

IP0**Dnes Knig Prize Lecture: Talk Title TBD**

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Zeev Dvir

Princeton University
zeev.dvir@gmail.com

IP1**Cell Complexes in Combinatorics**

Cell complexes of various kinds have been invented in topology to help analyze manifolds and other spaces. By introducing a combinatorial structure they make algorithms for computing topological invariants possible. Simplicial complexes are well-known examples. In the other direction, several structures studied in combinatorics naturally suggest associated cell complexes. Can the link to topology provided by these cell complexes be of use for dealing with purely combinatorial questions, or are they just idle curiosities? The answer is definitely "yes" in the simplicial case, as testified by several successes of what has come to be called "topological combinatorics". But what about more general cell complexes? In the talk this question will be discussed. Examples, old and new, arising in graph, group and number theory will be reviewed.

Anders Björner

Royal Institute of Technology (KTH)
bjorner@math.kth.se

IP2**On Sidorenko's Conjecture**

The Erdos-Simonovits-Sidorenko conjecture is well-known in combinatorics but it has equivalent formulations in analysis and probability theory. The shortest formulation is an integral inequality related to Mayer integrals in statistical mechanics and Feynman integrals in quantum field theory. We present new progress in the area. Part of the talk is based on joint results with J.L. Xiang Li. In particular we present a type of calculus (based on logarithmic functions) which can be used to prove inequalities between subgraph densities.

Balázs Szegedy

University of Toronto
Department of Mathematics
szegedyb@gmail.com

IP3**Forcing Large Transitive Subtournaments**

The Erdos Hajnal Conjecture states roughly that a graph with some induced subgraph excluded has a large clique or a large stable set. A similar statement can be formulated for tournaments (a tournament is an orientation of a complete graph), replacing cliques and stable sets by transitive subtournaments; and the two conjectures turn out to be equivalent. This talk will survey a number of recent results related to the latter conjecture. In particular, we will discuss a new infinite class of tournaments excluding which forces large transitive subtournaments; to the best of our knowledge this is the first such class not obtained by the so-called substitution operation.

Maria Chudnovsky
Columbia

mchudnov@columbia.edu

IP4**Adding and Counting**

In mathematics, the stuff of partitions seems like mere child's play. The speaker will explain how the simple task of adding and counting has fascinated many of the world's leading mathematicians: Euler, Ramanujan, Hardy, Rademacher, Dyson, to name a few. And as is typical in number theory, many of the most fundamental (and simple to state) questions have remained open. In 2010, the speaker, with the support of the American Institute for Mathematics and the National Science Foundation, assembled an international team of researchers to attack some of these problems. Come hear Professor Ono speak about their findings: new theories which solve some of the famous old questions.

Ken Ono

Emory University
Department of Mathematics and Computer Science
ono@mathcs.emory.edu

IP5**Coloring 3-colorable Graphs; Graph Theory Finally Strikes Back!**

We consider the problem of coloring a 3-colorable graph in polynomial time using as few colors as possible. Starting with Wigderson in 1982 ($O(n^{1/2})$ colors), Blum in 1990 came with the first polynomial improvements ($O(n^{3/8})$ colors). His improvement is based on graph theoretical approach. Karger, Motwani, Sudan in 1994 is the first to use semi-definite programming (SDP) to give improvement, and then Karger and Blum in 1997 combines Blum's method with the SDP improvement to show that $O(n^{0.2142})$ colors suffices. Since then, the only improvements in semi-definite programming have been made (Arora, Chlamtac, and Charikar in 2006 ($O(n^{0.2111})$ colors), and Chlamtac in 2007 ($O(n^{0.2072})$ colors)). We present the first improvement on the graph theory side since Blum in 1990. With a purely graph theoretical approach, we get down to $O(n^{4/11})$ colors (over Blum's $O(n^{3/8})$ colors). Combining it with SDP, we get down to $O(n^{0.2038})$ colors. Joint work with Mikkel Thorup (ATT Research)

Ken-ichi Kawarabayashi

National Institute of Informatics, Japan
k_keniti@nii.ac.jp

IP6**Talk Title TBA - Singh**

Abstract not available at time of publication.

