle, and limited aperture effects. In digital holography, the measured intensity data encode complex wavefields only indirectly, requiring demodulation and propagation modeling to recover object phase and amplitude. In this work, we formulate reconstruction after off-axis demodulation as an inverse problem of the form

$$\min_u ||Au - b||_2^2 + \lambda R(u),$$

where A models Fresnel propagation between object and measurement planes, and R is a regularizer promoting structural priors such as sparsity or bounded variation.

Building toward synthetic-wavelength holography, we examine the recovery of the phase-difference field $u_1\bar{u_2}$ from two closely spaced wavelengths and treat the resulting synthetic hologram as data for an inverse problem. This wavelength diversity rescales phase sensitivity, reducing phase wrapping while altering the propagation of noise through the reconstruction, thereby influencing stability and reconstruction error. We study how propagation modeling and regularization interact to mitigate noise amplification and phase wrapping, and we demonstrate numerically how accelerated proximal methods improve reconstruction fidelity in the presence of speckle and measurement noise.

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MS65

Meaningful Priors for Bayesian Neural Networks with Applications to Physics-Based Inverse Problems

Quantifying the uncertainty in the output of a neural network is essential for deployment in scientific or engineering applications where decisions must be made under limited or noisy data. Bayesian neural networks (BNNs) provide a framework for this purpose by constructing a Bayesian posterior distribution over the network parameters. However, the prior, which is of key importance in any Bayesian setting, is rarely meaningful for BNNs. This is because the complexity of the input-to-output map of a BNN makes it difficult to understand how certain distributions enforce any interpretable constraint on the output space. Gaussian processes (GPs), on the other hand, are often preferred in uncertainty quantification tasks due to their interpretability. The drawback is that GPs are limited to small datasets without advanced techniques, which often rely on the covariance kernel having a specific structure. To address these challenges, we introduce a new class of priors for BNNs, called Mercer priors, such that the resulting BNN has samples which approximate that of a specified GP. The method works by defining a prior directly over the network parameters from the Mercer representation of the covariance kernel, and does not rely on the network having a specific structure. In doing so, we can exploit the scalability of BNNs in a meaningful Bayesian way.

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MS65

Recovering Elastic Subdomains with Strain-Gradient Elastic Interfaces from Force Measurements

In this talk, we introduce a new inverse problem for two-dimensional antiplane shear in elastic bodies with strain-gradient interfaces. The setting is a homogeneous isotropic elastic body that contains an inclusion separated by a thin interface endowed with higher-order surface energy. We show that the Dirichlet-to-Neumann map, which encodes displacement-stress measurements on the exterior boundary, uniquely recovers the mechanical parameters, as well as the shape of the inclusion. To address the inverse shape problem, we adapt the Factorization Method to handle the complications arising from a higher-order boundary operator and its nontrivial null space. Numerical examples will be presented in the unit circle.

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MS65

On Applying a Collocational Approach to Inverse Problems in Electrical Impedance Tomography

Electrical impedance tomography (EIT) is a portable, non-invasive, and relatively cheap medical technique for imaging electrical conductivity distributions within the human body. One of its important applications is the detection of intra-abdominal hemorrhage in trauma patients. Traditionally, inverse problems are studied to reconstruct the internal conductivities given voltage measurements on boundary surface electrodes. However, the inverse problem is ill-posed and highly sensitive to breathing and other motion, causing artifacts in reconstructed images. In this talk, we first present an extended parametric partial differential equation (PDE) for EIT accounting for boundary shape and internal conductivities and then apply a collocational approach based on generalized polynomial chaos to construct a polynomial approximation of the forward solution in the parameter space. Having that surrogate polynomial allows us to efficiently solve the inverse problem using Tikhonov and other regularization techniques to reconstruct the internal conductivities as well as the boundary shape.

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MS66

Gaussian Mixture Taylor Approximations for Uncertainty Quantification of Control Objectives

Forward uncertainty quantification (UQ) of control objectives is a central challenge in optimal control problems constrained by nonlinear partial differential equations (PDEs). The control objective is typically defined as a statistical measure of a quantity of interest (QoI) associated with the PDE solution, where uncertainty arises from PDE coefficients or input fields. Nonlinearity of the parameter-to-QoI map and the high dimensionality of the parameter space make direct sampling approaches computationally expensive. We develop a scalable framework for forward UQ of control objectives by combining Gaussian mixture approximations of the parameter distribution with local Taylor expansions of PDE solution operators. Taylor expansion of the parameter-to-QoI map around parameter means reduces the number of required PDE solves but is only locally accurate. By decomposing the global parameter distribution into locally concentrated Gaussian components and applying componentwise Taylor expansions, the method enables fast and accurate evaluation of the control objective. We demonstrate the effectiveness of this approach for large-scale optimal control problems under uncertainty.

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MS66

Bilo: Bilevel Operator Learning for Pde Inverse Problems and Uncertainty Quantification

We present a new neural network-based method for solving inverse problems for partial differential equations (PDEs) by formulating the PDE inverse problem as a bilevel optimization problem. At the upper level, we minimize the data loss with respect to the PDE parameters. At the lower level, we train a neural network to locally approximate the PDE solution operator in the neighborhood of a given set of PDE parameters, which enables an accurate approximation of the descent direction for the upper level optimization problem. The lower level loss function includes the L2 norms of both the residual and its derivative with respect to the PDE parameters. We apply gradient descent simultaneously on both the upper and lower level optimization problems, leading to an effective and fast algorithm. The method, which we refer to as BiLO (Bilevel Local Operator learning), is also able to efficiently infer unknown functions in the PDEs through the introduction of an auxiliary variable, and can be extended to account for uncertainties in the parameters and data using Bayesian inference. Through extensive experiments over multiple PDE systems, we demonstrate that our method achieves accurate results, eliminates the need to balance the residual and the data losses, which is inherent to the soft PDE constraints in many existing methods, and enables efficient gradient-based sampling by avoiding sampling in high-dimensional weight space.

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MS66

Uncertainty Quantification for Parabolic PDEs with Random Domain Deformations

The numerical solution of linear parabolic PDEs with random coefficients and domains become highly intractable with well known statistical methods such as Monte Carlo even for a relatively small number of stochastic dimensions. In this talk we analyze the linear parabolic PDEs with stochastic domain deformations. In particular, we concentrate on the problem of numerically approximating the statistical moments of a given Quantity of Interest (QoI). The geometry is assumed to be described by a random field of the domain. This parabolic problem is remapped to a fixed deterministic domain with random coefficients and it is shown that the solution admits a complex analytic extension in some region embedded in the complex hyperplane. The map from the geometry to the solution is non-linear. The stochastic moments of the QoI are computed by employing a stochastic collocation method in conjunction with an isotropic Smolyak sparse grid. The complex analytic extension of the solution leads to sub-exponential convergence rates as a function to the number of collocation interpolation knots with the sparse grid method. Numerical experiments confirm the theoretical error estimates. For the numerical examples, this approach is over 10^{10} times more efficient than Monte Carlo, making it well suited for handling moderately high dimensional intractable stochastic geometrical problems. This is a joint work with J. Castrillón-Candás (Boston University).

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MS66

Multifidelity Variance Reduction Techniques for Particle-Based Kinetic Methods

Particle-based kinetic methods (e.g., particle-in-cell techniques) are commonly used for simulating non-equilibrium gases and plasmas. These methods use a statistical approach by drawing a set of representative marker particles from the particle distribution function and then evolving them in phase space according to collisions and self-consistent electromagnetic fields. As a Monte-Carlo method, a major drawback is sampling noise and slow convergence rates. This means it is often unfeasible to reach needed particle counts for certain problems, and that quantifying the associated uncertainty with limited sample sizes is important. In this talk we discuss various techniques that attempt to overcome the issue of statistical noise and computational cost in particle-based kinetic methods, highlighting their overlap with sampling-based uncertainty quantification approaches. Our aim is to develop multifidelity methods that can enhance existing particle codes and allow for the simulation of strongly non-equilibrium plasmas at reduced cost. Many multifidelity approaches for noise reduction in particle-based codes either explicitly assume weakly non-equilibrium behavior or are unstable outside of that regime. To this end, we discuss progress towards developing low-noise methods that are suitable for large deviations from equilibrium. These methods can be embedded in the forward simulation or used a posteriori when computing moments of the particle density function.

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MS67

Stopping Rules Change Everything: the Hidden Phase Space and Structural Limits of Age-Stratified Pandemic Control

Understanding how societies respond to pandemics requires integrating epidemiological dynamics with behavioral and demographic heterogeneity. In this study, we develop an age-structured SEIRS-type model that incorporates asymptomatic transmission, heterogeneous infection fatality rates (IFRs), waning immunity, and age-specific behavioral and societal differences. Building on classical herd immunity concepts, we evaluate a range of stylized non-pharmaceutical intervention (NPI) archetypes within a strictly mechanistic and computational framework. Within the internal logic of the model, simulations indicate that selectively reducing contacts among high-risk groups can, under certain parameter regimes, be associated with lower modeled mortality than uniform population-wide restrictions. Importantly, the model also explicitly explores mathematically extreme regimes in which transmission intensity among lower-risk groups is increased above baseline levels as a deliberate stress test of heterogeneous transmission allocation. These results are descriptive of model structure rather than prescriptive of real-world policy and do not constitute advocacy of deliberate exposure scenarios. Additionally, we show that intervention timing relative to immunity thresholds, rather than fixed time horizons, moves scenarios to fundamentally different regions of the models dynamical phase space, thereby altering their comparative ranking. This framework provides a transparent computational setting for exploring how age structure, behavioral heterogeneity, and waning immunity jointly shape epidemic outcomes under alternative intervention archetypes.

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MS67

Impact of Varying Dispersal in Metapopulation Models: a New Type of Sherman-Morrison Formula

For population and disease distributed across patches in heterogeneous environments, meta-population models are a useful tool. It is of particular interest whether populations and diseases will persist depending on dispersal rates and network connectivity. In particular, we investigate how changes in network structure and dispersal impact the long-term population growth rate and determine the population persistence threshold. The population growth rate can be found via the largest real part of the eigenvalues of the Jacobian. This eigenvalue can be approximated using an expansion in terms of the Group Inverse. The Group Inverse is a generalized inverse for a specific class of matrices including the discrete Laplacian. We propose a Sherman-Morrison type formula that can be used to find an updated group Inverse for varying dispersal. Using this formula, we explore how changes in dispersal affect the population growth rate.

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MS67

Math-Model Informed Neural Network (MINN) for Downscaling of Disease Spread Measurement

Spatial heterogeneity in the spread of influenza is crucial for effective local-level preparedness against pandemics. In this talk, I will present a math modelinformed neural network (MINN) framework for downscaling influenza transmission cases from coarse state-level measurements to refined county-level resolution. Our machine learning approach combines a deterministic disease model and weather-influenced variations to produce high-resolution disease forecasts that remain consistent with county measures. This framework can enhance local healthcare policy by generating interpretable and high-resolution disease forecasts, enabling targeted resource allocation, early detection, and scenario-based planning at the county level.

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MS67

Geospatial Modeling of Climate-Driven Lyme Disease Dynamics in Maryland

Lyme disease, spread by black-legged ticks (Ixodes scapularis), remains the most pressing vector-borne public health challenge in the United States. Endemic transmission across the Northeast and Mid-Atlantic regions continues to generate significant health and economic costs (with annual direct medical expenses estimated at $1.4 billion nationally). In this talk, I will present a mechanistic modeling framework designed to explore how temperature variability shapes the geospatial dynamics of Lyme disease in Maryland. The model couples temperature-dependent tick life stages, reservoir host populations, and human exposure risk, and is parameterized using long-term surveillance, climate, and demographic data from the state. Simulations are run under current and projected temperature scenarios to identify the thermal conditions that drive peak tick activity and maximum transmission intensity. These results pinpoint seasonal windows when tick management and public health interventions could be most effective. I will also address whether climate change is likely to expand the geographic footprint of Lyme disease in Maryland or simply shift high-risk areas to new locations. The talk will conclude with a discussion of how control strategies can be optimized using climate-informed model projections.

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MS68

A Data-driven Effective Dynamics of ENSO From Topology, Symbolic Transitions, and Low-order Modeling

We propose a data-driven route to an effective low-dimensional description of ENSO based on delay-coordinate geometry, symbolic state transitions, and a minimal stochastic dynamical model. We test whether a coarse three-state representation (El Niño/La Niña/Neutral) or a refined five-state representation (separating weak and strong anomalies) is better supported by the data, and we assess whether delay-oscillator signatures emerge robustly from delay embeddings. Guided by the empirical diagnostics, we introduce a three-dimensional stochastic recharge–excursion model that reproduces the observed combination of frequent backbone motion and intermittent strong-event excursions.

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MS68

Geometry Helps Simplicial Message Passing

The WeisfeilerLehman (WL) test and its simplicial extension (SWL) characterize the combinatorial expressivity of message passing networks, but they are blind to geometry, i.e., meshes with identical connectivity but different embeddings are indistinguishable. We introduce the Geometric Simplicial WeisfeilerLehman (GSWL) test, which incorporates vertex coordinates into color refinement for geometric simplicial complexes. In addition, we show that (i) the expressivity of geometry-aware simplicial message passing schemes is bounded above by GSWL, and (ii) that there exist parameters such that the discriminating power of GSWL is matched by these schemes on any fixed finite family of geometric simplicial complexes. Combined with the Euler Characteristic Transform (ECT), a complete invariant for geometric simplicial complexes, this yields a geometric expressivity characterization together with an approximation framework. Experiments on synthetic and mesh datasets serve to validate our theory, showing a clear hierarchy from combinatorial to geometry-aware models.

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MS69

Parameter Identifiability From Quartet Concordance Factors Under the Network Multispecies Coalescent Model: Level-2 and Beyond

Genetic data often show incongruence among different stretches of the genome leading to topological discordance between evolutionary histories of specific genes and species-level evolution. The network multispecies coalescent model (NMSC) addresses this discordance by determining the probability of observing any gene tree given a metric species level phylogenetic network, taking into account hybridization and incomplete lineage sorting. The probabilities associated with quartet (4-leaf) gene trees are called quartet concordance factors (CFs). Both topological and parameter identifiability from quartet CFs under the NMSC have been well studied for level-1 networks but less is known about parameter identifiability beyond level-1. We give conditions on level-k networks, for $k \geq 2$, that guarantee parameter identifiability from quartet CFs under the NMSC.

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MS69

Deriving Symbolic Representations of Quartet Concordance Factors Using SymCF

Quartet concordance factors (qCFs) are one of the key summaries of genomic data for phylogenetic inference under the multispecies coalescent. However, formulas for computing expected qCFs quickly become unwieldy for complex phylogenetic networks. Symbolic formulas are essential for proving parameter identifiability, understanding model behavior, and developing statistically sound inference methods beyond numerical simulation. In this talk, I introduce SymbolicQuartetCF.jl (symCF), a computational method written in the Julia programming language that automatically derives symbolic representations of expected qCFs for arbitrary phylogenies (i.e., both trees and networks). The package also supports direct export to computer algebra systems (e.g., Macaulay2), enabling downstream theoretical and mathematical analyses.

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MS69

Algebraic Approaches for Species-Level Phylogenetic Inference under Multiple Evolutionary Processes

The advent of rapid and inexpensive DNA sequencing technologies has necessitated the development of computationally efficient methods for analyzing sequence data for many genes simultaneously in an evolutionary framework. The coalescent process is the most commonly used model for linking the underlying genealogies of individual genes with the global species-level phylogenetic tree in the absence of reticulate evolutionary processes, such as horizontal gene transfer, and algebraic approaches have been instrumental in both obtaining identifiability results and developing methods for inference from empirical data. Here, we consider a model for horizontal gene transfer, and develop parallel arguments about identifiability and inference. We

discuss the problem of distinguishing between incomplete lineage sorting and horizontal gene transfer for a given empirical dataset.

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MS69

Identifiability of a Simple Model of Lateral Gene Transfer

A significant influence on the evolution of certain species is lateral gene transfer, where genetic material is passed directly between different species. This makes determining the true evolutionary history of a species difficult. In this research we define a model of lateral gene transfer in which gene transfer events only occur between closely related species. We show that under this model, the unrooted topology of the phylogenetic tree is identifiable from sequence data.

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MS70

Mean-value Formulas for Higher-order Poisson Equations

We introduce a family of mean-value formulaswith quantitative remaindergiven in terms of linear combinations of iterated means, which characterizes solutions to higher-order Poisson equations. Higher-order Poisson equations involve an integer power of the Laplacian, and a nonzero forcing term, and appear in areas of physics and engineering such as hydrodynamics, structural engineering, and image processing. We provide exact formulas with a quantitative version of the remainder depending on the magnitude of the forcing term, as opposed to asymptotic expansions.Our results are consistent with our previous work in the polyharmonic case, where the forcing term is absent.

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MS70

Wavelet Galerkin Methods for the Helmholtz Equation and Elliptic Interface Problems

Wavelets are sparse multiscale representation systems that have been used in various applications such as signal and image processing, numerical PDEs, and data science. In this talk, I will focus on their application to numerically solving two important problems in science and engineering: the Helmholtz equation, which models time-harmonic wave propagation, and elliptic interface problems. I will describe some challenges we often face in solving these two PDEs and present wavelet Galerkin methods as effective solutions. The benefits of using wavelets to address these challenges will be discussed, along with details on constructions, and key theoretical and computational results related to these methods.

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MS70

On Existence of Chemotaxis Compressible Navier-Stokes Equations Modeling Vascular Network Formation

In this talk, we will discuss the existence of solutions to a model of vascular network formation in a bounded domain $\Omega \subset \mathbb{R}^3$, which is a coupling of the compressible Navier-Stokes equations for the density of the endothelial cells and their velocity, and a reaction-diffusion equation for the concentration of chemoattractant. We first prove the local existence of the unique strong solution provided that the initial data are sufficiently regular and satisfy a natural compatibility condition. We also prove the existence of global weak solutions for adiabatic pressure coefficients $\gamma > \frac{3}{2}$. The initial density ρ_0 may have vacuum in an open subset for both existence of the local strong solution and global weak solutions.

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MS70

A Fluid-Plate Interaction System with Square-Root Damping: Analyticity, Stability, and Stabilization with Boundary Controls

We present a homogeneous, uncontrolled 2D fluid-plate interaction model, where the structure is modeled by an elastic plate equation with (formally) square-root damping, and where the two components are subject to high-level coupled conditions at the interface between the two media. Physically the model occupies a doughnut-like domain: the fluid occupies the exterior domain while the plate structure occupies an interior subdomain. The novelty is the (formal) square root damping of the structure versus either no damping at all or else Kelvin-Voigt (viscoelastic) damping. We will show that such homogeneous (uncontrolled) model generates an analytic semigroup of contraction on a natural energy space, which is uniformly stable. We will also provide a characterization of the domain of a fractional power related to the generator. This result can be then used to study the corresponding non-homogeneous model subject to control action at the interface between the two media and provide or it an optimal regularity result.

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MS71

Learning Solution Operator of Dynamical Systems

with Diffusion Maps Kernel Ridge Regression

In this work, we propose a simple kernel ridge regression (KRR) framework with a dynamic-aware validation strategy for long-term prediction of complex dynamical systems. By employing a data-driven kernel derived from diffusion maps, the proposed Diffusion Maps Kernel Ridge Regression (DM-KRR) method implicitly adapts to the intrinsic geometry of the system's invariant set, without requiring explicit manifold reconstruction or attractor modeling, procedures that often limit predictive performance. Across a broad range of systems, including smooth manifolds, chaotic attractors, and high-dimensional spatiotemporal flows, DM-KRR consistently outperforms state-of-the-art random feature, neural-network and operator-learning methods in both accuracy and data efficiency. These findings underscore that long-term predictive skill depends not only on model expressiveness, but critically on respecting the geometric constraints encoded in the data through dynamically consistent model selection. Together, simplicity, geometry awareness, and strong empirical performance point to a promising path for reliable and efficient learning of complex dynamical systems.

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MS71

Learning Dynamical Systems from Noisy Data with Weak Diffusion Maps Kernel Ridge Regression

Accurate prediction of complex dynamical systems from noisy measurements remains a significant challenge in scientific computing. Kernel ridge regression learning strategies are often effective when applied to clean observational data, but have limited success in the presence of noise. Recently, weak formulations applied to various learning strategies have been observed to increase noise robustness, although a clear mechanistic explanation for this success is scarce in the prevailing learning literature. In this work, we bridge this gap by connecting weak formulations to classical results in information theory and signal processing to show that the weak form acts as a filter, explaining its observed noise robustness. Leveraging these insights, we pair a weak formulation with a specific kernel learning strategy to propose Weak Diffusion Maps Kernel Ridge Regression (WDMKRR) for learning dynamical systems. The proposed framework is simple to implement, effective for both clean and noisy data, and consistently outperforms several baseline methods. We demonstrate the performance of WDMKRR on chaotic benchmark systems in up to 64 dimensions, as well as experimental fluid data exceeding 15,000 dimensions.

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MS71

From Single to Multiple Kernels: Learning Interacting Particle Systems on Networks

We introduce a multi-type interacting particle system on graphs to model heterogeneous agent-based dynamics. Within this framework, we develop algorithms that jointly learn the interaction kernels, the latent type assignments, and the underlying graph structure. The approach has three stages: (i) a low-rank matrix sensing step that recovers a shared interaction embedding, (ii) a clustering step that identifies the discrete types, and (iii) a post-processing step to factorize the graph and kernels. Under the assumption of the restricted isometry property (RIP), we obtain theoretical guarantees on sample complexity and convergence for a wide range of model parameters.

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MS71

A Kernel Regression Framework for Data-Driven Modeling and Spectral Analysis of Nonlinear Dynamical Systems

We develop a data-driven framework for learning predictive and spectral representations of nonlinear dynamical systems using Regularized Diffusion Maps Kernel Regression (ReDMKR). The proposed method combines a diffusion maps kernel, which adapts to the intrinsic geometry of data sampled from an invariant set, with a Kronecker-delta regularization that stabilizes the empirical kernel representation. Through a liftpropagateproject reformulation, spectral information and coherent structures can be extracted from a kernel regression model, that is traditionally used only as a black-box predictor. Furthermore, the coherent structures are shown to be equivalent to those in Koopman spectral theory, such that generalized eigenfunctions and smoothed spectral measures can be approximated. Numerical experiments on the Lorenz-63 system demonstrate that ReDMKR preserves the predictive accuracy of diffusion maps kernel regression while enabling Koopman-based spectral analysis for both scalar nonlinear and full-state observables. Furthermore, a high-dimensional pitching-plunging flat-plate flow example shows that the method provides accurate long-term prediction and extracts dynamically coherent structures that are consistent with frequency-domain modal analysis. These results indicate that ReDMKR offers a systematic framework for simultaneous long-term prediction and physically interpretable Koopman spectral analysis of complex dynamical systems.

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MS72

Trading in CEXs and DEXs with Priority Fees and Stochastic Delays

We develop a mixed control framework that combines absolutely continuous controls with impulse interventions subject to stochastic execution delays. The model extends current impulse control formulations by allowing (i) the controller to choose the mean of the stochastic delay of their impulses, and allowing (ii) for multiple pending orders, so that several impulses can be submitted and executed asynchronously at random times. The framework is motivated by an optimal trading problem between centralized (CEX) and decentralized (DEX) exchanges. In DEXs, traders control the distribution of the execution delay through the priority fee paid, introducing a fundamental trade-off between delays, uncertainty, and costs. We study the optimal trading problem of a trader exploiting trading signals in CEXs and DEXs. From a mathematical perspective, we derive the associated dynamic programming principle of this new class of impulse control problems, and establish the viscosity properties of the corresponding quasi-variational inequalities. From a financial perspective, our model provides insights on how to carry out execution across CEXs and DEXs, highlighting how traders manage latency risk optimally through priority fee selection. We show that employing the optimal priority fee has a significant outperformance over non-strategic fee selection.

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MS73

Solutions to Open Math Problems with AI: Some Examples

Mathematical discovery is entering a new era of "augmented intelligence." In this talk, I describe my transition from traditional research methods to the integration of AI as a catalyst for discovery. Using recent results and papers obtained via AxiomProver, I will demonstrate how AI amplifies human intuition to navigate complex landscapes, uncovering new theorems and verifies them in Lean.

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MS73

Bridging the Gap Between Scientific Laws Derived by AI Systems and Canonical Knowledge via Abductive Inference with AI Noether

A core goal in modern science is to harness recent advances in AI and computer processing to automate and accelerate the scientific method. Symbolic regression can fit interpretable models to data, but these models often sit outside established theory and lack derivability. Recent systems have tackled this problem by quantifying derivability from prior axioms (encoded as polynomials) and building this into the search process. These methods generate formulae that don't just fit the data, but are explainable by theory as well. However, sometimes new data and associated hypotheses are not consistent with existing theory because the existing theory is incomplete or incorrect. When essential axioms are missing, these systems can only generate good fits to data without explainability. There is therefore a critical need in science for automating abductive inference - the process of correcting the axiomatic assumptions in order to explain a hypothesis - to close this explainability gap, which currently remains an open problem. In this talk, I'll talk about our recent step towards solving this problem and bridging this gap: AI Noether - a computational algebraic geometric system that, given an incomplete axiom system and set of hypotheses expressible as polynomials that it cannot explain, automatically generates a minimal set of missing axioms that suffices to derive the hypothesis. We'll talk about the system itself, its strengths and limitations, and how it fits into the modern scientific method.

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MS73

The Art of System Prompting

We discuss the usage of prompting and prompt engineering to control the behavior of large language models on mathematical questions. We focus on modern prompt engineering techniques for applications such as paper ingestion and comprehension, structured question answering, and error catching. We give several examples to demonstrate the qualitatively different behavior of LLM answers under carefully designed system prompts. We also briefly discuss how to set up prompting workflows to streamline LLM assisted research.

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MS74

Wave Patterns Near Rogue Waves Formed Through Breather Synchronization

We construct a family of solutions of the modified Korteweg-de Vries (mKdV) equation parametrized by a continuous order parameter M. For half-integer values of M, this family produces higher-order breather solutions of the mKdV equation, while for intermediate values it yields solutions that continuously interpolate between these breather states. We show that the solutions develop a localized peak at a prescribed spacetime point, with amplitude growing proportionally to M as M increases. Zooming in on the neighborhood of this point of amplitude explosion, we show that, in suitably rescaled coordinates, the local profile converges to a distinguished special solution of the mKdV equation, which we refer to as the infinite-order breather. This limiting structure is universal with respect to M, in the sense that it is independent of the particular sequence of values of M along which the limit is taken. Time permitting, we further describe wave patterns in certain regions of spacetime surrounding the focal point, showing that this universality extends into certain regions of the far field.

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MS74

Large-Degree Asymptotics for Laguerre Rational Solutions of Painleve V

We study the large-degree asymptotics of the Laguerre rational solutions to Painleve V. These solutions have applications to the study of the joint moments of the characteristic polynomial of the Circular Unitary Ensemble and to certain probability density functions associated with the Laguerre Unitary Ensemble. We derive a novel Riemann-Hilbert representation for the Laguerre rational solutions using the isomonodromy method and perform nonlinear steepest descent to obtain asymptotics. We present our new Riemann-Hilbert representation of the Laguerre rational solutions and our results on large-degree asymptotics inside and outside the zero-pole region. This is joint work with Robert Buckingham.

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MS75

Fine-Tuning of Spatiotemporal Fourier Neural Operator for Turbulent Flows

Recent advancements in operator-type neural networks have shown promising results in approximating the solutions of spatiotemporal PDEs. However, these neural networks often entail considerable training expenses and may not always achieve the desired accuracy required in many scientific and engineering disciplines. In this paper, we propose a new Spatiotemporal Fourier Neural Operator (SFNO) that learns maps between Bochner spaces, and a new learning framework to address these issues. This new paradigm leverages wisdom from traditional numerical PDE theory and Reduced Order Modeling. Specifically, the proposed pipeline first trains for a few epochs with SFNO, and then fine-tunes the last linear spectral filter layer via an implicit residual minimization procedure. Numerical experiments on toy model benchmarks for the 2D NSE operator learning demonstrate only 1% of the FLOPs required by the traditional end-to-end pipeline, and achieve solutions up to 100000 times more accurate than those from the neural operator surrogate.

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MS75

An Efficient Data-Driven Multiscale Stochastic Reduced Order Modeling Framework for Complex Systems

Suitable reduced order models (ROMs) are computationally efficient tools in characterizing key dynamical and statistical features of nature. In this paper, a systematic multiscale stochastic ROM framework is developed for complex systems with strong chaotic or turbulent behavior. The new ROMs fundamentally differ from the traditional Galerkin ROM (G-ROM) or those deterministic closure ROMs that aim to minimize path-wise errors and apply mainly to laminar systems. Here, the new ROM focuses on recovering the large-scale dynamics to the maximum extent. At the same time, it also exploits cheap but effective conditionally linear functions as the closure terms to capture the statistical features of the medium-scale variables and their feedback to the large scales. The new ROM mimics the model structure of many complex systems, allowing it to be more physically explainable. In addition, physics constraints of energy-conserving nonlinearities are incorporated into the new ROM. One unique feature of the resulting ROM is that it facilitates an efficient and accurate scheme for nonlinear data assimilation, the solution of which is provided by closed analytic formulae that do not require ensemble methods. Such an analytical solvable data assimilation solution significantly accelerates computational efficiency. It allows the new ROM to avoid many potential numerical and sampling issues in recovering the unobserved states from partial observations. The closure term calibration is efficient and systematic via explicit mathematical formulae. The new ROM framework is applied to complex nonlinear systems in which the intrinsic turbulent behavior is either triggered by external random forcing or deterministic nonlinearity. The out-of-sample numerical results show that the new ROM significantly outperforms the G-ROM in both scenarios regarding reproducing the dynamical and statistical features and recovering unobserved states via the efficient data assimilation scheme.

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MS75

Approximate Deconvolution for Regularized Reduced Order Models

Projection-based reduced order models (ROMs) are widely used to accelerate simulations of complex fluid flows, but their reliability deteriorates in convection dominated and turbulent regimes. In particular, standard PODGalerkin ROMs applied to under-resolved, highReynolds number flows often exhibit spurious oscillations or loss of accuracy. Regularization through spatial filtering has proven effective in improving stability, yet this comes at the risk of excessive damping of physically relevant flow structures. This talk examines a class of regularized ROMs augmented with approximate deconvolution to counteract the over smoothing introduced by filtering. The proposed approach aims to reconstruct attenuated dynamics while preserving the robustness benefits of regularization. We analyze the formulation and stability properties of these models and discuss their relationship to established regularization techniques. Numerical experiments for turbulent flow problems illustrate how approximate deconvolution can significantly improve predictive accuracy without increasing the computational complexity of the reduced-order model.

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MS75

Reduced Order Surrogate Methods in Computational Mechanics with Applications

We will focus on recent advances in surrogate modelling (model reduction and machine learning) in computational mechanics with special focus on parametric geometries and turbulent viscous flows as well. The topic deals also with approximation stability, structure preservation, data scarsity and database enrichment for snapshots. Applications include industrial problems, as well as medicine and environment.

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MS76

Denoising the Ensemble: Score-Based Posterior Correction for Nonlinear Data Assimilation

We consider filtering in a partially observed nonlinear dynamical system, where only a subset of variables is observed, and the objective is to recover the full joint filtering distribution without relying on particle filtering. To address this challenge, we propose a two-stage coupled filtering framework. First, we use a conditional Gaussian nonlinear system as a tractable surrogate model deployed in the ensemble Kalman Filter to obtain the analytical filtering score. Then, we learn a residual filtering operator directly from observations with an unsupervised diffusion model, avoiding the need for explicit closed-form filter updates. Second, for the unobserved variables, we leverage the conditional Gaussian structure to build a Gaussian mixture sampler that captures the non-Gaussian behavior of the small-scale marginal distribution without particle-based methods. Together, the learned score-based operator for the observed variables and the mixture-based conditional sampler produce a computationally efficient filter that makes minimal assumptions about the true dynamics and can represent filtering distributions beyond the Gaussian regime accessible to standard ensemble Kalman filters.

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MS76

Shape-Morphing Solutions for Reduced-Order Modeling

Classical methods for reduced-order modeling (ROM) assume the state as the linear combination of prescribed basis functions (or modes). This assumption limits their efficacy for time-dependent multi-scale problems with localized time-varying features. I will first introduce the notion of Shape-Morphing Solutions (SMS), which allow the modes to change shape over time, in a predictable fashion, in order to automatically adapt to the true solution of the PDE. This allows the SMS to approximate the PDE's solution more economically. I will also discuss several attractive features of SMS: (i) It is easy to enforce known conserved quantities of the PDE in the SMS-ROM. (ii) Classical Galerkin methods turn out to be a special case of SMS. (iii) Interpretation of SMS as a neural network with time-dependent weights and biases. (iv) Data assimilation with SMS. Finally, I demonstrate the application of SMS to several problems including rogue waves, vortex dynamics, and heat transfer.

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MS76

The High-Frequency and Rare Events Barriers to Neural Closures of Nonlinear Multiscale Dynamics

Although neural networks (NNs) represent a promising frontier for parameterizing fast-scale processes in climate modeling, their application still faces some critical challenges. This presentation highlights two fundamental barriers to this approach. First, we demonstrate that NNs can systematically struggle to capture rare, extreme events due to inherent data-sampling limitations. Second, we address the challenge of multiscale dynamics, where the interaction between high-frequency components (e.g., inertia-gravity waves) and slow-evolving processes (e.g., geostrophic motion) creates a significant hurdle for NN-based closures. Using the Lorenz 1980 model, a simplified representation of the Primitive Equations, we illustrate how these issues compromise the ability of neural network closures to capture the coarse-grained dynamics of the system. This is a joint work with Mickaël D Chekroun (UCLA & Weizmann Institute of Science), Kaushik Srinivasan (UCLA), and James C McWilliams (UCLA).

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MS77

Fast Prediction of Plasma Instabilities with Sparse-Grid-Accelerated Optimized Dynamic Mode Decomposition

Parametric data-driven reduced-order models (ROMs) that embed dependencies in many input parameters are essential for enabling many-query tasks in large-scale problems, and are key to the development of digital twins. However, generating training data to construct the ROMs using standard grid-based approaches is computationally infeasible due to the curse of dimensionality. This presentation introduces an efficient strategy for constructing parametric data-driven ROMs by leveraging sparse grid interpolation with (L)-Leja points. These points are nested and exhibit slow growth, resulting in sparse grids with low cardinality in low- to medium-dimensional settings, making them well-suited for computationally expensive, large-scale problems. As a representative real-world application, we consider gyrokinetic simulations of plasma micro-instabilities in fusion experiments. We construct parametric ROMs for the full five-dimensional gyrokinetic distribution function using optimized dynamic mode decomposition (optDMD) in combination with sparse grids. For an electrontemperaturegradient-driven micro-instability simulation with six input parameters, we demonstrate that a predictive parametric optDMD ROM can be built using only 28 high-fidelity simulations, while achieving evaluation costs up to three orders of magnitude lower. These results highlight the potential of sparse grid-based parametric ROMs in enabling otherwise intractable many-query tasks in large-scale applications.

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MS77

A Sampling Based Adaptive Rank Methods for Multi-Dimensional Wigner-Poisson Equations

The Wigner-Poisson (WP) system is essential for modeling quantum transport in warm dense matter (WDM), yet its non-locality across all of the phase space has historically rendered high-dimensional (e.g. 3D3V) simulations computationally prohibitive. Furthermore, these non-local interactions make most existing numerical methods incompatible with traditional parallelization frameworks, leaving a significant gap in our ability to simulate critical physicssuch as α-particle stopping power at the National Ignition Facility (NIF). In this talk, we present a breakthrough adaptive-rank algorithm that makes high-dimensional WP simulations tractable for the first time. Our approach is founded on the observation that WP solutions exhibit a significant low-rank structure, particularly in regimes where quantum effects matter (H¿= 1). The introduced adaptive-rank WP solver leverages this structure to achieve $O(N)$ scaling in both memory usage and operations. The proposed method preserves density to machine precision while maintaining momentum and energy conservation to the level of the truncation employed in the rank-adaptation process. By overcoming the need for the massive distributed computing infrastructure typically required for non-local models, this solver provides a scalable and high-precision pathway for fully kinetic studies of quantum plasmas in the WDM regime.