Mona Singh

Princeton University
msingh@cs.princeton.edu

IP7**The Hub Labeling Algorithm**

This is a survey of Hub Labeling results for general and road networks. Given a weighted graph, a distance oracle takes as an input a pair of vertices and returns the distance between them. The labeling approach to distance

oracle design is to precompute a label for every vertex so that distances can be computed from the corresponding labels. This approach has been introduced by [Gavoille et al. '01], who also introduced the Hub Labeling algorithm (HL). HL has been further studied by [Cohen et al. '02]. We study HL in the context of graphs with small high-way dimension (e.g., road networks). We show that under this assumption HL labels are small and the queries are sublinear. We also give an approximation algorithm for computing small HL labels that uses the fact that shortest path set systems have small VC-dimension. Although polynomial-time, precomputation given by theory is too slow for continental-size road networks. However, heuristics guided by the theory are fast, and compute very small labels. This leads to the fastest currently known practical distance oracles for road networks. The simplicity of HL queries allows their implementation inside of a relational database (e.g., in SQL), and query efficiency assures real-time response. Furthermore, including HL data in the database allows efficient implementation of more sophisticated location-based queries. This approach brings the power of location-based services to SQL programmers

Andrew Goldberg
Microsoft Research Silicon Valley
goldberg@microsoft.com

IP8

Algorithms, Graph Theory, and the Solution of Laplacian Linear Equations

We survey several fascinating concepts and algorithms in graph theory that arise in the design of fast algorithms for solving linear equations in the Laplacian matrices of graphs. We will begin by explaining why linear equations in these matrices are so interesting. The problem of solving linear equations in these matrices motivates a new notion of what it means for one graph to approximate another. This leads to a problem of graph sparsification—the approximation of a graph by a sparser graph. Our algorithms for solving Laplacian linear equations will exploit surprisingly strong approximations of graphs by sparse graphs, and even by trees. We will survey the roles that spectral graph theory, random matrix theory, graph sparsification, low-stretch spanning trees and local clustering algorithms play in the design of fast algorithms for solving Laplacian linear equations.

Daniel Spielman
Yale University
spielman@cs.yale.edu

CP1

On Antimagic Vertex Labeling Of Hypergraphs

Let $H = (V, E)$ be a graph with vertex set $V(H)$ and edge set $E(H)$. Moreover suppose that $v = |V(H)|$, $e = |E(H)|$ and N denotes the set of non negative integers. An antimagic (magic) vertex labeling is a bijection “f” from $V(H)$ to the set of consecutive integers $1, 2, \dots, v$ if the induced edge labeling “g” from $E(H)$ to the set of non negative integers N defined by $g(e) = \sum_{v \in e} f(v)$ for all v in $E(H)$ is injective (constant) function. A hypergraph H is called antimagic (magic) iff there exist an antimagic (magic) vertex labeling of H . In this paper we formulate antimagic vertex labeling on star and disjoint union of star hypergraph.

Akhlaq Bhatti
FAST-NUCES LAHORE, PAKISTAN

akhlaq.ahmad@nu.edu.pk

Muhammad Javaid
FAST-National University of Computer and Emerging Sciences
Lahore Campus, Lahore, Pakistan
javaidmath@gmail.com

CP1

Distinguishing with Nordhaus Gaddum graphs

Albertson and Collins introduced the distinguishing number in 1996 and Collins and Trenk introduced the distinguishing chromatic number of a graph which requires that the coloring be proper as well as distinguishing in 2006. We revisit the Nordhaus-Gaddum inequalities which give bounds on the sum and the product of $\chi(G)$ and $\chi(\overline{G})$ for any graph G , and give analogues of these inequalities for the distinguishing chromatic number. We provide a new characterization of those graphs that achieve equality for the upper bound in the sum Nordhaus-Gaddum inequality, which leads to a polynomial-time recognition algorithm for this class and efficient computation of their chromatic numbers.

Karen Collins
Wesleyan University
kcollins@wesleyan.edu

Ann N. Trenk
Wellesley College
atrenk@wellesley.edu

CP1

On Super (a,d)-Edge Antimagic Total Labeling of Subdivided Caterpillar

Let $G = (V, E)$ be a graph with $v = |V(G)|$ vertices and $e = |E(G)|$ edges. An (a, d) -edge antimagic total labeling is a bijection “f” from $V(G) \cup E(G)$ to the set of consecutive integers $1, 2, \dots, v + e$, such that the weights of the edge $W = \{w(xy) : xy \in E(G)\}$ form an arithmetic progression with the initial term “a” and common difference “d” where $w(xy) = f(x) + f(y) + f(xy)$. “W” is called the set of edge-weights of the graph G. Additionally, if $f(V) = 1, 2, \dots, |V(G)|$ then f is called super (a, d) -edge antimagic total labeling and G is called super (a, d) -edge antimagic total. In this paper we formulate, super (a, d) -edge antimagic total labeling on subdivided caterpillar for different integral values of d .

Muhammad Javaid
FAST-National University of Computer and Emerging Sciences
Lahore Campus, Lahore, Pakistan
javaidmath@gmail.com

Akhlaq Bhatti
FAST-NUCES LAHORE, PAKISTAN
akhlaq.ahmad@nu.edu.pk

CP1

On Two Conjectures About Graceful Digraphs

A digraph D with p vertices and q arcs is labeled by assigning a distinct integer value $g(v)$ from $\{0, 1, \dots, q\}$ to each vertex v . The vertex values, in turn, induce a value $g(u, v)$ on each arc (u, v) where $g(u, v) = (g(v) - g(u)) \pmod{q+1}$.