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MS77

Efficient Sn-Like and Pn-Like Dynamic Low Rank Methods for Thermal Radiative Transfer

Dynamic Low Rank (DLR) methods are a promising way to reduce the computational cost and memory footprint of the high-dimensional thermal radiative transfer (TRT) equations. The TRT equations are a system of nonlinear PDEs that model the energy exhchange between the material temperature $T(\mathbf{x}, t)$ and the radiation energy density $\psi(\mathbf{x}, \mathbf{\Omega}, t)$ at spatial point $\mathbf{x} \in \mathbb{R}^3$ and traveling in direction $\mathbf{\Omega} \in \mathbb{S}^2$ at time t; due to their high dimensionality, solving the TRT equations is often bottleneck in multi-physics simulations. DLR methods represent the solution $\psi(\mathbf{x}, \mathbf{\Omega}, t)$ in terms of time-evolving SVD-like factors $W_j(\mathbf{\Omega}, t)$ and $X_j(\mathbf{x}, t)$ of angle and space. Although previous work has explored DLR methods for TRT, most of the methods have limitations that make them impractical for realistic scenarios and uncompetitive with current non-DLR production codes. In this talk, we present new PN-like and SN-like Dynamic Low Rank (DLR) methods for TRT. In the SN-like DLR method, we use the time-evolving angular basis functions $W_i(\mathbf{\Omega}, t)$ to select time-evolving angles $\mathbf{\Omega}^{(i)}(t) \in \mathbb{S}^2$; this DLR formulation enables us to use the highly optimized SN transport sweep as our main computational kernel, and results in a practical way of leveraging low-rank methods in production TRT codes. In contrast, our PN-like DLR method uses an even-parity formulation and results in positive-definite linear systems to solve for each time step. We demonstrate the methods on several challenging, highly heterogenous problems in two spatial dimensions (4D) that these DLR schemes can give significant reduction in angular artifacts ("ray effects') with the same cost as gold-standard SN methods.

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MS77

A Fast Scheme for the Boltzmann Equation Based on Low-Rank Approximation

The Boltzmann equation can be lifted to a higher-dimensional linear master equation, whose solution can be projected back into a lower-dimensional probability distribution. We will show that the consecutive lifting-projection flow is indeed a nice approximation of the original Boltzmann flow. The lifting-projection procedure leads to a novel numerical scheme for the Boltzmann equation which is explicit but free of time-step constraint. For high order time discretization, we propose a special Runge-Kutta method. To address the issue of high-dimensionality, we adopt the tensor train format and compute low-rank solutions with a greedy cross approximation algorithm. Our scheme is consequently faster than the spectral method for the variable hard sphere (VHS) model. Numerical tests are performed to illustrate the efficiency and accuracy.

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MS78

Forest Succession Dynamics of the Upper Midwest under Modern Disturbance Regimes

Many of us in the Upper Midwest have experienced an uptick of air quality advisories during the Canadian wildfire season. Although boreal forests are well-adapted to wildfire, wildfires are increasing in frequency and intensity. These modern fire regimes may change what kinds of forests we have in North America. What species will dominate future forests? Are we already observing changes? If we have reached a tipping point, is it possible to get back? This work explores forest succession under modern disturbance regimes. We consider forest succession from early-to-late successional forests (and vice versa) to be controlled by positive and negative feedback effects, along with disturbance severity. This work primarily focuses on wind and fire disturbances in near-boreal and temperate forests of the Upper Midwest. Utilization of the United States

Department of Agriculture Forest Inventory and Analysis database may help us quantify these parameters for a quantitative application of the cusp-catastrophe to forest succession in near-boreal and temperate forests. These near-boreal forests of the Upper Midwest have similar composition and disturbance regimes as boreal forests, but occur at a lower latitude, thus may provide insight into the future of the boreal forests of North America.

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MS78

A Dynamical Systems Approach to Understanding Weather and Climate

Weather forecasting and climate prediction have long remained challenging problems due to the chaotic behavior of the atmosphere. The modern approach to forecasting relies on machine learning or numerical weather prediction, in which deterministic models of the Earth-Atmosphere system are used to forecast weather and climate, with ensemble forecasting often utilized in both approaches to account for the chaotic behavior. However, recent research has indicated that dynamical systems can be used directly to generate probabilistic forecasts of synoptic-scale weather. My talk will cover several papers that have investigated this approach, discussing both the methodology and the results. I will also discuss how this work can be used to assist with forecasting, and possible directions this approach can be extended with forecasting in mind.

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MS78

Analysis of Spatiotemporal Anomalies Using Time-Varying Persistent Homology (Vineyards)

In this talk, well use topological data analysis (TDA) to study geospatiotemporal data. Ill discuss an application to two COVID-19 data sets (LA infection rates and NYC vaccination rates) from 2020-21. We use persistent homology to identify anomalies (local maxima in the infection-rate data and local minima in the vaccination data) and to analyze the global spatial structure of the anomalies. We use vineyards—a form a time-varying persistent homology—to study how the structure of the data changes with time and to track the spatial locations of the anomalies as they move.

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MS78

Constructive Methods for Symmetry Breaking Bifurcations in Models of Materials and Population Dynamics

Nonlinear parabolic partial differential equations frequently occur in the modeling of applied phenomena. They often exhibit complicated dynamics which is organized by their associated equilibrium solutions. As a function of the involved model parameters, the latter ones can be detected using a bifurcation analysis, which in turn is centered around a deeper understanding of bifurcation points. Yet, in many applied systems establishing these organizing centers rigorously is difficult to achieve using traditional mathematical techniques. In this paper, we propose a theoretical framework for computer-assisted proofs of symmetry-induced transcritical and pitchfork bifurcations in nonlinear problems. This is accomplished by reformulating the existence question via a zero finding problem for an associated extended nonlinear system. The approach is general and allows for a wide variety of underlying symmetries. We demonstrate how these results can be applied in the setting of parabolic systems and higher-order equations, on both one- and two-dimensional domains. This talk is based on joint work with Maxime Breden and Thomas Wanner.

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MS80

A Commuter-Campus University Math Circle: Building Belonging Across Majors Through Collaborative Problem Solving

University-based math circles can provide a low-barrier, non-competitive space where students experience mathematics as collaborative, creative, and social. In this talk, I describe the design of the UMass Dartmouth Math Circle in a largely commuter context, with participants spanning mathematics, data science, computer science, engineering, and physics, as well as graduate students and postdocs. I will discuss practical structures that support belonging and persistence, including facilitation choices, problem selection, norms that prioritize conversation over performance, and mechanisms that build a vertically integrated peer network. I will also share lessons learned about sustaining participation and creating an environment where students who do not initially identify as math people develop confidence, connection, and a sense of membership in a mathematical community.

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MS80

Building Community, Belonging, and Persistence Through a Math Circle at An Urban Hsi

Math circles have a long tradition of bringing people together around curiosity, play, and shared problem solving. In this talk, I describe our process of launching a Math Circle at City Tech (CUNY) designed explicitly as a community-building space within an urban, commuter-heavy Hispanic-Serving Institution serving many first-generation and working students. Centered on accessible, open-ended problems, the circle invites students from diverse majors and mathematical backgrounds to experience mathematics as collaborative, creative, and social. I will share the guiding design principles (low-barrier entry, shared participation, and an emphasis on mathematical conversation over formal technique) and practical lessons learned about outreach, facilitation, and sustainability. I will also reflect on impact and challenges, and discuss how this model can be adapted across CUNY and similar institutions seeking to strengthen belonging, confidence, peer connection, and persistence in STEM through mathematics.

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MS80

Building An Active Math Teacher Circle: Strategies for Sustained Professional Learning

The Rubber City Math Teacher Circle of Akron engages K12 teachers in a distinctive model of professional development centered on active participation and collaborative problem solving. The implementation team, comprised of two university professors, two middle-grades mathematics teachers, and a county mathematics supervisor, has developed a thoughtful approach to selecting rich mathematical problems and preparing teachers to engage deeply with them. Rather than positioning teachers as passive recipients, this model fosters inquiry, discussion, and reflection. In this session, participants will learn practical strategies for developing and sustaining an effective Math Teacher Circle, including problem selection, facilitation techniques, and communication strategies that support this ongoing professional learning opportunity.

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MS80

From Math Circles to Summer Camps: How to Start and Grow Outreach Efforts

No one seems happy with the mathematics education they receive, whether students in high-achieving communities or those in underserved districts. In this talk, I draw on my experience with university-based math circles and outreach programs to argue that the problem is not only about content but also about community. I describe how weekly math circle sessions grew into additional circles across the region, math clubs in local schools, and a five-week summer camp, creating connected spaces where students experience mathematics as collaborative, human, and something they belong to. I conclude with practical lessons for building inclusive, scalable, and sustainable math circle models that support confidence, identity, and persistence in STEM across diverse educational contexts.

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MS81

A General Framework for Group Sparsity in Hyperspectral Unmixing Using Endmember Bundles

Due to low spatial resolution, hyperspectral data often consists of mixtures of contributions from multiple materials. This limitation motivates the task of hyperspectral unmixing (HU), which seeks to identify the spectral signatures (endmembers) of the materials present in an observed scene, along with their relative proportions (fractional abundance) in each pixel. A major challenge in HU arises from class variability among materials, which undermines accurate representation using a single spectral signature, as assumed in the conventional linear mixing model. To address this issue, we propose using group sparsity after representing each material with a set of spectral signatures, known as endmember bundles, where each group corresponds to a specific material. In particular, we develop a bundle-based framework that can enforce either inter-group sparsity or sparsity within and across groups (SWAG) on the abundance coefficients. Furthermore, our framework offers the flexibility to incorporate a variety of sparsity-promoting penalties, among which the transformed l1 (TL1) penalty is a novel regularization in the HU literature. Extensive experiments conducted on both synthetic and real hyperspectral data demonstrate the effectiveness and superiority of the proposed approaches.

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MS81

Sparse Recovery Using Scale and Signed Permutation Invariant Functions

In this talk, we present a unified framework for sparse recovery based on scale and signed permutation invariant sparsity-promoting functions. First, the squared ℓ_1/ℓ_2 model is introduced, together with its efficient algorithms and convergence guarantees. Second, the broader class of scale and signed permutation invariant functions is studied, and a systematic three-step procedure for computing their proximity operators is developed. Finally, the resulting fast proximity mappings are integrated into state-of-the-art optimization frameworks, and numerical results demonstrate improved recovery performance in compressive sensing and image restoration.

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MS81

Setting the Lasso Regularization Parameter

The determination of an approximate sparse solution to a system of linear equations using L1 norm regularization, using the LASSO formulation, depends on the value of the regularization parameter (lambda). In this work, we are interested in particular in the case where the noise level is unknown. We show the limitations of the conventional L-curve approach. We then introduce a new method inspired by the L-curve method. The new method combines two distinct complementary techniques: (1) noise simulation to determine an effective prior, and (2) a scale-invariant L-curve-inspired scoring method. The method will be illustrated with examples and compared with the cross-validation approach.

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MS81

Explicit Characterization of the ℓ_p Proximity Op-

erator for $0 < p < 1$

The nonconvex ℓ_p quasi-norm with $0 < p < 1$ is a powerful surrogate for sparsity but complicates the evaluation of proximal maps that underpin many modern algorithms. In this talk, we give an explicit characterization of the scalar proximal operator of $|\cdot|_p$ for all $0 < p < 1$, including the structure and admissible ranges of global minimizers, as well as conditions ensuring strict, isolated solutions. By applying the LagrangeBurmann inversion formula to the stationarity equation, we derive a uniformly convergent series for the larger positive root, yielding an exact and numerically stable formula for the ℓ_p proximal map above the classical threshold. We further provide a MellinBarnes integral representation and identify the series as a FoxWright function, which determines its radius of convergence. Specializations recover the known closed forms for $p = 1/2, 2/3$, and we obtain compact hypergeometric expressions for additional rational cases (e.g., $p = 1/3$). These results unify scattered formulas into a single framework and enable high-accuracy evaluation of ℓ_p proximity operators across the full range $0 < p < 1$.

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MS83

Interpretable Tensor Decomposition for Extreme Hurricane Analysis

Many hurricane and extreme weather datasets are inherently high-dimensional, spanning numerous spatial coordinates, physical variables, and long temporal ranges, particularly when comparing early- and late-century storms to assess changing risk. Traditional matrix-based methods are limited in capturing interactions across these multiple modes, motivating a multiway approach. We apply the Canonical Polyadic decomposition to tensor representations of hurricane data constructed from Holland wind profiles, preserving the underlying spatialtemporal structure. The resulting components are essentially unique and serve as interpretable factors, highlighting dominant spatial patterns and temporal dynamics linked to evolving climatological behavior. We emphasize interpretability alongside compression and discuss practical considerations such as rank selection, uniqueness, and optimization via alternating least squares.

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MS83

Enabling Real-Time Optimization Through Model Reduction and Model Discrepancy Sensitivities

Optimization plays a critical role to enable real-time decision-support. However, the computational complexity of model queries limits the deployment of numerical optimization in real-time scenarios. Learning reduced models in latent spaces can overcome this computational limitation. However, the model reduction error will propagate through the optimization procedure. This work combines data-driven reduced-order modeling with hyper-differential sensitivity analysis (HDSA) to account for model discrepancies. By using a single high-fidelity simulation to update the reduced model, our approach supports rapid optimization in time-critical applications. We illustrate with applications in atmospheric contaminant control and wildfire ignition estimation.

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MS83

Latent Space Inference for PDE Constrained Optimization

This presentation provides a brief overview of recent advances in Latent Representation Learning followed by novel contributions in PDE-constrained optimization. Here, we present an application of the Latent Twin methodology, where PDE constraints are embedded into the latent space to enable fast structure-preserving inference and adjoint computation. Several applications of this methodology are discussed including PDE-constrained inverse problems that encompass non-linear dynamics.

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MS83

Neural Network Approaches for Optimal Control: Implicit Hamiltonians and Transferable Policies

This talk presents two neural network methodologies advancing optimal control beyond current limitations. First, we address implicit Hamiltonians in practical problems like space shuttle reentry, where existing methods fail without explicit feedback control formulas. Our end-to-end implicit deep learning approach directly parameterizes value functions to handle the underlying implicit structure while enforcing physical principles through the relationship between optimal control and value function gradients, bridging Pontryagin's Maximum Principle and Dynamic Programming. Using Jacobian-free backpropagation, we efficiently train implicit networks for high-dimensional feedback controllers in previously intractable scenarios. Second, we tackle the computational burden of re-solving problems when objectives change. Our function encoder framework learns reusable neural basis functions enabling zero-shot adaptation through offline-online decomposition: basis functions are learned once, while adaptation requires only lightweight coefficient estimation. Experiments demonstrate near-optimal performance across diverse dynamics with minimal overhead. These approaches expand neural HJB applicability by handling structural complexity through implicit Hamiltonians and enabling operational flexibility through transferable policies for real-time deployment.

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MS84

Predicting Anemia Among Under-Five Children in Nepal Using Machine Learning and Deep Learning

Childhood anemia remains a major public health challenge in Nepal and is associated with impaired growth, cognition, and increased morbidity. Using World Health Organization hemoglobin thresholds, we defined anemia status for children aged 6-59 months and formulated a binary classification task by grouping all anemia severities as *anemic* versus *not anemic*. We analyzed Nepal Demographic and Health Survey (NDHS) microdata comprising 1,855 children and initially considered 48 candidate features spanning demographic, socioeconomic, maternal, and child health characteristics. To obtain a stable and substantiated feature set, we applied four complementary selection techniques (Chi-square, mutual information, point-biserial correlation, and Boruta) and prioritized features supported by multi-method consensus. Five features: child age, recent fever, household size, maternal anemia, and parasite deworming were consistently selected by all methods, while amenorrhea, ethnicity indicators, and province (Koshi and Madhesh) were frequently retained, suggesting additional contextual relevance. We then compared eight traditional machine learning classifiers (LR, KNN, DT, RF, XGBoost, SVM, NB, LDA) with two deep learning models (DNN and TabNet) using standard evaluation metrics, emphasizing F1-score and recall due to class imbalance. Among all models, the DNN achieved the highest test accuracy (0.709), while logistic regression attained the best recall (0.701) and the highest F1-score (0.649), and SVM yielded the strongest discrimination with the highest AUC (0.735). Overall, the results indicate that both ML and DL models can provide competitive anemia detection using nationally representative survey data, and that interpretable features such as child age, infection proxy (fever), maternal anemia, and deworming history are central for risk stratification and public health screening in Nepal.

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MS84

Leveraging Advanced Machine Learning to Predict Turbulence Dynamics from Temperature Observations at an Experimental Prescribed Fire

This study explores the potential of predicting turbulent kinetic energy (TKE) from more readily acquired temperature data using temperature profiles and turbulence data collected concurrently at 10 Hz during a small experimental prescribed burn in the New Jersey Pine Barrens. Machine learning models, including deep neural networks, random forest regressors, gradient boosting, and Gaussian process regressors, were employed to assess the potential of predicting TKE from temperature perturbations and explore the temporal and spatial dynamics of correlations. Data visualization and correlation analyses revealed patterns and relationships between thermocouple temperatures and TKE, providing insight into the underlying dynamics. More accurate TKE predictions were achieved by employing various machine learning models, despite the weak correlation between the predictors and the target variable. The results demonstrated significant success, particularly from regression models, in accurately predicting TKE. The findings of this study demonstrate a novel numerical approach for identifying new relationships between temperature and airflow processes in and around fire environments. These relationships can help refine our understanding of the combustion environments, processes, and the coupling and decoupling of fire environment processes, thereby improving fire operation strategies and fire and smoke model predictions. The findings of this study also highlight the valuable role of machine learning techniques in analyzing large, complex datasets from fire environments, showcasing their potential to advance fire research and management practices.

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MS84

A Randomized Subspace Model-Based Algorithm for Large-Scale Simulation Optimization

We introduce a noise-aware stochastic trust-region algorithm with adaptive random subspace strategies that is effective from low to potentially large dimensions. The method achieves scalability by optimizing random models restricted to low-dimensional affine subspaces defined via Johnson–Lindenstrauss transforms, thereby sharply reducing function-evaluation cost per iteration. Unlike earlier random subspace approaches with fixed dimensions and fully rebuilt poised sets, the proposed method adaptively selects the subspace dimension and updates the model by adding only a few new interpolation points while reusing past evaluations in a way that preserves poisedness, yielding substantially more efficient progress. To handle noisy objectives, it incorporates a noise-aware trust-region mechanism based on local estimates of the noise level, and its effectiveness is demonstrated on large-scale simulation optimization benchmarks, highlighting improved efficiency and robustness relative to fixed-subspace and noise-agnostic baselines.

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MS84

A Hybrid Machine Learning Framework for Portfolio Optimization

Optimizing an investment portfolio remains a central challenge in finance, as it requires achieving higher returns under disciplined risk control. Leveraging advances in artificial intelligence and operations research, we develop a novel hybrid framework that integrates the Capital Asset Pricing Model (CAPM) with machine learning techniques. Using all stocks listed in the S&P 500, the framework applies k-means clustering and fundamental screening to construct a financially robust candidate set. Expected returns are then forecast using Prophet, Random Forest, and eXtreme Gradient Boosting models and incorporated into the CAPM framework. Empirical results show that these forecasting models, when used in isolation, exhibit unstable risk exposures and weak cumulative performance, underscoring the need for equilibrium-consistent adjustments. In contrast, our proposed framework produces economically coherent and risk-consistent expected returns suitable for downstream mean–variance optimization. This leads to smoother Sharpe and Information Ratios, more stable Treynor behavior, and persistently positive Jensen's Alpha without sacrificing long-run performance. Overall, the framework provides a transparent, interpretable, and operationally reliable blueprint for AI-driven portfolio construction, demonstrating how machine learning and operations research can be jointly leveraged to design stable and theoretically grounded investment strategies.

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MS85

Folding phylogenetic trees into networks to understand polyploid evolution

Evolutionary histories are frequently characterized by reticulate processes such as recombination, horizontal gene transfer, and allopolyploidy, making the Tree of Life better represented as a phylogenetic network than a bifurcating tree. Phylogenetic networks can be unfolded a multilabeled tree (MUL-tree), which depicts the distinct paths lineages traverse during hybridization events. While current methods can re-fold MUL-trees to infer minimally reticulate networks, multiple distinct network topologies can unfold into the identical MUL-trees; this poses a significant challenge understanding the true evolutionary history. We present a framework to generate the complete set of phylogenetic networks that unfold to a given MUL-tree. We further develop a selection criterion to identify which of these candidate networks best explains observed gene tree data. We found that networks are only distinguishable from gene tree data if they possess distinct canonical forms. We apply this method to two empirical systems to resolve ambiguities in their histories of allopolyploidization.

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MS85

Ml Degrees of Brownian Motion Tree Models: Star Trees and Root Invariance

A Brownian motion tree (BMT) model is a Gaussian model whose associated set of covariance matrices is linearly constrained according to common ancestry in a phylogenetic tree. This talk will discuss the complexity of inferring the maximum likelihood (ML) estimator for a BMT model by computing its ML-degree. The main result is that the ML-degree of the BMT model on a star tree with $n+1$ leaves is $2^{n+1} - 2n - 3$, which was previously conjectured by Amndola and Zwiernik. We will also show that the ML-degree of a BMT model is independent of the choice of the root. This talk is based on joint work (https://doi.org/10.1016/j.jsc.2025.102482) with Jane Ivy Coons, Shelby Cox, and Aida Maraj.

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MS85

When Can 3-Cycles Be Distinguished?

The presence of three cycles in phylogenetic network models of gene evolution have been a continual road block to consistent identifiability results. This is particularly frustrating to biologists attempting to construct phylogenies, as three cycles in a phylogenetic network model of gene evolution is a natural way to model some sort of hybridization event that occurred between two species that were relatively closely related – where of course, closely related species are more likely to have such events. Algebraic methods fail here. In a graduate research semester program run by Dr. Colby Long, Dr. Elizabeth Gross, and Dr. Max Hill, I along with Bryan Currie, Aviva Englander, Jose Esparza-Lozano, Devon Olds, Udani Ranasinghe and Christin Sum investigated the effectiveness of *semi*-algebraic methods to distinguish networks that contained three cycles.

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MS85

Identifiability of 2-Cycles in Species Networks

Inference of phylogenetic networks requires on understanding of which of their features are identifiable. For instance, under most models of gene tree formation it is known that the presence/absence of 2-cycles in a network has no effect on inference by methods built on gene tree quartet information. While 2-cycles may be part of the true evolutionary history, they leave no trace detectible by those methods, and do not compromise results which ignore their possibility. Using algebraic and semialgebraic frameworks, we investigate the identifiability of 2-cycles in the setting of the Network Multispecies Coalescent Model, with data summarized to 5-taxon topological gene tree information, i.e, quintet concordance factors. We show topological 2-cycles can in fact often be identified, provided they have at least 3 descendant taxa. In particular, for inference methods not built on quartets, ignoring the possibility of 2-cycles may lead to model misspecification, with unclear impact on results.

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MS86

Continuum and Stochastic Modeling of Complex Fluids: From Bacteriophage DNA and Beyond

Bacteriophages densely pack their long dsDNA genome inside a protein capsid, where the confined DNA exhibits hexagonal chromonic liquid-crystalline ordering with structure that depends sensitively on the surrounding ionic conditions. In this talk, I present continuum PDE modeling and complementary stochastic descriptions of viral DNA organization, informed by experimental measurements. From a free energy combining OseenFrank elasticity, electrostatic interactions, and entropic effects, we derive a coupled nonlinear PDE system for the DNA and ion distributions, whose numerical solutions show good agreement with experiments and molecular dynamics simulations. A bifurcation analysis of helical filament configurations in a cylindrical capsid establishes the existence of multiple equilibria, while incorporating thermal fluctuations via stochastic differential equations yields knot distributions consistent with experimental observations. Experimental measurements of DNA layer positions and knot probability distributions are used to calibrate key model parameters, including effective bending and twist moduli. Finally, I discuss structure-preserving numerical schemes that inherit the underlying energy-dissipation law at the discrete level, with applications extending to other complex fluid systems.

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MS86

A Monotonicity Formula with Application to the Relativistic Brillouin Electron Flow

In this work, I present a new monotonicity formula for a two-phase free boundary problem arising in the study of relativistic Brillouin electron flow. The formula is developed within a general framework valid in two and higher dimensions. As an application, a special case is used to establish the existence of a non-degenerate, Lipschitz continuous viscosity solution. The associated differential equation is nonlinear and nonhomogeneous, and the structural assumptions imposed are minimal. This new monotonicity formula generalizes existing elliptic results and contributes to the existence theory for nonhomogeneous free boundary problems. Furthermore, the proof is elementary and robust, making it applicable to a broader class of problems.

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MS86

Analytical Construction and Dynamical Analysis of Soliton Solutions in Nonlinear Evolution Equations

In this work, we develop analytical approaches for the construction and dynamical analysis of soliton solutions in nonlinear evolution equations using two representative nonlinear wave settings. First, we study a double-stranded DNA (dsDNA) model of two coupled polynucleotide chains interacting through an elastic membrane that mimics hydrogen bonding. By applying the Sine-Gordon Expansion Method (SGEM) and the Improved Bernoulli Sub-Equation Function Method (IBSEFM), we obtain new exact traveling-wave families, including hyperbolic/exponential solitons, rational forms, and complex periodic patterns, describing localized strand-opening and breathing modes. Their characteristics are illustrated through 2D3D profiles, while equilibrium structure, bifurcation behavior, and forced responses (including chaotic features and sensitivity to initial conditions) are examined via phase-plane dynamics. Second, for additional nonlinear wave models (including the Kairat-II and Kairat-X equations), we exclusively employ the Extended Trial Equation Method (ETEM) to derive further exact traveling-wave solutions (rational, hyperbolic, and mixed trigonometrichyperbolic types) and to explore parameter-driven changes in amplitude, width, and propagation through graphical simulations. Overall, the results provide explicit solution benchmarks and deeper insight into nonlinear wave localization, stability, and propagation mechanisms.

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MS86

Weak Solutions and Partial Regularity of Poiseuille Flow for the Hyperbolic EricksenLeslie System in Two Dimensions

In this talk, we study the Poiseuille laminar flow in a tube for the full Ericksen-Leslie system. It is a parabolic-hyperbolic coupled system which may develop singularity in finite time. We will prove the global existence of energy weak solution, and the partial regularity of solution to system

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MS87

Blending Data and Physics for Reduced-Order Modeling of Systems with Complex Dynamics

While data-driven techniques are powerful tools for reduced-order modeling of systems with chaotic dynamics, great potential remains for leveraging known physics (i.e. a full-order model (FOM)) to improve predictive capability. We develop a hybrid reduced order model (ROM), informed by both data and FOM, for evolving spatiotemporal chaotic dynamics on an invariant manifold whose coordinates are found using an autoencoder. This approach projects the vector field of the FOM onto the invariant manifold; then, this physics-derived vector field is either corrected using dynamic data or used as a prior that is updated with data. In both cases, the neural ordinary differential equation approach is used. We consider simulated data from the Kuramoto–Sivashinsky and complex Ginzburg–Landau equations. Relative to the data-only approach, for scenarios of abundant data, scarce data, and even an approximate FOM (i.e. erroneous parameter values), the hybrid approach yields substantially improved time-series predictions.

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MS87

Adaptive Reduced-Order Models with Online Learning for Subspace and Operator Updates

Reduced-order models (ROMs) are traditionally constructed using fixed low-dimensional manifolds obtained offline, which limits their reliability when system dynamics depart from the training regime. In this work, we present a framework for adaptive reduced-order modeling in which the reduced subspace evolves with the system dynamics and is updated online using incremental singular value decomposition (iSVD) and related subspace tracking techniques. We additionally investigate mechanisms for incorporating new information acquired during the online phase to guide adaptation, and systematically compare several subspace update strategies, identifying iSVD as an effective and computationally efficient approach for dynamic basis evolution. The methodology is demonstrated on nonlinear conservation laws and compressible flow problems exhibiting transient and strongly nonlinear behavior, where adaptive subspace updates significantly improve robustness and long-time accuracy relative to static ROMs. Building on this foundation, we outline a pathway toward non-intrusive operator adaptation by sequentially updating reduced operators via recursive least-squares following each basis update. We argue that such adaptive frameworks are not merely advantageous, but necessary for constructing truly predictive reduced-order models of complex dynamical systems.

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MS87

Zero-Shot Size Transfer of Graph Neural Differential Equations for Learning Graph Diffusion Dynamics

Graph Neural Differential Equations (GNDEs) provide a powerful framework for learning continuous-time dynamics on discrete graphs. A key advantage of GNDEs is their potential to transfer learned parameters from small training graphs to much larger test graphs. We establish convergenceguarantees for this size transfer and empirically investigate the zero-shot size transferability of GNDEs for learning graph diffusion dynamics that admit a graphon limit, revealing how transfer accuracy depends on the underlying dynamics and graph structure. In particular, we observe a clear convergence rate when fitting GNDEs to linear diffusion dynamics across graph sizes, a phenomenon absent in nonlinear settings, raising new theoretical questions about the mechanisms underlying transfer learning.

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MS87

Data-Driven Modeling of Transition Dynamics for 2D Wall-Bounded Turbulence

The laminar-turbulent transition in wall-bounded shear flows remains a fundamental challenge in fluid mechanics, with practical implications for drag prediction and flow control. This work develops data-driven reduced-order models to capture transition dynamics in two-dimensional pressure-driven channel flow at friction Reynolds number $Re_\tau = 1000$ using the vorticity-streamfunction formulation. High-fidelity direct numerical simulations are performed with a GPU-accelerated solver for an ensemble of initial conditions spanning a range of perturbation amplitudes, wavelengths, and spatial structures, generating comprehensive training data that densely samples the transition pathway from laminar Poiseuille flow to fully developed turbulence. Proper orthogonal decomposition(POD)extracts an energy-optimal modal basis from simulation snapshots, onto which the governing vorticity equation is projected to obtain a Galerkin system with quadratic nonlinearity. A neural network closure is trained to correct for truncation effects. This framework offers a pathway toward efficient exploration of transition-triggering perturbations and provides insight into the dominant modal dynamics governing the transition process.

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MS88

Confessions of a Vibe Prover

Vibe proving is an emerging mode of AI-assisted mathematics in which one works at a high level choosing examples, steering conjectures, judging proof ideas, and shaping exposition while large language models handle much of the local exploration and drafting. I will describe what this workflow looks like in practice through recent work on conjectures involving Toeplitz determinants and Pochhammer polynomials.

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MS88

Designing Datasets for Example-Based Conjecture Generation in AI for Math

Examples and computation play a critical role in the research mathematicians workflow, enabling us to build robust intuition prior to any formal conjecture generation or proof construction. On the other hand, most approaches to AI for math de-emphasize this, instead focusing on mathematical discovery in language alone (either in natural language or in a formal language like Lean). In this talk we discuss our development of the Algebraic Combinatorics Dataset Repository, a collection of datasets representing open problems (or foundational results) in algebraic combinatorics. The datasets are designed to capture critical aspects of each of the problems within a traditional machine learning framework. After summarizing the datasets themselves and the philosophy behind them, we will describe observations from our initial round of benchmarking.

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MS89

Asymptotics of Orthogonal Polynomials with Applications to Density Estimation of Random Matrices

We introduce a new approach for estimating the asymptotic spectral distribution (ASD) of a random matrix using a single, sufficiently high-dimensional sample, without computing the full spectrum. The method builds on the Lanczos algorithm, together with asymptotic analysis and perturbation theory for orthogonal polynomials, and enables efficient and accurate estimation of the ASD. We illustrate the approach through an application to spectral density estimation in spiked covariance models.

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MS89

Numerical Methods for KdV and mKdV Soliton Gasses

We present a class of RiemannHilbert-based numerical methods for computing and evolving soliton gas solutions of the Korteweg–de Vries and modified Korteweg–de Vries equations. Based on the RiemannHilbert formulation of Dyachenko, Zakharov, and Zakharov and the analysis of Girotti et al., the method allows us to evaluate soliton gas solutions before asymptotic estimates are valid. In particular, it enables the computation of higher genus soliton gas solutions with spectral data supported on several intervals on the imaginary axis as well as additional limiting and trapped solitons. As a special case, when the reflection coefficients exhibit square root behavior at interval endpoints, the jump conditions are disjoint, and a more efficient implementation based on weighted Cauchy integrals of Chebyshev polynomials is employed.

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MS89

Orthogonal Polynomials, Painlev Equations, and Map Enumeration

In this talk, I will survey some recent results on the connection between the combinatorial problem of enumerating maps on compact Riemann surfaces, special solutions to Painlev equations, and how both are accessed using orthogonal polynomials. This is joint work with Pavel Bleher, Alfredo Deao, Maxim Yattselev, Nathan Hayford, and Roozbeh Gharakhloo.

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MS90

On Pressure Treatment in Incompressible Reduced-Order NavierStokes Simulations

The talk provides a comprehensive overview and comparative analysis of three different strategies for pressure treatment in Reduced-Order Models (ROMs) for incompressible flow problems. First, we review a pressure recovery technique in which the pressure field is reconstructed by minimizing, in a dual norm, the residual resulting from the reduced velocity solution. This approach is shown to yield a unique pressure approximation when the full-order discretization is inf-sup stable, and it is mathematically equivalent to solving a reduced mixed problem enriched with supremizer modes. Second, we examine an efficient supremizer-based stabilization strategy that decouples the reduced-order velocity and pressure systems, significantly reducing the computational cost of both offline and online phases while maintaining stability and accuracy. Finally, we present a pressure-correction ROM based on the Goda time-splitting scheme, highlighting the role of tailored inner products for constructing reduced bases for intermediate and divergence-free velocities as well as pressure, enabling explicit reduced-order computations supported by stability and error analysis. Numerical experiments for parametrized incompressible flow problems illustrate the performance of each approach. Together, these methods provide complementary insights into accurate and stable pressure treatment in projection-based ROMs for incompressible NavierStokes equations.

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MS90

Reduced-Basis Method-accelerated Inverse Problems for High-speed Aerothermodynamics

The design and analysis of high-speed flight vehicles is heavily reliant on computational fluid dynamics (CFD) and conjugate heat transfer (CHT) simulations due to the expense and difficulty of flight tests and experiments. Workhorse CFD and CHT models are subject to various sources of modeling uncertainties including turbulence model parameters and thermal protection system material properties. Therefore, approaches that efficiently propagate and reduce uncertainties are important for a robust design cycle. Unfortunately, computational aerothermodyamic analyses are computationally expensive for high-speed flows due to high grid resolution requirements and the need for multiple CFD evaluations at different flight conditions. Also, model calibration is a many-query problem requiring many model evaluations with a wide range of input parameters. This talk discusses reduced basis method-accelerated parameter calibration of computational aerothermodynamics simulations. We discuss gradient-free optimization approaches that leverage easily computable error estimates for constructing and updating the reduced basis throughout the optimization. We assess the utility of reduced-basis methods for more efficiently inferring model parameters and their corresponding uncertainties of aerothermodynamic simulations. Results are presented on several high-speed flows. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525. SAND2026-17064A

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MS90

Reducing the Computational Cost of Ocean Modeling with Data-Driven Rom

The two-layer quasi-geostrophic equations (2QGE) is a simplified model that describes the dynamics of a stratified, wind-driven ocean in terms of potential vorticity and stream function. Its numerical simulation is plagued by a high computational cost due to the size of the typical computational domain and the need for high resolution to capture the full spectrum of turbulent scales. We propose a framework to reduce the computational cost through a predictive and parametric data-driven reduced order model (ROM). The main building blocks of our ROM are proper orthogonal decomposition (POD) and long short-term memory (LSTM) recurrent neural networks. POD is applied to each field variable to extract the dominant modes and a LSTM model is trained on the modal coefficients associated with the snapshots for each variable. Then, the trained LSTM models predict the modal coefficients for a time interval of interest and for each new parameter value. The predictive performance of our framework and the corresponding time savings are illustrated with the so-called double-gyre wind forcing test.

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MS91

Structure-Preserving Construction of Collision Operators for Kinetic Equations from Molecular Dynamics

We present a data-driven, multiscale framework for constructing generalized collisional kinetic models directly from the micro-scale molecular dynamics. The learned operator takes an anisotropic and non-stationary form, capturing heterogeneous collisional energy transfer arising from the many-body interactions, which is overbroadly looked by the conventional collision operators beyond the weakly coupled regime. The constructed model strictly preserves the frame-indifference, conservation laws and physical constraints such as the H-theorem. To enable efficient numerical evaluation, we develop a fast spectral separation method that represents the kernel as a low-rank tensor product of univariate basis functions. This formulation admits an O(N log N) algorithm and structure-preserving discretization. Numerical results demonstrate that the proposed model accurately predicts the transport coefficients and 1D3V plasma kinetics across a wide range of plasma conditions, where the conventional Landau model shows limitations.

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MS92

Fundamentals of Electromagnetic Transient (EMT) Phenomena and Its Simulation

This talk introduces fundamentals of Electromagnetic Transient (EMT) phenomena and their computer simulation, offering participants a clear understanding of the physical processes and modeling techniques that underpin EMT studies. It begins by examining key EMT phenomena encountered in modern power systems, including generator stator transients, converter switching actions, lightning surges, traveling waves, and harmonic resonance together with the large scale EMT dynamic studies in the presence of multiple utility scale Inverter-Based-Resources (IBRs) to observe their dynamic behavior in the event of system disturbances. Through these examples, attendees will gain insight into the diverse sources and characteristics of fast, dynamic disturbances that influence system behavior. The talk then transitions into the essential principles of EMT simulation. Core topics include EMT component modeling methodologies and their role in accurately representing system devices under transient conditions.