If the arc values are all distinct then the labeling is called a graceful labeling of digraph. In this talk we present the proofs of two conjectures namely, Bloom and Hsu's conjecture (1985) on graceful unicyclic wheels and Du and Sun's conjecture (1994) on the gracefulness of the digraph $n.C_m^{\rightarrow}$.

Shivaraj Kumar
NITK Surathkal
shivaraj_04@yahoo.co.in

Suresh Hegde
NITK Surathkal, India
smhegde@nitk.ac.in

CP2

Saving Sets of Vertices in the Firefighter Problem

The Firefighter Problem is a discrete-time model of the spread of a fire using a simple graph. At each time step a player has an opportunity to defend some vertex (or set of vertices) and then the fire spreads from all burning vertices to all of their undefended neighbours. Here we examine the decision problem that asks if a specified set of vertices can be saved from burning.

Christopher Duffy, Gary MacGillivray
University of Victoria
duffy@uvic.ca, gmacgill@math.uvic.ca

CP2

A Game on Zero Forcing Sets

We consider the two player game on a graph where players alternate turns, with one player selecting a vertex to color black on each turn and the other player selecting a vertex to color white on each turn. The black player wins if after all of the vertices have been colored, the black vertices form a zero forcing set. This game will be discussed for several classes of graphs.

Kara Greenfield, Alyssa Gottshall
Worcester Polytechnic Institute
kgreenfield@wpi.edu, agottshall@wpi.edu

Steve Butler
UC Los Angeles
USA
butler@math.ucla.edu

Young Michael
Iowa State University
myoung@iastate.edu

CP2

A Generalization of the Nim and Wythoff Games

We define a two-player game $\mathcal{G}(\parallel, \setminus)$ (with $k \leq n$) as follows: each player chooses up to k stacks from a total of n stacks and removes an equal number of tokens from the selected stacks. The first player who cannot move loses. $\mathcal{G}(\infty, \setminus)$ is ordinary Nim and $\mathcal{G}(\in, \in)$ is Wythoff. We will present a conjecture on the structure of the losing positions of this class of games and prove a special case of the conjecture.

Silvia Heubach
California State University Los Angeles

sheubac@calstatela.edu

Matthieu Dufour
University of Quebec at Montreal
dufour.matthieu@uqam.ca

CP2

Structure of Weighted Graphs with Forbidden Subdivision and Graph Sharing Games

We show that every weighted graph excluding subdivision of a fixed (small) graph contains one of the following structures:

- a connected subgraph separating the graph into heavy balanced components,
- a heavy set of vertices connected by paths as in a cycle.

This characterization yields a strategy for the first player to gather a positive fraction of the total weight in a variant of graph sharing game played on graphs with forbidden subdivision.

Piotr Micek
Jagellonian University
piotr.Micek@tcs.uj.edu.pl

Adam Gagol
Maria Curie-Sklodowska University
adam.gagol@gmail.com

Bartosz Walczak
Jagiellonian University
walczak@tcs.uj.edu.pl

CP3

2-Switches and Isomorphism Classes

A 2-switch is an operation that changes adjacencies in a graph while preserving vertex degrees. The resulting graph may or may not have the same isomorphism class; we show that if a 2-switch changes the isomorphism class of a graph, then it takes place in one of four configurations. We also present a sufficient condition for 2-switches to change graph isomorphism classes and examine consequences for graphs determined up to isomorphism by their degree sequences.

Michael Barrus
Black Hills State University
Department of Mathematics
michael.barrus@bhsu.edu

CP3

The Number of Spanning Trees in Self-Similar Graphs.

The number of spanning trees of a graph is an important invariant related to its topological and dynamic properties (reliability, communication, synchronization, etc.) Its calculation remains a challenge, particularly for large networks. We describe a method to find an exact analytical expression for the number of spanning trees (and tree entropy) for several relevant graph families, including Hanoi graphs, Apollonian networks and some maximal outerplanar graphs. The method is based on the self-similarity of the graphs considered.

Francesc Comellas

Universitat Politecnica de Catalunya
comellas@ma4.upc.edu

Zhongzhi Zhang
Fudan University, China
zhangzz@fudan.edu.cn

CP3

On the 2-Edge Clique Cover Numbers of Graphs

Let \mathcal{F} be a multifamily of subsets of the vertex set of a graph G . The multifamily \mathcal{F} is called a 2-edge clique cover of G if for any two distinct $I, J \in \mathcal{F}$, $I \cap J$ is a clique of G , and the family $\{I \cap J \mid I, J \in \mathcal{F}, I \neq J\}$ is an edge clique cover of G . The minimum size of a 2-edge clique cover of G is called the 2-edge clique cover number of G . In general, it is hard to compute a 2-edge clique cover of a graph. In this talk, we study relationships between the 2-edge clique cover number and the edge clique cover number of a graph. Then we focus on the 2-edge clique cover numbers of a path and a cycle, and then give a bound for 2-edge clique cover number of a star $K_{1,n}$ by using a block design.

Jung Yeun Lee
National Institute of Mathematical Science
South Korea
jungyeunlee@gmail.com

Suh-Ryung Kim
Seoul National University
srkim@snu.ac.kr

Boram Park
DIMACS
Rutgers University
boramp@dimacs.rutgers.edu

Yoshio Sano
National Institute of Informatics
y.sano.math@gmail.com

CP3

Dual-Chordal and Strongly Dual-Chordal Graphs

If a subgraph is defined to be strength- k whenever it is in $\geq k$ maxcliques, then a graph is (strongly) chordal if and only if (for all $k \geq 1$) every cycle of (strength- k) edges either has a (strength- k) chord or is a (strength- k) triangle. A carefully crafted notion of dual strength (using cycle/cutset duality) allows parallel characterizations of (strongly) dual-chordal graphs and a listing of all 3-connected strongly dual-chordal graphs.

Terry McKee
Wright State University
Department of Mathematics & Statistics
terry.mckee@wright.edu

CP3

Well-Covered Graphs Without C_4, C_5, C_6

Let $G = (V, E)$ be a graph and $w : V \rightarrow R$ be a weight function. Then G is w -well-covered if all its maximal independent sets are of the same weight. The set of weight functions w such that G is w -well-covered is a *vector space*. Given an input graph G without cycles of length 4, 5, and 6 (not necessarily induced), we characterize polynomially the vector space of weight functions w for which G is w -

well-covered.

David Tankus
Ariel University Center of Samaria, Israel
davidta@ariel.ac.il

Vadim E. Levit
Ariel University Center of Samaria and Holon Inst. of Tech.
Dept. of Computer Science & Mathematics
levitv@ariel.ac.il

CP4

Construction of nonuniform p-wavelet packets

A generalization of Mallat's classical multiresolution analysis for which the translation set is a discrete set which is not a group, was defined by Gabardo and Nashed. In this talk, we introduce nonuniform multiresolution p-analysis on $L^2(R^+)$, analogy of Gabardo-Nashed definition and then we will construct the associated p-wavelet packets for such an multiresolution p-analysis on $L^2(R^+)$.

Jahangir Cheshmavar
Payame Noor University (PNU)
j.cheshmavar@gmail.com

CP4

Application of New Variational Method Using Hamiltonian for Nonlinear Oscillators with Discontinuities

In this paper, we used Hamiltonian for nonlinear oscillators with discontinuities. The maximal relative error for the frequency obtained by new variational method compared with the exact solution indicates the remarkable precision of this method. Some examples are given to illustrate the effectiveness and convenience of the method

Waseem A. Khan
CIIT, ISLAMABAD, PAKISTAN
waseemasg@gmail.com

CP4

A Comparison of Conventional and Fuzzy Methods in Performance Appraisal Process

The purpose of this paper is to address the performance appraisal process via conventional and Fuzzy satisfied methods. Conventional methods for solving performance appraisal decision making problem are by using statistical methods (chi-square, correlation etc) on the measurement of performance based on specific appraisal criteria. This research shows that the Fuzzy satisfied method is an easy to understand and realistic technique as it enables us to understand the relative strengths and weaknesses of employees, thus providing useful information for improving competitive advantage.

Idowu A. Osinuga
Department of Mathematics, College of Natural Sciences,
Federal University of Agriculture, Abeokuta, Nigeria
osinuga08@gmail.com

Adegboyega Adekoya
Department of Mathematical Sciences, Olabisi Onabanjo Univ
Ago-Iwoye, Nigeria

princeoluseyi2005@yahoo.com

CP4

On the Structure of Some Groups Containing $L_2(13)wrL_2(17)$

In this paper, we will show the structure of some groups containing the wreath product $L_2(13)wrL_2(17)$. Some symmetric and alternating groups are constructed in view of such wreath product. Some other related cases are also included.

Basmah Shafee

Umm Al qura University
dr.basmah_1391@hotmail.com

CP4

Fixed Points Of a Fuzzy Semantics Function

The meaning of a program is given by specifying the function (from input to output) that corresponds to the program. The denotational semantic definition, thus maps syntactical things into functions. A fuzzy relational semantics is a mapping of programs to relations. We consider that the input-output semantics of a program is given by a fuzzy relation on its set of states. In a nondeterministic context, this relation is calculated by considering the worst behavior of the program (*demonic fuzzy relational semantics*). In this paper, we concentrate on while loops. We will present some interesting results about the fixed points of the while fuzzy semantics function; $f(X) = Q \cup_f uz P_f uz X$ where $PQ =$, by taking $P := tB$ and $Q := t$, one gets the demonic semantics we have assigned to while loops in previous papers. We will show that the least angelic fixed point is equal to the greatest demonic fixed point of the fuzzy semantics function.