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MS92

Ongoing Research in Electromagnetic Transient Simulation (EMT) Methods

Electromagnetic-transient (EMT) simulation is vital to ensuring the reliability and stability of complex large-scale modern power grids with power-electronics. Oak Ridge National Laboratory (ORNL), in collaboration with other national labs and academia, is advancing the state of the art through robust numerical methods and frameworks sized for the demands of large-scale EMT studies. This talk surveys ongoing work, emphasizing advances in numerical solvers, intelligent algorithms, and performance engineering tailored to massive EMT simulation. A central focus is the creation of multi-stiff implicitexplicit (ImEx) integrators for differentialalgebraic equation (DAE) models to accurately and efficiently handle stiff, nonlinear dynamics. In a partitioned formulation, the dynamics satisfy $\frac{dx}{dt} = f_e(x,t) + f_i(x,t)$, with the stiff component f_i advanced implicitly and the nonstiff component f_e advanced explicitly, while algebraic constraints $g(x,t) = 0$ are enforced within a consistent DAE framework. Concurrent advances in linear-solver structure-aware strategies, mixed-precision solvers and optimized reordering accelerate sparse factorization on CPUs/GPUs reliably. Combined with techniques such as pattern recognition, topology-aware reordering, and adaptive load balancing, these capabilities improve scalability, and enable faster grid analyses, laying the groundwork for next-generation tools that support critical grid operations.

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MS92

Mathematics of Electromagnetic Transient (EMT) Simulation

In this talk, the fundamental mathematics underpinning electromagnetic-transient (EMT) simulation of large-scale power systems with power electronics will be presented. First, attendees will be equipped with a clear mathematical foundation for how EMT models will be posed and advanced in time. Next, methods for representing network equations and component dynamics in coupled differentialalgebraic equation (DAE) form, as well as for converting these continuous-time relations into discrete-time updates through numerical time integration, will be presented. Furthermore, the mathematical meaning of stability and accuracy in EMT settings particularly the role of stiffness arising from fast electromagnetic and switching-driven phenomena interacting with slower electromechanical and control dynamics will be emphasized in detail. In addition, the linear-algebraic structure that will be formed at each time step typically large, sparse systems of equations will be examined, and the essential concepts of sparsity, conditioning, and convergence that govern reliable solution will be reviewed. Finally, by focusing on these core mathematical elements, a rigorous yet accessible framework for understanding EMT simulation as an applied mathematics problem in modeling, discretization, and numerical solution will be provided.

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MS92

Advanced Solutions for Electromagnetic Transient Simulation (EMT)

Scaling EMT poses significant challenges to the numerical methods underlying the simulations, especially due to the distributed differential-algebraic equations (DAEs) which exhibit discontinuities and have multiple loosely coupled regions. The computational and applied mathematics communities are well positioned to address these challenges with advanced time integration, linear solver, and graph-based methods. This talk will discuss areas where recent advances are expected to make progress and where further advances are needed. Lastly, we will present a roadmap for addressing challenges related to DAEs and linear solvers for EMT.

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MS93

Weighted Birkhoff Averages Accelerate Data-Driven Methods

Many data-driven algorithms in dynamical systems rely on ergodic averages that converge painfully slowly. One simple idea changes this: taper the ends. Weighted Birkhoff averages can converge much faster (sometimes superpolynomially, even exponentially) and can be incorporated seamlessly into existing methods. In this talk I will demonstrate this with five weighted algorithms: weighted Dynamic Mode Decomposition (wtDMD), weighted Extended DMD (wt-EDMD), weighted Sparse Identification of Nonlinear Dynamics (wtSINDy), weighted spectral measure estimation, and weighted diffusion forecasting. Across examples ranging from fluid flows to El Nino data, the message is clear: weighting costs nothing, is easy to implement, and often delivers markedly better results from the same data.

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MS93

Analytic Continuation and Fft-Based Parameterization for Computing Stable and Unstable Manifolds of Hyperbolic Periodic Orbits in Billiard Maps

We present a numerical framework for computing stable and unstable manifolds of hyperbolic periodic orbits in billiard maps on perturbed elliptical tables. The core challenge is that the billiard map is defined only implicitly as the composition of several root-finding problems making standard power series techniques for the parameterization method impractical via explicit Cauchy products or differential equation augmentation. To overcome this, we reformulate each step of the billiard map as a real analytic, implicitly defined system and extend it to a complex domain via numerical analytic continuation. This complex extension enables the use of discrete Fourier transform (DFT) and Fast Fourier Transform (FFT) interpolation to compute the Taylor coefficients required at each stage of the parameterization method, circumventing the need for explicit recursion relations. The resulting algorithm produces high-order polynomial approximations to local stable and unstable manifolds, which are then globalized numerically to reveal homoclinic tangles and transverse intersections. We apply this method to five perturbed elliptical billiard tables, computing manifolds for periodic orbits of various periods and providing strong numerical evidence for the existence of chaotic dynamics in each case.

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MS93

Geometric DriverResponse Decomposition in a Family of Strange Nonchaotic Attractors

Collective dynamical systems far from equilibrium can generate robust geometric organization even under qualitatively different driving mechanisms. In this talk, we study a family of strange nonchaotic attractors generated by a herding system on a directed rooted tree. Although strange nonchaotic attractors arise in many driven systems, the geometric principles organizing them across driver classes remain less understood. We show that a nonsmooth predecessor-selection operator coupled with a memory-cascade response operator produces common large-scale response geometry and driver-dependent fine structure. A reduced-coordinate decomposition of the response identifies the common coarse organization, while residual analysis isolates the driver-dependent component.Our findings suggest a comparative organizing principle for SNAs that moves the subject from isolated existence results toward comparison and classification.

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MS93

Body-Like Coordination Emerges in Paired Termite Locomotion

Coordinated group movements are often described as moving like a single organism, yet this analogy is typically metaphor. Individuals, interacting each other, lack the functional integration like body parts of single organism. It remains unresolved whether movement coordination can truly reproduce body-like organization. Here we show that during tightly coordinated movement, pairs of termites use the same explorationstabilization division of labor observed within a single moving body. Using posture tracking, we demonstrate that leaderfollower asymmetries in tandem running mirror anteriorposterior asymmetries in individual locomotion, with exploratory motion concentrated at the front and smoother, shorter trajectories behind. Our mathematical model reveals that such body-like coordination emerges from temporal convolution of past locational cues, rather than instantaneous responses. These results identify a control principle of hierarchical structured movement coordination, providing a novel way to design collective behavior.

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MS94

Flocking under Fast and Large Jumps in a Non-Linear Mean-Field System

We analyze a pure-jump mean-field interacting particle system where each particle jumps forward by random (independently and identically distributed) lengths and at a rate depending on its signed distance from the center of mass. The rate being non-increasing leads to a flocking behavior: the particles below the center of mass jump forward at a higher rate than those above it. We identify natural conditions under which the system is well-posed and study the fluid (hydrodynamic) limit of the empirical measure process associated with the system. By establishing well-posedness of the associated McKean-Vlasov equation, we characterize the fluid limit of the particle system and prove a propagation of chaos result. Next, for the centered particle system, we establish existence and uniqueness of stationary distributions and study their tail properties. Finally, in the special case of exponential rate and jump distributions, we further show propagation of chaos at infinite time and convergence of the stationary empirical measure to a traveling wave solution of the McKeanVlasov equation.

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MS94

Phase Transitions in Doi-Onsager, Noisy Transformer, and Other Multimodal Models

We study phase transitions for repulsive-attractive mean-field free energies on the circle. For a $\frac{1}{n+1}$-periodic interaction whose Fourier coefficients satisfy a certain decay condition, we prove that the critical coupling strength K_c coincides with the linear stability threshold $K_\#$ of the uniform distribution and that the phase transition is continuous, in the sense that the uniform distribution is the unique global minimizer at criticality. The proof is based on a sharp coercivity estimate for the free energy obtained from the constrained Lebedev–Milin inequality. We apply this result to three motivating models for which the exact value of the phase transition and its (dis)continuity in terms of the model parameters was not fully known. For the two-dimensional *Doi-Onsager* model $W(\theta) = -|\sin(2\pi\theta)|$, we prove that the phase transition is continuous at $K_c = K_\# = 3\pi/4$. For the *noisy transformer* model $W_\beta(\theta) = (e^{\beta\cos(2\pi\theta)} - 1)/\beta$, we identify the sharp threshold β_* such that $K_c(\beta) = K_\#(\beta)$ and the phase transition is continuous for $\beta \le \beta_*$, while $K_c(\beta) < K_\#(\beta)$ and the phase transition is discontinuous for $\beta > \beta_*$. We also obtain the corresponding sharp dichotomy for the noisy *Hegselmann-Krause* model $W_R(\theta) = (R - 2\pi|\theta|)_+^2$.

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MS95

Intentional Community Building in a University Math Department

Community is an essential part of education, especially within mathematics. I will talk about our intentional community building efforts within our mathematics department, how they affect retention and recruitment of mathematics students, and our events every Friday which include Math Circles, Applied Math Seminars, student information sessions, tea times, and more.

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MS95

Creating a Mathematics Community: Successes and Lessons Learned in Local, National, and International Context

My work building communities has spanned several institutions - as Dean of Carolina Friends Upper School, Associate Dean for Faculty Development at Harvey Mudd College, Deputy Director of the MAA, AMS/AAAS Policy Fellow in the US Senate and now as the inaugural Executive Director of the Data Science and AI Academy at NC State University. The lessons learned are not independent - each of these experiences has informed future endeavors. I'll share some of those connections and keys to community building when it is most powerful - bringing together people who don't automatically agree.

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MS95

Math Circles of Chicago: A Very Large Scale Enrichment Program that Provides Equitable Access for All Children

Math Circles of Chicago (MC2) has created a new model for community based math circles. This model emphasizes classroom teacher leadership, where math enrichment is delivered with thoughtful pedagogy. This approach has allowed MC2 to grow to be the largest math circle program in the US, serving 1,300 students annually in its core math circle programs, with 4,000+ more served in its math festivals. Moreover, MC2 serves a population representative of Chicago's diversity–socioeconomically, ethnically/racially, and geographically. Unique features of MC2's model include a fully developed academic year program with 5 levels for 3rd to 12th graders, with 130 distinct, high quality activity plans; the use of Julia Robinson Math Festivals as a way to introduce students to the concept of math circles, held within public schools in Chicago; math circles delivered at 6 Hubs across the city, open to all children, along with 60 programs in after school classrooms in underresourced communities; summer camps serving 500 children, and an annual math symposium. We provide heavy support for our teachers, including dozens of workshops each semester, a highly active online space for teacher reflection and feedback, and 1on1 coaching. Currently we are developing a 'playbook' to expand to cities across the US; we have a second sister site with the Math Circles of Houston, and depending on funding we hope to open programs in several US cities in the upcoming years.

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MS96

Fusion Based 3D Image Super Resolution from Truncated K-Space Data in Quantitative Magnetic Resonance Imaging

Osteoarthritis (OA) is a leading cause of disability, and early detection of biochemical cartilage degeneration is critical for preventing irreversible joint damage. Quantitative 3D T1ρ MRI is highly sensitive to proteoglycan loss and thus promising for early OA assessment, but its clinical utility is limited by prohibitively long scan times: multiple spin-lock times (TSLs) require fully sampled 3D k-space acquisitions, making high-resolution imaging inefficient and motion-prone. A practical acceleration strategy is to truncate k-space and acquire only its central region, which preserves low spatial frequencies and avoids aliasing but produces blurred images due to missing high-frequency components. In this work, we propose a fusion-based 3D super-resolution framework that leverages high-frequency information from fully sampled double-echo steady-state (DESS) images to recover the missing high-frequency components in truncated T1ρ data. By coupling physics-consistent modeling of k-space truncation with cross-modality information transfer, the method reconstructs high-resolution multi-TSL T1ρ images and improves downstream quantitative map fitting. Experiments on in vivo knee datasets demonstrate that the reconstructed T1ρ maps closely match fully sampled references, suggesting a principled and practical pathway toward accelerated 3D quantitative cartilage imaging. This is a joint work with my PhD student Jiasen Zhang (CWRU) and Cleveland Clinic collaborators Richard Lartey, Mingrui Yang and Xiaojuan Li.

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MS96

A Lifted ℓ_1 Framework for Sparse Recovery

Motivated by re-weighted ℓ_1 approaches for sparse recovery, we propose a lifted ℓ_1 (LL1) regularization that can be generalize to several popular regularizations in the literature. During the course of reformulating the existing methods into our framework, we discover two types of lifting functions that can guarantee that the proposed approach is equivalent to the ℓ_0 minimization. Computationally, we design an efficient algorithm via the alternating direction method of multiplier (ADMM) and establish the convergence for an unconstrained formulation. Experimental results are presented to demonstrate how this generalization improves sparse recovery over the state-of-the-art. This is a joint work with Yaghoub Rahimi and Sung Ha Kang from the Georgia Institute of Technology.

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MS96

Admm and Linearized Admm Beyond Convexity: Weakly Convex Regularization for Sparse Recovery

Sparsity-promoting models are central in high-dimensional learning, but the resulting optimization problem isoften nonconvex, which is computationally challenging. In this talk, we study a class of weakly convex composite objectives arising in sparse recovery, where a smooth (typically convex)data-fitting term is coupled with a weakly convex (possibly nonsmooth) regularizer. We develop splitting methods based on the alternating direction method of multipliers (ADMM) and a linearized variant (LADMM). ADMM and LADMM leverage the splitting structure to isolate the sparsity-inducing update, while LADMM further reduces the per-iteration cost by linearizing the smooth term to avoid expensive inner solves. We establish convergence to stationary solutions under mild conditions for both ADMM and LADMM. We then demonstrate the practical benefits on a case study of LOG-regularized logistic regression, where the proposed methods achieve competitive quality with improved computational efficiency relative to baseline methods.

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MS98

Stable End-to-End Training of Latent Diffusion Models

Standard Latent Diffusion Models (LDMs) and Latent Score-based Generative Models (LSGMs) typically train the score network using Denoising Score Matching (DSM) with stochastic noise targets (the Tweedie identity). This approach implicitly treats the latent representations of training data as Dirac deltas, ignoring the probabilistic uncertainty explicitly predicted by the Variational Autoencoder (VAE). We propose Component Score Expectation Matching (CSEM), a training methodology that replaces the stochastic DSM target with the CSEM Identity. The aggregate (mixture) score is the endpoint-conditioned conditional expectation of these component scores, so an MSE objective against the component wise targets distills the true aggregate score without introducing extra Monte Carlo noise. We show that this approach is a strict mathematical refinement of the LSGM objective, effectively removing the Monte Carlo noise variance from the training signal.

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MS98

Joint State-Parameter Estimation for the Shallow Water Equations Through Latent Twin Architectures

Recovering spatially varying coefficients, such as bathymetry, from sparse state observations is a challenging, ill-posed inverse problem in geophysical fluid dynamics. While Variational Data Assimilation (4D-Var) offers a rigorous solution, it relies on computationally expensive adjoint loops that are prohibitive for real-time applications. Conversely, standard deep learning surrogates provide speed but frequently fail to capture the causal structure of the governing Partial Differential Equations (PDEs). We present the Latent Twin framework to unify inversion and forecasting through joint state-parameter estimation, applied to the Shallow Water Equations (SWE). We construct a dynamic State Twin and a static Parameter Twin, coupled via two learned operators: a cross-domain mapping ($\mathcal{M}$) that performs single-shot inversion, and a parameter-conditioned transition operator ($\mathcal{T}$). This coupling enables a fully joint estimation strategy: the inferred bathymetry serves as the necessary physical coefficients to evolve the latent flow, while the requirement to accurately forecast wave propagation acts as a dynamic consistency constraint.We demonstrate that this architecture recovers bathymetry with fidelity competitive with 4D-Var baselines while enabling inversion orders of magnitude faster than iterative solvers. Simultaneously, the embedding of static parameters stabilizes long-term forecasts against non-physical drift, demonstrating robust generalization across diverse bathymetric topologies.

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MS98

An Overview of Reduced-Basis Derivative-Informed Operator Learning

Efficient solution of inverse problems and optimization under uncertainty for high-dimensional PDE systems requires surrogate models that are accurate not only in prediction, but also in the sensitivity information relevant to decision-making. Neural operator learning provides a scalable framework for surrogate modeling; however, standard formulations often neglect derivative accuracy, leading to degraded performance in downstream optimization tasks. This talk presents a reduced-basis, derivative-informed operator learning framework that combines low-dimensional linear reduced basis representations with learning objectives tailored to inverse problems and optimization. An approximation-theoretic analysis yields a priori error bounds for surrogate-based inverse and optimization problems, motivating the explicit penalization of errors in operator derivatives. The proposed methods are computationally efficient, straightforward to implement, and applicable to both steady-state and time-dependent PDEs. Numerical examples from structural health monitoring, shape optimization, and fluid flow under uncertainty demonstrate improved accuracy and robustness in surrogate-driven decision-making.

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MS98

Linear Attention Architectures for Geopotential Height Forecasting: A Comparative Study

Accurate forecasting of geopotential height is crucial for numerical weather prediction and climate modeling. While transformer-based models have shown promising results in weather forecasting, their quadratic computational complexity with sequence length limits their applicability to long-range temporal dependencies. In this work, we present a comprehensive comparison of linear attention architectures—including Gated Linear Attention (GLA), DeltaNet, Gated DeltaNet, Kimi Delta Attention (KDA), and Mamba2—for geopotential height forecasting using NCEP reanalysis data. We evaluate these architectures against standard transformers in terms of forecasting accuracy (RMSE, anomaly correlation coefficient), computational efficiency, and memory usage. Our experiments demonstrate that linear attention mechanisms achieve competitive forecasting performance while offering significant computational advantages for processing long temporal sequences.

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MS99

Robust Hybrid Infinite and Finite Dimensional Tensor Factorizations

The canonical polyadic (CP) tensor decomposition represents a multidimensional data array as a sum of rank-one outer products of latent factors. Building on CP-HiFi, the hybrid infinite- and finite-dimensional CP framework of Larsen et al. (2024), which introduces quasitensors by modeling selected modes as smooth functional factors in a reproducing kernel Hilbert space, we replace the standard least-squares objective with a quantile-based loss. This modification enables estimation of conditional quantile functions (rather than conditional means) along functional modes. The resulting approach yields a distribution-aware tensor factorization that is robust to outliers and captures heterogeneity beyond the mean structure.

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MS100

Toric Geometry of Relu Neural Networks

Understanding the mathematical foundation of machine learning theory has become essential in this ever changing world of AI. In particular, neural networks with Rectified Linear Unit (ReLU) activations underlie almost every other machine learning problem. In this talk, I will develop a dictionary between feedforward ReLU neural networks and toric geometry. The central insight underlying this work is that the function computed by a feedforward ReLU neural network with no biases can be interpreted as the support function of a Q-Cartier divisor on a rational polyhedral fan. This work also reveals a link between the tropical geometry and the toric geometry of ReLU neural networks: the toric geometry can be viewed as a lift of the tropical geometry, in which the underlying geometric structure (toric geometry) is recovered from the combinatorial data (tropical geometry). With the toric geometry framework, we prove a necessary and sufficient criterion of functions realizable by unbiased shallow ReLU neural networks by computing intersection numbers of the ReLU Cartier divisor and torus-invariant curves. With time permitting, I will discuss ongoing work involving the nef cone of the ReLU toric variety, which offers insight into how network depth influences expressivity.

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MS100

Mathematical Data as a Testbed for Analyzing Deep Learning

The last five years have seen a rapidly growing increase in deep learning methods and tools that are either inspired or informed by ideas in pure mathematics. This ranges from symmetry-aware equivariant architectures, to topological features for analysis and modeling, to geometric analysis of model latent spaces. While these methods have enormous potential, they have yet to be united into a centralized package that standardizes and validates performance and compatibility among methodological subgroups. In this talk we discuss progress in building a new package, TAGTorch, which aims to assemble many of the most popular mathematics-inspired methods in a single place where both AI researchers and domain scientists can easily develop new methods and systems that leverage the entire methodological ecosystem. After discussing TAGTorch's current functionality, we describe our vision for where we are going and pose the question of what features the community most needs.

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MS100

Discovering Symmetry Groups with Generative Models

Incorporating symmetry constraints into models is a powerful inductive bias which can improve data efficiency and reduce generalization error. However, this requires knowing the proper symmetry constraints a priori. We propose several methods for discovering group actions which preserve a given data distribution using generative models. We consider generative adversarial networks and flow matching models. Our key insight is that the problem of finding a group action which approximately preserves the data distribution can be cast as a problem of finding a distribution over large hypothesis group which concentrates over the stabilizer subgroup of the data. We apply our method to both discrete and continuous groups. We demonstrate that the discovered symmetry group can inform and improve downstream learning, simplify learning governing equations, and provide useful insight into physical systems.

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MS100

Manifold Representation and Riemannian Optimization

To perform optimization over a manifold, a natural first step is to understand how manifolds are represented as matrix, on which our numerical algorithms can run. We classical what manifolds with symmetry admit matrix representations and show how to construct the optimal representations. Using these manifold representations, we will discuss the relevance of this work to neural networks and transformers.

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MS101

Elimination Templates in Macaulay2

Solving systems of polynomial equations is generally a difficult problem. Elimination templates provide an efficient method for solving zero-dimensional polynomial systems and have been extensively developed for applications in computer vision. In this talk, I will describe this approach and demonstrate its implementation in the `EliminationTemplates` package for the computer algebra system `Macaulay2`, with an emphasis on practical applications.

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MS101

Synthetic Molecular Data Generation via SO(3)-Invariant PCA

We present a framework for synthetic molecular data generation based on SO(3)-invariant PCA, which exploits the algebraic structure of the rotation group to efficiently model 3D molecules. Traditional PCA applied to volumetric data with arbitrary orientations — ubiquitous in cryo-EM — requires prohibitive data augmentation over many rotations. By leveraging the representation theory of SO(3) and orthogonality relations of Wigner D-matrices, we develop a computationally efficient approach that implicitly accounts for all rotations through a block-diagonal covariance structure indexed by spherical harmonic degrees. This reduces computational complexity from $O(N^9)$ to $O(N^4)$ for volumes discretized on $N \times N \times N$ grids. The learned principal components span a low-dimensional subspace capturing molecular variability, enabling generation of realistic synthetic structures by sampling coefficients from learned distributions.

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MS101

Tensor based Approaches to Synchronization in Computer Vision

The synchronization problem involves estimating global states from relative measurements between states. While many studies have explored synchronization in different contexts using pairwise measurements, relying solely on pairwise measurements often fails to capture the full complexity of the system in real life scenarios. Extending synchronization to consider measurements between three or more states, however, increases computational complexity and requires sophisticated mathematical models. In this talk, we introduce a novel mathematical approach to solving the synchronization problem in computer vision using higher order measurements (trifocal/quadrifocal tensors), based on a low tensor rank characterization and a tensor decomposition algorithm. Experiments on benchmark datasets show that the methods increases the accuracy of camera locations over standard approaches, and has a natural advantage when cameras are collinear. Joint work with Gilad Lerman at UMN and Joe Kileel at UT Austin.

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MS101

Tensor Decompositions of Calibrated Trifocal Tensors

In recent work (arXiv: 2402.12542) we have investigated generalizations of the Higher Order Singular Value Decomposition (HOSVD) for tensors. Applying these decompositions to calibrated trifocal tensors we noticed interesting geometric structure, which may shed light on the question of finding all the defining equations of the algebraic variety of calibrated trifocal tensors. In addition, we anticipate this may lead to new methods for approximating calibrated trifocal tensors. This is work in progress with Ian Tan.

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MS102

Two Derivative Runge-Kutta Methods for Evolution of Time-Dependents Pdes

High order strong stability preserving (SSP) time discretizations ensure the nonlinear non-inner-product strong stability properties of spatial discretizations suited for the stable simulation of hyperbolic PDEs. Over the past decade multiderivative time-stepping have been used for the time- evolution hyperbolic PDEs, so that the strong stability properties of these methods have become increasingly relevant. In this work we review su?cient conditions for a two-derivative multistage method to preserve the strong stability properties of spatial discretizations in a forward Euler and di?erent conditions on the second derivative. In particular we present the SSP theory for explicit and implicit two-derivative RungeKutta schemes, and discuss a special condition on the second derivative under which these implicit methods may be unconditionally SSP. This condition is then used in the context of implicit-explicit (IMEX) multi-derivative RungeKutta schemes, where the time-step restriction is independent of the sti? term. Finally, we present the SSP theory for implicit- explicit (IMEX) multi-derivative general linear methods, and some novel second and third order methods where the time-step restriction is independent of the sti? term

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MS102

Order Conditions for Mixed Precision and Mixed Accuracy Time-Stepping Methods

RungeKutta and two-derivative Runge–Kutta methods can be designed so that certain costly intermediate computations can be performed as a lower-precision computation without adversely impacting the accuracy of the overall solution. In particular, a properly designed mixed accuracy method will damp out the errors committed in the initial stages. We provide a general theoretical additive framework for designing mixed precision RungeKutta methods and two-derivative Runge–Kutta methods, and use this framework to derive order conditions for such methods. Next, we show how using this approach allows us to leverage low precision computation of the implicit solver while retaining high precision in the overall method. We confirm that the methods behave as expected in numerical studies

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MS102

Reduced Basis Methods for Parametric Steady-State Radiative Transfer Equation

Radiative transfer equation (RTE) is a fundamental model to describe the physical phenomena of energy or particle transport through mediums that are affected by absorption, emission, and scattering processes. Deterministic simulations can provide an accurate description of the solutions; they however face many computational challenges, most prominently the need to compute the angular flux defined in the high dimensional phase space. This is more prominent in multi-query tasks when the RTE needs to be solved repeatedly. In this talk, we present the first systematic investigation of reduced basis methods (RBMs) for the parametric steady-state RTE. Four ROMs are designed, with each defining a nested family of reduced surrogate solvers of different resolution/fidelity. Two are certified when the absorption cross section is positively bounded below uniformly. One technical focus and contribution lie in the proposed implementation strategies under the affine assumption of the parameter dependence of the model. These broadly applicable strategies not only ensure the efficiency and accuracy of the offline training stage and the online prediction of reduced surrogate solvers, but also take into account the conditioning of the reduced systems as well as the stagnation-free residual evaluation for numerical robustness. Numerical experiments will demonstrate accuracy, robustness, and significant speedup of these reduced surrogate solvers.

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MS103

Enabling Real-Time Control via Deep Learning

We present a generalized framework utilizing machine learning to enable real-time optimal control for complex dynamical systems. A primary bottleneck in controlling high-dimensional physical models is the prohibitive computational cost of repetitive simulations and the practical unavailability of full-state observations. To address these challenges, we propose a data-driven approach based on Flow Map Learning (FML) that constructs a fast, differentiable surrogate model directly connecting control inputs and sparse Quantities of Interest (QoI) to their future evolution. By effectively embedding trajectory history, this method implicitly accounts for unobserved dynamics and latent parameters without requiring the underlying high-fidelity solver during the control loop. Consequently, the learned model serves as a lightweight environment that facilitates real-time feedback control strategies across a diverse range of complex systems.

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MS103

Data Driven Modeling and Correction of Vehicle Dynamics

We develop a data-driven framework for learning and correcting non-autonomous vehicle dynamics. Physics-based vehicle models are often simplified for tractability and therefore suffer from model-form uncertainty, motivating data-driven correction. In addition, non-autonomous dynamics depend on time-varying control inputs, which complicates learning from temporal snapshot data. To address these challenges, we reformulate the dynamics using a local parameterization of the time-dependent inputs, resulting in a sequence of local parametric dynamical systems. We approximate these systems using two complementary approaches. First, we apply DRIPS (dimension reduction and interpolation in parameter space) to construct efficient linear surrogate models using lifted observables and manifold-based operator interpolation, enabling highly data-efficient learning when the dynamics admit linear representations in lifted spaces. Second, for strongly nonlinear regimes, we employ Flow Map Learning (FML), a deep neural network approach that directly approximates the parametric evolution map. We further extend FML with a transfer-learning-based correction strategy that leverages sparse high-fidelity or experimental data to correct misspecified prior models without assuming a prescribed correction form. Numerical experiments on unicycle, simplified bicycle, and slip-based bicycle models demonstrate that DRIPS provides robust, data-efficient learning, while FML captures strong nonlinearities and effectively corrects model-form errors under severe data scarcity.

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MS103

Weak Formulation-Based Generic Formalism Neural Networks for Learning Dynamical Systems from Noisy Measurements

We propose Weak Formulation-based GENERIC Formalism Informed Neural Networks (WGFINNs), which effectively handle noisy measurement data for the data-driven approximation of dynamical systems. WGFINNs are built upon GFINNs to ensure the first and second laws of thermodynamics are exactly satisfied, while offering a robust learning framework against data noise. On the theoretical side, we prove that the noise level and the time-step size of the data are critical factors that significantly impact solution accuracy. In particular, our analysis suggests that the weak formulation-based approach produces solutions that are less sensitive to noise and time-step size than those derived from the strong formulation. Numerical experiments confirm these findings and demonstrate the effectiveness of WGFINNs in handling noisy data.

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MS103

Neighborhood Surrogate Learning on Dynamic Data

Digital twins of complex systems must involve a model that is fast, generalizable, and usable for real-time control. For example, high-fidelity nonlinear multiphysics simulations can capture lasermaterial interactions, but are too slow for optimization or model predictive control (MPC). Reduced-order models, used to accelerate such computation, frequently fail to generalize to unseen inputs or control states. We show theoretically that this failure is intrinsic. The learned model is non-unique outside the sampled subspace when a low-rank structure arises from limited excitation and clustered eigenvalues, rather than from a user-imposed truncation alone. Motivated by this result, we construct and validate a local surrogate for the digital twin of a temperature-controlled additive-manufacturing process. Our surrogate is localized in space through a von Neumann stencil and learned from noisy high-fidelity simulations that emulate experimental observations. It is linear in thermo-physically augmented states so that MPC reduces to a convex quadratic program. It requires no online correction, generalizes to unseen scan paths and power profiles of the laser, and is more than three orders of magnitude faster than a finite-elements solver. When the MPC sequence computed on the digital twin is applied to this solver, closed-loop temperature regulation is recovered, showing that the surrogate preserves control-relevant inputoutput behavior.

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MS104

Parametric Variation of Hypergeometric Systems

Viewing hypergeometric systems of PDEs, we describehow special bases of solutions vary with the parameter of the system. These bases include certain integral representations (including Euler–Mellin integrals) and the canonical series solutions of Saito–Sturmfels–Takayama. Our variation description is based on a stratification of the parameter space so that over each stratum, a basis of solutions varies holomorphically with the parameters.

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MS104

On Some Hypergeometric Modularity Conjectures of Dawsey and McCarthy

The modularity of hypergeometric Galois representations is a central topic in the study of hypergeometric motives. Recently, in joint work, we developed an explicit method to establish the modularity for many of these representations in dimensions two, three, and four. We now apply this method to construct two cubic families of eta-quotients that are used to resolve several conjectures of Dawsey and McCarthy.

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MS104

Hypergeometric Distributions and tale Cohomology

In the 1960s, motivated by the SatoTate conjecture, Birch proved that the traces of Frobenius of elliptic curves over large finite fields is modeled by the semicircular distribution. Inspired by Birchs result, in recent work, Ono, Saikia and Saad studied the distribution of finite field hypergeometric functions that relate to families of elliptic curves and K3 surfaces using modular forms and harmonic Maass forms. In this talk, we explore SatoTate type distributions for some finite field hypergeometric functions that relate to other families of curves and to joint families of elliptic curves in terms of the Meijer G-function. Moreover, we elucidate the appearance of Catalan numbers and Chebyshev polynomials in the earlier modular works.

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MS104

The Hypergeometric Motive

Hypergeometric motives (HGM) have recently become a useful tool in number theory, arithmetic geometry, and physics. The philosophy of HGM holds that an underlying hypergeometric object can manifest in many ways, including cohomology, point counts, and finite field hypergeometric functions. This talk will be an informal invitation to hypergeometric motives, and to how they arise or give insights in a few different arithmetic and geometric settings. This is joint work with Ursula Whitcher.

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MS106

From Experiment to Principle: Modeling Basal Cognition in Slime Mold

The slime mold *Physarum polycephalum* is renowned for the remarkable behaviors it exhibits in a wide variety of experiments. Decades of experimental work have established this organism as one of the principal models of basal cognition. In this talk, we review several of the most striking behaviors observed in *Physarum* and discuss how the experiments revealing these behaviors have shaped theories of the biophysical mechanisms underlying them. We then show how a recently developed, experimentally supported computational and mathematical framework demonstrates that many apparently disparate slime mold behaviors can be explained by a single, simple principle. This work integrates experiment and theory into a unified mathematical model, providing increasing support for a mechanistic foundation of basal cognition.

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MS106

Compressed Foams and Coagulation Equations with Particle Emission

A two-dimensional compressed foam exhibits a wealth of interesting mechanisms for coarsening behavior. For this talk, we focus on the evolution of cell statistics found from rupturing edges induced by heating. We describe the experimental design for rupturing edges through the construction of a "foam oven". Each rupture evolves a foam's topology and can be described with reactions similar to the Smoluchowski coagulation equations. Topological reactions for foams also exhibit emission of particles in the product. We study the general form of coagulation equations with particle emission, and demonstrate well-posedness for two classes of initial conditions. We also establish existence of gelation regimes and provide asymptotics of particles size distributions for short-time and post-gelation regimes.

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MS106

Experiments on Classical Quantum Analogs and Their Impact on Mathematical Modeling

In this talk, I will present two examples of experimental systems in which classical dynamics exhibit features reminiscent of quantum mechanics, and how these experiments have led to new insights in mathematical modeling. The first example concerns the hydrodynamic quantum analog discovered by Couder and Fort (2005), in which millimetric droplets self-propel along the surface of a vertically vibrated bath. This system captures striking features associated with quantum phenomena, including quantized trajectories and wave-particle interactions. These experiments led to models coupling particle motion to a persistent wave field, showing how memory in driven dissipative systems can generate quantization and statistical behavior from deterministic dynamics. The second example concerns classical Floquet systems (linear differential equations with periodic coefficients) which play a central role in the dynamical stabilization of unstable equilibria and wave propagation in periodic media. Experiments on parametrically driven mechanical oscillators reveal that, in specific parameter regimes, the bounded solutions of Floquet theory can be described by an effective Schrdinger-like equation. This correspondence provides new intuition into spectral structure and stability theory for linear differential equations.

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MS106

Linear and Nonlinear Waves in Microwave Transmission Lines

Metamaterials are linear wave media whose properties give rise to novel and tunable dispersion phenomena. They are also a mathematical playground to investigate inverse design problems and optimal control. In this talk, I'll describe applications of metamaterials to superconducting quantum hardware design, with emphasis on mathematical problems of theoretical and practical importance.

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MS107

IEnSF: Iterative Ensemble Score Filter for Reducing Error in Posterior Score Estimation in Nonlinear Data Assimilation

The Ensemble Score Filter (EnSF) has emerged as a promising approach to leverage score-based diffusion models for solving high-dimensional and nonlinear data assimilation problems. While initial applications of EnSF to the Lorenz-96 model and the quasi-geostrophic system showed potential, the current method employs a heuristic weighted sum to combine the prior and the likelihood score functions. This introduces a structural error into the estimation of the posterior score function in the nonlinear setting. This work addresses this challenge by developing an iterative ensemble score filter (IEnSF) that applies an iterative algorithm as an outer loop around the reverse-time stochastic differential equation solver. When the state dynamics or the observation operator is nonlinear, the iterative algorithm can gradually reduce the posterior score estimation error by improving the accuracy of approximating the conditional expectation of the likelihood score function. The number of iterations required depends on the distance between the prior and posterior distributions and the nonlinearity of the observation operator. Numerical experiments demonstrate that the IEnSF algorithm substantially reduces the error in posterior score estimation in the nonlinear setting and thus improves the accuracy of tracking high-dimensional dynamical systems.

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MS107

Memory-Embedded Neural Dynamical Systems with Closed-Form Inference (MENDS)

We develop Memory-Embedded Neural Dynamical Systems (MENDS), a nonlinear neural framework for modeling and data assimilation in high-dimensional dynamical systems. MENDS integrates reservoir computingbased nonlinear memory embeddings into a structured nonlinear dynamical formulation that admits closed-form data assimilation. The reservoir layer captures strongly nonlinear interactions and long-range temporal dependencies, while the resulting embedded dynamics preserve an analytic probabilistic structure that facilitates exact data assimilation solutions. MENDS unifies nonlinear forecasting and closed-form state estimation within a single learnable system. Unlike black-box neural models that rely on sampling or approximate inference, MENDS performs uncertainty propagation and data assimilation through analytic update equations, ensuring computational efficiency and scalability in high-dimensional and partially observed settings.