Fairouz Tchier

King saud University
ftchier@ksu.edu.sa

CP4

Binary Sequences, Fractals, and Primes

The concept of a fractal transformation is discussed. A 1-dimensional example leads to connections between the topics in the title.

Andrew Vince

Department of Mathematics
University of Florida
avince@ufl.edu

Michael Barnsley

Australian National University
michael.barnsley@anu.edu.au

CP5

Order Dimension and Coloring of Planar Point Sets

The Erdős-Szekeres Conjecture of planar point sets in general position will be discussed using convex geometries or anti-matroids. We study this problem with two graphs, one based on the lattice of closed sets and the other from the copoints of the convex geometry. We use these graphs to show that any point set in general position with at least

$2^{n-2} + 1$ has order dimension at least n .

Jonathan E. Beagley

George Mason University
jbeagley@gmu.edu

CP5

Universal Cycles for Weak Orders and a Problem of Knuth

A weak order on $[n] = \{1, 2, \dots, n\}$ is a string $w_1 w_2 \dots w_n$ such that $\{w_1, w_2, \dots, w_n\} = [n]$, for some height $h \leq n$. Knuth asked: For which n does there exist a Gray code for all weak orders on $[n]$ using operations of the form $w_i \leftrightarrow w_{i+1}$ and $w_i \leftrightarrow w_{i+2}$? We prove such existence for a class of weak orders with the additional operation $w_i \leftrightarrow w_{i+2}$ and discuss open problems for fixed height weak orders that are related to solving the original problem. Furthermore, we present constructions of universal cycles for weak orders, as well as for weak orders of fixed height or weight.

Victoria Horan, Glenn Hurlbert

Arizona State University
vhoran@asu.edu, hurlbert@asu.edu

CP5

Zeta Polynomials for Shellable Posets and Their Applications

The zeta polynomial $Z(P, n)$ for a poset P is the number of multichains in P of length $n - 2$, and a shellable poset P is a graded poset whose maximal chains explain the structure of chains in P . Using shellability, we establish theorems on computations of zeta polynomials for shellable posets. Applying these theorem, we also derive new results on multi-dimensional partitions, multidimensional Young tableaux, lattice paths, and multiset permutations.

Joon Yop Lee

ASARC, KAIST
flutelee@postech.ac.kr

CP5

The Largest Size Versus the Largest Weight of Families of Sets Without a Poset P

We are interested in how large a family of subsets of $[n] := \{1, 2, \dots, n\}$ not containing a given poset P as a subposet can be. Such a family is called a P -free family and the largest size of a P -free family is denoted by $\text{La}(n, P)$. Griggs and Lu conjectured that $\pi(P) := \lim_{n \rightarrow \infty} \text{La}(n, P) / \binom{n}{\lfloor \frac{n}{2} \rfloor}$ exists and is an integer for any finite P . The Lubell function of a family \mathcal{F} of subsets of $[n]$ is $\bar{h}_n(\mathcal{F}) := \sum_{\mathcal{E} \in \mathcal{F}} \binom{n}{|\mathcal{E}|}^{-1}$ which can be viewed as the weighted sum of sets in \mathcal{F} . It gives an upper bound of $|\mathcal{F}|$, which is crucial in solving the forbidden subposet problem above. We will study the limit of $\lambda_n(P) := \max_{\mathcal{F}} \bar{h}_n(\mathcal{F})$ over all P -free families \mathcal{F} as n increases and demonstrate a class of posets satisfying $\pi(P) = \lim_n \lambda_n(P)$. We will also show that for many posets $\lim_n \lambda_n(P)$ exists and can be evaluated, although $\pi(P)$ is unknown.

Jerry Griggs

University of South Carolina, Columbia
griggs@math.sc.edu

Wei-Tian Li

Department of Mathematics

Univeristy of South Carolina
weitianli@math.sinica.edu.tw

CP5**Searching Algorithms in Partially Ordered Set**

Using conceptual graphs and graph homomorphism it is possible to build a basic query-answering mechanism based on semantic search. Because graph homomorphism is NP-Complete, the main requirement for conceptual graph database building and managing algorithms is to reduce the homomorphism checks. Graph homomorphism defines a partial order over conceptual graphs. Searching is a basic operation for building and managing operations as ordering, updating, and retrieval. We propose two new searching algorithms in a poset.