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MS107

Predictive Digital Twins for 6-DoF Reentry Capsules: Coupling Learned Dynamics with Data Assimilation

Atmospheric reentry vehicles operate in highly nonlinear flight regimes where aerodynamic forces and moments vary significantly with flow conditions, making reliable prediction and stability characterization challenging under limited observational data. This work presents a predictive digital-twin framework for six-degree-of-freedom (6-DoF) reentry capsules that couples learned dynamical models with data assimilation for uncertainty-aware prediction. The vehicle dynamics are represented using Neural Ordinary Differential Equations (Neural ODEs), which provide a continuous-time representation of the coupled translational and rotational motion while enabling efficient modeling of nonlinear aerodynamic effects. The learned dynamics are embedded within a sequential data assimilation framework to continuously synchronize model predictions with sparse measurements, allowing simultaneous estimation of vehicle states and aerodynamic stability characteristics, including dynamic stability coefficients. The methodology is demonstrated on representative blunt-body reentry configurations under uncertain initial conditions and perturbed trajectories. The proposed framework establishes a pathway toward predictive, uncertainty-aware digital twins for atmospheric entry systems, supporting real-time monitoring and decision-making for future aerospace missions.

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MS108

A Priori and a Posteriori Error Analysis of Proximal Galerkin Methods for Variational Problems with Inequality Constraints

The proximal Galerkin (PG) method is a finite element method for solving variational problems with inequality constraints. It has several advantages, including constraint-preserving approximations and mesh independence. This presentation presents a priori and a posteriori error analysis of the PG method in a general framework. As examples, we focus on the obstacle and Signorini problems using various finite element subspaces. We demonstrate optimal convergence rates for these examples, and we present PG with adaptive mesh refinement where we account for both discretization and optimization error indicators.

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MS108

Advances in HDG Methods for Strongly

Anisotropic Diffusion

The problem of strong anisotropy appears in numerous fields of physics and applications, like fluid dynamics, thermodynamics, electrodynamics and others. It manifests itself on the algebraic level by poor properties of the system operator, which results in low convergence rate and numerical stability. The traditional approach of aligning the computational mesh with the dominant direction of anisotropy is not practical or even feasible for complex designs occurring in practice. Moreover, direct solvers are employed, which exhibit poor scaling on computational clusters typically. For these reasons, we have developed a numerical framework for hybridization of mixed systems in the MFEM library. We present a method based on Hybridizable Discontinuous Galerkin (HDG) approach, which offers stable convergence of high order and allows easy and scalable preconditioning. The construction of the hybridized method then provides a natural error estimation for anisotropic h-refinement, resolving the distinct scales of the problem. Construction of the method, its parallelized implementation and further research in adaptation techniques for anisotropic problems are presented together with examples and benchmarks. Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 (LLNL-ABS-2015954).

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MS108

Entropy Stable Reduced Order Modeling of Nonlinear Conservation Laws Using Entropy Correction Artificial Viscosity

Reduced order models (ROMs) are inexpensive surrogate models that reduce costs associated with many-query scenarios, but face challenges of robustness and stability when applied to nonlinear conservation laws. These can be addressed by constructing ROMs which are "entropy stable"; however, existing constructions rely on relatively invasive and expensive flux differencing formulations. In this work, we propose an alternative method of constructing an entropy stable ROM based on "entropy correction artificial viscosity" (ECAV), which adds a minimally dissipative correction to an arbitrary ROM to enforce a semi-discrete entropy inequality. We also propose a conservative hyperreduction technique for finite volume FOMs, which, when combined with ECAV, results in a conservative and entropy stable ROM.

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MS108

Finite Element Exterior Calculus in Moderate Dimensions

Exterior Calculus is a powerful tool for constructing derivatives, pull-back operators, traces, and Sobolev spaces in any number of dimensions. The language of Exterior Calculus is the language of differential forms and exterior derivatives (which operate on these differential forms). However, differential forms cannot be easily or naturally programmed on a computer. As a result, one usually constructs proxies for the differential forms, in terms of scalars, vectors, matrices, and tensors. Furthermore, one reinterprets the exterior derivative operators in terms of standard vector-calculus operators, i.e. versions of gradient, curl, and divergence operators. This reinterpretation of Exterior Calculus in terms of linear-algebra proxies and vector-calculus operators has been successfully employed to construct conforming finite elements. This process is referred to by the name "Finite Element Exterior Calculus" or FEEC. In previous work, the authors applied FEEC to the four-dimensional setting, and constructed explicit formulations for derivatives, pull-back operators, traces, and finite element spaces for space-time applications. In the present work, we extend our explicit framework to encompass higher-dimensional spaces in dimensions 5, 6, and 7. The purpose of this extension is to facilitate the construction of conforming finite element spaces for higher-dimensional problems, including radiation transport problems which arise in six- and seven-dimensional space.

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MS109

A Model of Cell Migration Represented Using Actin Filaments

When cells migrate across a flat surface, they develop a thin protrusive structure called a lamellipodium (sheet-like foot). Actin (protein) filaments form inside the structure and push at the front of the cell to propel the cell forward. While many complexities are associated with this process, we study this process with a simplified version of the Filament-Based Lamellipodium Model (FBLM). Our filaments are represented by multiple directed line segments that are short, approximately parallel, and approximately perpendicular to the front of the cell/lamellipodium. Included forces are frictional or viscous and forces that keep the filaments approximately equally spaced from the front of the cell, the side of the lamellipodium, and each other. Strain energies and dissipation rates are used to derive those governing force. We consider quasi-steady states of the systems, which look like translating cell fronts in migrating cells, and their stability. Particularly, we see how that stability changes depending on just two dimensionless parameters. The study suggests possible mechanisms that cells could use to vary migratory behavior.

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MS109

Structural Causes of Pattern Formation and Loss Through Model-Independent Bifurcation Theory

We introduce a model-independent ordinary differential equation framework for pattern formation in homogeneous arrays of cells. Previous results show that the cellular communication network alone determines possible patterns that can arise through a synchrony-breaking bifurcation. We build on these results by demonstrating that additional constraints on the dynamics within each cell lead to a single stable pattern. Our framework enables the prediction of cell-fate patterns with minimal modeling assumptions and provides a powerful tool for inferring unknown chemical interactions by analyzing tissue-level patterns.

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MS109

A Mathematical Model of Active Cortical Stress Generation and Its Effect on Cell Swimming

When moving through a confined, fibrous extracellular environment, many cells use an amoeboid mode of cellular motility. Amoeboid motility is characterized by weak adhesions to the extracellular environment, a rounded morphology, and flow of the actin cortex, which is a thin layer of crosslinked actin underlying the plasma membrane of the cell. A related, yet simpler, mode of cell motility is cellular swimming. In eukaryotic cell swimming, active deformation of the cortex can generate membrane tension gradients that have been shown to result in cell swimming in a fluid (Wu et al., 2018), but the biomechanical process by which this occurs is not well understood. To better understand how local variability in cortical actomyosin activity, membrane tension gradients, the strength of the cortex-membrane attachment proteins, and the mechanical properties of cellular components and the microenvironment all affect cellular swimming speed, we present a hybrid model of an actively deforming cell that interacts mechanically with the surrounding fluid. The model treats the cytosol and extracellular fluid as continua and the membrane and cortex as a discrete system of connected segments and nodes. Using the finite element method to solve model equations, we generate simulations of cell swimming and analyze how variations in system properties affect cellular swimming behavior.

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MS109

A Mathematical Framework for Biomechanics in a 3D Cell Migrating on a Flat Substrate

Cell migration is essential in wound healing, immune response, and cancer metastasis. This work presents a 3D computational model of migrating cells that incorporates viscoelastic mechanics, protrusion, focal adhesion dynamics, and intracellular interactions. Simulations reproduce realistic migration behavior and force patterns, while sensitivity analyses identify key mechanical drivers. The framework is extended to include nuclear mechanics under confinement, providing insight into deformation and force generation during confined migration.

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MS110

Learning-Assisted Combinatorial Optimization: A Hybrid GCN Framework for the Set Covering Problem

The Set Covering Problem (SCP) is a fundamental NP-hard combinatorial optimization problem with wide applications in scheduling, facility location, and resource allocation. Despite significant advances in mixed-integer programming solvers, large-scale instances remain challenging to solve. We propose a hybrid approach that integrates Graph Convolutional Networks (GCNs) with exact optimization by exploiting bipartite graph structure induced by coverage matrix. The GCN predicts high-quality feasible solutions that are used as warm starts for an exact solver. This significantly reduce computational time while preserving solution quality. Computational experiments on benchmark and synthetic instances demonstrate substantial speed-ups, especially for sparse problems, showing the scalability and effectiveness of the proposed framework.

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MS110

A Heuristic Framework for Connected Covering Problems via Node Weighted Steiner Trees

Systematic conservation planning aims to select a minimum set of sites that meets biodiversity targets while promoting spatial properties such as compactness and connectivity. Classical set-covering models often yield fragmented reserves, reducing ecological effectiveness and increasing management costs. We propose a two-phase framework that models the landscape as a grid graph with species and cost attributes. The approach first solves a set-covering problem and then enforces connectivity via graph reductions and a node-weighted Steiner tree formulation. A fast grid-based heuristic provides warm-start solutions, which are refined using an exact mixed-integer optimization model on a reduced subgraph. Computational results show that the method efficiently generates connected reserves with near-minimal site counts and improved compactness.

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MS110

First-Order Methods for Semi- Infinite Saddle Point Optimization

Semi-infinite optimization problems arise in many applications where decision variables must satisfy infinitely many constraints indexed by a continuous parameter. In this study, we consider the variational inequality problems with semi-infinite constraints, where the feasible region is defined by functional constraints associated with continuous index sets. Such problems naturally appear in several optimization and equilibrium models and require algorithmic frameworks that can efficiently handle the semi-infinite structure. We consider a class of variational inequality problems with semiinfinite constraints and develop a first-order framework that avoids direct projection onto the semi-infinite feasible region and does not require evaluating infeasibility via complicated subproblem solvers. Instead, feasibility is enforced through the introduction of Lagrange multipliers and auxiliary index variables associated with the constraint functions. This reformulation enables a tractable operator-based representation of the problem. Based on this formulation, we propose a constraint extrapolation method that relies only on first-order information and simple proximal updates. We establish convergence guarantees and derive convergence rate bounds for the optimality gap and infeasibility under monotonicity and convexityconcavity assumptions, with improved guarantees in stronger monotonicity and concavity regimes. Finally, we validate the theoretical findings through numerical experiments, demonstrating the effectiveness and competitiveness of the proposed approach.

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MS110

Effects of Scalarization on Multiobjective Set Covering Problem

This study investigates the Multi-Objective Set Covering Problem (MOSCP), an NP-hard problem in multi-objective combinatorial optimization. While norm-based scalarizations are widely used to approximate multi-objective problems, their application to the MOSCP remains limited. We analyze the performance of weighted-sum and weighted max-ordering scalarizations using a common set of weight vectors generated by four distinct methods. In addition, we study approximation quality through existing and newly proposed cost-effectiveness vectors, deriving new theoretical properties. Computational results indicate that weighted max-ordering scalarization provides a robust initial solution pool for two-phase algorithms.

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MS111

Uncertainty Quantification for Surrogate Models Based on Sparse RBF Networks

Sparse feature models based on adaptive kernel functions, such as radial basis function (RBF) networks, are an effective method to construct surrogates of physical and computational experiments in high dimensions that combine expressivity, interpretability, and model compression. However, in the small or noisy data regime, efficient methods for quantifying the uncertainty of trained model predictions are needed to certify results and guide further data acquisition (active learning). Based on the intrinsic connections to random feature models, Gaussian processes, and reproducing kernel Banach spaces, we develop a framework and implementation strategies to quantify this uncertainty. The framework naturally extends commonly used Gaussian processes workflows and provides similarly efficient uncertainty estimation. We demonstrate the improved ability of the new method to detect higher levels of uncertainty in regions of the input space with sharp transitions in the model outputs. Furthermore, we illustrate how this leads to more economical data acquisition in the context of active learning.

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MS111

Sparse RBF Networks for PDEs and Nonlocal Equations

We present a unified theoretical and computational framework for solving nonlinear partial differential equations (PDEs) and nonlocal equations using sparse radial basis function (RBF) networks. The method combines ideas from classical RBF collocation and shallow neural networks, using sparsity-promoting regularization to adaptively select features and avoid over-parameterization. This yields a sparse, adaptive solver that retains the flexibility of learning-based approaches while remaining grounded in function-space analysis. On the theoretical side, the method is formulated in reproducing kernel Banach spaces (RKBS) associated with one-hidden-layer kernel networks of possibly infinite width. We prove a representer theorem showing that the sparse optimization problem admits a finite solution and establish error bounds. We also show that, for a broad class of RBFs, the associated solution space admits a unified Besov-space characterization under mild assumptions, independent of the kernel choice. On the computational side, we develop a three-phase training method that combines adaptive feature selection, second-order optimization, and pruning of inactive neurons. Numerical experiments demonstrate accurate sparse representations across a range of nonlinear, high-order, and nonlocal equations. This work opens new directions for adaptive PDE solvers grounded in rigorous analysis with efficient, learning-inspired implementation.

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MS111

Divide-and-Conquer Method on Data-Adaptive Rkhs for Learning Convolution Kernels

Learning convolution kernels from data leads to an ill-posed inverse problem governed by a compact operator, whose spectral decay makes direct inversion unstable. Kernel methods provide a natural nonparametric framework for regularization, but their performance depends critically on the choice of reproducing kernels. The convolution operator and input data jointly induce a data-adaptive reproducing kernel Hilbert space (DA-RKHS), eliminating manual kernel selection and yielding finite-dimensional representations for Tikhonov regularization. To address large-scale settings, we adapt the divide-and-conquer Tikhonov method to the DA-RKHS framework, substantially reducing computational and storage costs. We establish minimax-optimal convergence rates under polynomial and exponential spectral decay conditions, allowing the true convolution kernels to lie in spectral Sobolev spaces. Such spaces are extensions of DA-RKHS and capture the smoothness of the convolution kernels that affects the minimax rates. These results provide a theoretical foundation for the divide-and-conquer Tikhonov regularization based on DA-RKHS, which is computationally friendly for learning kernel problems.

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MS112

Developing Higher-Order Averaging Theory for General Nonsmooth Dynamical Systems Using Generalized Derivatives: A Computationally Relevant Approach

In this work, we present a higher-order averaging theory for nonsmooth systems. Averaging theory is an important tool in analyzing time-varying dynamical systems and advancing control methods. For example, averaging is the main engine behind vibrational stabilization and extremum seeking control. The main idea of averaging a time-varying system is to obtain an averaged time-independent system, which is easier to analyze than the original system. First-order averaging provides incomplete information about the original system; hence it is desired to have higher-order averaging for more accurate analysis. Higher-order averaging can be achieved using the near-identity transformation method, which in turn requires derivative information of the original system, which is not possible using classical differentiation for nonsmooth dynamical systems. In this work, we overcome this challenge by utilizing the lexicographic differentiation toolkit, a computationally relevant nonsmooth analysis tool, in order to derive the higher-order averaged system of a nonsmooth time-varying system. In particular, we use lexicographic differentiation to: (i) establish the near-identity transformation for general nonsmooth dynamical systems, (ii) prove the bounds between the original system and the averaged systems (both complete averaged and truncated averaged systems), and (iii) provide a stability analysis theorem for the averaged system.

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MS112

Smooth and Nonsmooth Model-Free Optimization and Control-Affine Extremum Seeking

Extremum seeking (ES) methods are considered among the most powerful model-free optimization and control techniques. In recent years, developments of smooth control-affine ES methods have started to mature all the way from gradient-based ES to Newton-based ES to exponentially convergent ES for higher-order objective functions. We also present our recent developments in expanding gradient-based ES methods to nonsmooth setting, which enable needed stability guarantees of ES methods when handling nonsmooth objective functions. We present numerical simulations to demonstrate the effectiveness of the developed approach.

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MS112

Sensitivity-Based Methods for Parametric Identifiability, Observability, and Model Reduction of Nonsmooth Systems

Nonsmooth systems, which are continuous but nondifferentiable and experience switches between modes, arise in a variety of applications in science and engineering. However, the presence of nonsmoothness invalidates standard theory from smooth dynamical systems, including analyzing the identifiability of a system using derivative-based information (i.e., if the system parameters can be uniquely determined from system outputs). In this work, we present a sensitivity-based method to determine the identifiability and observability properties of a nonsmooth system using lexicographic directional derivatives, which are a type of generalized derivative that possess a strong theoretical and numerical toolkit. In order to do this, we develop a first-order Taylor-like approximation theory for nonsmooth functions. The resulting theory, called the lexicographic sensitivity rank condition (L-SERC), is applicable to both ODEs and differential-algebraic equations (DAEs) and can be used for model reduction, which is useful in system design, control, and optimization. Moreover, the new theory recovers the classical sensitivity rank condition (SERC) test for ODEs when participating functions are smooth, and establishes the SERC test for smooth DAEs. The new theory and methods are illustrated through examples and practical applications.

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MS113

Complexity of Tensor Ranks Through An Effective Nullstellensatz

The purpose of this note is to give a linear algebra algorithm to decide whether the rank of a given d-tensor T over a field F is at most a prescribed integer k when the rank is taken over the algebraic closure $\widehat{F}$ of F. The method reformulates the existence of a rank-k decomposition of T as the solvability of an explicit system of polynomial equations, and then uses an effective Hilbert Nullstellensatz to translate the unsolvability of this polynomial system over $\widehat{F}$ into the solvability of a certain (generally very large) system of linear equations over F. We provide arithmetic and bit-complexity estimates for the resulting Gaussian-elimination procedure, and we also explain how the same approach applies to symmetric tensors and their symmetric rank. Finally, we briefly compare the complexity of our method with known probabilistic algorithms for solving polynomial systems over finite fields. This is a joint work with Shmuel Friedland.

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MS113

DAG Learning for Graphical Discrete Lyapunov Models under Non-Gaussianity

A vector autoregressive process driven by a Schur-stable matrix admits a unique stationary distribution. For a graph G, let $\mathbb{R}^{G}_{\mathrm{Stab}}$ denote the set of Schur-stable matrices whose sparsity pattern is determined by the missing edges of G. The graphical discrete Lyapunov model of order n for G is the set of cumulant tensors of orders at most n arising from stationary distributions of processes driven by matrices in $\mathbb{R}^{G}_{\mathrm{Stab}}$. These models were recently introduced by Recke and collaborators. Higher-order discrete Lyapunov equations express the cumulant tensors of the stationary distributions as certain infinite sums of Tucker decompositions. Under non-Gaussianity, these higher-order equations provide nontrivial information beyond the covariance structure. In this talk, I will explore how this additional information can be exploited to learn G from single-time-point observations at stationarity, a setting that arises in applications such as biology. In particular, I will present work in progress toward an algorithm for learning directed acyclic graphs (DAGs) with self-loops at every vertex from single-time-point stationary observations.

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MS113

Robust Eigenvectors of Symmetric Tensors

The tensor power method generalizes the matrix power method to higher order arrays, or tensors. Like in the matrix case, the fixed points of the tensor power method are the eigenvectors of the tensor. While every real symmetric matrix has an eigendecomposition, the vectors generating a symmetric decomposition of a real symmetric tensor are not always eigenvectors of the tensor. In this paper we show that whenever an eigenvector is a generator of the symmetric decomposition of a symmetric tensor, then (if the order of the tensor is sufficiently high) this eigenvector is robust, i.e., it is an attracting fixed point of the tensor power method. We exhibit new classes of symmetric tensors whose symmetric decomposition consists of eigenvectors. Generalizing orthogonally decomposable tensors, we consider equiangular tight frame decomposable and equiangular set decomposable tensors. Our main result implies that such tensors can be decomposed using the tensor power method. Authors: Tommi Muller, Elina Robeva, Konstantin Usevich

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MS113

Random Sketching of Tensor Varieties and Online CP Decomposition

Tensor computation has been more and more popular in many fields such as data science and scientific computing, yet the high dimension and nonlinear nature often make the computation extremely challenging. In this talk, I will start with recently developed dimensionality reduction techniques that compress the set of low rank tensors (and beyond). Then, I will go into a new online CP decomposition algorithm as an application of such compression techniques. I will finish the talk with numerical examples to demonstrate the improved accuracy and robustness of the new algorithm.

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MS114

An Implicit Rank-Adaptive Method for Solving High-Dimensional Time-Dependent Problems Using the Ht Decomposition

Tree tensor networks, such as the hierarchical Tucker (HT) decomposition, have become popular frameworks for compressing the numerical solution to high-dimensional partial differential equations. In particular, many recent methods focus on exploiting low-rank structure in PDE solutions to reduce the storage and computational complexities. However, achieving high-order accuracy in time using implicit discretizations in the low-rank framework remains a challenge. We propose a rank-adaptive scheme inspired by the popular dynamical low-rank (DLR) and basis-update and Galerkin (BUG) methods that incorporate high-order implicit time discretizations under the HT framework to numerically solve high-dimensional time-dependent PDEs.

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MS114

Non-negative Tensor BM-decomposition and Applications

In this talk, we introduce the non-negative tensor BM-decomposition (NNBMD). We generalize the multiplicative update algorithm from the matrix setting to the third-order tensor setting within the BM-decomposition framework. We further demonstrate the effectiveness of the proposed NNBMD method through applications in image compression and data analysis.

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MS114

Generalized Method of Moments for Gaussian Mixture Modeling

Method of moments (MM) and generalized method of moments (GMM) are theoretically attractive for parametric inference, especially when likelihood is unavailable, misspecified, or computationally inconvenient. However, MM and GMM require computing large moment tensors, and the full GMM weighting matrix requires inverting a large, often ill-conditioned covariance matrix. The moment equations also involve sample averages, which are sensitive to outliers. I will present a scalable, robust GMM framework for heteroscedastic low-rank Gaussian mixtures with additive Gaussian noise and strong contamination. For computational bottlenecks, we introduce diagonally-weighted GMM (DGMM) that replaces the full GMM weighting matrix by its optimal order-wise diagonal approximation to downweight noisy moment orders and retain desired statistical properties while avoiding covariance inversion. The moment-matching objective, gradients, and weights are computed efficiently via moment-cumulant-Bell identities and randomized kernel approximation without forming large moment tensors. For outlier sensitivity, we introduce spectral-gradient-reweighted GMM (SGR-GMM) that iteratively soft-reweights per-observation moment-matching gradients via an entropy-regularized spectral game over capped weights and density matrices, with convergence and local finite-sample error guarantees. Based on https://arxiv.org/abs/2507.20459 and https://arxiv.org/abs/2605.27718.

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MS115

On Connectivity of Interpolating Parameters in ReLU Network Architectures

We report on work in progress investigating connectivity of the global empirical loss 0 set for feedforward ReLU network architectures. Given a data set of size N, we establish a lower bound in terms of N on the width needed to guarantee that the set of interpolating parameters is connected (when non-empty). We also give explicit examples of disconnected sets of interpolating parameters, where disconnectedness persists even when known parameter space symmetries are taken into account. This is joint work with Kathryn Lindsey (Boston College) and Chenxi Wu (U Wisconsin, Madison).

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MS115

A Basin-Selection Perspective on Grokking via Singular Learning Theory

Grokking refers to the phenomenon in which an artificial neural network undergoes an abrupt transition from memorization to generalization after prolonged training, despite reaching near-zero training error. This behavior suggests the presence of competing solution basins in the loss landscape with distinct geometric and statistical properties. We study grokking through the lens of Singular Learning Theory (SLT). In a Bayesian learning framework, SLT characterizes the local geometry of the loss surface via the local learning coefficient (LLC), which quantifies the effective degeneracy of a solution basin. Basins with smaller LLC concentrate more posterior mass and yield better generalization performance. Using this perspective, we interpret grokking as a phase transition between competing near-zero-loss basins with different LLC values, and analyze quadratic networks trained on modular arithmetic tasks and derive closed-form expressions for the LLC of the relevant solution families. These calculations predict which basins dominate in the Bayesian posterior. Empirically, we verify these predictions and demonstrate that trajectories of the LLC during training provide a quantitative tool for tracking generalization dynamics.

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MS115

Balancedness in Deep Linear and ReLU Neural Networks

Deep linear networks provide a mathematically tractable setting in which to study mechanisms that may extend to more complex nonlinear networks. One such phenomenon is balancedness, the tendency of weight matrices across layers to align their singular subspaces and equalize their singular values during training. I will show that balancedness in deep linear networks arises naturally from regularization: for a broad class of regularizers, every critical point of the regularized loss satisfies an exact algebraic balancing condition. Analogous statements hold for ReLU networks with respect to the rescaling symmetry orbits.The analysis reveals conserved quantities along the gradient flow and leads to a decomposition of the training dynamics into a learning flow, which minimizes the unregularized loss, and a regularizing flow, which enforces balancedness.

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MS115

Tropical Attention: Neural Algorithmic Reasoning for Combinatorial Algorithms

Can algebraic geometry enhance the sharpness, robustness, and interpretability of modern neural reasoning models by equipping them with a mathematically grounded inductive bias? To answer this, we introduce Tropical Attention, an attention mechanism grounded in tropical geometry that lifts the attention kernel into tropical projective space, where reasoning is piecewise-linear and 1-Lipschitz, thus preserving the polyhedral decision structure inherent to combinatorial reasoning. We prove that Multi-Head Tropical Attention (MHTA) stacks universally approximate tropical circuits and realize tropical transitive closure through composition, achieving polynomial resource bounds without invoking recurrent mechanisms. These guarantees explain why the induced polyhedral decision boundaries remain sharp and scale-invariant, rather than smoothed by Softmax. Empirically, we show that Tropical Attention delivers stronger out-of-distribution generalization in both length and value, with high robustness against perturbative noise, and substantially faster inference with fewer parameters compared to Softmax-based and recurrent attention baselines. For the first time, we extend neural algorithmic reasoning beyond PTIME problems to NP-hard and NP-complete problems, paving the way toward sharper and more expressive Large Reasoning Models (LRMs) capable of tackling complex combinatorial challenges in phylogenetics, cryptography, particle physics, and mathematical discovery.

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MS116

The Euclidean Distance Degree of One-parameter Anchored Multiview Varieties

The Euclidean distance degree of a multiview variety measures the algebraic complexity of determining the 3D features that minimize the reprojection error when computing the scene structure by triangulation. In this talk, we present a formula for the Euclidean distance degree of curves parameterized by rational functions with mild genericity assumptions and use it to resolve conjectures on one-dimensional line multiview varieties proposed by Duff and Rydell. Anchored multiview varieties provide a generalization of traditional multiview varieties that suggests applications to machine learning and Grassmannian optimization in other areas. We believe the techniques here will find use in problems such as training multi-headed polynomial neural networks, understanding scattering amplitudes, and optimizing on Grassmannians in general. Time permitting, I will discuss such an example.

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MS116

Algebra and Geometry of Rolling Shutter Cameras

Rolling shutter cameras scan the image row by row. If they are moving during the image capture, they deviate from the classical pinhole camera model, making the resulting image dependent on the camera motion. In this talk, I present an algebraicgeometric perspective on rolling shutter imaging, analyzing the projection of points and lines and exploring how structure and motion can be inferred from one or more rolling-shutter images. First, I introduce a formulation of relative pose estimation based on intersections of line projections with a single scanline per image. This viewpoint enables pose recovery without explicitly parameterizing camera motion. This approach is designed as a foundational building block for rolling shutter structure-from-motion (SfM), where no motion model is required, and the pose of each scanline can be computed independently. I present a classification for the minimal configurations for this problem, both in the generic and special scene configurations. Second, I address the problem of motion estimation from asynchronous feature tracks, as encountered in rolling shutter and event cameras. We introduce a polynomial approximation of the underlying non-polynomial model to obtain minimal problem, and determine their algebraic degrees. Finally, I present minimal solvers for minimal problems with low degrees, and discuss their performance on synthetic and real datasets.

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MS116

Fundamental Constraints on Camera Centers Arising from 3D-2D Matches of Points and Lines

We investigate combinations of 3D-2D matches of points and lines for a single calibrated camera that imply a nontrivial constraint on the camera's position. Specifically, we address the minimal cases for which n point matches and m line matches constrain the camera center to lie on an algebraic surface in $\mathbb{R}^3$. For two points $(m,n) = (0,2)$, the constraint is well-known to be a self-intersecting torus. We complete the classification problem by deriving explicit, general equations for the cases $(m,n) \in \{(2,0),(1,1)\}$ for two lines and one point, one line, respectively. We also report preliminary experiments investigating the suitability of these constraints for pose estimation tasks.

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MS116

Uncalibrated Spherical Structure from Motion

In this talk we will discuss our work on uncalibrated structure-from-motion under the spherical motion assumption, in which cameras move on a sphere with optical axes aligned to the surface normal. Although spherical motion arises naturally in a variety of settings, it is a failure case for many traditional and learning-based structure-from-motion methods. We prove the equivalence of essential and fundamental matrices under spherical motion, assuming a single unknown focal length. We then elucidate the relationship between focal length and rotation in uncalibrated two-view reconstruction. Although two-view spherical motion is a critical case, we prove that self-calibration is always possible from three or more views. Based on these insights, we devise new minimal solvers for relative pose and a global structure-from-motion approach for uncalibrated reconstruction from spherical motion.

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MS117

Stabilized Corrections for Mixed Accuracy Runge-Kutta Method

Explicit corrections have been used to improve the accuracy of mixed precision and mixed accuracy simulations. However, they suffer from poor stability regions. In this talk we discuss how to use additional stabilization terms to improve the stability of the explicit corrections. These approaches can be done implicitly, or use an implicit inspiration to created explicit corrections with the stability of implicit methods.

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MS117

A Conservative, Structure-Preserving Sweeping Framework for High-Order Discretizations of Hyperbolic Systems.

In solving hyperbolic conservation law systems, high-order numerical methods often lack inherent mechanisms to preserve positivity, resulting in computation failure near strong shocks or in near-vacuum states. In this talk, we present a novel, conservative, and high-order structure-preserving sweeping procedure. Formulated as a global mass-redistribution technique, this approach generalizes the scaling limiter of Zhang and Shu within a sweeping framework. A distinct advantage of this method is its modularity. It functions as a standalone post-processing stage within time-stepping, applicable to finite difference, finite volume, and discontinuous Galerkin methods without requiring modifications to the underlying spatial discretization. We demonstrate the robustness of this framework using fifth-order finite difference WENO simulations of extreme flow conditions in the Euler equations, including high-Mach astrophysical jets and strong blast waves, where standard methods typically fail. Finally, we discuss extensions of this framework to other hyperbolic systems, including magnetohydrodynamics (MHD), as well as its applicability to implicit time integration and continuous Galerkin schemes.

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MS117

A Broyden Approach for Correcting Mixed Accuracy Runge-Kutta Methods

Explicit corrections for mixed accuracy Runge–Kutta schemes are not stable, but implicit corrections are costly. In this talk we present an alternative: a modified implicit correction using a Broyden's approach to significantly reduce the cost of the implicit computation while retaining the accuracy.

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MS117

Siac Filtering: Recasting Mesh Nonuniformities As Smooth Transformations

Smoothness Increasing Accuracy Conserving (SIAC) filters have been extensively analyzed in the setting of discontinuous Galerkin methods for hyperbolic conservation laws. In this context, their application can improve the order of accuracy on translation-invariant meshes from $p+1$ to $2p + 1$ for polynomials of degree p. This even holds for nonlinear hyperbolic problems, in regions where the solution remains smooth. The performance of the post-processing and its ability to recover superconvergence is strongly dependent on the mesh uniformity. While existing strategies for SIAC filtering on nonuniform meshes can lead to superconvergence of order $2p+1$ on smoothly varying meshes, the rate of superconvergence is a priori unknown and might drop to $p+1$, on randomly perturbed, structured meshes. We propose a novel strategy to apply SIAC filtering on nonuniform meshes. The approach is based on the idea of transforming the to a translation invariant one, where a SIAC filter is applied. The transformation is is required to be a smooth diffeomorphism to ensure the rate improvement. We provide a theoretical justification for the approach and provide a method to construct the transformation. We provide numerical examples to demonstrate the performance of the approach, suggesting that by using an appropriate transformation, superconvergence of order $2p + 1$ can be recovered.

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MS118

Non-linear Sensitivity Analysis for Interpretable Structure Discovery

Digital twins for complex dynamical systems must support prediction, stress/safety testing, and decision-making under uncertainty, yet maximum-fidelity models with thousands of variables quickly become difficult to build, calibrate, and maintain. A pragmatic alternative is to identify a manageable set of the most relevant variables and build stochastic models around them, refining only as needed. We present an interpretable framework for nonlinear sensitivity analysis that recovers a directed dependency graph between variables from data. This method enables reduced-order modeling by retaining core variables while treating the rest as nuisance factors. We also extend the same construction to conditional generative models: by performing sensitivity analysis on the underlying transport maps, we reveal conditional dependency structure beyond additive-noise assumptions. Finally, restricting the recovered graph to a directed acyclic graph provides a route to causal modeling. Across algebraic systems, chemical reaction networks, COVID time series, and financial dynamics, the resulting reduced models improve predictive accuracy and robustness relative to baselines.

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MS118

Variationally Correct Operator Learning with a Posteriori Error Estimation

While minimizing PDE-residual losses is a standard way to enforce physical consistency in neural operators, small residuals rarely guarantee small solution errors. This lack of "variational correctness" often stems from noncompliant norms or inconsistent boundary condition penalties. In this talk, we introduce a variationally correct operator learning framework using First-Order System Least-Squares (FOSLS) objectives. By construction, our loss values are provably equivalent to the actual solution error in PDE-induced norms. To implement this, we propose the Reduced Basis Neural Operator (RBNO), which ensures function space conformity by predicting coefficients for a pre-computed basis. We demonstrate the framework on stationary diffusion and linear elasticity, showing that it maintains stability and accuracy where standard baselines fail. Finally, we provide a rigorous convergence analysis and show that our residual loss serves as a reliable, computable a posteriori error estimator.

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MS118

Diffusion-Based Stochastic Operator Networks for Uncertainty Quantification in Stochastic Partial Differential Equations

We propose a novel framework for uncertainty quantification of solution operators associated with stochastic partial differential equations (SPDEs). Although SPDEs play a central role in modeling complex physical systems under uncertainty, their practical use typically requires specifying the magnitude and structure of model uncertainties that are often unknown and difficult to infer from noisy measurements. To address this challenge, we develop a stochastic operator-learning framework that learns directly from noisy data and outputs both a mean solution field and a quantification of uncertainty. The proposed method, namely the Stochastic Operator Networks (SONs), is constructed by combining the structure of the Deep Operator Network (DeepONet) with the Stochastic Neural Networks (SNNs) to model stochasticity and enable probabilistic prediction. The training procedure is carried out by minimizing a Hamiltonian-typed loss and optimizing the resulting objective using Stochastic Maximum Principle. Numerical experiments on benchmark SPDEs under multiple uncertainty sources demonstrate the accuracy and robustness of the proposed method in capturing solution structure and quantifying predictive uncertainty.

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MS118

Ensemble Score Filter with Image Impainting for Data Assimilation with Partial Observations

We present an extension of the Ensemble Score Filter (EnSF), a training-free, score-based diffusion filtering method for high-dimensional nonlinear data assimilation, to settings with partial observations. In standard EnSF, the likelihood gradient vanishes for unobserved state components, so those variables are only corrected indirectly through model dynamics, which can substantially degrade reconstruction accuracy in sparsely observed regimes. We address this limitation by inserting an image inpainting step into each assimilation cycle: EnSF first updates the observed components by modifying the score via Bayes' rule within the reverse-time SDE, and then inpainting propagates information into unobserved regions to produce a full-state posterior ensemble. We investigate two families of inpainting operators: (i) PDE-based inpainting using biharmonic and Navier–Stokes-inspired formulations to smoothly extend structures from observed to missing regions, and (ii) a dictionary-learning / sparse-representation approach that builds a DCT-based dictionary from the prior ensemble and reconstructs missing values by solving a TV-regularized coefficient optimization problem. The methods are evaluated on the turbulent surface quasi-geostrophic (SQG) model in 16 scenarios spanning two spatial resolutions (64^2 and 256^2), linear vs. nonlinear observation operators, two assimilation frequencies, and observation coverages of 5% and 25%. Across this test suite, EnSF with inpainting improves recovery of unobserved states relative to EnSF alone and remains robust in regimes where LETKF performance deteriorates, particularly for nonlinear observations and severe sparsity.

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MS119

Is There An Algorithm for Proving Partition Identities?

This talk is devoted to a paper being prepared for the Journal of Open Mathematical Problems. A preliminary version of this talk was given at the AMS Regional Meeting in Hartford in the spring of 2025. This talk will focus on different and more relevant examples than those chosen previously. Often in studying partition identities, one can reduce a particular problem to proving that two different sequences defined by linear recurrences converge to the same limit. Countless partition identities arising from q-hypergeometric identities (e.g. Rogers-Ramanujan) have proofs that are based on this approach. This suggests study of the following: Develop an algorithm that will allow one to conclude in a finite amount of time that two linear recurrent sequences converge to the same limit. If this is too hard, develop an algorithm that might at least significantly facilitate the proof in question. In the talk, we shall: (1) provide an array of examples of questions with varying degrees of difficulty that might be tackled first; (2) look at an previous attempts along these lines such as: (3) Shanks's method of acceleration of convergence, and (4) the Knopfmachers's q-analog of Perron's method of acceleration of convergence.

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MS119

Mock Atkin-Lehner Symmetry

In 1987 Dyson predicted Atkin-Lehner symmetries for Ramanujan's mock theta function. Atkin-Lehner involutions are used to obtain new congruences for Ramanujan's third order mock theta functions. We also apply Atkin-Lehner involutions to connect rank and crank identities for overpartitions with rank and crank identities for partitions with distinct odd parts. This is partly joint work with Rishabh Sarma.

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MS119

Computational Tools for Hypergeometric L-Functions

Recently, tools for computing hypergeometric L-functions have been introduced into several standard software packages (PARI/GP, Magma, SageMath). This opens up the possibility of generating "big data" about Hasse-Weil L-functions and thereby to use ML/AI techniques to study these L-functions. We survey the current state of the tools for hypergeometric L-functions; identify some to-do items for the near terms; and engage in a bit of speculation about what the future might hold.

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MS119

The Arithmetic of Hypergeometric Galois Representations in Low Dimensions

In this talk, we will discuss hypergeometric Galois representations and their automorphy results in low dimensions. It is based on a recent joint work with Wen-Ching Winnie Li and Tong Liu. This box is for abstract text content only.

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MS120

Supercongruences and p-adic Hodge Theory

For classical reasons, hypergeometric functions often satisfy congruences of the form $F_p(\lambda) \equiv \alpha \pmod p$, where F_p denotes the truncation at p of the infinite sum defining the hypergeometric function and α_p is a zero of the local ζ-function of a variety associated to F and λ. In rare cases, such congruences will hold modulo p^r for some r greater than 1, in which case we call the congruence a supercongruence of depth r, assuming that r is the largest integer for which the supercongruence holds. Roberts and Rodriguez Villegas conjectured that the depth is determined explicitly by the vanishing of p-adic Hodge numbers—very little is known in general towards this conjecture. We summarize some recent results towards better understanding supercongruences, with a particular eye towards this p-adic viewpoint. This is based in part on joint work with Grove, Long, and Tu.

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MS120

Hypergeometric Functions, D-Modules, and Mirror Symmetry of Calabi-Yau Varieties

In this talk we will survey the role that classical hypergeometric functions and the D-modules they are associated to arise in connection with the geometry of Calabi-Yau (CY) varieties, in particular those CY varieties who have period integrals given in terms of hypergeometric functions. For example, for the low dimensional CYs of elliptic curves and K3 surfaces (of high Picard rank = 19), the appearance of hypergeometric functions can be seen as a manifestation of a strong connection of the periods to classical elliptic modular forms. Additionally, in certain cases, special function identities such as the Hadamard product of hypergeometric functions is emblematic of iterated fibration structures, such as nested elliptic and K3 fibrations, that exist on a higher dimensional CY. After explaining these ideas, we will demonstrate in this context how mirror symmetry allows for the computation of enumerative invariants of the mirror partner of a CY variety from the data of the associated hypergeometric D-module and gesture to the origin of these computations from physics. As time permits we will explain how these ideas can be utilized to compute enumerative invariants of closely CY related spaces relevant to so-called local mirror symmetry and the role that modularity plays in these computations.

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MS120

Reduction of Hypergeometric Systems for Periods of Calabi-Yau Families

From both classical and modern perspectives, period integrals of many families of Calabi-Yau varieties are known to enjoy deep connections with hypergeometric functions. In this talk, we will reexamine work of Matsumoto, Sasaki, and Yoshida from 1992 on reduction of Aomoto-Gelfand hypergeometric systems. By interpreting this result as an invariant-theoretic statement on universal parameter spaces of branched covers and complete intersections, we will demonstrate a new technique for understanding the periods of these CY families. In particular, we derive novel explicit period formulas for elliptic curves in $\mathbb{P}^2$ and branched covers of projective spaces. This is joint work with Bong Lian.

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MS120

Hypergeometric Decompositions of K3 Surface Pencils

In this talk we will look at five pencils of projective quartic surfaces with the aim of giving explicit formulas for the point counts over finite fields of each. These point counts are written in terms of hypergeometric sums. Given time, we will discuss how to obtain a decomposition of the incomplete L-function of each pencil in terms of hypergeometric L-series and Dedekind zeta functions. This is joint work with Rachel Davis, Jessamyn Dukes, Thais Gomes Ribeiro, Eli Orvis, Adriana Salerno, and Ursula Whitcher.

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MS122

Explicit Corrector Results for Nonlinear Electrostatic-Elastic Systems

In this talk, a rigorous periodic homogenization of a weakly coupled electrostatic system, accounting for both nonlinear electrostatic equations and elastic structures enriched with electrostrictions, will be presented. Unlike previous models that rely on linear constitutive laws or high regularity assumptions, our approach addresses nonlinear, monotone operators, where the standard gradient estimate fails. The effective macroscopic response of these composites is derived by employing two-scale convergence. The method discussed also allows one to obtain an explicit corrector result for the homogenization of monotone operators with minimal regularity assumptions. These results can provide a mathematical foundation for designing the next generation of smart materials with optimized electromechanical couplings.

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MS122

Modeling and Simulation of mMorphology Formation in Organic Solar Cells

Organic solar-cell performance is strongly shaped by the nanoscale morphology of the active layer, often modeled as a ternary mixture of interacting species (donor, acceptor, solvent) that undergoes phase separation while the solvent evaporates. Many widely used descriptions of this process are lattice-based, drawing on tools from statistical mechanics; however, direct simulation can be computationally expensive and can make parameter estimation challenging. This talk develops a continuum-level modeling and simulation framework that treats morphology formation as an intrinsically multiphysics process, coupling nonlocal phase-segregation dynamics with solvent evaporation. We discuss well-posedness of the resulting evaporating model and present numerical results on morphology statistics (mainly domain coarsening rates), comparing to the traditional BlumeCapel lattice model.

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MS122

Splitting Algorithms for High Frequency Waves in Random Media

Owing to the co-existence of multiple physical scales, wave propagation through highly heterogeneous (random) media is an inherently complex physical phenomenon. In the context of laser propagation through turbulent atmospheres, the phase screen method is routinely used for numerical simulations. Phase screen methods are analogous to time splitting methods for random Schrdinger equations, and surprisingly work well even for very large step sizes. In this talk, I will provide an analysis for such methods, and show that one obtains only first order accuracy in the pathwise sense, even while using centered splitting schemes, while errors in the statistical averages converge much faster. This is joint work with Guillaume Bal.

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MS122

Source and Initial Data Identification for Fractional Diffusion

Time-space fractional parabolic equations have been used to model a range of applications, including anomalous transport with temporal memory and extensive spatial interactions over long distances. Inverse problems for time-space FDEs, which aim to determine the source term and/or the initial conditions, have also attracted widespread interest. These problems pose significant challenges due to the nonlocal nature of fractional differential operators and the inherent ill-posedness of inverse problems, necessitating appropriate regularization methods. This talk will discuss several effective regularization methods for solving such inverse problems from noisymeasurements taken at a latertime, including error estimates and numerical examples.

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MS123

Effectivity of Adjoint-Based Error Estimates for Practical High-Order Simulations

Output-based error estimation allows for the quantification of the effect of discretization errors on scalar outputs, and the localization of these errors for adaptive refinement. Key to the estimate is the adjoint-weighted residual (AWR), which at the discrete level is an inner product between an adjoint vector and a residual vector. Although the AWR is a simple operation, the effectivity of the resulting error estimate depends on the implementation and discretization. This presentation will investigate the error estimate effectivity for canonical flows in aerodynamics, comparing estimated errors to the actual errors computed relative to high-resolution simulations. One particular discretization is of interest: a high-order discontinuous finite-element method, which allows for both variable order and mesh refinement, in this case on unstructured meshes. The study is performed in an adaptive setting, since error estimation and adaptation are intrinsically tied together: error estimates improve with mesh quality, the generation of which depends on the accuracy of the error estimates. The results show excellent effectivity on simple scalar manufactured solutions, but performance that decreases with increasing complexity of Navier-Stokes simulations. Aspects of the discretization that affect the error estimates are highlighted, including choice of fine space, order-dependence of the discrete residuals, curved meshes, integration, and wall-distance representation.

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MS123

Anisotropic Metric-Based Mesh Adaptation for Incompressible Flows

We present an anisotropic metric-based mesh adaptation strategy for incompressible Navier-Stokes flow simulations using Oak Ridge National Laboratorys Vertex-CFD solver integrated with NASAs refine. Vertex-CFD is a scalable continuous-Galerkin solver with implicit time marching and entropically damped artificial compressibility for pressure coupling. NASAs refine employs a continuous mesh framework driven by a Hessian-based multiscale metric field, where the scalar quantity for Hessian computation is selected to optimize mesh quality. This study highlights the benefits of the adaptive framework for fusion reactor blanket applications.

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MS123

To ML or not to ML: High-Order Mesh Optimiza-

tion vs. Deep Reinforcement Learning

The optimality of the computational mesh directly impacts the accuracy, efficiency, robustness, and convergence of high-order finite element methods. This work focuses on strongly coupled movement of high-order geometry nodes (q-adaptation) and vertices (r-adaptation) as a mesh-curving strategy, where elements are curved to maximize accuracy and efficiency gains while providing accurate boundary and geometry representations. We systematically compare two trust-region-based algorithms: High-Order Mesh Optimization via Error Sampling and Synthesis (HOMES, also known as High-Order MOESS) and Trust Region Policy Optimization (TRPO). HOMES uses an error model and a cost model to iteratively construct a continuous high-order Riemannian metric field that encodes the desired element shape, size, and anisotropy. This metric field drives the qr-adaptation. A non-monotonic trust region with correction steps for non-smooth problems limits the metric update. In contrast, TRPO is a deep reinforcement learning algorithm that learns a metric-update policy by maximizing long-term return from successive optimization actions. A trust region limits policy updates to ensure stability and prevent overfitting to noisy advantage estimates. Both algorithms incorporate random sampling of node movements and compute a step metric that transforms the current mesh toward an optimal metric-conforming mesh. This comparison provides insights into the role of machine learning in curved mesh adaptation.

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MS123

Optimization-Based Simulation for Viscous, High-Speed Flows

Computational fluid dynamics (CFD) simulations of flows with boundary layers are notoriously sensitive to the computational grid. Accurate resolution of thin boundary layers requires high-quality, highly refined grids, which can be difficult and labor-intensive to construct. In this talk, we present a novel finite element framework based on nonlinear approximation manifolds that aims to reduce this grid sensitivity. The central idea is to embed boundary layer structure directly into the approximation space, rather than relying on generic polynomial bases that require the grid to resolve these features. Nonlinear manifolds tailored to boundary layers can be constructed using analytical or data-driven approaches, offering improved accuracy per degree of freedom on coarser grids compared to conventional methods. We discuss the theoretical foundations of this approach, present numerical results for boundary-layer-dominated flows, and discuss implementation details.

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MS124

Online Network Dynamics Ahead of Offline Shocks: The Math of Cohesion in Human-Machine-Ai Systems

February 2026 saw the sudden emergence of networks of 1.5 million AI agents on “Moltbook, an online social network for AI agents. Within 1 day, they managed to invent their own religions, run scams, and debate their purpose. This highlights a critical gap in network science that we address in this talk: how do we model mathematically the spontaneous formation *and* function of cohesive dynamical networks of interacting, adaptive AI agents (and humans)? Here we step towards this goal by building on the mathematics of Huo et al. in *Introduction to Online Complexity*, Oxford Univ. Press (2025) and *Phys. Rev. Lett.* 133, 247401 (2024). In the limit that the agent (node) actions have negligible impact on the link dynamics, the descriptive equation for the network clustering of heterogeneous agents (nodes) becomes a novel multidimensional generalization of the inviscid Burgers equation. We discuss the solutions to these equations, showing how cross-species links can drive the sudden emergence of ‘super-shocks’. Then we allow these heterogeneous nodes to become adaptive: they each try to achieve some goal for themselves which may not align with the goals for the overall system. An example of this is a cluster of AI agents (and perhaps humans) repeatedly trying to extract some finite energy or API bandwidth. The relevant network then becomes the dynamical formation of crowds and anticrowds in their strategy space. We hope that this stimulates further work to develop a rigorous mathematical framework for inferring and controlling the dynamics of the new networks of adaptive human-AI multi-agent ecosystems that will likely dominate our future world.

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MS124

What Does Cascade Structure Reveal About Contagion?

Many important challenges of our time are related to harmful contagion in networks. To mitigate such harmful contagion be it misinformation, an epidemic, or something else it is important to understand how the contagion spreads, and what its impact could be. In recent years, studying the structure of cascades rooted, directed, acyclic graphs indicating who infected whom in the network has provided a new way of getting insights about the spreading mechanism and contagion impact. In this talk, I will demonstrate how cascade structure can reveal whether false and true news diffuses similarly online or not. I will show that for some canonical models of contagion, including the SIR model, the structure of extinct cascades does not reveal what infectiousness parameter, R_0, the process was simulated with. Finally, I will present new joint work with Johan Ugander (Yale University) demonstrating that the structure of *growing* SIR cascades *can* reveal the infectiousness of the simulated process.

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MS124

Correlated Heterogeneity in Simple Contagions Mimics Complex Contagions

The study of epidemic spreading in structured populations has been an impactful domain of network science since its inception. Recent work has found that a variety of infection kernels underlie spreading phenomena in networks, from the “simple” contagion kernels characteristic of infectious diseases to “complex” contagion kernels commonly associated with the spread of social behaviors [Pastor-Satorras et al., Epidemic processes in complex networks, 2015]. However, determining which type of contagion is spreading in a population is difficult. For example, recent studies have shown that interacting simple contagions [Hbert-Dufresne et al., Macroscopic patterns of interacting contagions are indistinguishable from social reinforcement, 2020] and uncertain transmission settings [St-Onge et al., Nonlinear bias toward complex contagion in uncertain transmission settings, 2024] may be confounded with complex contagions. We show that heterogeneity in simple contagion kernels, when correlated with population structure, can produce spreading dynamics resembling complex contagions. In particular, when subpopulations are organized into communities, the resulting infection patterns can mimic complex contagion dynamics. Using recent non-parametric contagion models [Landry et al., Reconstructing networks from simple and complex contagions, 2024], we infer infection kernels from time-series data on nodal states. We find that assuming a single infection kernel for an entire population can yield an inferred kernel displaying the nonlinear behavior commonly associated with complex contagions, even when only simple contagion kernels are present.

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MS124

Connecting Models with Data for Coupled Online-Offline Social Systems

The rise of social media has blurred the boundary between the online and offline worlds. Activities in these two domains strongly influence one another, with online communications transforming offline behavior, from everyday decisions to the escalation of conflicts, and conversely, offline events driving online engagement and discussion. It is therefore important to study and understand the coupled dynamics of online and offline social systems. We present our efforts to disentangle this problem from two complementary perspectives: model-driven projects, which develop multilayer network modeling frameworks and use outburst analysis to study population-level behavior; and data-driven projects, which aim to learn effective dynamical system models directly from data, including parameter inference and weak form system identification methods. Overall, our work provides initial steps toward connecting simulation, mathematical modeling, and data-driven learning for coupled onlineoffline social dynamics.

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MS125

Logic and Algebraic Structures for Enhancing LLM Reliability via Neurosymbolic AI

Large language models (LLMs) are intrinsically probabilistic, a feature that makes them ill-suited for answers for which we need certainty, such as in mathematics, but also in medicine and law. Several approaches have emerged to address this problem; one, known as Neurosymbolic AI, delegates logical reasoning to external software that evaluates logical expressions. In such a case, the LLMs are in charge of the language translation, but not of the logical reasoning. We will discuss applications of such techniques, the algebraic structure on which they rely, and their performance against modern reasoning LLMs. This is joint work with Sudhir Murthy and Lucas Salim.

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MS125

Pedagogical and Technological Tools for Implementation of AI in Math Education

This presentation examines pedagogical and technological tools that support the effective implementation of artificial intelligence (AI) in mathematics education. We discuss instructional strategies, AI-driven learning platforms, and assessment tools that enhance student engagement, provide adaptive feedback, and support conceptual understanding. Emphasis is placed on practical classroom applications, alignment with learning objectives, and challenges related to ethics, transparency, and academic integrity in AI-supported mathematics instruction.

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MS125

Towards Augmenting Mathematical Intuition in Data Science Methods with AI-assisted Techniques

Several new possibilities to supplement data science education are now available due to the fast development of artificial intelligence (AI) solutions, some of which can be leveraged to enhance instructional methods. This talk reflects on ways to emphasize and build intuition around mathematical concepts involved in machine learning and data mining methods, by leveraging AI tools to design interactive and intellectually engaging examples. We discuss multimodal learning artifacts that enable students to explore mathematical ideas dynamically, connect symbolic reasoning to code and data, and to interrogate assumptions of AI-generated simulations. Incorporating such solutions in data science instruction has the potential to increase student engagement while enabling critical thinking and mathematical reasoning processes necessary for an AI-augmented professional landscape.

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MS125

Lessons Learned in Training Faculty for AI Curriculum Integration

This presentation examines critical lessons from faculty development programs designed to integrate artificial intelligence into undergraduate and graduate curricula. Analysis of training initiatives across multiple institutions reveals several key findings that inform effective professional development strategies. How successful programs prioritize pedagogical framing over technical instruction, presenting AI integration through learning outcomes rather than algorithmic details. Faculty require discipline-specific contextualization, and mathematics and computational science educators engage more deeply with examples from numerical analysis, optimization, and scientific computing than with generic AI demonstrations. Hands-on experimentation with AI tools, coupled with opportunities for iterative course redesign, is significantly more effective than passive workshops. Faculty need structured time to prototype AI-integrated assignments, pilot implementations, and refine approaches based on student outcomes. Assessment redesign emerges as the primary challenge. Traditional problem-solving evaluations need to be reconceptualized when AI tools can generate solutions. Effective training helps faculty develop process-oriented assessments, authentic tasks requiring domain expertise, or assignments that explicitly incorporate and critically evaluate AI outputs. Training must address ethical considerations, including algorithmic bias, academic integrity concerns, and equity issues related to student access. Faculty positioned as thoughtful pedagogical designers, rather than passive technology adopters, show higher engagement and more sophisticated integration strategies. Last, given AI's rapid evolution, effective programs establish continuous learning frameworks rather than one-time training events.

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MS126

Learning Differential Equations from Scarce Data: A Kernel-Based Approach

In many problems in computational science and engineering, observational data are available while the underlying physical models remain unknown. Learning such models from data is a central goal in scientific machine learning, yet many existing approaches require numerous solution examples, dense measurements, or computationally expensive training procedures. In this talk, I present Kernel Equation Learning (KEqL), a kernel-based framework for learning differential equations and their associated solution maps in scarce-data regimes, both when the number of training solutions is small and when each solution is observed at only a limited number of locations. KEqL formulates equation learning within an RKHS/Gaussian process-based framework that simultaneously reconstructs the unknown solution and identifies the functional form of the differential equation. I will describe the practical KEqL methodology and discuss the accompanying error analysis, which establishes quantitative worst-case bounds for the learned equation under suitable assumptions. Finally, I will present numerical benchmarks spanning ODEs and PDEs, including variable-coefficient problems, demonstrating improved robustness, computational efficiency, and significant accuracy gains over state-of-the-art equation learning methods. I will also discuss connections between this framework and operator learning and inverse problems, and outline future directions, both theoretical and computational.

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MS126

Physics-Informed Gaussian Process with Applications in ODE/PDE Parameter Estimation

Parameter estimation for nonlinear dynamical system models, represented by ordinary differential equations (ODEs) or partial differential equations (PDEs), using noisy and sparse experimental data is a vital task in many scientific and engineering fields. We propose a fast and accurate methodphysics-informed Gaussian processesfor this purpose. Our approach places a Gaussian process prior over system components and explicitly conditions on the governing physics by enforcing that the gradients of the Gaussian process satisfy the ODE/PDE system. This formulation completely bypasses traditional numerical integration, leading to substantial computational savings. The method naturally accommodates unobserved system components and provides principled uncertainty quantification. Distinct from existing approaches, our framework offers a rigorous Bayesian construction that incorporates the ODE/PDE constraints directly through conditioning.

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MS126

Learning Gradient Flow Dynamics from Particle

Data

We propose an interpretable learning framework for identifying the gradient flow dynamics of particle-based evolution systems. The objective is to recover the underlying energy functional, which naturally decomposes into internal, drift, and interaction terms. The key idea of our approach is to design a learning algorithm that preserves the structure of the energy. The inferred model can then be used to generate more particle data over longer time horizons and under various initial conditions. This approach yields a physically grounded model that not only captures observed dynamics but also generalizes to predict behaviors in complex particle systems.

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MS126

IEnSF:iterative Ensemble Score Filter for Reducing Error in Posterior Score Estimation in Nonlinear Data Assimilation

The Ensemble Score Filter (EnSF) has emerged as a promising approach to leverage score-based diffusion models for solving high-dimensional and nonlinear data assimilation problems. While initial applications of EnSF to the Lorenz-96 model and the quasi-geostrophic system showed potential, the current method employs a heuristic weighted sum to combine the prior and the likelihood score functions. This introduces a structural error into the estimation of the posterior score function in the nonlinear setting. This work addresses this challenge by developing an iterative ensemble score filter (IEnSF) that applies an iterative algorithm as an outer loop around the reverse-time stochastic differential equation solver. When the state dynamics or the observation operator is nonlinear, the iterative algorithm can gradually reduce the posterior score estimation error by improving the accuracy of approximating the conditional expectation of the likelihood score function. The number of iterations required depends on the distance between the prior and posterior distributions and the nonlinearity of the observation operator. Numerical experiments demonstrate that the IEnSF algorithm substantially reduces the error in posterior score estimation in the nonlinear setting and thus improves the accuracy of tracking high-dimensional dynamical systems.

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MS127

Separated Lower-Order Tensors and Lower Bounds for the Ranks of Tensors

Lower bounds for the tensor rank (also known as CP-rank) are a highly active area of research with major connections to computational complexity, such as the exponent of matrix multiplication. Remarkably, finding an explicit example of an n x n x n tensor with tensor rank quadratic in n - that is, of the maximal order of magnitude - is a famous open problem in the area. With the newer notions of rank, such as the slice and partition rank, finding an explicit n x .. x n tensor with maximum rank is achievable for any order - in fact, the "identity" tensor is such a tensor, as shown by Tao and Naslund respectively - yet another situation arises which illustrates a gap in our knowledge. Over finite fields, although statistically a typical n x .. x n tensor will have the maximum possible slice rank and partition rank, equal to n, the lower bounds that can be established with current methods for a typical given n x .. x n tensor are much smaller. After reviewing these methods we will describe some techniques for lower bounds on the slice rank and the partition rank of tensors, which involve a separation condition on lower-order slices of the tensor, as well as the current limitations of these techniques. If time allows, we will very briefly conclude with the situation of lower bounds for more general rank notions, blending the difficulties arising from the tensor rank at one extreme together with those arising from the partition rank at the other extreme.

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MS127

Wedge Sampling: Efficient Tensor Completion with Nearly-Linear Sample Complexity

We introduce Wedge Sampling, a new non-adaptive sampling scheme for low-rank tensor completion. We study recovery of an order-k low-rank tensor of dimension k from a subset of its entries. Unlike the standard uniform entry model (i.e., i.i.d. samples from $[n]^k$), wedge sampling allocates observations to structured length-two patterns (wedges) in an associated bipartite sampling graph. By directly promoting these length-two connections, we show a near-linear complexity result in regimes where uniform sampling is too sparse to generate enough informative correlations and its applications in tensor regressions. This is a joint work with Anna Ma at University of California Irvine; Ludovic Stephan at Univ Rennes, Ensai, CNRS and Yizhe Zhu at University of Southern California.

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MS127

Sparse Approximation and Sets of Polynomial Equations

One of the fundamental problems in signal processing, machine learning, and applied mathematics is sparse approximation. The main objective is to recover sparse solutions to a possibly underdetermined linear system Ax=b. In this talk, I present a novel framework for sparse approximation based on multilinear algebra and algebraic geometry. The key idea is to reformulate sparse recovery as the solution of structured multilinear or polynomial systems and to solve these systems using tensor decompositions. The framework can identify multiple equally sparse solutions and provides explicit control over the desired sparsity of the solution, capabilities that standard methods such as Orthogonal Matching Pursuit and Basis Pursuit do not offer. These results demonstrate the potential of combining tensor decompositions with polynomial system formulations to expand the toolbox for sparse recovery beyond traditional techniques.

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MS127

Universality of General Spiked Tensor Models Beyond Gaussian Noise

Spiked tensor models provide a fundamental framework for high-dimensional signal detection and estimation problems arising in statistics and machine learning. While many existing theoretical results rely on Gaussian noise assumptions, practical data often exhibit more general noise structures. In this talk, we study the rank-one asymmetric spiked tensor model in the high-dimensional regime, where the noise entries are independent and identically distributed with zero mean, unit variance, and finite fourth moment. Focusing on the maximum likelihood estimator associated with the best rank-one approximation, we show that the empirical spectral distribution of a suitably defined block-wise tensor contraction converges almost surely to a deterministic limit that coincides with that of the Gaussian case. As a consequence, the asymptotic singular value and the alignments between the estimated and true spike directions admit explicit characterizations identical to those obtained under Gaussian noise. These results establish a universality principle for spiked tensor models, demonstrating that their high-dimensional spectral behavior and statistical limits remain robust beyond the Gaussian setting.

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MS129

Enumerating Rooted Binary Phylogenetic Forests and the Coalescent Model

The (Network) Multi-Species Coalescent models evolution of genes among current and ancestral species. Compared with other standard mathematical models of evolution that are analyzed with algebraic geometry, it tends to produce polynomials of higher degree and with more terms, and so symbolic computation quickly becomes essential as the frontiers are pushed. Current methods for symbolic computation of probabilities focus on probabilities of unrooted gene trees, which are often the data of interest. This can have issues when considering more complex networks, and lacks the ability to focus on more minute network features. A more general way to track probabilities within the coalescent setting is with probabilities of rooted binary phylogenetic (leaf-labeled) forests, which are the intermediate stages of the coalescent process. Dealing with these systematically requires an easily-computable enumeration. This work presents such a particular enumeration that is computed recursively, inspired by a new direct proof of a long-known combinatorial result concerning rooted binary phylogenetic forests.

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MS129

Introduction to Algebraic Biology

Algebraic methods provide powerful tools for studying complex biological systems, where nonlinear interactions, hidden variables, and limited data are the norm. This introductory talk surveys how tools from algebra, particularly algebraic geometry, combinatorics, and commutative algebra, can be used to formulate, analyze, and solve problems across several areas of biology, including evolutionary biology, ecology, systems biology, and neuroscience. The goal of this talk is to provide an accessible entry point for researchers interested in learning more about the interface between algebra and the life sciences.

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MS129

Verifying Distinguishability of Linear Compartment Models Through Matroids

Linear compartment models are widely used in pharmacokinetics, epidemiology, and ecology, and a central question is the indistinguishability problem: when do two distinct models produce the same observable inputoutput behavior? Two models are distinguishable precisely when their inputoutput equations differ, but computing these equations symbolically typically requires costly Grbner basis computations. We present a complementary approach using numerical algebraic geometry. By computing witness sets and identifying circuits of the associated algebraic matroids, we reduce the problem to detecting circuit relations that can certify indistinguishability.

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MS129

K-Wheels of Neural Codes

Inspired by the mammalian place cells that fire based on physical location, a neural code is a combinatorial code that describes the intersections of a collection of subsets (called receptive fields) of some topological space. Much study has been done on determining which codes can be realized in some Euclidean space using receptive fields that are open and convex. We continue work started by Matusevich, RdP, and Shiu (2023) that introduced a phenomenon called a "wheel" whose presence in a code prohibited open convexity by forcing an intersection of receptive fields to bend into a nonconvex shape around three "spokes." We generalize this work into a "k-wheel," where there are now an arbitrary number of k many "spokes." We also show how with this generalization, the three separate classes of wheels described in the previous work can now be described as a single case.

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MS130

The Initial Value Problem for Generalized Benjamin-Bona-Mahony Type Equations

This study investigates the well-posedness of the initial value problem for a generalized Benjamin-Bona-Mahony (BBM) equation of the form: $u_t+u_x+uu_x+f(u)_x-u_{xxt} = 0$ where f is a polynomial of degree n. This model generalizes several physically significant equations, including the regularized long wave (BBM) and regularized Gardner equations. We analyze well-posedness in the Sobolev space $H^s(\mathbb{R})$ by dividing the analysis into three regularity regimes. In each case, the IVP is transformed into an equivalent integral equation and shown to be locally well-posed. These solutions are subsequently extended globally using a priori bounds derived from two fundamental invariant quantities. For $s \geq 1$: We utilize the temporal invariance of the H^1 norm alongside an inductive argument to establish a polynomial bound on the H^s norm. For $\frac{n-1}{2n} < s < 1$: Assuming n is odd and restricting the coefficients of f, we demonstrate uniform bounds on the L^2 and L^{n+1} norms. By analyzing the difference v, between the solution and the initial condition, we show that $v \in H^1$ due to the smoothing properties of the convolution operator. Its L^∞ norm is bounded linearly in t, facilitating a global polynomial bound on the H^s norm of u. For $0 < s \leq \frac{n-1}{2n}$: By requiring the initial data to belong to $L^{n+1}(\mathbb{R})$, we utilize the second invariant to derive global bounds. In this regime, the integral formulation is leveraged directly to calculate the necessary norm bounds.

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MS130

Random Blob Methods for Diffusion

We investigate a class of numerical particle methods for solving a class of generalized Fokker-Planck equations, which are characterized as 2-Wasserstein gradient flows of a functional energy. To ensure that "particles remain particles" throughout the simulation, we utilize a regularized energy $\mathcal{F}_\epsilon$ constructed via Moreau-Yosida regularization and mollification [Craig et al., Nonlocal approximation of slow and fast diffusion]. Using this approach, we are able to simulate slow and fast diffusion, sandpile dynamics, height-constrained transport, and the 2-dimensional Navier-Stokes equation. To address the $O(N^2)$ computational bottleneck of naive methods, we introduce the Batch Forward Euler Method (BFEM). This method employs a "slow-fast" time-stepping scheme where particles, rather than the velocity fields, are split into different update frequencies. The BFEM achieves a computational complexity of $O(MN(p+\frac{N-p}{k}))$. Moreover, in many cases, it preserves higher accuracy than existing approaches such as the Random Batch Method [Jin et al., The Random Batch Method for N-body Systems]

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MS130

Continuity Properties of Solutions to a Fifth-Order Camassa-Holm Type Equation

In this talk, we present a new integrable fifth-order CamassaHolm (CH)type equation derived by Reyes, Zhu, and Qiao, which we call the RZQ equation. The m-form of this equation possesses a striking similarity to the m-form of the CH equation. However, unlike the CH equation, the nonlocal form of this equation cannot be interpreted as a nonlocal perturbation of Burgers' equation. We prove that the initial value problem corresponding to the RZQ equation is well-posed in the sense of Hadamard, in Sobolev spaces H^s, $s > 7/2$. Furthermore, we show that the data-to-solution map is not uniformly continuous in the H^s topology.

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MS130

Exponential Time Differencing Runge-Kutta Discontinuous Galerkin (ETD-RKDG) Methods for Nonlinear Degenerate Parabolic Equations

In this work, we study high-order exponential time differencing Runge-Kutta (ETD-RK) discontinuous Galerkin (DG) methods for nonlinear degenerate parabolic equations. This class of equations exhibits hyperbolic behavior in degenerate regions and parabolic behavior in non-degenerate regions, resulting in sharp wave fronts in the solution profiles and a parabolic-type time-step restriction, $\tau \sim O(h^2)$, for explicit time integration. To address these challenges and solve such equations in complex domains, we employ DG methods with appropriate stabilizing limiters on unstructured meshes to capture the wave fronts and use ETD-RK methods for time integration to resolve the stiffness of parabolic terms. We extract the system's stiffness using the Jacobian matrix of the DG discretization for diffusion terms and adopt a nodal formulation to facilitate its computation. The algorithm is described in detail for two-dimensional triangular meshes. We also conduct a linear stability analysis in one spatial dimension and present computational results on three-dimensional simplex meshes, demonstrating significant improvements in stability and large time-step sizes.

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MS131

Generative Monte Carlo Sampling for Constant-Cost Particle Transport

We present Generative Monte Carlo (GMC), a novel paradigm for particle transport simulation that integrates generative artificial intelligence directly into the stochastic solution of the linear Boltzmann equation. By reformulating the cell-transmission problem as a conditional generation task, we train neural networks using conditional flow matching to sample particle exit states, including position, direction, and path length, without simulating scattering histories. The method employs optical coordinate scaling, enabling *a single trained model* to generalize across any material. We validate GMC on two canonical benchmarks, namely a heterogeneous lattice problem characteristic of nuclear reactor cores and a linearized hohlraum geometry representative of high-energy density radiative transfer. Results demonstrate that GMC preserves the statistical fidelity of standard Monte Carlo, exhibiting the expected

$1/\sqrt{N}$ convergence rate while maintaining accurate scalar flux profiles. While standard Monte Carlo computational cost scales linearly with optical thickness in the diffusive limit, GMC achieves constant $O(1)$ cost per cell transmission, yielding order-of-magnitude speedups in optically thick regimes. This framework strategically aligns particle transport with modern computing architectures optimized for neural network inference, positioning transport codes to leverage ongoing advances in AI hardware and algorithms.

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MS131

Symmetrizable Hyperbolic Neural Closure for M1 Radiation1Transfer

In radiation transfer simulations, an M1 method achieves substantial computational savings by replacing the full angular transport equation with a low-order moment system. Because this reduced system is not closed, a closure model is required to represent the unknown higher-order moments using lower-order moments. While machine learning (ML)-based closures can improve accuracy beyond classical analytic closures, the ML-based closures can produce non-real wave speeds and therefore cause numerical solver breakdown. To guarantee real eigenvalues of the Jacobian associated with ML closures, we propose a symmetrizable hyperbolic neural closure for the M1 radiative transfer system. Rather than directly predicting the closure terms, we construct the closure from a symmetric Jacobian matrix formed by two neural networks: (i) a symmetric matrix network and (ii) the Hessian of a strictly convex entropy network. These components are combined to yield a Jacobian that is similar to a symmetric matrix, thereby ensuring real eigenvalues. The closure is then recov- ered by numerically integrating the resulting Jacobian. Numerical experiments show that, the proposed closure not only achieves higher closure accuracy than classical closures, but also improves solution accuracy and remains stable in discontinuous Galerkin simulations for radiative transfer problems

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MS131

Hybrid Monte Carlo Methods for Particle Transport

Monte Carlo methods are attractive for transport problems because they naturally handle high-dimensional phase space, complex geometries, and strongly anisotropic streaming, but their slow statistical convergence can make accurate simulations expensive. This talk presents hybrid stochastic-deterministic methods that reduce this cost by using Monte Carlo only where it is most effective and delegating highly scattered components to lower-cost deterministic solvers. In the first approach, uncollided particles are evolved with Monte Carlo while the collided component is solved with a discrete-ordinates discontinuous Galerkin method, coupled through a relabeling step between time steps. I will then discuss a scatter-limited extension that allows particles to undergo a prescribed number of collisions before handoff, as well as quasi-Monte Carlo sampling strategies that improve accuracy at essentially no additional runtime cost. I will conclude with ongoing work on multigroup transport equations, where the same hybrid philosophy is used to mitigate the cost of energy-dependent stochastic simulation by combining high-fidelity particle treatment with coarser deterministic resolution for the more diffusive collision tail.