Abdurashid R. Mamadolimov
MIMOS, Malaysia
rashid.mdolimov@mimos.my

CP5**The Bkr Inequality on Finite Distributive Lattices**

The van den Berg-Kesten-Reimer inequality, or BKR inequality, is a well-known result in combinatorial probability with applications in percolation. The BKR inequality applies to product spaces X equipped with product probability measures. For events A and B , the box product of A and B is the set of tuples x in X that lie in A and B disjointly, i.e. x lies in A due to the values of one set of x 's coordinates and in B due to a disjoint set of coordinates. The BKR inequality states that for any two events A and B of any finite product probability space the measure of the box product of A and B is less than or equal to the product of the measures of A and B . We extend the box product and the BKR inequality to finite distributive lattices with log modular measures, analogues of product measures. A product space can be made into a distributive lattice by linearly ordering each member of the product. The new box product of A and B will then contain the old box product. Furthermore the containment is often strict, improving the BKR inequality.

Clifford D. Smyth
University of North Carolina Greensboro
cdsmyth@uncg.edu

CP6**On the Locating-Chromatic Number of a Corona Product of Two Graphs**

The problem of determining the locating-chromatic number for a general graph is an NP-hard problem. Therefore, there is no efficient algorithm to determine this number of arbitrary graph. Some heuristics have been developed and some studies were done to find the locating-chromatic number for certain graphs. In this paper, we investigate the locating-chromatic number for a corona product $G \odot H$. Some upper bound will be derived. We also determine the locating-chromatic number of certain graphs.

Edy T. Baskoro, Ira Purwasih
Institut Teknologi Bandung
Indonesia
ebaskoro@math.itb.ac.id, ira_apni_p@students.itb.ac.id

CP6**On The Structure Of The γ -Graph Of A Tree**

The γ -graph of a graph G has vertex set comprised of all minimum dominating sets of G . There are two ways to define adjacency in the γ -graph: where dominating sets are adjacent if they agree in all but one vertex, or where dominating sets are adjacent if they agree in all but one vertex and the differing vertices are adjacent. Here we answer open questions on maximum degree, diameter, and order of γ -graphs for trees.

Michelle Edwards, Gary Macgillivray
Mathematics and Statistics
University of Victoria
michelle@math.uvic.ca, gmacgill@math.uvic.ca

CP6**Some Unsolved Problems on Cycles**

Hajos' conjecture that every simple even graph on n vertices can be decomposed into at most $(n-1)/2$ cycles. Let $f(n)$ be the maximum number of edges in a graph on n vertices in which no two cycles have the same length. P. Erdos raised the problem of determining $f(n)$. P. Erdos conjectured that there exists a positive constant c such that $ex(n, C_{2k}) \geq cn^{1+1/k}$. This talk summarizes some results on these problems and the conjectures that relate to these. It seems to me that Hajós conjecture is false.

Chunhui Lai
Zhangzhou Normal University
laichunhui@fjzs.edu.cn

Mingjing Liu
Department of Mathematics and Information Science
Zhangzhou Normal University
liumingjing1983@163.com

CP6**On Signed Star Domination and Domatic Numbers of Complete Multipartite Graphs**

The signed star domination and domatic numbers of a graph G , $\gamma_{SS}(G)$ and $d_{SS}(G)$, were first introduced in [B. Xu, On edge domination numbers of graphs, Discrete Mathematics, 294 (2005), 311–316.] and [M. Atapour, S. M. Sheikholeslami, A. N. Ghameshlou and L. Volkman, Signed star domatic number of a graph, Discrete Applied Mathematics, 158 (2010), 213–218.]. We give new constructions to complete the proofs of $\gamma_{SS}(K_{m,n})$ and $d_{SS}(K_{m,n})$. We also obtain $\gamma_{SS}(K_{m(n)})$ and $d_{SS}(K_{m(n)})$.

Wu-Hsiung Lin
Departement of Applied Mathematics
National Chiao Tung University
d92221001@ntu.edu.tw

Chiuyuan Chen, Well Y. Chiu, ALLEN Y. Wang
Departement of Applied Mathematics,
National Chiao Tung University
cychen@mail.nctu.edu.tw, well.am97g@nctu.edu.tw, dogyhaypay@hotmail.com

CP6**Decompositions of Complete Multipartite Graphs**

into Gregarious Long Cycles

The notion of gregarious cycles in complete multipartite graphs was introduced by Billington and Hoffman in 2003 and was modified by Billington, Smith, and Hoffman in 2007. In this talk, we propose more general definition of “gregarious” cycles which is a common generalization of both the definitions. With our definition, we can consider the problem to characterize complete multipartite graphs which are decomposable into gregarious long cycles, and we give some results on this problem.