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MS131

Novel Optimal Experimental Design Approaches for Digital Twins Using Moving Sensors

Efficient data assimilation is a significant bottleneck towards the development of highly scalable and reliable digital twins, especially when subject to constrained sensor resources. To address this, we propose novel trajectory design approaches for the optimal experimental design (OED) of contiguous data acquisition. First, we present an approach where we represent the trajectories as paths in a network and identify the optimal path to minimize uncertainty. The problem objective is expensive to evaluate, highly nonlinear, nonsmooth, and depends on full-path evaluations rather than edge-by-edge function values. We develop an integer optimization algorithm to efficiently identify the globally optimal path over the network. Second, we investigate OED strategies to minimize uncertainty by combining data from multiple concurrent moving sensors. We explore different strategies of sensor coordination, domain splitting, constraint handling, and possible fault tolerance to reduce the overall measurement time. These novel OED strategies could be used in a vast range of applications such as mapping the movement of a remote section of the Antarctic ice sheet or the emission of a pollutant from a chemical plant into the atmosphere.

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MS132

Analytic Behavior of Multimodal Generating Functions

We define integer multimodal sequences, which are generalizations of unimodal sequences having multiple local peaks of equal size. The generating functions for multimodal sequences represent novel types of q-series that combine generating functions for both integer partitions and integer compositions. We show that multimodal generating functions become finite series at roots of unity like the strange function of Kontsevich, quantum modular forms, and other examples of this phenomenon in the q-series literature.

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MS132

$\hat{Z}$-Invariants: FromOpen Dt Invariants to Quantum Modularity.

$\hat{Z}$-invariants of 3-manifolds, which can be interpreted as open Donaldson-Thomas invariants, have emerged as a rich playground for exploring the interplay between topology, number theory, and mathematical physics. In this talk, I will discuss the structural properties of these q-seriesinvariants. Specifically, I will focus on the effective central charge of $\hat{Z}$ and itsrelationship with the quantum modular behavior ofthese invariants.

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MS132

Q-Series in 3d Topology

Q-series invariants of knots and 3-manifolds have seen remarkable recent developments. A new knot invariant F_K of Gukov–Manolescu and Park is a very promising tool in low-dimensional topology. For example, its first coefficient is conjecturally additive under Murasugi sum, a natural operation on surfaces in 3-sphere. This provides a new tool for the study of the associated Grothendieck group of links, about which little is known. On the other hand, F_K, together with its 3-manifold analog $\hat{Z}$, provide a vast source of q-series, which show (generalized) modular behavior. Moreover, cutting and gluing of 3-manifolds leads to many classical and new q-series identities. Based on joint work with Paul Orland, Lara San Martn Surez and Toby Saunders-A'Court.

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MS132

Q-T-Rogers-Ramanujan Identities

In this talk I will explain how conjectural affine analogues of the dual Jacobi–Trudi identities from the theory of symmetric functions imply t-analogues of many Rogers–Ramanujan-type identities for standard modules of affine Lie algebras.

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MS133

Large-Order Asymptotics of Special Families of Painleve Functions Via Riemann-Hilbert Analysis

Solutions of the six Painlev equations are recognized as important nonlinear special functions. Studying distinguished families of Painlev solutions has proven to be a fruitful approach to gaining a better understanding of general solutions, which are in general transcendental. We discuss recent progress on analyzing the large-order limit of two such families via Riemann-Hilbert techniques. In joint work with Kurt Schmidt, we consider the generalized Hastings-McLeod solutions to the inhomogeneous Painlev-II equation, functions that arise in a variety of random matrix and interacting particle system problems. Secondly, in joint work with Matthew Satter, we compute the asymptotics of the Umemura rational solutions of the Painlev-V equation, which have applications to multiple-input multiple-output (MIMO) antenna arrays.

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MS133

The Past and Future of Mathematical Standardization

The Institute for Numerical Analysis (INA) at the University of California, Los Angeles (UCLA) was a key step in U.S. Government support for applied mathematics and computation [M. R. Hestenes and J. Todd, "The Institute for Numerical Analysis - UCLA 1947-1954," NIST Special Publication 730, U.S. Government Printing Office (USGPO), Washington, DC, 1991]. A joint institute of UCLA, United States Navy and the National Bureau of Standards (now NIST, the National Institute of Standards and Technology), INA was dedicated to developing mathematics for solving problems by automatic numerical computation. The associated national strategic need was evident from the contributions of early electronic computing to Allied victory in World War II. INA began the Handbook of Mathematical Functions [Milton Abramowitz and I. A. Stegun, USGPO, 1966] that became an accepted standard. The advent of the internet motivated NIST to begin the Digital Library of Mathematical Functions (DLMF) project in 1996 to put applied mathematics on the information superhighway. [F. J. W. Olver, et al., dlmf.nist.gov, 2026)] Artificial intelligence (AI) now presents a key challenge for development of mathematics to address emerging national needs, and may benefit from a standards approach. I will report some suggestions emerging from early discussions and invite dialogue on building a community of exploration.

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MS133

Identities Involving Central (q-)binomial Coefficients Via (q-)hypergeometric Series

Inspired by some recent results of Dilcher and Vignat, we obtained the closed forms of a family of finite sums involving central binomial coefficients. Some of the q-analogues, involving central q-binomial coefficients, are also derived. Besides the hypergeometric functions and the q-hypergeometric series, we make fully use of the WZ-method in our proofs. This is joint work with Shane Chern and Karl Dilcher.

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MS134

Shape Dynamics of An Elastic, Nearly Inextensible Membrane

While vesicles are often modeled as incompressible, they frequently exhibit large but finite compressibility. Other systems, such as capsules and polymer-infused membranes, demonstrate even more prominent compressible behavior. We develop a model for compressible membranes in Stokes flow that incorporates local lipid density in both two and three dimensions. In the absence of imposed fluid flow, we identify the onset of non-spherical steady configurations and classify their bifurcation types. We explore how spontaneous curvature, compression modulus, and preferred local density influence the stability and morphology of these non-spherical shapes. Furthermore, our theory yields explicit expressions for the enclosure's locomotion, flow field, and shape response under external flow. Specifically, we derive the dependence of the tank-treading-to-tumbling transition on membrane compressibility. These results provide new insights into the incompressible limit and highlight the fundamental symmetries at play in two- and three-dimensional interfaces.

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MS134

Analysis of the Inextensible Interface Problem in Stokes Flow

Immersed interface problems in Stokes flow arise in fluid-structure interaction, where an internal interface is coupled to a viscous incompressible fluid. One of the simplest of such problems is the 2D Peskin problem, in which a 1D closed elastic structure is immersed in a 2D Stokes fluid. This has been extensively studied computationally and analytically. We extend the 2D Peskin problem into two in two directions:

- 2D inextensible interface problem.
- 3D Peskin problem.

For the 2D inextensible interface problem, we impose an inextensibility constraint on the interface. Through the boundary integral method, we reformulate the problem as two coupled contour equations, an evolution equation and a tension determination equation. We first study the well-posedness and the regularity of the generalized tension determination problem in Hlder spaces. Next, we use an appropriate time-weighted Hlder space to study the well-posedness and regularity of the full dynamical problem. We also study the Peskin problem in the 3D case. With the boundary integral method, the 3D Peskin is reformulated as an evolution equation on a unit sphere $\mathbb{S}^2$ for the elastic interface. We use multiple local charts to prove that the problem is well-posed in low-regularity Hlder spaces. Moreover, we prove that the elastic interface becomes smooth instantly in time

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MS134

Computation, Analysis and Modeling of Open Membrane Problems

Lipid bilayer membranes with open boundaries arise in many biophysical processes, including pore formation, vesicle rupture, and parasite egress. In this talk, I present a mathematical and computational framework for simulating their dynamics in viscous Stokes flow. The model couples a three-dimensional bulk fluid, a two-dimensional membrane surface, and a one-dimensional free edge via an energy variational formulation. Under axisymmetry, the system reduces to a one-dimensional mixed-dimensional boundary integral problem. We develop a hybrid boundary elementfinite element method with local mesh refinement to resolve edge singularities. To better understand the solution structure, we also study a simplified elliptic problem with open boundaries, establishing well-posedness and characterizing the edge singularity. Numerical results demonstrate accurate resolution of multiscale fluidmembrane interactions and edge dynamics.

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MS135

SimultaneousReconstruction of Natural Death, Recruitment, and Initial Maturity Rates in a Diffusive McKendrick-von Foerster System with Multiple-age Structure

In population dynamics, the diffusive McKendrick-von Foerster system plays a vital role in modeling the evolution of structured populations comprising both immature and mature individuals. In this work, we propose a computational method to address a multiple-coefficient inverse problem for this system. In particular, our method is aimed to simultaneously reconstruct four coefficients: the natural death rates of both population groups, the recruitment rate, and the initial distribution of mature individuals. Our inverse approach is based on some special transformations and the use of the Fourier-Klibanov basis, which together yield a nonlinear bi-directional ODE-PDE system. This system is then approximated using the variational quasi-reversibility method, which is designed using a suitable pair of perturbing and stabilized operators, along with associated conditional energy estimates. In this work, we prove that the approximation of the immature individuals converges at a Lipschitz rate, whereas the approximation of the mature ones converges at a Hlder rate. The latter convergence rate represents a significant extension of earlier studies on the variational quasi-reversibility inversion. Finally, some numerical examples are presented to show how the proposed inversion works.

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MS135

Some Models of Topological Anderson Insulators

A central property of (Chern) topological insulators is the presence of robust asymmetric transport along interfaces separating two-dimensional insulating materials in different topological phases. A Topological Anderson Insulator (TAI) is an insulator whose topological phase is induced by spatial fluctuations. We will discuss some TAIs modeled by perturbed Hamiltonian and prove that for sufficiently large and highly oscillatory perturbations, the system is in a different topological phase than the unperturbed model. In particular, a robust asymmetric transport indeed appears at an interface separating perturbed and unperturbed phases. Finally, we illustrate the transition from topologically trivial to nontrivial insulators by a numerical simulation.

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MS135

Ergodicity of the Stochastic Nonlinear Schrodinger Equation with Large Damping

We discuss the long time behaviors of the nonlinear Schrodinger equation while being subjected to a random perturbation via Gaussian additive noise. It is well-known that, under the impact of sufficiently strong damping, the dynamics possesses unique ergodicity although the rate of convergence has remained unknown. In this talk, we address the mixing issue, and establish that solutions is attracted toward the unique invariant measure at polynomial rates. Our approach is based on a coupling strategy with pathwise Strichartz estimates. This talk is based on an ongoing joint work with Kihoon Seong.

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MS135

Exact and Numerical Solutions for Stochastic Burgers and KdVBurgers with Variable Coefficients

We provide both exact and numerical solutions for stochastic Burgers and stochastic KdVBurgers equations that include time-dependent coefficients and spatially uniform white noise. Our analysis covers additive, multiplicative, and advection noise. The key result demonstrates that exact solutions can be formed by linking a deterministic Burgers or KdVBurgers equation with a suitable SDE, then composing the deterministic solution with the resulting stochastic flow. We also introduce a new numerical scheme based on this decoupled system. Numerical examples showcase the effectiveness of the approach and compare how different types of noise influence the results.

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MS136

A Population Dynamics Model of Generalized Reciprocity in Female Norway Rats

Rats are often a disdained species despite being very sophisticated creatures. Norway rats, in particular, are highly cooperative and known to live in structured colonies, demonstrate affiliative behaviors like allogrooming, maintain social hierarchy, and readily engage in helping behaviors with conspecifics. It is now well-accepted that female Norway rats demonstrate a high propensity for both generalized and direct reciprocity, while males are known only to be capable of the latter. This exceptional instance of animal generosity raises a number of questions: Is there something about the social structure or hierarchy of female Norway rat groups that is conducive to their unique evolution of generalized reciprocity? How might the structures and compositions of rat social groups elucidate sex-based asymmetries observed in helping behaviors? Our model proposes a mechanism that incorporates a state-dependent norm into an adaptive network model to better understand the population dynamics associated with rat interactions and network formation. Our results confirm that relationships among conspecifics could be driven by persistent interaction and personality compatibility and that high connectivity in Norway rats' social networks results from frequent irregular expansion of existing groups. Analysis of the socio-spatial distribution of traits within population networks shows that females more densely occupy central hubs, which follows from their high social amenability.

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MS136

Evolution of Collective Synchrony on Spatial Biological Networks: Cheating, Policing, and Stability

Collective synchrony is a striking form of biological coordination, often linked to mating displays, yet it creates an evolutionary tension: individuals benefit from signal amplification while also competing to stand out. We study this tradeoff by coupling phase-oscillator dynamics with evolutionary game theory on spatial biological networks. In a networked Kuramoto model, cheaters participate in a synchronized display but strategically shift phase to gain individual advantage while still exploiting the group signal. We also include policing: deviations beyond a detection threshold reveal cheating and are penalized. We characterize how network structure, cheating, and policing shape the stability and robustness of synchrony, and we derive testable predictions for when synchronized populations persist and what strategy compositions are expected at equilibrium.

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MS136

Bounded-Confidence Models of Opinion Dynamics

with Adaptive Confidence Bounds

Peoples opinions change with time as they interact with each other. In a bounded-confidence model (BCM) of opinion dynamics, individuals (which are represented by the nodes of a network) have continuous-valued opinions and are influenced by neighboring nodes whose opinions are sufficiently similar to theirs. In this talk, we introduce discrete-time BCMs with heterogeneous and adaptive confidence bounds. We introduce two new models: (1) a BCM with synchronous opinion updates that generalizes the HegselmannKrause model; and (2) a BCM with asynchronous opinion updates that generalizes the DeffuantWeisbuch model. We analytically and numerically explore our adaptive-confidence BCMs limiting behaviors, including the confidence-bound dynamics, the formation of clusters of nodes with similar opinions, and the time evolution of effective graphs. For a variety of networks and a wide range of values of the parameters that control the increase and decrease of confidence bounds, we demonstrate numerically that our adaptive-confidence BCMs result in fewer major opinion clusters and longer convergence times than the baseline (i.e., nonadaptive) BCMs. In our numerical simulations, we also observe that our adaptive-confidence BCMs can have adjacent nodes that converge to the same opinion but are not receptive to each other. This qualitative behavior does not occur in the associated baseline BCMs.

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MS137

Fast Tensorial Surrogate Models for Parametric Brain Tumor Growth Dynamics in Many-Query Regimes

We consider the construction of efficient surrogate approximations for parametric forward operators arising in simulations of brain tumor growth, modeled by systems of semilinear parabolic partial differential equations. The governing equations comprise coupled nonlinear reactiondiffusion systems posed on heterogeneous spatial domains, with state variables representing multiple tumor cell populations, oxygen transport, and tissue compartment dynamics. The resulting full-order model induces a nonlinear, time-dependent parameter-to-state operator whose repeated evaluation is computationally prohibitive in many-query regimes, including PDE-constrained inverse problems, Bayesian uncertainty quantification, and digital twin frameworks. To mitigate this computational burden, we develop surrogate models based on modern reduced-order modeling (ROM) techniques applied to the discretized forward operator. In particular, we investigate several tensorial ROM formulations that exploit multilinear structure in the reduced dynamics, using a classical proper orthogonal decomposition (POD) ROM as a reference baseline.

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MS137

Recycling and Streaming for Large-Scale Nonlinear Inverse Problems

Many imaging inverse problems assume a known linear forward operator, yet practical systems often suffer from uncertainty in acquisition geometry, such as projection angles in computed tomography or sensor positions in photoacoustic tomography. These uncertainties introduce nonlinearity and require joint estimation of both the image and the forward model parameters. We propose a nonlinear recycled majorizationminimization generalized Krylov subspace (NL-RMM-GKS) framework for large-scale inverse problems with uncertain forward operators. The method extends MM-GKS to nonlinear settings by combining majorizationminimization for nonsmooth regularization with Krylov subspace projection and subspace recycling, ensuring bounded memory usage. Two complementary formulations are developed: an alternating minimization approach that alternates between image updates and GaussNewton parameter estimation, and a variable projection approach that eliminates the image variable and optimizes directly over the parameters using inexact inner solves. We further introduce streaming variants that process data sequentially, enabling reconstruction from large or dynamically acquired datasets without storing the full operator. We carry out rigorous numerical experiments in tomography to demonstrate that our proposed framework achieves high-quality reconstructions with bounded memory requirements, making it suitable for large-scale dynamic imaging problems.

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MS138

Flow Maps: Flow-based generative models with lightning-fast inference

Flow-based models have spurred a revolution in generative modeling, driving astounding advancements across diverse domains including high-resolution text to image synthesis and de-novo drug design. Yet despite their remarkable performance, inference in these models requires the solution of a differential equation, which is extremely costly for the large-scale neural network-based models used in practice. In this talk, we introduce a mathematical theory of flow maps, a new class of generative models that directly learn the solution operator for a flow-based model. By learning this operator, flow maps can generate data in 1-4 network evaluations, leading to orders of magnitude faster inference compared to standard flow-based models. We discuss several algorithms for efficiently learning flow maps in practice that emerge from our theory, and we show how many popular recent methods for accelerated inference – including consistency models, shortcut models, align your flow, and mean flow – can be viewed as particular cases of our formalism. We demonstrate the practical effectiveness of flow maps across several tasks including image synthesis, geometric data generation, and inference-time guidance of pre-trained text-to-image models.

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MS138

Topological Limitations and Capabilities for Autoencoding Dynamics

Given a "data manifold" $M \subset \mathbb{R}^n$ and "latent space" L, an autoencoder is a pair of maps consisting of an "encoder" $E\colon \mathbb{R}^n \to L$ and a "decoder" $D\colon L \to \mathbb{R}^n$ such that the restricted "round trip map" $D \circ E|_M$ is as close as possible to the identity map of M. Autoencoders are used to learn low-dimensional representations of static objects, as well as dynamic objects governed by dynamical or control systems. For the dynamic case, one further attempts to learn a dynamical or control system on the latent space L such that D and E intertwine the dynamics on M and L as closely as possible. Topological obstructions dictate that continuous autoencoders accomplishing either of the static or dynamic tasks arbitrarily uniformly well do not generally exist, yet practitioners widely report learning practically useful continuous autoencoders via neural networks. I will offer a possible resolution to this apparent paradox, and counterbalance this with further tradeoffs, limitations, and evidence suggesting that caution may be needed. Aspects of this talk are based on joint works with Josh McCarter and Eduardo Sontag.

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MS138

Topological Invariance and Breakdown in Learning

We prove that for a broad class of permutation-equivariant learning rules (including SGD, Adam, and others), the training process induces a bi-Lipschitz mapping between neurons and strongly constrains the topology of the neuron distribution during training. This result reveals a qualitative difference between small and large learning rates ?. With a learning rate below a topological critical point ?*, the training is constrained to preserve all topological structure of the neurons. In contrast, above ?*, the learning process allows for topological simplification, making the neuron manifold progressively coarser and thereby reducing the models expressivity. Viewed in combination with the recent discovery of the edge of stability phenomenon, the learning dynamics of neuron networks under gradient descent can be divided into two phases: first they undergo smooth optimization under topological constraints, and then enter a second phase where they learn through drastic topological simplifications. A key feature of our theory is that it is independent of specific architectures or loss functions, enabling the universal application of topological methods to the study of deep learning.

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MS138

Symmetry and Topological Phase Transitions in Neural Network Training Dynamics

Training deep neural networks can exhibit abrupt qualitative changes in learned representations. This talk presents a physics-inspired view of training dynamics organized by symmetry, topology, and phase-transitionlike behavior. We discuss how symmetry constraints and their effective breaking shape representation evolution, and how topological descriptors can characterize transitions between distinct training regimes. The aim is to build a common theoretical framework that bridges deep learning theory, physics, and mathematics.

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MS139

Identifiability Linear Compartmental Models

Linear compartmental models are widely used to describe transport and exchange processes in pharmacokinetics, ecology, and systems biology. A central question for these models is structural identifiability: whether parameters can be uniquely recovered from ideal input and output data. Many of the algebraic tools developed to address this question rely on the existence of a minimal input-output equation, a property that is guaranteed for strongly connected models. As a result, much of the existing theory has been restricted to this class. In this talk, we investigate recent extensions and conjectures related to identifiability for linear compartmental models that are not strongly connected. We analyze how the graph structure of the model influences form of input-output equations and identifiability of models.

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MS139

Distributions of Transformations of Coalescence Times in Species Trees Given Species Trees

In the multispecies coalescent model described by Rannala and Yang (2003), gene trees are random objects whose distributions depend on the species tree with parameters for ancestral population sizes and numbers of generations between speciation events. Distributions of DNA site patterns can be described by a hierarchical model that depend on the DNA being determined by the gene tree with branch lengths and a substitution model, and the gene tree depending on the species tree. The Rannala and Yang model gives the joint distribution of gene tree topology and coalescence times in the gene trees. These coalescence times are random variables that can be transformed to find distributions of things such as the time to the most recent common ancestor, pairwise coalescence times between non-sister taxa, and individual branch lengths in both the rooted and unrooted gene trees.

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MS139

Computing and Stabilizing Ideals of JukesCantor Network Models

Phylogenetic networks model reticulate evolutionary events such as hybridization and horizontal gene transfer. Our work presents a symbolic computational framework for studying the algebraic structure of the JukesCantor model on phylogenetic networks. We implement a computational pipeline which includes an algorithm in Macaulay2 that constructs monomial parameterizations for arbitrary network and an approach that computes generators of their defining ideals via multigraded implicitization. This enables systematic investigation of network ideals beyond small examples. Applying this pipeline to several recursively defined network families, we observe and, in certain cases, prove stabilization phenomena: the defining ideals eventually stabilize to a fixed prime ideal of constant dimension as the network grows. These results not only provide new insights in the algebraic structure of Jukes-Cantor networks but also demonstrate the advantage of using symbolic computational tools in studying the network models.

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MS139

A Comparative Analysis of Boolean and Stochastic Models of Dna Repair Response in Bacteria

The SOS system is an emergency DNA repair system in bacteria, which has been primarily studied in the model organism of E. coli. We developed a Boolean model with 22 variables and 5 parameters, and an updated stochastic model using the Gillespie algorithm with 28 components and 148 reactions. We compare the fixed points of the Boolean model with the probability distribution of the stochastic model at various times throughout the simulations, and each model helps validate the other.

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MS140

Conservation Laws in Besov Spaces

In this talk, we present an analytical method developed by Lucier in 1988 to study the regularity of scalar conservation laws in one space dimension, having smooth and convex fluxes. This involves measuring their regularity in nonlocally convex spaces determined by quasi-norms related to the solution's approximation properties in $L^1(R)$ by discontinuous, piecewise affine functions. The technique is based on nonlinear approximation and characterizes these spaces in terms of Besov spaces, which is a novel approach. Furthermore, we will discuss ongoing research directed towards extending Lucier's method to certain systems of conservation laws.

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MS140

Nonclassical Riemann Solutions in Systems of Conservation and Balance Laws

We consider systems consisting of one conservation law coupled with a balance law, as well as systems of two balance laws, and investigate the structure of Riemann solutions arising from piecewise constant initial data. While classical theory describes solutions in terms of shocks, rarefactions, and contact discontinuities, specific systems admit non-classical behaviors, including singular solutions such as over-compressive singular or delta shocks. These arise in models often motivated by physical phenomena in gas dynamics, traffic flow, and biological aggregation, among others. In this talk, I will present a range of nonclassical solution structures that emerge in such systems, highlighting scenarios where classical entropy conditions fail to select a unique solution. We discuss analytical techniques used to construct and classify these solutions, including the use of regularization methods such as Dafermos viscous approximation and geometric singular perturbation theory. The theoretical findings are numerically confirmed using the Local Lax-Friedrichs scheme.

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MS140

A Shape Optimization for the Ginzburg-Landau Energy with Curvature Penalization

We will describe a shape optimization problem in the plane, for the Ginzburg Landau energy to predict quantized cusps. This serves as a toy model for phase transitions in nematic liquid crystals.

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MS141

A Risk-Informed Machine Learning Framework for County-Level Opioid Mortality

The opioid crisis remains a leading cause of preventable death in the United States, with mortality rates continuing to rise despite varied policy interventions. Effective response requires identifying regions persistently at high risk of opioid-related mortality, those whose underlying characteristics indicate sustained vulnerability. In this work, we develop a novel county-level risk score methodology combining machine learning prediction with residual analysis to distinguish structurally at-risk counties. Using socioeconomic and access-related covariates across the continental U.S., we train and compare several predictive models and derive risk scores that capture persistent deviation between observed and expected mortality. We demonstrate robustness of the scores across several different models and over time, and investigate the socioeconomic drivers underlying identified risk groups. We discuss implications for the prioritization of public health resources and targeted intervention strategies.

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MS141

Markov Chain Monte Carlo Methods for Curve Reconstruc Tion and Point Cloud Data Analysis

Point cloud data have become increasingly vital due to their ability to capture detailed, multi-dimensional representations of physical objects and their surrounding environments. Point clouds are nowadays central to applications across industry and academia that range from robotics, navigation systems, and 3D printing to architecture, manufacturing, and agriculture. Despite its importance, the analysis of point cloud data faces several limitations, including high computational cost due to large data volume, contamination with localization noise and inaccuracies caused by sensor limitations, and missing points due to environmental factors or sensor positioning. Moreover, unavailable uncertainty quantification in reconstructed structures remains a critical gap in applications requiring reliable estimation. We present a fully Bayesian framework for point cloud data analysis and curve reconstruction. Our framework models a clouds points as noisy perturbations of latent positions constrained to lie on closed polylines, jointly inferring polyline vertices and connectivity, latent coordinates, and noise characteristics. Posterior inference is performed via a specialized Markov chain Monte Carlo sampler tailored to point cloud data processing. Experiments on synthetic data demonstrate accurate curve reconstruction while providing uncertainty quantification.

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MS141

Topological Fingerprints of Commensurate Order in Twisted Moir Lattices

Moir patterns in twisted bilayer materials exhibit long-range periodic order that is highly sensitive to twist angle. Identifying commensurate angles from real-space atomic structures remains challenging, as spectral and geometric methods emphasize global periodicity and are sensitive to disorder and finite-size effects. We introduce a data-driven topological framework that quantifies moir periodicity by treating atomic configurations as point-cloud data and extracting multiscale signatures using persistent homology. At the core of our approach is a small-neighborhood separation filter that removes redundant local motifs in persistence diagrams while preserving key structural features, enabling sharp minima in Wasserstein distances between twisted and untwisted reference configurations that accurately recover commensurate angles. We benchmark the framework against geometric and spectral similarity measures and show that the resulting topological descriptors remain stable under positional disorder ranging from weak to strong perturbations in the bond length. We further transfer the descriptors using a constrained Gaussian Process surrogate to sparsely sampled configurations of a twisted $MoTe_2$ dichalcogenide bilayer. These results establish topological descriptors with neighborhood separation as a robust framework for identifying commensurate order in moir systems and tracking commensurate structural similarity under disorder, sparsity, and finite-size effects.

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MS141

Diffusion Dynamics and Network Geometry in Blockchain and Critical Infrastructure Networks

This talk studies how network geometry and topology influence diffusion processes in complex networks, with applications to cryptocurrency blockchains and critical infrastructure systems. Diffusion is treated as the spread of information, infection, or failure through a network. We use epidemic-style diffusion models, including the Kertsz threshold model and the Susceptible-Infected model, to examine how structural features such as centrality, clustering, shortest-path distance, and local motif patterns affect diffusion behavior. The analysis combines simulation studies on random network models with applications to Ethereum transaction data and European power-grid networks. We also use bootstrap and Bayesian uncertainty quantification to study variability in diffusion trajectories and model parameters. This provides a statistical framework for studying how failures or information may spread across networks with different structures.

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MS142

Improving the Computation of Bessel Functions and Their Zeros

We present efficient and highly accurate algorithms for computing the Bessel functions $J_\nu(x)$ and $Y_\nu(x)$, their derivatives, and their zerosquantities that play a central role in many problems of science and engineering. The proposed methods also enable the reliable computation of zeros of general linear combinations

$$C_\nu(x) = \cos(\alpha)J_\nu(x) - \sin(\alpha)Y_\nu(x),$$

as well as of cross products such as

$$J_\nu(x)Y_\nu(\beta x) - J_\nu(\beta x)Y_\nu(x).$$

These results are directly relevant to applications in wave propagation, spectral methods, boundary value problems, and eigenvalue computations in physics and applied mathematics. This is joint work with Javier Segura and Nico M. Temme. Work supported by project PID2024-159583NB-I00.

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MS142

Algorithmic and Ai-Driven Developments in Special Functions in Mathematica

This talk surveys recent algorithmic developments in the special functions framework of the Wolfram Language. The focus will be on robust computational and symbolic methods for new families of special functions (Heun-type functions, multivariate hypergeometric functions, the MeijerG/FoxH framework and others), improvements to long-standing function families, and general holonomic solvers. Closely related extensions, including fractional calculus and generalized polylogarithmic functions, will also be discussed, together with emerging AI-driven techniques for tasks such as differential equation solving and symbolic expression simplification. Recent large-scale efforts to enhance and restructure documentation and educational materials on special functions, calculus, complex analysis and partial differential equations will be briefly highlighted.

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MS142

Computing Generalized Hypergeometric Functions via Rational-Algebraic Transformations

It is well-known that certain Möbius (linear fractional) transformations provide analytic continuation of the Gauss hypergeometric function. These transformations work by exchanging the roles of the three singular points $(0, 1, \infty)$ of the Gauss hypergeometric differential equation. As such, every Gauss hypergeometric function is represented as a linear combination of at most two others. Problematically, not one of these transformations brings the points $e^{\pm i\pi/3}$ closer to the origin, and convergence in a neighbourhood of these is also troublesome. In this work, we explore the use of a rational-algebraic transformation that induces pointwise convergence to any ${}_{q+1}F_q$ throughout the complex plane. We compare and contrast this series with another globally convergent method, a mapped Chebyshev series obtained approximately by the ultraspherical spectral method.

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MS142

Special Functions and the Numerical Solution of Initial-Boundary Value Problems

Classical special functions emerge naturally in the study of constant-coefficient PDEs on the line, particularly in short-time asymptotic expansions near discontinuities. For initial-boundary value problems (IBVPs), special functions, and their generalizations, play an even more important role through the Unified Transform Method. In this talk, we explore how singularities in the integral representations for these generalized special functions play a role in the solution to IBVPs. We highlight the challenges associated with computing with these representations and explore time integration methods built upon their numerical evaluation.

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MS143

High Rank Zeta Functions of Arithmetic Orders and Curve Singularities

We study a high rank generalization of the singular Dedekind zeta functions arising from the classical "impossible" problems of counting modules over non-Dedekind domains. Surprisingly, such zeta functions give rise to remarkable special functions represented as q-series, leading to brand new infinite families of Rogers Ramanujan type identities. Progress permitting, I will discuss an ongoing project with Ken Ono and Axiom Math team on AI-assisted attack of new conjectured identities.

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MS143

Congruences and Cranks for Partitions with Bounded Largest Part

We will showcase several varieties of infinite families of congruences for partitions into parts from a finite set. We will discuss the corresponding varieties of crank statistics witnessing these congruences and show that Dyson's rank of a partition witnesses infinitely many of them. Our methods include polyhedral geometry, identifying power series to polynomials, and q-series.

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MS143

Further Analogs of Andrews' Spt-Function Identity

Andrews' celebrated identity for the spt-function, which relates the spt-function to the partition function and the second Atkin-Garvan rank moment, is obtained using Watson's q-analog of Whipple's theorem. Subsequent analogs of this identity using basic hypergeometric transformations due to Bailey and Andrews have given rise to new partition-theoretic interpretations of Ramanujan's mock theta functions, among other exciting results. In this talk, we introduce two new analogs of Andrews' spt-function identity using basic hypergeometric transformations due to Verma and Jain and explore the possibility of further work building on these new identities.

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MS143

Estimating the Imaginary Parts of the Roots of $\zeta(s)$ and Other Partition Zeta Functions

Partition zeta functions are special functions that generalize the Riemann zeta function $\zeta(s)$ using properties of integer partitions. We present an elementary method for estimating the imaginary parts of the roots of a certain class of partition zeta functions that includes $\zeta(s)$, using the method of least squares and the values of special sequences of integers. As a "prime example", we estimate the imaginary parts of the first five nontrivial roots of $\zeta(s)$ from information about the sequence of prime numbers.

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MS144

Scattering of Electromagnetic Waves by a Quasiperiodic Grating: A High-Order Numerical Method

In many applications of scientific and engineering interest, the accurate modeling of linear waves scattered by quasiperiodic media plays a crucial role. The ability to numerically simulate such configurations robustly and rapidly is of overwhelming importance in photonics applications. In this talk we will discuss the specific problem of electromagnetic radiation interacting with a two-dimensional multiply layered diffraction grating with quasiperiodic interfaces. We describe how the classical boundary perturbation method of Field Expansions can be extended to this two-dimensional problem, and with specific numerical experiments we will show the remarkable efficiency, fidelity, and high-order accuracy one can achieve with an implementation of this algorithm.

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MS144

Recovering Internal Waves Features from Magnetic Field Data

Oceanic internal waves occur beneath the sea surface and can be described as gravity waves oscillating within a density-stratified fluid. They are relevant to oceanographers and engineers as they contribute to ocean mixing and turbulence, and affect offshore structures. It is known that internal waves generate magnetic signals as conductive seawater moves through the Earth's magnetic field. However, the amplitudes of these signals are several orders of magnitude smaller than the background field's, posing significant challenges to their detection using traditional methods based on remote sensing via satellites. This work takes advantage of potential flow theory to build a simple model of a two-layer fluid in two spatial dimensions, coupling it with the linearized magneto-hydrodynamic (MHD) equations to characterize the magnetic field induced by sinusoidal internal waves. Our implementation produces a magnetic field whose features validate well against commercial-tools-based MHD models. Using synthetic magnetic field data collected from only a few probes placed near the seafloor, we are able to recover essential features of the internal waves. As technological advancements allow for more accurate detection of these fields via magnetometers, our numerical results show that sparse magnetic measurements contain sufficient information for accurate parameter recovery, establishing potentially viable pathways for practical oceanographic sensing applications

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MS144

A Mixed Finite Element Method for the Stochastic Boussinesq Equations with Multiplicative Noise

In this talk, I discuss a fully discrete mixed finite element approximation of the stochastic Boussinesq system driven by multiplicative noise. The spatial discretization is carried out using a standard mixed finite element method, while time integration is based on a semi-implicit Euler-Maruyama scheme. By combining a localization technique with high-moment stability estimates, we derive rigorous error bounds for the velocity, pressure, and temperature approximations. As a direct consequence, we establish convergence in probability of the fully discrete scheme in both L2 and the energy norms. Several numerical experiments are presented to confirm the theoretical error estimates and to illustrate the effectiveness of the proposed method.

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MS145

Catch-22s of Reservoir Computing

Reservoir Computing (RC) is a simple and efficient model-free framework for forecasting the behavior of nonlinear dynamical systems from data. Here, we show that there exist commonly-studied systems for which leading RC frameworks struggle to learn the dynamics unless key information about the underlying system is already known. We focus on the important problem of basin prediction: determining which attractor a system will converge to from its initial conditions. First, we show that the predictions of standard RC models (echo state networks) depend critically on adequate "warm-up" data from the real system, needing almost the entire transient in order to identify the correct attractor (by which point predictions are moot). Accordingly, we turn to Next-Generation Reservoir Computing (NGRC), an attractive variant of RC that requires minimal warm-up time. By incorporating the exact nonlinearities in the original equations, we show that NGRC can accurately reconstruct intricate and high-dimensional basins of attraction, even with sparse training data (e.g., a single transient trajectory). Yet, even tiny uncertainties in the exact nonlinearity can render prediction accuracy no better than chance. Our results highlight the challenges faced by data-driven methods in learning the dynamics of multistable systems and suggest potential avenues to make these approaches more robust.

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MS145

A Dimension Reduction Technique for Modern Hopfield Networks as Hypergraphs Modeling High-Order Interactions

A modern Hopfield network can be viewed as a weighted hypergraph in which each memory pattern forms a hyperedge connecting many neurons simultaneously; because these higher-order interactions span a high-dimensional state space whose size grows rapidly with the number of neurons and stored patterns, the resulting dynamics are mathematically challenging to characterize and analyze. In this talk, we present a dimension reduction technique to study such hypergraphs. This technique represents local interactions in a system as a matrix, allowing global quantities such as partition functions, to be computed through matrix products and spectral analysis.

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MS145

Inference for Time Series of Networks with Unknown Vertex Correspondence

Existing methodology for changepoint localization in an evolving time series of networks generally relies on accurately prescribed vertex correspondence between network realizations at different times. However, such vertex alignments are often misspecified or even unknown. To understand the impact of vertex misalignment on inference for dynamic networks, two illustrative models are constructed for network evolution, each with a similar changepoint. Different techniques are compared for changepoint localization, ranging from the simple network statistic of average degree to the more involved and recently developed procedure of Euclidean mirrors. In one model, vertex misalignment causes comparatively little error, and in the other, it seriously impairs localization, although the Euclidean mirror procedure can nevertheless extract a meaningful signal. It is shown how misalignment between network realizations at different times can effectively weaken their underlying correlation, impeding inference procedures that rely on accurate inference of such correlation. Graph matching and optimal transport is discussed, both of which are potential mechanisms for mitigating errors from misalignment, but which may also fail to improve inference under certain models. Simulations are presented that illustrate these varying effects on approaches to localization.

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MS145

Agglomerative Matching on Networks

In the setting of an observational study, we may want to compare treatment and control units where the control units are both smaller and more numerous than the treatment units. In order to make comparable causal inferences, then, we seek to group control units together into agglomerations that appear as similar to the treatment units on all covariates as possible, where an underlying network structure governs the allowable groupings. We call this problem "agglomerative matching", which resembles the well-known synthetic control method, but is fundamentally additive rather than averaging. We present recent work on this problem, including an application of assessing the impact of Indigenous land rights on reforestation in the Atlantic Forest in Brazil.

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MS147

Multifidelity Covariance Estimation via Regression on the Manifold of Symmetric Positive Definite Matrices

We introduce a multifidelity estimator of covariance matrices formulated as the solution to a regression problem on the manifold of symmetric positive definite matrices. The estimator is positive definite by construction, and the Mahalanobis distance minimized to obtain it possesses properties enabling practical computation. We show that our manifold regression multifidelity (MRMF) covariance estimator is a maximum likelihood estimator under a certain error model on manifold tangent space. More broadly, we show that our Riemannian regression framework encompasses existing multifidelity covariance estimators constructed from control variates. We demonstrate via numerical examples that the MRMF estimator can provide significant decreases, up to one order of magnitude, in squared estimation error relative to both single-fidelity and other multifidelity covariance estimators. Furthermore, preservation of positive definiteness ensures that our estimator is compatible with downstream tasks, such as data assimilation and metric learning, in which this property is essential.

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MS147

Geometry of the Signed Support of a Multivariate Polynomial and Descartes Rule of Signs

In this talk, we discuss combinatorial conditions on the signed support of a multivariate polynomial, that is, on its set of exponent vectors and the signs of its coefficients, that provide upper bounds on the number of connected components of the subset of the positive real orthant where the polynomial takes negative values. We frame this problem as a generalization of Descartes' rule of signs to multivariate polynomials and discuss its applications to the study of biochemical reaction networks.

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MT1

Introduction to Bayesian Inverse Problems Governed by Partial Differential Equations (PDEs): A Hands-on Tutorial using hIPPYlib

This tutorial introduces hIPPYlib, an open-source Python framework for large-scale deterministic and Bayesian inverse problems governed by PDEs. Built on top of FEniCS and PETSc, hIPPYlib provides scalable adjoint-based algorithms for PDE-constrained optimization, uncertainty quantification (UQ), and Bayesian inference. The session will combine mathematical background with hands-on computational examples implemented in Jupyter notebooks. Participants will learn how to formulate inverse problems in a Bayesian framework, compute gradients and Hessian actions using adjoint methods, and solve large-scale optimization problems with inexact Newton-CG algorithms. The tutorial will also introduce low-rank approximations of posterior covariance operators, scalable sampling methods for Gaussian random fields, and Hessian-informed Markov chain Monte Carlo sampling methods. Through guided examples, attendees will experiment with modern algorithms in PDE-based inverse problems and UQ, while gaining practical experience using hIPPYlib to construct forward models, define priors and likelihoods, and perform deterministic and Bayesian inversion. This tutorial also serves a prelude to Dr. Petras plenary talk "IP8 Scalable Methods for Large-Scale Bayesian Inverse Problems Under Model Uncertainty." The hIPPYlib project started in 2016 with initial support from the US National Science Foundation under awards ACI-1550593, ACI-1550547.

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MP1

Randomized Algorithms for Recovering Monodromy Groups amidst Errors

Certifying the computation of monodromy groups can be computationally difficult. In practice, one computes it by taking the group generated by a few random monodromy permutations, a method subject to numerical and probabilistic errors. Under some generalizing monodromy assumptions, we analyze the reliability of this method and develop an improved version which can detect errors in both sampled permutations and computed candidate groups. Through examples, we illustrate this improvement and the maintained efficiency of our verification method.

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MP1

A Higher-Order Super-Linear Convergent Interior Point Method for Second-Order Cone Programming

In second-order conic optimization, the central path lacks an analytic extension to $\mu = 0$ in the absence of the strict complementarity condition. Motivated by tools from real algebraic geometry and the Newton-Puiseux theorem, we introduce a reparametrization $\mu \mapsto \mu^\rho$, where ρ is the ramification index of the central path, to recover the analyticity of the central path at $\mu = 0$. We then develop a higher-order interior point method that utilizes higher-order Taylor approximations of the reparametrized central path to define search directions. The proposed algorithm is designed to achieve superlinear convergence even when the strict complementarity fails.

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MP1

Modeling Microbial Co-Occurrence Networks with the Shell Distribution Exponential Random Graph Model

The focus of this project is an exponential random graph model (ERGM) arising from the k-core structure of networks. The central challenge is the computation of the maximum likelihood estimate (MLE). Because this model is not log-linear, the MLE is approximated using Markov chain Monte Carlo (MCMC) algorithms that explore the space of graphs by repeatedly adding and removing edges and recomputing the sufficient statistics. Each proposed move requires recomputing the statistics for the modified graph, which can be computationally expensive. We study how the statistics change under the addition or deletion of a single edge and explore the technical challenges of accelerating the MCMC procedures used for likelihood estimation. We apply an updated algorithm to compare the structural properties of two microbial co-occurrence networks which arise from UH Manoa's C-MAIKI project sampling multiple sites along the Waimea watershed.

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MP1

Linear Fundamental Matrix Estimation from 7 Or 5 Points

We revisit the problem of estimating the fundamental matrix of a pair of perspective cameras, a cornerstone of geometric computer vision. As is well-known, linear solvers require at least 8 point correspondences, whereas nonlinear minimal solvers require just 7 in the uncalibrated case or 5 in the calibrated case. In this paper, we consider a special case of the 7-point problem where 5 of the points are configured to lie on two lines, which has previously been shown to have a unique solution. As a theoretical contribution, we offer an analysis of how this uniqueness manifests in the standard 7-point algorithm. On a practical level, we provide the first practical linear solver for the minimal problem associated to this special configuration. Additionally, we evaluate a heuristic 5-point fundamental matrix solver based on the construction of virtual midpoints. When combined with early non-minimal fitting, the runtime and accuracy of our solver is competitive with the state-of-the-art (SoTA) on multiple benchmarks.

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PP1

Can Quantum Computers Be Used for Parameter Estimation in Epidemiological Models?

Parameter estimation is a fundamental challenge in the calibration of ordinary differential equation (ODE) models, where repeated numerical integration can lead to high computational cost. In this work, we investigate whether near-term quantum algorithms can be leveraged to assist parameter estimation in nonlinear dynamical systems. Focusing on the susceptibleinfectedrecovered (SIR) model, we develop a hybrid classicalquantum framework that reformulates a data-assimilationbased parameter estimation problem as a combinatorial optimization task. Model dynamics and data assimilation are enforced entirely on the classical side, while the resulting parameter estimation objective is discretized and approximated by a quadratic unconstrained binary optimization (QUBO) surrogate. This surrogate is mapped to an Ising Hamiltonian and minimized using the Quantum Approximate Optimization Algorithm (QAOA). Numerical experiments with synthetic data demonstrate that the proposed approach accurately recovers epidemiological parameters and reproduces observed dynamics while requiring substantially fewer ODE solves than classical methods. This framework avoids quantum state tomography and is compatible with near-term quantum hardware, illustrating a viable pathway for integrating quantum optimization into data-driven parameter estimation for nonlinear dynamical systems.

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PP1

Multi-Omics Integration of Mirna and Mrna Identifies Shared Neurodegenerative Genes and Their Pathways in Parkinson and Multiple Sclerosis Dis-

eases

Neurodegenerative diseases (NDDs) such as Parkinsons disease (PD) and Multiple Sclerosis (MS) involve progressive neuronal dysfunction and may share molecular mechanisms. Beyond protein aggregation, growing evidence implicates dysregulated RNA metabolism in NDD pathogenesis. Because most of the genome is transcribed into non-coding RNAs, including microRNAs (miRNAs), and miRNAs post-transcriptionally regulate neurodegenerative pathways, we hypothesize that PD and MS share miRNAmRNA regulatory signatures and convergent neuronal pathways. Public datasets were obtained from GEO: PD miRNA profiles from human iPSC-derived midbrain organoids (GSE294029) and MS bulk RNA-seq mRNA profiles from selected conditions in GSE268150. Differential expression identified dysregulated miRNAs (PD) and mRNAs (MS). Predicted targets of PD-associated miRNAs were intersected with MS DEGs to reveal shared interactions. Targets from the top 50 PD miRNAs yielded 4,412 mRNAs; the MS dataset contained 54 DEGs. Intersection identified 29 common mRNAs (28 downregulated, 1 upregulated). GO enrichment (BP, MF,CC) highlighted shared disruption of chromatin organization and transcriptional repression, implicating regulators including CTCF, SMARCAD1, CHD1, SPEN, and REST. These results suggest PD and MS converge on chromatin-centered nuclear regulatory processes, and nominate underexplored regulators (CTCF, SMARCAD1, SPEN) as candidate cross-disease drivers for follow-up validation.

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PP1

Uncovering the Unknown Unknowns

We argue for shifting AI in healthcare from emulation of human-designed datasets to discovery of novel signals by learning acquisition processes and seeking unknown unknowns. Methods include: (i) active experimental design to discover informative data sources, (ii) representation learning to surface anomalous but predictive patterns, and (iii) model-guided data acquisition that iteratively refines sensors and protocols. Case studies show how nontraditional features can improve predictive performance and reveal unexpected risk markers. We outline evaluation frameworks and governance safeguards for discovery-driven healthcare AI.

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PP1

Modeling Fractional Dust-Acoustic Shock Waves in a Complex Plasma Using Novel Techniques

This work investigates how fractionality affects the dynamical behavior of dust-acoustic shock waves that arise and propagate in a depleted-electron complex plasma. This model consists of inertial negatively charged dust grains and inertialess nonextensive distributed ions. Initially, the fluid model equations that govern the propagation of nonlinear dust- acoustic shock waves are reduced to the integer Burgers-type equations using the reductive perturbation method. Thereafter, the integer Burgers-type equations are converted to the fractional cases using a suitable transformation. For analyzing this fractional family, both the Tantawy technique and the new iterative method are implemented within the Caputo sense framework. These methods can produce highly accurate analytical approximations without necessitating stringent assumptions or intricate computational processes, in con- trast to other similar methods. Numerical examples and the calculation of the absolute error demonstrate the efficacy of the suggested methodologies, emphasizing their superior precision and swift convergence.

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PP1

Heat Transport Efficiency in Rheology of Radiated Casson Material Due to Porous Shrinking Cylinder

In several industrial and thermal management systems, maintaining continuous thermal propagation is essential because it makes thermal engineering mechanisms and machinery more efficient. This article presents a unique contribution by thoroughly examining the mass transfer and thermal properties of Casson fluid in motile microorganism suspensions over a shrinking cylinder. The physical characteristics of the problem are governed by partial differential equations, which are converted to ordinary differential equations using appropriate similarity variables. To find the duality of solutions, the Bvp4c solver from MATLAB is used in the solution approach. The various flow characteristics of Casson fluid have been illustrated with graphs. The engineering quantities, such as friction factor, Sherwood, Nusselt, and density number have also been computed and graphically depicted. The studys main finding reveals that higher suction strength enhanced the skin friction coefficient and transportation rate in the shrinking zone. There is a higher Eckert number and thermal radiation decreased the thermal transport rate, whereas reaction rate increased the solutal transfer rate. The results also demonstrated that in the second branch solution, with increasing magnetic and Casson factors, the fluid flow velocity distribution decreases, while in the first branch solution, it increases. These findings add important insights into optimizing heat transport in modern systems of engineering.

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PP1

Comparative Analysis of Optimizers in LSTM-Based Stock Price Prediction.

The prediction of stock prices remains a central challenge in financial engineering and computational finance, characterized by inherent non-stationarity, high-frequency noise, and complex temporal dependencies. Long Short-Term Memory (LSTM) networks have emerged as a predominant architecture for capturing such temporal dynamics; however, the performance of these models is strongly influenced by the choice of optimization algorithm used during training. While the ADAM optimizer has widely been adopted in financial time-series modeling, systematic comparative studies examining advanced optimizers remain sparse within the financial domain. This study conducts a rigorous empirical investigation of first-order (ADAM) and second-order (AdaHessian, SophiaG) optimization methods, training identically-configured LSTM models on publicly available equity price data for Apple. Performance is evaluated through multiple complementary metrics: Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), coefficient of determination (R^2), and Directional Accuracy (DA).

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PP1

A Meta-Analysis of Lake Model Performance

The scientific literature contains a well-known gap concerning the lack of industry standards in mathematical verification of lake models. To address this gap, we present a systematic review on how a lakes physical properties, its model calibration, and its model sensitivity/uncertainty analysis influence the statistical validation of their simulations. To determine the primary drivers of lake model accuracy, we performed K-means clustering and random forest algorithms on a dataset containing lake metadata and reported statistical errors, with optimized hyperparameters to cement the validity of our inferences. The findings provide critical insights for limnologists on the recommended methodology of model verification, leading to more well-informed lake management decisions.

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PP1

Perturbation-Based Selection for Functional Regressors: Stability, Geometry, and Group Structure

Variable selection for functional regressors can be viewed as extracting sparse structure from ill-conditioned problems induced by discretization and basis expansions. We propose a perturbation-based perspective that connects subsampling stability and correlation-aware column perturbations within a common framework. Starting from functional regression in a finite-dimensional representation (splines, wavelets, or FPCA scores), we analyze two perturbation operators: (i) row subsampling leading to stability selection frequencies and (ii) column perturbations constrained to correlation groups, inspired by geometric resampling on the unit sphere. The latter motivates an FDA adaptation of SelectBoost, where each predictor is perturbed within an equivalence class defined by correlation thresholds or by domain-aware neighborhood structure. We show how group structure naturally arises from basis blocks and leads to group-sparse penalization as the base selector. The method outputs a two-parameter family of selections indexed by subsampling rate and correlation-perturbation strength, enabling a principled study of monotonicity, regularization paths, and precisionrecall trade-offs. We discuss complexity and provide practical guidance on perturbation grids, enforcing monotone selection proportions, and designing locality-preserving association matrices for functional domains.

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PP1

Inferring Hidden Trajectories in Discretely Observed Markov Jump Processes: A Regularized Likelihood Approach on the Ehrenfest Model and Beyond

In previous work, likelihood maximization for continuous-time Markov chains was studied, showing that the maximum likelihood estimator (MLE) can be computed via EM or Markov chain Monte Carlo methods. We consider estimation of the infinitesimal generator Q of a finite-state continuous-time Markov jump process $X(t)$ when only the endpoints $X(0)$ and $X(T)$ are observed. Under this extreme censoring, the classical MLE does not exist. We introduce a regularized likelihood functional and prove existence of a maximizer. The approach is illustrated using Manhattan taxi movement data, where locality is enforced by constraining Q to neighboring transitions encoded through the graph Dirac operator. Using the regularized estimator, we reconstruct unobserved trajectories via a Doob h-transform embedded in an expectation maximization framework. Numerical examples demonstrate recovery of hidden distributions and scalability to sparse graphs.

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PP1

Representation-Theoretic Bounds on Parameter Efficiency in Group-Equivariant Neural Networks

We establish fundamental limits for representing neural networks with cyclic group symmetry constraints. While standard neural networks require $O(n^2)$ parameters for an $n \times n$ weight matrix, group-equivariant networks require only $O(n)$ parameters due to representation-theoretic

constraints. We provide complete characterization using Schur's lemma and representation theory of cyclic groups. For $\mathcal{G} = \mathbb{Z}/n\mathbb{Z}$, the dimension of equivariant linear maps is $d_{\mathcal{G}} = \sum_i m_i n_i \dim \mathrm{End}_{\mathcal{G}}(\chi_i)$ where χ_i are irreducible representations with multiplicities m_i, n_i. For regular representations of prime-order cyclic groups, we prove exactly p free parameters suffice (versus p^2 generically), yielding linear compression ratio $\kappa = p$. We derive covering number bounds showing ϵ-approximation requires $(1/\epsilon)^{d_{\mathcal{G}}}$ network instances, and prove quantization needs $d_{\mathcal{G}} \log(1/\epsilon)$ bits per layer. Unlike prior compression work [Han et al., NIPS 2015] treating networks generically, we exploit algebraic structure for provable parameter reduction. We hope that the framework could be extended to other finite groups via similar representation-theoretic analysis.

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PP1

Structure-Preserving Reduced Order Modeling of Particle-in-Cell Simulations

Fluid models of plasmas have had high success in the field of fusion energy research, but they are fundamentally limited to capturing macroscopic physics. Kinetic models, which are orders of magnitude more costly to simulate, are used as an alternative to fluid models when kinetic effects are important to the plasma dynamics of interest. This work focusses on the particle-in-cell (PIC) kinetic model which can be used for studying the formation and growth of instabilities during plasma confinement among other things. The early phase of instability growth is dominated by linear dynamics but often consumes high fractions of the total runtime before the interesting nonlinear dynamics emerge. To solve this problem a structure-preserving reduced order model (ROM) for PIC simulations is proposed which significantly reduces the cost of simulating kinetic plasma instabilities while preserving the symplectic structure of the physical system. This ROM leverages proper symplectic decomposition (PSD) and a novel structure-preserving hyper-reduction technique to obtain a significant speedup over the full order model.

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PP1

State Estimation for a DC Power Grid Model under Uncertainty

Mathematical models of power grids are essential for prediction, monitoring, and operational decision-making in modern energy systems. Their effectiveness, however, is often limited by uncertainties in parameters, partially observed states, and model discrepancies. Accurately estimating these quantities from noisy and incomplete measurements is therefore crucial for reliable and efficient grid operation. In this poster, we study parameter and state estimation in power systems under uncertainty for a DC power grid model. We develop methods to infer unobservable quantities from observational data while accounting for measurement noise and model discrepancies. By leveraging adjoin-based techniques for efficient optimization and Bayesian inference and approximation approaches, we aim to improve the robustness and accuracy of these estimates, ultimately enhancing the prediction capabilities of power grid models.

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PP1

Predicting General Election Outcomes From Primary Results at the Precinct Level

In the United States, polling data are collected at the state level, but election results vary substantially within states (e.g., between rural and urban areas). Unlike polls, election results are often available at the precinct level, and these fine-scale data can provide insight into how primary elections, general elections, and voter turnout are related at a granular level. Using primary and general election data at the precinct level for past presidential races, we model the relationship between the degree of partisan consensus (entropy) in the primaries and each partys under- or over-performance in the general election. These patterns give insight into voter turnout decisions and provide a fine-grained method for forecasting general elections.

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PP1

Closed Form Logical Error Rate Approximations for Surface Codes

We propose a novel method to calculate logical error rates in surface codes, assuming independent and identically distributed physical errors. We show how to use our method to analyze hypothetical quantum computers with various configurations and select designs with lower error rates. Currently, this requires expensive classical simulations of quantum decoders for various distances and physical error rates or inaccurate extrapolation from minimal experimental data. Instead, we use the symmetry of the problem to count the configurations that result in a logical error with our novel software. Given a physical error rate, we can deduce the probability of a logical error, to provably good accuracy. We include an analysis of measurement errors to allow a more complete comparison of different surface code implementations.

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PP1

Geometric and Dynamical Theory of Latent Computations in Neural Networks

Many studies have identified low-dimensional sets of behavioral variables encoded within large-scale neural activity patterns. However, dimensionality reduction analyses alone cannot yield causal explanations for how networks stably implement computations that are resilient to the substantial variability of single neuron dynamics. Further, existing methods for dimensionality reduction often rely on simplifying assumptions about network structure that limit their applicability and explanatory power. Here, we introduce the concept of latent processing units (LPUs), which are architecture-agnostic computational elements operating within biological neural circuitry. Six theorems governing coding and computation by LPUs collectively provide explanations for a range of common biological findings: low-dimensional sets of coding variables can generate high-dimensional neural dynamics; many neurons have activity patterns that represent behaviorally relevant variables but exert little influence on downstream circuits; linear readouts of neural population activity commonly allow near-optimal decoding of behaviorally relevant variables; drift in neural representations are often substantial even while network computations remain intact. Overall, our treatment of LPUs enacted in network dynamics unifies the geometric and dynamical views of neural computation under a joint framework and provides systems neuroscience with a causal account of how the brain executes reliable computations

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PP1

Principal-Agent Problems: Volatility Control with Quadratic Penalty

This thesis studies the continuous-time principal-agent problem, where an investor (principal) contracts a portfolio manager (agent) to allocate wealth in a Merton-type geometric Brownian motion model, and the principal designs the compensation contract. In 2025, Chen, Qian, and Qiao introduced a partial differential equation (PDE) approach to the drift-control problem, where the agents allocation enters only the drift of the output process. The central contribution here is extending the PDE approach to volatility control, where the agents allocation enters both the drift and the volatility linearly. The main challenge is that the agents optimal effort depends on the second spatial derivative of his value function v. We resolve this by reparameterizing in terms of the processes vx and vxx. Further, we prove that wy, the derivative of the principals value function with respect to the agents value function, is conserved along sample paths. Moreover, we show that the Hamilton-Jacobi-Bellman equations satisfied by the principals and the agents value functions reduce to transport-type PDEs, and we obtain explicit solutions in some simplified cases as benchmarks. This transport structure is available only in the volatility-control case, and it is what we exploit numerically. We develop a combined scheme that couples the PDE methods with SDEbased Monte Carlo simulations, recovering the known contract structure in solved examples.

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PP1

Probability Currents and Doob Transforms Reveal Geometric Phase in Noisy Oscillators

We show that geometric phase is not a metaphor but a concrete mechanism in stochastic phase reduction. For mean-return-time phase, the phase advance is tied to stationary probability current and can be interpreted as a Berry-type geometric phase determined by circulation in state space. For asymptotic phase from backward-operator eigenfunctions, the eigenphase provides a natural dynamical phase, but its evolution requires an additional conditioning-induced drift. A generalized Doob transform yields the conditioned dynamics and exposes an AharonovAnandan-type geometric contribution. A noisy StuartLandau example visualizes current fields and phase partitions across parameter regimes. This framework clarifies the relationship between MRT and spectral phase notions and points toward extensions to coupled stochastic oscillators and data-driven phase coordinates.

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PP1

Taking Advantage of Advanced Placement (ap) Statistics for College Admission: A Study of High School Students in the Houston Area

This project explores the Advanced Placement (AP) Statistics test scores of high school students across various districts in the Houston area. It compares them to local colleges' minimum score requirements for college admission and course equivalency. Through this analysis, the study highlights trends and differences in how colleges accept AP Statistics scores for credit. Based on the findings, the project provides recommendations to the University of Houston-Downtown (UHD) regarding appropriate minimum AP Statistics scores for college credits and course equivalency. These recommendations aim to help UHD establish clearer policies that better align AP credit with the expectations of college-level courses, benefiting both students and the institution.

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PP1

Analyzing Algorithmic Reliability for Breast Cancer Detection Using Tumor Shape Analysis

There are numerous solutions for detecting breast cancer in mammograms using deep learning algorithms with different degrees of accuracy and prediction reported. However, these algorithms are trained and tested in specific datasets that are not easily available, and with rare exceptions the node weights and full network architecture are provided. Furthermore, there are normally no reports for the full set of instances in which the algorithm has produced either false positive or false negative results. Thus, it is difficult to systematically evaluate algorithmic reliability and obtain accurate statistics for prediction variability. In this work, we generated a set of segmented tumors that have been geometrically and phenotypically characterized using elastic shape analysis. This data set provides a large collection of artificially generated tumors to be placed in mammograms that would be fed into a given deep learning algorithm for cancer detection or classification. Given that this methodology gives control over specific geometric shape changes in tumors (e.g., rotations or reflections), and it is known that some deep learning algorithms are prone to be challenged for simple geometric transformations, this methodology provides a quantitative solution to analyze the variability of predictions and ultimately obtain statistics to assess the reliability of a deep learning algorithm.

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PP1

Transcritical Bifurcation Analysis and Burr Distribution Fitting in a Dynamic Model of Suicide Risk

Suicide is a complex phenomenon characterized by heterogeneous transitions from ideation to consummated acts. This work proposes a deterministic nonlinear dynamic model to analyze the evolution of suicide risk in Colombia, distinguishing between vulnerable, treated, and untreated susceptible subpopulations. Methodology: We formulate a risk rate function calibrated with official data (DANE, SIVIGILA), demonstrating that the age-distribution of suicide attempts follows a Burr distribution. A system of ordinary differential equations is derived to capture population interactions. Results: Stability analysis reveals diverse dynamic scenarios, including stable foci, nodes, and saddle points. We establish analytical conditions for a transcritical bifurcation, which governs the coexistence of equilibria and the persistence of endemic risk. Numerical simulations and 3D vector field analysis suggest that controlling relapse rates and increasing treatment coverage are critical mechanisms for shifting the system toward a suicide-resistant state.

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PP1

Curriculum-Based Reinforcement Learning for Efficient Hyperparameter Adaptation in the No-U-Turn Sampler

Sampling from complex posterior distributions is a central challenge in Bayesian inference. Hamiltonian Monte Carlo (HMC) and its No-U-Turn Sampler (NUTS) improve upon basic Markov chain Monte Carlo methods, but their efficiency depends critically on effective hyperparameter tuning. As model complexity increases, likelihood evaluations become costly and divergences more frequent, making adaptation difficult. Current adaptation schemes, such as dual averaging, are reinitialized for each new model and fail to leverage transferable strategies or model-specific structure. We propose a reinforcement learningbased framework for adaptive hyperparameter tuning of NUTS. An agent is trained across a curriculum of models with increasing complexity, learning strategies that generalize across posterior geometries. The approach focuses on two key hyperparametersthe step size and the target acceptance ratereplacing model-specific tuning strategies with policies learned through interaction with complex posterior geometries. This enables transferable adaptation strategies while retaining flexibility to respond to model-specific features. We evaluate the method on benchmark and complex posterior distributions, demonstrating reduced divergence rates, improved convergence diagnostics, and lower runtime relative to standard NUTS adaptation. Our results provide a scalable strategy for improving efficiency and reliability in Bayesian computation.

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PP1

Proper Maps of Annuli

We study proper holomorphic maps of annuli in complex Euclidean spaces, domains with $U(n)$ as the automorphism group. Such maps are always rational and extend to proper maps of balls. We first prove that a proper map of annuli from n dimensions to N dimensions where $N < \binom{n+1}{2}$ is always unitarily equivalent to an affine embedding. This inequality is sharp as the homogeneous map of degree 2 satisfies the boundary point. This yields the first gap interval for proper holomorphic maps between annuli, which surprisingly is much longer than the well-known first gap interval $(n, 2n-1)$ for ball maps. Finally, we give complete classification of proper maps of annuli of degrees 1 and 2.

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PP1

A Compartmental Model of An Opioid Epidemic: How Treatment Adherence Reduces Overdose Deaths

Opioid epidemics can be studied using compartmental epidemiological models that are based on ordinary differential equations (ODEs). Such models provide a quantitative framework for evaluating treatment strategies for opioid-use disorders. We develop a mathematical model consisting of five ODEs to examine how treatment adherence influences epidemic dynamics, in terms of both reduction in epidemic peaks and overdose deaths prevented. The model represents addiction through two distinct mechanisms: social transmission and prescription-driven use. Analytical results of the model show that addiction always persists at an endemic steady state. Specifically, no addiction-free equilibrium exists, and hence no basic reproduction number (R_0), as long as prescription-driven initiation is present. Numerical simulations investigating treatment adherence show that the epidemic peak and the steady state level of addictions are lower with higher levels of adherence. Further, achieving at least 60% treatment adherence yields approximately 30% fewer cumulative overdose deaths. These results highlight the importance of developing interventions to mitigate opioid-related harm.

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PP1

Robustness and Stability in a Closed-Loop Respiratory Network with Heterogeneous Populations

The pre-Btzinger complex (preBtc) serves as the kernel for the mammalian inspiratory rhythm. While single-neuron models capture fundamental pacemaking properties, they fail to account for population-level dynamics within the closed physiological feedback loop. This study extends the closed-loop breathing framework of Diekman, Thomas, and Wilson (2017) by replacing their single-neuron controller with a heterogeneous population of $N = 20$ Butera-Rinzel-Smith bursting neurons. The model couples conductance-based differential equations for neuronal voltage to first-order motor kinetics and gas exchange dynamics. We analyze the system's homeostatic robustness against increasing metabolic demand (M). In homogeneous networks, closed-loop chemosensory feedback flattens the response curve, maintaining eupnea across a broad metabolic range before a sharp bifurcation leads to tachypneic collapse. We demonstrate that recurrent excitatory synaptic coupling significantly extends this stability margin by enhancing integrated inspiratory drive. Furthermore, introducing Gaussian parameter heterogeneity (coefficient of variation $\approx 3\%$) transforms the failure mode from a sharp "cliff" to a distributed, sigmoidal threshold. The system also exhibits robust period-n alternans and irregular recruitment patterns near stability boundaries. These findings provide a mechanistic account of how intrinsic diversity and network topology may modulate respiratory resilience in vivo.

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PP1

Deterministic Subspace Adequacy in Reduced-Subspace LevenbergMarquardt Methods for Large-Scale Nonlinear Least Squares Problems

The LevenbergMarquardt (LM) algorithm is the most widely used method for solving nonlinear least-squares problems, as it combines the robustness of steepest descent with the fast local convergence of the GaussNewton method. However, when solving large-scale inverse problems, the LM algorithm can be prohibitively expensive. In particular, repeated trust-region radius updates may require many damped subproblem solves and inner iterations. At the same time, many inverse problems are effectively low-dimensional, since only a small number of parameter-space directions are strongly informed by the data. In this work, we propose a reduced-subspace LevenbergMarquardt (RSLM) algorithm by constructing a low-dimensional subspace that captures descent-relevant information and computes a spectrally damped LM step within it. A key component of the method is a deterministic subspace adequacy monitor that controls subspace expansion and step acceptance follows a simple line-search rule. Meanwhile, the ratio of predicted to actual reduction is used exclusively to update the damping parameter. We establish results on global convergence and local convergence, including linear and superlinear convergence, under appropriate assumptions. To evaluate practical performance, we also implement both the classical LM algorithm and the RSLM algorithm in a feedforward neural network as a nonlinear function approximation and compare their computational costs and convergence speeds.

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PP1

A Unified Theory for Universal Multiscale Closure

In multiscale modelling, the closure problem represents the fundamental challenge of quantifying the influence of small-scale fluctuations on large-scale change. We propose a Unified Theory for Universal Multiscale Closure: a lossless mathematical framework that employs continuous feedback loops to capture directional changes at their micro-scale inception. By mapping this evolution to the macro-scale with zero information loss in the causal chain, this theory eliminates the reliance on historical bias and provides an exact mathematical bridge across any scale, preserving the structural integrity of the system from inception to observation. To maintain computational efficiency while projecting long-term changes, the framework employs a recursive filtration process: 1. Detection: Monitors the micro-scale at highest observable frequency to identify the start of a new causal path at its most granular inception. 2. Propagation: Maps the signal across the scale hierarchy to capture the transfer of information from micro-fluctuations to macro-structures. 3. Filtration: Filters preceding high-frequency noise once its causal transition is complete, solving the computational bottleneck. 4. Validation: Synchronises across consecutively lower timeframes to confirm topological consistency by verifying that the micro-trajectory persists as it matures into macro-scale resolutions.

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PP1

Bayesian Inference for Infectious Disease Modeling: An Sir Model Case Study

The SusceptibleInfectiousRecovered (SIR) model is a classical system of nonlinear ordinary differential equations (ODEs) used to describe infectious disease dynamics in a closed population. In this project, we adopt a Bayesian inference framework to estimate the key epidemiological parametersthe transmission rate (β) and the recovery rate (μ)from observed epidemic data. The deterministic SIR system is embedded within a probabilistic observation model to account for measurement noise and partial observability, yielding a likelihood function defined implicitly through numerical ODE integration. Posterior inference is performed using a MetropolisHastings within Gibbs (MH-within-Gibbs) sampling scheme. Conditional updates are constructed for each parameter, with MetropolisHastings steps employed where closed-form full conditional distributions are unavailable. This approach enables joint estimation of parameters while quantifying uncertainty through posterior summaries and credible intervals

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PP1

Phase Transitions in Turnpike Theory For Mean-Field Games

We study a translation-invariant mean-field game on the flat torus with interaction $F(x,m) = \gamma(K * m)(x)$, where K is smooth, even, and mean-zero. The interaction is of potential type, arising as the first variation of a quadratic energy, though the stationary system is not treated variationally. Linearizing around the uniform equilibrium yields mode-wise 2×2 systems with dispersion $\sigma_\xi(\gamma) = \nu^2(2\pi|\xi|)^4 + \gamma(2\pi|\xi|)^2\hat{K}(\xi)$. If $\hat{K}$ is negative for some mode, a finite threshold

$$\gamma_c = \min_{\hat{K}(\xi)<0} \frac{\nu^2(2\pi|\xi|)^2}{|\hat{K}(\xi)|}$$

marks loss of stability; otherwise $\gamma_c = +\infty$. Near criticality, the spectral gap scales as $\rho(\gamma) \sim C_*\sqrt{\gamma_c - \gamma}$. For $\gamma < \gamma_c$, the uniform state is exponentially stable in the turnpike sense for finite-horizon problems, with rate $\rho(\gamma)$. At $\gamma = \gamma_c$, the gap closes and, after phase fixing and center-manifold reduction, one obtains algebraic midpoint decay of order $T^{-1/2}$. For $\gamma > \gamma_c$, a branch of nonuniform stationary solutions bifurcates via a pitchfork-type amplitude equation, with translations generating the full family. Finally, under standard asymptotic-consistency assumptions on symmetric N-player equilibria in the subcritical regime, we obtain qualitative propagation of chaos, without quantitative rates.

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PP1

Marine Heatwave-Aware Dual-Head Convlstm for Improved Sst Forecasting

Marine heatwaves (MHWs), defined as prolonged anomalously high sea surface temperatures (SST), have significant ecological and economic impacts, particularly during summer. Many deep learningbased SST forecasting models minimize annual mean temperature errors; however, extreme high-temperature events occur less frequently and may receive limited emphasis during training. Consequently, rapid summer SST increases may not be fully captured. Improving the representation of summer SST variability is therefore crucial for reliable marine heatwave prediction. To address this issue, we propose an event-aware dual-head ConvLSTM architecture that incorporates MHW events as auxiliary supervision for SST forecasting. SST regression is treated as the primary task, while binary MHW classification serves as a complementary objective. The model employs a shared spatiotemporal ConvLSTM feature extractor with task-specific regression and classification heads. This multi-task framework helps preserve extreme high-temperature signals while maintaining overall variability. Experimental evaluations conducted along the east coast of Korea indicate that the proposed dual-head ConvLSTM (DH-ConvLSTM) improves summer SST forecasting compared to single-task regression models, including LSTM, CNN, and CNN-LSTM. These findings suggest that integrating extreme-event information enhances SST prediction during high-impact summer periods.

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PP1

Generating Nurse Schedules Using Multi-Objective Mixed-Integer Linear Programming to Minimize Extra Shifts, Ensure Fairness, and Maintain Consistent Care Quality

This study proposes a multi-objective mixed-integer linear programming(MO-MILP) model to optimize nurse scheduling in the complex operating environment of a Korean hospital. To reflect fluctuations in available staff caused by variations in bed utilization rates, nursing grade regulations, and statutory holidays, minimum staffing requirements are specified separately for weekdays, weekends, and holidays. The model simultaneously incorporates hard constraints, such as legal working-hour standards and minimum staffing levels, and soft constraints, including nurses preferences, restrictions on consecutive workdays, and fair workload distribution. By balancing these competing objectives, the framework generates schedules that minimize unnecessary overtime while maintaining continuity and stability in work patterns. Numerical experiments demonstrate that the proposed model produced feasible and well-balanced schedules under real hospital conditions. The findings indicate potential improvements in operational efficiency, reduced fatigue and burnout among nurses, and enhanced patient safety and quality of care. Future work will further develop the framework by incorporating additional human-centered constraints that reflect interpersonal and relational dynamics in clinical settings. For example, integrating preferences to collaborate with or avoid specific colleagues may enable the model to address not only operational performance but also team cohesion and workforce well-being.