Jeongmi Park, Jung Rae Cho
Department of Mathematics
Pusan National University
jm1015@pusan.ac.kr, jungcho@pusan.ac.kr

Yoshio Sano
National Institute of Informatics
sano@nii.ac.jp

CP6

A New Upper Bound for the Broadcast Domination Number of a Graph

The *broadcast domination number* of a graph G , denoted $\gamma_b(G)$, is the minimum cost of a dominating broadcast on G . We present an improvement to the well-known Bollobás-Cockayne bound from $\gamma_b(G) \leq \min\{rad(G), \gamma(G)\} \leq 2 \text{ir}(G) - 1$, to $\gamma_b(G) \leq \frac{3}{2} \text{ir}(G)$. We also show the existence of a graph G with $\gamma_b(G) - \text{ir}(G) = k$ for any positive integer k .

Laura E. Teshima, Christina Mynhardt
University of Victoria
LTeshima@uvic.ca, c.m. mynhardt

CP7

The Edge Density of Critical Digraphs

Let $\chi(G)$ denote the chromatic number of a graph G . We say that G is k -critical if $\chi(G) = k$ and $\chi(H) < k$ for every proper subgraph $H \subset G$. Over the years, many properties of k -critical graphs have been discovered, including improved upper and lower bounds for $\|G\|$, the number of edges in a k -critical graph, as a function of $|G|$, the number of vertices. In this note, we analyze this edge density problem for directed graphs, where the chromatic number $\chi(D)$ of a digraph D is defined to be the fewest number of colours needed to colour the vertices of D so that each colour class induces an acyclic subgraph. For each $k \geq 3$, we construct an infinite family of sparse k -critical digraphs for which $\|D\| < (\frac{k^2-k+1}{2})|D|$ and an infinite family of dense k -critical digraphs for which $\|D\| > (\frac{1}{2} - \frac{1}{2^{k-1}})|D|^2$. One corollary of our results is an explicit construction of an infinite family of k -critical digraphs of digirth l , for any pair of integers $k, l \geq 3$. This extends a result by Bokal et al. who used a probabilistic approach to demonstrate the existence of one such digraph.

Richard Hoshino, Ken-Ichi Kawarabayashi
National Institute of Informatics
richard.hoshino@gmail.com, k keniti@nii.ac.jp

CP7

On the Density of Nearly Regular Graphs with a

Good Edge-Labelling

A good edge-labelling of a simple graph is a labelling of its edges with real numbers such that, for any ordered pair of vertices (u, v) , there is at most one non-decreasing path from u to v . Say a graph is good if it admits a good edge-labelling, and is bad otherwise. Our main result is that any good n -vertex graph whose maximum degree is within a constant factor of its average degree (in particular, any good regular graph) has at most $n^{1+o(1)}$ edges. As a corollary, we show that there are bad graphs with arbitrarily large girth, answering a question of Bode, Farzad and Theis. We also prove that for any Δ , there is a g such that any graph with maximum degree at most Δ and girth at least g is good.

Abbas Mehrabian

Department of Combinatorics and Optimization
University of Waterloo
amehrabi@uwaterloo.ca

CP7

Bounds on Shannon Capacity and Ramsey Numbers from Product of Graphs

We study Shannon capacity of channels in the context of Ramsey numbers. We overview some of the results on channel capacity, and how Ramsey-type constructions may enhance them. A new lower bound for a special type of multi-color Ramsey numbers is presented, which implies that the supremum of the Shannon capacity over all graphs with independence 2 cannot be achieved by any finite graph power. This generalizes to graphs with any bounded independence number.

Xiaodong Xu
Guangxi Academy of Sciences
xxdmaths@sina.com

Stanisław P. Radziszowski

Department of Computer Science
Rochester Institute of Technology
spr@cs.rit.edu

CP7

Colorings of Uniform Hypergraphs with Large Girth

The talk deals with a combinatorial problem concerning colorings of uniform hypergraphs with large girth. Let H be a hypergraph and $\Delta(H)$ denote the maximum vertex degree of H . By using a continuous-time random recoloring process we prove that if H is an n -uniform non- r -colorable hypergraph with girth at least 6 then

$$\Delta(H) \geq c \frac{n^{n-1}}{\ln n},$$

where $c > 0$ is an absolute constant.

Dmitry A. Shabanov
Moscow State University
shabanov@mech.math.msu.su

Andrei Kapavskii
Moscow Institute of Physics and Technology
kupavskii@yandex.ru

CP7**Embedding Spanning Bipartite Graphs of Small Bandwidth**

Böttcher, Schacht and Taraz gave a condition on the minimum degree of a graph G on n vertices that ensures G contains every r -chromatic graph H on n vertices of bounded degree and of bandwidth $o(n)$, thereby proving a conjecture of Bollobás and Komlós. We strengthen this result in the case when H is bipartite by relaxing the condition on G to a condition on the degree sequence of G .