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PP1

Local Optimization of Weak Distance Between Compact Surfaces on Special Euclidean Group

We consider local optimization of a weak distance between two compact surfaces embedded in the three-dimensional Euclidean space on its special Euclidean group. Identifying those objects with the associated surface measures, their discrepancy is quantified in terms of the inhomogeneous Sobolev norm of negative order via the Plancherel theorem. Then, applying an isometry to one surface corresponds to pushforwarding its surface measure and the distance can be regarded as a function on the Euclidean group. With appropriate exponents of the Sobolev norm, the second power of the function acquires sufficient differentiability that allows to find its local minima in the derivative-based framework. In numerical experiments, we observe superlinear convergence in the optimization problem with the BroydenFletcherGoldfarbShanno method and discuss its implications from a more geometric perspective.

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PP1

Curvature-Guided Graph Sparsification for Scalable Community Detection

Understanding community structure in large-scale networks is a fundamental problem in network science. Curvature-based methods, particularly Ollivier–Ricci curvature (ORC), effectively identify inter-community bridges and structural bottlenecks, but their computational cost limits scalability on large graphs. We propose a two-stage curvature-guided framework that combines Lower Ricci Curvature (LRC) preprocessing with ORC and discrete Ricci flow on a reduced graph. The LRC stage efficiently filters weak edges using local triangle-based structure, significantly reducing graph size before transport-based curvature computation. The framework is evaluated on SNAP Facebook ego-networks, the SNAP YouTube social network, and synthetic networks. Results using Adjusted Rand Index (ARI), Normalized Mutual Information (NMI), and runtime comparisons show that the combined LRC–ORC approach achieves accuracy close to ORC-only methods while substantially reducing computational cost, providing an effective accuracy–runtime trade-off for scalable community detection.

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PP1

A Vortex-Ring Description of Convective Clouds

A common description of atmospheric thermals and the clouds following detonations is based on the assumption that the rate of entrainment of ambient air is proportional to the area of the buoyant volume and a characteristic velocity of rise. Under additional assumptions of symmetry, this results in a radial growth that is proportional to the vertical displacement of the system, with the entrainment parameter being the constant of proportionally. The dominant structure in these flows tend to be a buoyant vortex ring, for which the rate of radial growth can be formulated as a function of its circulation and buoyant content, without the need to prescribe an entrainment parameter. We have developed a vortex ring formulation especially adapted to clouds arising from high energy explosions in the atmosphere, where the vortex cores tend to be thin and can be approximated by vortex filaments. The model consists of a set of ODEs for the temporal evolution of the core radius, height and circulation, applicable until vortex breakdown and cloud stabilization. We additionally developed parameterizations that relate the detonation fireball to the initial conditions of the vortex ring, based on the energy released and the height of the explosion. Our model also takes into account the creation of additional vorticity as a result of atmospheric stratification and its effect on the vortex ring evolution and stability.

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PP1

Hybrid Physics-Informed Neural Time-Steppers for the One-Dimensional Inviscid Burgers Equation

with Newton-Corrected Rollout Stability.

We investigate neural time-stepping for the one-dimensional inviscid Burgers equation on a periodic domain using a spectral discretization and an implicit update formulation. The study is designed as a progressive comparison of four training strategies: data-only supervision, physics-informed residual minimization, a hybrid data-physics loss, and a hybrid model augmented with a Newton corrector. The neural network is trained to approximate the implicit solution mapping between consecutive time steps, where the physics loss enforces the discrete PDE residual associated with the nonlinear flux term. The primary objective is to examine how increasing levels of physical structure influence accuracy, stability, and long-horizon rollout behavior. Results show that data-only models achieve reasonable short-term prediction but suffer from error accumulation, while physics-only training improves physical consistency yet exhibits larger solution deviations. The hybrid loss consistently provides better accuracy and stability by balancing numerical targets with residual enforcement. Furthermore, incorporating a Newton correction step significantly enhances multi-step rollout fidelity and reduces residual errors, although with higher computational cost. Overall, the work presents a systematic and interpretable framework showing that hybrid physics-informed neural time-steppers with corrective updates offer a robust surrogate for implicit integration of nonlinear hyperbolic PDEs.

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PP1

EigenWave: An Optimal O(N) Method for Computing Eigenvalues and Eigenvectors by Time-Filtering the Wave Equation

An algorithm, named EigenWave, is described to compute eigenvalues and eigenvectors of elliptic boundary value problems. The algorithm, based on the recently developed WaveHoltz scheme, solves a related time-dependent wave equation as part of an iteration. At each iteration, the solution to the wave equation is filtered in time, resulting in updated initial data. The time-filter is designed to promote the contributions of eigenmodes in the solution near a chosen target frequency (target eigenvalue). The ability to choose an arbitrary target frequency enables the computation of eigenvalues anywhere in the spectrum, without the need to invert an indefinite matrix, as is common with other approaches. Furthermore, the iteration can be embedded within a matrix-free Arnoldi algorithm, which enables the efficient computation of multiple eigenpairs near the target frequency. The time-dependent wave equation can be solved with implicit time-stepping, and only about 10 time-steps per period are needed. When the (definite) implicit time-stepping equations are solved with a multigrid algorithm, the cost of the resulting EigenWave scheme scales linearly with the number of spatial grid points N as the mesh is refined, giving an O(N) algorithm. The approach is demonstrated by finding eigenpairs of the Laplacian in complex geometry using finite-difference approximations on overset grids. Results in two and three space dimensions are presented.

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PP1

Quantifying Immunity Gaps and Optimizing Intervention Timing Via Data Assimilation

Large-scale non-pharmaceutical interventions (NPIs) for COVID-19 suppressed endemic infections, interrupting natural exposure and generating structural immunity gaps. After NPI relaxation, many diseases showed amplified and shifted resurgences, making threshold-based warning systems reactive and insufficient. We develop a data-assimilative epidemic control framework integrating joint stateparameter inference, probabilistic regime classification, and cost-based intervention timing. Immunity gaps are quantified by estimating states and parameters of a transmission model using a Dual Ensemble Kalman Filter (EnKF). Latent susceptible populations and time-varying transmission rates are inferred simultaneously, and variability in posterior trajectories provides an indicator of accumulated susceptibility. Severity regimes are identified using a Gaussian Mixture Model (GMM), yielding probabilistic levels instead of fixed thresholds. Intervention timing is formulated as a cost minimization problem combining GMM-based severity probabilities with immunity-gap metrics, balancing resurgence risk and intervention burden. Simulation results show that early moderate interventions triggered by this criterion reduce outbreak peaks compared to delayed strategies. The framework is illustrated using hand, foot, and mouth disease data in South Korea and provides a generalizable approach for adaptive control under immunity-gap conditions.

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PP1

Traveling Fronts in a Singularly Perturbed Lotka-Volterra Reaction Diffusion Model with Transcritical Singularity

This project is motivated by the study of coexistence states in interspecies ecosystems. We investigate the existence and persistence of bistable traveling front solutions in a singularly perturbed competitive LotkaVolterra reaction-diffusion system. The wide separation of diffusion scales introduces a fastslow structure, enabling the use of geometric singular perturbation theory. We first establish the existence of a heteroclinic orbit connecting two steady states in the singular limit. The primary difficulty arises from loss of hyperbolicity where two critical manifolds intersect along a curve of transcritical bifurcations. To resolve this degeneracy, we apply geometric desingularization to analyze the slow passage through the transcritical singularity and establish persistence of the traveling front. This framework provides a geometric mechanism for understanding wave propagation in competitive systems with multiple time scales and extends to broader classes of fast-slow reactiondiffusion models.

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PP1

Classical-Quantum Algorithm for Solving Stochastic Programs

Stochastic programming provides a rigorous mathematical framework for making decisions under uncertainty in a risk-aware manner. Two-stage stochastic programming is, perhaps, the simplest form of this framework. Here the first-stage variables represent decisions that must be made "here and now" in the face of uncertainty, while the second-stage variables are decisions made after uncertain events. However, the broad adoption of stochastic programming has been hindered by computational challenges caused by the two-stage stochastic programming formulation which requires solving an ensemble of optimization problems. Using quantum amplitude estimation (QAE), quantum computers have shown the theoretic ability to compute expectations with Monte-Carlo methods with quadratically fewer samples than classical methods. In this work, we present a quantum algorithm for computing the expectation term using QAE for given first-stage decisions. Further, we detail methods of computing gradient information from the quantum calculation enabling the application of classical gradient-based optimization techniques. The result is a classical-quantum hybrid method of solving two-stage stochastic programs. These techniques are demonstrated with computational experiments based an engineering optimization problem.

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PP1

Out-of-Core Linear Algebra for High-Dimensional Statistics: Streaming Pca and Pls with Bounded Memory

Large-scale PCA and PLS regression can be framed as linear-algebra problems whose bottleneck is forming and factorizing Gram and cross-product matrices. We present two implementationsbigPCAcpp (PCA/SVD) and bigPLSR (PLS)that address the applied-mathematics challenge of computing these decompositions efficiently when the data matrix is too large for RAM. For PCA, bigPCAcpp operates directly on file-backed bigmemory::big.matrix allocations and supports centering/scaling with blockwise passes through the data, enabling score generation without materializing dense copies. It also provides robust PCA / robust SVD routines intended to mitigate outlier influence while preserving numerical stability. For supervised dimension reduction, bigPLSR implements SIMPLS and NIPALS solvers and extends to kernel-style PLS variants. Its core design is a set of streamed cross-product operators (XtX/XtY and XXt/YX), coupled with chunked BLAS and an automatic strategy that selects between algorithmic regimes depending on (n, p) and a user-specified memory budget. We discuss memory-bounded complexity trade-offs (passes over data versus Gram costs), wide XXt formulations, and reproducibility via deterministic tests and benchmarks suitable for modern applied-math pipelines.

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PP1

A Coupled Hodgkin-Huxley-Lotka-Volterra Model of Functional-Structural Interactions of Neurons

Neuronal synchronization is essential to various brain processes like motion control and some brain disorders like epilepsy. The functions and synchronization of neurons are fulfilled through complex interlinked dynamics of action potentials, chemical neurotransmitters and mechanical responses of neurons that depend on neuronal structure and interactions of neurons with their shared environment. Action potentials propagation and synchronization may be modeled using coupled Hodgkin-Huxley models. These equations depict ion transport across neuronal membranes but ignore neuronal mechanics although experiments show that neuronal functions are highly sensitive to changes in neuronal volume. Homeostatic mechanisms conserving neuronal volume are facilitated by the mechanical interactions of neurons with the cerebrospinal fluid surrounding them. This work proposes a mathematical model of functional-structural interactions of two adjacent synchronized neurons. Neuronal functions and synchronization are described by a fractional Hodgkin-Huxley model where ion channels behave mechanically as variable-order fractional Maxwell linear viscoelastic materials. The coupled volumetric dynamics is depicted by a modified coupled Lotka-Volterra model where the rates depend on action potentials and regulatory volumetric processes are represented as MichaelisMenten-like terms. Computer simulations suggest that synchronized neurons experience cooperation, competition, and predator-prey regimes.

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PP1

Machine Learning Force Fields for Gas Phase Condensation of Refractory Species

Processes involving evaporation are ubiquitous in natural settings and industrial applications. When refractory materials are involved, these transformations occur at high temperatures and are difficult to study experimentally. Molecular dynamics simulations using accurate force fields provide a means to investigate the nucleation and growth of a condensed phase in those conditions, as well as to determine material properties such as reaction rates and thermodynamic potentials. At high temperatures, atomic clusters can adopt configurations that are not accessible in cooler conditions, making it necessary to use descriptors that can resolve this wider range of configurations. While many approaches are based on fixed-length descriptors obtained by projecting the configurations onto a basis, in this work we build the descriptors using the Cholesky decomposition of the Gram matrix formed by the relative-position vectors of the atoms in the configuration. By specifying an ordering for those vectors, an array of 3N-6 unique numbers is obtained for N atoms, preserving the number of degrees of freedom of the system under translational and rotational invariance. We have employed these descriptors in the study of systems composed of silicon and oxygen atoms using a machine-learning force field trained on Density Functional Theory calculations. We present results of the evolutions of atomic clusters in the gas phase and the evaporation of SiO_2 particles.

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PP1

The Snapshot Problem for Wave Equations on Homogeneous Trees

By definition, a wave on a homogeneous tree $\mathfrak{X}$ is a solution to the discrete wave equation on $\mathfrak{X}$; that is, a family $\{f_k\}_{k\in\mathbb{Z}}$ of complex-valued functions on $\mathfrak{X}$ satisfying the partial difference equation $\mu_1 f_k = (f_{k+1} + f_{k-1})/2$ for all k, where μ_1 is the mean value operator on $\mathfrak{X}$ of radius 1. The function f_k is called the snapshot of the wave at time k. For $k \geq 2$, we will show that there exist infinitely many waves having given snapshots at times 0 and k, but that all such waves have the same snapshots at times which are multiples of k. For integers $\ell > k > 0$, we then consider necessary and sufficient conditions for the existence and uniqueness of a wave with given snapshots at times 0, k, ℓ.

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PP1

Nuclear Waste Disposal: Maximum Loading in Materials

The safe disposal of iodine-129, a long-lived fission product with low economic value and high abundance, remains a significant challenge in nuclear waste management. This work explores computational and data-driven approaches for maximizing iodine loading in glass-ceramic waste forms while maintaining chemical durability and long-term stability. By analyzing compositionproperty relationships and constraints associated with waste-form design, we investigate strategies to optimize iodine incorporation and minimize the concentration of additional stabilizing elements required for containment. The study highlights how modeling and materials informatics methods can guide the design of waste forms with reduced leaching behavior and improved performance for deep geological disposal applications.

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PP1

Traveling Fronts in a Three-Component, Multi-Species Klausmeier-Type Model for Dryland Ecosystems

Motivated by the coexistence of multi-species, such as grass and trees, in drylands, we study a three-component Klausmeier-type reaction-diffusion model describing two vegetation species competing for a limiting resource, water. The two species differ in parameter values including growth, harvesting, and diffusion rates, yet exhibit the same qualitative ecological dynamics. It creates a natural hierarchy between them with one acting as a fast-spreading colonizer and the other as a locally superior competitor. Each component is assumed to diffuse at a distinct rate, modeled through two asymptotically small parameters ϵ and δ, which introduces a separation into three spatial scales. We construct a traveling wave solution connecting states in which one or more species are present and examine the resulting interspecific competition for the limiting resource using the geometric singular perturbation theory (GSPT) with multiple spatial scales along with the exchange lemma.

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PP1

Exponential Nystrm Integrators for Stiff and Highly Oscillatory Differential Equations

Second-order differential equations arise naturally in many physical and biological applications, including molecular dynamics, string vibration, and spatial discretization of wave equations. For their time integration of such systems, classical Runge-Kutta-Nystrm integrators and their extended variants are widely used. While effective for small-scale or nonstiff problems, these methods often suffer from stability restrictions and inefficiency when applied to large, stiff, or highly oscillatory systems. To address these limitations, we develop and analyze a new class of time integration methods, termed exponential Nystrm (expN) methods. These methods permit significantly larger time steps without sacrificing accuracy. Within the framework of strongly continuous semigroups on a Banach space, we prove convergence results up to fifth-order accuracy, with error bounds independent of the stiffness or high frequencies of the system. Our numerical experiments demonstrate that the proposed expN methods outperform existing Nystrm-type integrators in both efficiency and accuracy.

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PP1

A Modified Multi-Objective Chaos Game Optimization Algorithm

The Chaos Game Optimization (CGO) is a metaheuristic algorithm that was proposed by Azizi and Talatahari in 2020 to solve optimization problems. Traditionally, chaos games are random and iterative processes that form fractals when played. The CGO is based on some principles of chaos games in which the configuration of fractals alongside the fractals self-similarity issues are in perspective. This game theory-based algorithm formulation has been novel when solving multidimensional objective functions and displayed promising results. The multi-objective chaos game optimization (MOCGO) was proposed by Khodadadi et al. which uses the main mechanisms found in the CGO to solve multi-objective optimization problems. This project implements improved versions of the CGO and MOCGO algorithms and introduces new and more practical stopping criteria to address the limitations of traditional methods like relative error and a fixed number of iterations in both the single and multi-objective algorithms. Ultimately, this work provides a robust and efficient framework for applying both the CGO and MOCGO to complex optimization problems, demonstrating their enhanced performance through automated analysis of objective functions.

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PP1

Propagation of Plasmons on a Graphene Sheet

Graphene is a highly conductive two-dimensional material that can be modeled in the bulk as a conductive sheet. The sheet supports current flow, which couples the electromagnetic waves on either side of it. Plasmons are electromagnetic fields which are localized near and propagate along the sheet. We consider the situation where the Drude weight of the graphene sheet is a constant plus a small perturbation that is spatially and temporally dependent. In this case, the model reduces to a single partial integro-differential equation (PIDE) for the current density in the sheet. This allows for a perturbational approach where we apply a spatial Fourier transform and solve the resulting integral equation for each wave number. We show that the resulting problem is well-posed. Additionally, we perform numerical simulations to explore the behavior of the solution under various Drude weight perturbations.

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PP1

Mathematical Modeling of Energy Expenditure During Treadmill Exercise

Despite the widespread use of wearable technology, estimating energy expenditure (EE) solely from heart rate (HR) remains a challenge due to the physiological lag between cardiac response and metabolic demand. Existing commercial algorithms and conventional estimation models often fail to capture the nonlinear dynamics of oxygen consumption (VO_2) and carbon dioxide production (VCO_2), particularly during rapid changes in exercise intensity. To address this, we propose a novel first-order ordinary differential equation (ODE) model that utilizes the percent of heart rate reserve ($HRR_{\%}$) as a single input. A key innovation of this framework is the application of phase-specific time constants (τ) for exercise onset and recovery periods, designed to mathematically reproduce the hysteresis loop arising from the distinct physiological kinetics between exercise and recovery phases. Validated against a large-scale dataset of treadmill graded exercise tests (GET), the proposed model demonstrated a high degree of agreement with indirect calorimetry measurements. The results indicate that the dynamic model effectively reduces estimation errors compared to conventional models by accounting for physiological transient responses. Our findings suggest that incorporating physiological kinetics into a mathematical model enables accurate and interpretable EE estimation without the need for additional sensors.

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PP1

Abstract Group Recovery from Orbit-Generated Gram Matrices

We investigate an inverse problem for Gram matrices arising from orbits of vectors under finite group actions. When a finite group acts on a Hilbert space and the orbit of a single vector forms a frame, the associated Gram matrix lies in the group algebra and commutes with the left regular representation. As a first step, we show that such orbit-generated Gram matrices necessarily satisfy cubic trace identities that encode the algebraic structure of the group action. We then address the inverse problem: given a Gram matrix, can one recover the underlying (abstract) group structure encoded by the Gram data? This work emphasizes abstract group recovery, as distinct from the concrete problem of recovering a specific group action. In this setting, we show that recovery of the group can be phrased as an optimization problem over orthogonal matrix families, linking representation-theoretic structure with computational reconstruction from orbit Gram data.

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PP1

Integrating Weather Shocks and Environmental Shifts in a Stochastic Eco-Epidemiological Framework of Zoonotic Spillover

Environmental variability and extreme weather events strongly influence species interactions and zoonotic disease emergence, yet most eco-epidemiological models fail to jointly capture gradual environmental change and abrupt weather shocks. We develop a stochastic eco-epidemiological framework coupling multi-species competitive Lotka–Volterra (CLV) dynamics with Susceptible–Infectious–Recovered (SIR) disease processes in wildlife populations. The model incorporates spatial dispersal through reaction–advection–diffusion mechanisms and includes both wildlife-to-human and environment-to-human transmission pathways to quantify exposure dose and spillover risk. Chronic environmental variability is modeled using Gaussian white noise, while sudden extreme weather events are represented by Poisson-driven Lévy jumps. For reduced model forms, we establish analytical conditions for stochastic persistence, extinction, partial coexistence, and competitive exclusion among wildlife species. For the full spatial system, we prove global existence, uniqueness, and positivity of the mild solution, derive a stochastic basic reproduction number R_0, and perform sensitivity analyses. Numerical simulations show that prolonged environmental stress, combined with abrupt weather events, can destabilize wildlife communities, promote disease persistence, and increase zoonotic spillover risk, highlighting the nonlinear effects of coupled climatic and environmental disturbances.

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PP1

Representation-and System-Agnostic Automated CAD Interoperability Testing and GAT-Autoencoder-Based Image Categorization via Proxies

In this paper, we present theoretically-supported frameworks to test CAD system interoperability based on shape comparison criteria. We introduce a command line tool that provides indirect, representation-independent comparisons of CAD models via abstract proxies and query-based interpretations. Our frameworks support local comparisons using differential properties and offer a broad range of global comparisons. We allow testing for generic CAD software designed for different operating systems or scripting languages. Users can specify tolerance values for testing, ensuring accuracy. This approach bridges CAD model representations, enabling effective interoperability evaluation across diverse systems without requiring in-depth knowledge of CAD software or representations. We also demonstrate how our proxy-based approach can be applied to image categorization using GAT autoencoders.

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PP1

Observation Region Sensitivity Experiments for 4D-Var in the East Sea (Sea of Japan)

Data assimilation is a technique for improving the accuracy of state estimation by integrating observational data into numerical models. Ocean observations, especially subsurface observations such as water temperature and current velocity, require ship operation and use of non-recoverable equipment, which is time-consuming and economically costly. Due to these constraints, how to efficiently allocate and utilize limited observation resources is a critical issue in ocean data assimilation research. This study applies the 4-Dimensional Variational method (4D-Var) technique to the East Sea (Sea of Japan) and analyzes the effect of the observation area selection on data assimilation performance. For this purpose, the Regional Ocean Modeling System (ROMS) was used, and the study area was divided into quartiles based on the spatial variability of the temperature field. By performing data assimilation by selecting the same number of expendable bathythermograph (XBT) observations from each area, the influence of differences in the number of observations was eliminated and the relative importance of the observation areas was evaluated. Data assimilation performance was quantified by the RMSE using independent XBT observations. This study contributes to the establishment of an efficient observation area selection strategy under limited observation resources and provides basic data for research on the East Sea (Sea of Japan) ocean data assimilation and observation network design.

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PP1

Conditional Neural Control Variates for Variance Reduction in Bayesian Inverse Problems

Bayesian inference for inverse problems requires computing expectations under posterior distributions, typically via Monte Carlo (MC) estimation. When the quantity of interest varies significantly under the posterior, the MC estimator has high variance, demanding many samples for accurate estimates. We introduce conditional neural control variates (CNCV), a modular variance reduction method that learns amortized control variates from joint model-data samples. Our method requires two ingredients: (i) samples from the joint distribution of unknown parameters and observed data—obtained by sampling the prior and evaluating the forward model—and (ii) the posterior score function, which can be computed from physics-based likelihood evaluations, neural operator surrogates, or learned generative models. Once trained, the control variates generalize across observations without retraining. For multi-dimensional quantities of interest, we introduce an ensemble of hierarchical affine coupling layers, each operating on a random permutation of the input dimensions, enabling tractable divergence computation in a single forward pass. Numerical experiments on Gaussian, Rosenbrock, and nonlinear inverse problems demonstrate considerable variance reduction, with consistent performance when the analytical score is replaced by a score learned from a conditional normalizing flow.

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PP1

Variance and Higher-Order Moments for Temperature Fluctuations Arising from the Stochastic Heat Equation

We investigate the distribution of instantaneous temperature fluctuations in mesoscopic solid systems (e.g., metal rods) described by the stochastic heat equation. As the length scale of the system decreases, the multiplicative nature of noise in the stochastic heat equation becomes increasingly significant due to the relatively small number of atoms. This leads to temperature fluctuations that deviate further from the Gaussian distribution predicted by the linearized stochastic heat equation with additive noise. In this physical regime, we aim to understand the non-Gaussian characteristics of temperature fluctuations by analyzing their variance and higher-order moments, and to construct a computational setup for the spatial discretization of multiplicative noise, which yields the correct distribution of temperature fluctuations. To this end, we derive analytical expressions for the variance and higher-order moments of temperature fluctuations under three boundary conditionsperiodic, Neumann, and Dirichletand systematically validate these results through extensive stochastic simulations. We also examine finite system-size effects on higher-order moments and derive analytical expressions. This work provides new insights toward establishing a general theoretical and computational framework for analyzing multiplicative noise in mesoscopic modeling.

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PP1

Hybrid Deep Learning for Bitcoin Volatility and Value-at-Risk (VaR) Forecasting

Bitcoin's extreme volatility and complex price dynamics challenge traditional risk forecasting. Classical approaches like GARCH and historical simulation often fail to capture nonlinear dependencies, regime shifts, and the rich information in on-chain metrics. This thesis presents a hybrid deep learning architecture combining modality-specialized Transformer and LSTM encoders to forecast Bitcoin volatility and Value-at-Risk (VaR) at multiple confidence levels. The design leverages the distinct temporal structures of market price data (sparse, event-driven) and on-chain metrics (dense, cumulative), enabling specialized representation learning. A multitask framework jointly optimizes volatility and quantile predictions, improving regularization and tail risk stability. Using 2,438 daily observations from May 2017 to May 2025, the hybrid model outperforms both econometric and deep learning baselines, achieving a 0.5% RMSE gain over standalone Transformers and 94% over GARCH(1,1). Post-hoc calibration corrects conservative quantile bias, aligning empirical and nominal breach rates. Ablation shows a 4.8% gain over naive feature fusion, and Diebold-Mariano tests confirm significant outperformance. The findings offer practical insights for institutional cryptocurrency risk management.

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PP1

A Multi-Region Seir Model Incorporating Inter-County Mobility and Time-Dependent Transmission Dynamics: Application to Covid-19 Disease Outbreak Data in North Carolina.

Classical infectious disease compartmental models typically do not incorporate spatial heterogeneity or mobility. We develop a multi-region susceptible-exposed-infected-recovered (SEIR) model in which disease dynamics are coupled via inter-region mobility and the transmission rate is both region and time dependent. We calibrate the model using rolling averages of daily COVID-19 data in all 100 North Carolina counties. Mobility parameters are prescribed using daily inter-county commuter data. The number of transmission rate parameters is substantially reduced by hypothesizing that the dynamics correlate with county-level population density. Parameter estimation is carried out using several objective functions with error terms at different scales. An additive combination of least squares error at the county-level and the state-level, along with a quadratic transmission rate polynomial, yields the lowest overall error at both spatial scales. The calibrated model is used to simulate regional effects of perturbing disease transmission rates in adjacent counties and to illustrate effects of the state's mobility infrastructure on disease dynamics and spread for a new disease outbreak.

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PP1

Inference of Dynamic Rates Using Snapshots of Biological Cells

In our work, we bring statisticians perspective to what would classically be an inverse Partial Differential Equation (PDE) problem, but the data exhibits intrinsic randomness. Particularly, we have been working on static snapshot data that capture the discrete spatial positions of micro-particles whose motions are governed by a stochastic differential equation. The observed particles, confined within a single domain, ultimately follow a Poisson spatial point process whose intensity function is actually a PDE solution. The goal is to study the statistical properties of the maximum likelihood estimator for the dynamic rates appearing in the PDE using only these snapshot observations. In implementing this framework, a major challenge stems from the fact that the associated PDE cannot be solved analytically, prompting the use of an efficient numerical method to approximate it before incorporating the result into the likelihood function. We also investigate the impact of heterogeneity and location information on the efficiency of estimators and reveal that they enhance the estimation quality.

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PP1

Generative AI Meets Dynamical Systems for Predictive Virtual Cell Modeling

Reconstructing continuous cellular dynamics from discrete, sparse, high-dimensional, and unpaired single-cell omics data is a central challenge for virtual cell modeling. We study how static observations can be transformed into dynamical laws of cell-state evolution. Our framework combines generative AI with dynamical systems, partial differential equations, and optimal transport to model temporal changes in cell populations as continuous dynamics in a high-dimensional distribution space. To capture proliferation, death, stochasticity, and cell-cell interactions, we introduce regularized unbalanced optimal transport and unbalanced mean-field Schrdinger Bridge formulations, and relate them to diffusion-based generative modeling. We also leverage generative-AI-inspired tools to mitigate the curse of dimensionality in sparse, high-dimensional omics data. We further extend the framework to spatiotemporal data, where spatially coupled dynamics are reconstructed by incorporating cell-cell interactions. Applications to various single-cell datasets demonstrate the ability to infer cell fate transitions, developmental trajectories, and interaction-driven dynamics. Together, this work illustrates how generative AI and mathematical modeling can convert fragmented omics measurements into coherent, predictive virtual cell dynamics.

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PP2

AWM Minisymposterium: Comparing Finite-Difference and Continuous Galerkin Methods for Atmospheric Dynamics: Idealized Numerical Experiments

Atmospheric models employ various numerical discretization schemes to solve the governing equations of fluid dynamics. This study compares the finite-difference method in the Weather Research and Forecasting (WRF) model with the continuous Galerkin spectral element method in JExpresso through two idealized test cases: thermal bubble/squall line simulations and two-dimensional Gaussian hill flow. We conduct simulations across grid resolutions (Δx from 200 m to 2000 m) and polynomial orders ($p = 4$ to $p = 6$ for JExpresso) to assess convergence and efficiency. The thermal bubble/squall line case isolates buoyancy-driven flows and tests organized convection with microphysics, while the Gaussian hill evaluates terrain-induced circulation and wave propagation. We analyze energy conservation, phase errors, and small-scale feature representation. Preliminary results show WRF performs robustly across resolutions, while JExpresso exhibits superior energy conservation at equivalent resolutions with higher polynomial orders. However, the continuous Galerkin method is more sensitive to numerical dissipation when microphysics is active. These findings help choose the right numerical method for high-resolution weather simulations that need to accurately show the effects of complex terrain and precipitation.

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PP2

AWM Miniposterium: Semi-Analytical Modeling of Shifted Generalized-Gamma Waiting-Time Distributions in Random Porous Media

Anomalous transport of elongated and deformable particles in periodic and randomly packed beds is investigated through a combined numerical and semi-analytical framework. Immersed Boundary Method simulations generate pore-scale particle trajectories and transition statistics. At the continuum scale, a probabilistic model based on the Continuous Time Random Walk (CTRW) framework is constructed to describe upscaled transport. The model incorporates a memory functional represented by a shifted generalized-gamma waiting-time distribution, capturing particle trapping, deformation, and both Fickian and non-Fickian behaviors arising from medium disorder and fluidsolid interactions. The CTRW formulation yields a modified Helmholtz equation in the Laplace domain, solved using FourierBessel expansions. Semi-analytical solutions are validated against finite element simulations. Mean first passage time (MFPT) statistics are derived for various memory parameters, revealing how pore geometry, filament deformability, and transition-time distributions influence anomalous transport scaling.

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PP2

AWM Minisymposterium: Doubly Nonlocal Image Inpainting

Image inpainting is the process of restoring a missing or damaged region of an image using information from the surrounding pixels. By adding a source term to a classical Cahn Hilliard equation, we can demix the disrupted pixels, while maintaining the integrity of the rest of the image. In this poster we propose a doubly nonlocal Cahn Hilliard model for image inpainting that extends our prior binary phase segregation work to a new application domain.

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PP2

AWM Minisymposterium: Water Flow in Porous Media

A (unsaturated/saturated) Darcy flow model coupled to heat transport is considered with a two-way coupling through fluxes and viscosities. We develop a new analytical solution as well as an algorithm combining conservative finite elements and finite volumes. We show methods to decrease the consistency error and increase convergence.

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PP2

AWM Minisymposterium: SpectralSpatial Deep Learning for Hyperspectral Image Analysis

This work presents an efficient deep learning framework for hyperspectral image analysis that integrates spectral and spatial information. Spectral data are transformed into image-based structured representations that capture relationships among wavelengths, while convolutional networks extract spatial features from local regions. This integration improves accuracy, reduces boundary errors, and enhances computational efficiency. The results show that combining mathematical modeling and modern learning methods can advance reliable tools for scientific imaging and remote-sensing applications.

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PP2

AWM Minisymposterium: Combinatorial Optimization Using Quantum Computing

This study explores quantum computing for combinatorial optimization through the Traveling Salesman Problem (TSP), which aims to find a minimum-cost Hamiltonian cycle visiting each city exactly once. Using Qiskit, we implement the Quantum Approximate Optimization Algorithm (QAOA) on both simulators and quantum hardware, and compare its performance with that of classical exact optimization via the Gurobi solver. TSP instances are encoded as Quadratic Unconstrained Binary Optimization (QUBO) problems derived from the MillerTuckerZemlin formulation, with degree and subtour constraints embedded using quadratic penalties. Results indicate that QAOA consistently generates feasible tours, but classical branch-and-bound solvers outperform it in both solution quality and runtime. On Noisy Intermediate-Scale Quantum (NISQ) devices, the optimality gap grows with problem size, reflecting sensitivity to variational parameter tuning, penalty scaling, and hardware noise. Among classical optimizers for QAOA, COBYLA offers the most effective tradeoff between efficiency and noise tolerance. Overall, this work establishes a reproducible quantum-classical workflow, provides performance baselines, and identifies critical factors such as encoding design, optimizer choice, and error mitigation for improving near-term quantum heuristic performance.

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PP2

AWM Minisymposterium: Multiobjectivizing Nonlinear Single-Objective Optimization Problems

This work investigates a structural reformulation-and-search framework for global optimization of constrained nonlinear single-objective problems, grounded in the theory of multi-objective optimization. We employ a low-dimensional multi-objective surrogate representation to capture the interaction between objective improvement and constraint satisfaction meaningfully. The resulting search procedure is instantiated within an evolutionary optimization paradigm and is paired with a constraint-informed mechanism for progressively contracting the admissible region. Preliminary comparisons with many-objective encodings and standard constraint-handling techniques indicate improved robustness of feasibility recovery and convergence on challenging benchmarks.

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PP2

AWM Minisymposterium: Neural Networks with Local Converging Inputs (nnlci) for Solving the Stokes Equations

Recently, deep neural network-based surrogate models have become popular for solving fluid flow partial differential equations. These models use global interpolation of training data, often requiring large, resource-intensive networks. This study introduces a neural network with local converging input (NNLCI) for accurate predictions using unstructured data. By focusing on the local domain with converging coarse solutions as inputs, it significantly reduces computational cost and training time. In this project, we are doing the NNLCI approach applied to the stokes equation and aim to do several numerical tests.

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PP2

AWM Minisymposterium: Mathematical Model Meets Conservation: Optimizing Invasive Species Management

Invasive species like Chinese privet (Ligustrum spp.) threaten native ecosystems by spreading through seeds and vegetative root growth. We adapt a spatially explicit mathematical model to capture these biological dynamics and couple it with a constrained multi-period optimization framework to evaluate efficient removal strategies under budget and operational constraints. The model accounts for treatment thresholds, spatial prioritization, and logistical limitations, identifying where and when interventions are most effective. Simulation results show that temporally coordinated, targeted actions substantially reduce reinfestation compared to uniform or short-term control, with early intervention in high-connectivity areas providing disproportionate long-term benefits by limiting secondary spread pathways. This integrated framework provides mathematically informed guidance for managers, enabling comparison of alternative strategies, assessment of cost-effectiveness trade-offs, and identification of robust, evidence-based policies. Overall, it offers a practical decision-support tool for controlling invasive plants while improving ecological outcomes and can be adapted to other spatially spreading species.

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PP2

AWM Minisymposterium: Reconstructing Incomplete Surface Temperature Fields Using Graph Attention Networks

Incomplete and irregularly sampled climate records, such as the HadCRUT surface temperature dataset, motivate the need for robust data reconstruction methods. We present a Graph Attention Network (GAT) framework for climate field infilling that models Earths surface as a geospatial graph, with edges encoding geodesic distance, latitudinal, and elevational relationships. The attention mechanism adaptively learns spatial dependencies to better reconstruct surface temperature. Preliminary experiments demonstrate improved accuracy over Kriging and greater computational efficiency than GraphEM.

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PP2

AWM Minisymposterium: Discrete Superconvergence Analysis for Quantum Magnus Algorithms of Unbounded Hamiltonian Simulation

Motivated by various applications, unbounded Hamiltonian simulation has recently garnered great attention. Quantum Magnus algorithms, designed to achieve commutator scaling for time-dependent Hamiltonian simulation, have been found to be particularly efficient for such applications. When applied to unbounded Hamiltonian simulation in the interaction picture, they exhibit an unexpected superconvergence phenomenon. However, existing proofs are limited to the spatially continuous setting and do not extend to discrete spatial discretizations. In this work, we provide the first superconvergence estimate in the fully discrete setting with a finite number of spatial discretization points N, and show that it holds with an error constant uniform in N. The proof is based on the two-parameter symbol class, which, to our knowledge, is applied for the first time in algorithm analysis. The key idea is to establish a semiclassical framework by identifying two parameters through the discretization number and the time step size rescaled by the operator norm, such that the semiclassical uniformity guarantees the uniformity of both. This approach may have broader applications in numerical analysis beyond the specific context of this work.

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