Andrew Treglown, Fiachra Knox
University of Birmingham
treglown@kam.mff.cuni.cz, knoxf@maths.bham.ac.uk

CP8**Forbidden Submatrices**

We consider an extremal hypergraph problem, where the order of the elements and of the hyperedges matter. In matrix terms, let F be a given $(0,1)$ -matrix. Among all m -rowed $(0,1)$ -matrices with no repeated columns and no submatrix F , what is the maximum number of columns? We call this $fs(m, F)$. It was conjectured by Anstee, Frankl, Füredi, Pach that if F has k rows then $fs(m, F)$ is $O(m^k)$. We give results for 2-rowed F .

Richard P. Anstee
Mathematics Department
University of British Columbia
anstee@math.ubc.ca

Ruiyuan Chen
UBC
Vancouver, Canada
ruiyuan@interchange.ubc.ca

Attila Sali
Renyi Institute
sali@renyi.hu

CP8**Intertwining Connectivities in Matroids Representable over a Finite Field**

Let N_1 and N_2 be matroids. An *intertwine* of N_1 and N_2 is a matroid that has both an N_1 - and N_2 -minor, and is minor-minimal with this property. Bonin proved that there exist matroids N_1 and N_2 with infinitely many intertwines. We prove that if we instead intertwine “connectivities” instead of minors, then there are a finite number of \mathbf{F} -representable intertwines, for \mathbf{F} finite.

Tony Huynh
University of Waterloo
tony.bourbaki@gmail.com

Bert Gerards
CWI Amsterdam
bert.gerards@cwi.nl

Stefan van Zwam
Princeton University
svanzwam@princeton.edu

CP8**The Minimum Rank of Universal Adjacency Matrices**

For a simple graph G on n vertices, a matrix of the form

$$U(\alpha, \beta, \gamma, \delta) = \alpha A + \beta I + \gamma J + \delta D$$

where A is the $0,1$ -adjacency matrix of G , J is the all ones matrix of size n , I is the identity matrix of size n , and D is the diagonal matrix with the degrees of the vertices in the main diagonal, and $\alpha \neq 0, \beta, \gamma, \delta$ are scalars, is called a *universal adjacency matrix* of G . An analogous parameter to the minimum rank of a given graph G is the minimum rank over all matrices in the set of universal adjacency matrices of G . This parameter is called the *minimum universal rank* of G , and is denoted by $\text{mur}(G)$. Graphs with $\text{mur}(G)$ equal to zero and one are characterized. The minimum universal rank of some families of graphs such as complete graphs, complete bipartite graphs, paths and cycles are presented. A formula for the minimum universal rank of a regular graph is given. Finally, it is shown that $\text{mur}(G)$ is not monotone on induced subgraphs. This is joint work with Discrete Mathematics Research Group at the University of Regina.

Shahla Nasserassr, Bahman Ahmadi, Fatemeh Alinaghpour
University of Regina
shahla.nasserassr@uregina.ca, ahmadi2b@uregina.ca, alinaghf@uregina.ca

Shaun M. Fallat
University of Regina
Canada
sfallat@math.uregina.ca

Yi-Zheng Fan
Anhui University
fanyz@ahu.edu.cn

Karen Meagher
University of Regina
Saskatchewan, Canada
karen.meagher@uregina.ca

CP8**The Supertail of a Subspace Partition**

Let $V = V(n, q)$ be a vector space of dimension n over the finite field with q elements, and let $d_1 < d_2 < \dots < d_m$ be the dimensions that occur in a subspace partition \mathcal{P} of V . Let $\sigma_q(n, t)$ denote the minimum size of a subspace partition of V in which t is the largest dimension of a subspace. For any integer s , with $1 < s \leq m$, the set of subspaces in \mathcal{P} of dimension less than d_s is called the s -supertail of \mathcal{P} . We show that the number of subspaces in an s -supertail is at least $\sigma_q(d_s, d_{s-1})$.

Esmeralda L. Nastase
Xavier University
nastasee@xavier.edu

Olof Heden
KTH
olohed@kth.se

Julianne Lehmann
Bremen University
jule.germany@googlegmail.com jjule.germany@googlegmail.com

Papa Sissokho
 Illinois State University
 psissok@ilstu.edu

CP8

Rank-Width and Well-Quasi-Ordering of Skew-Symmetric Or Symmetric Matrices

We prove that every infinite sequence of skew-symmetric or symmetric matrices M_1, M_2, \dots over a fixed finite field must have a pair M_i, M_j ($i < j$) such that M_i is isomorphic to a principal submatrix of the Schur complement of a nonsingular principal submatrix in M_j , if those matrices have bounded rank-width. This generalizes three theorems on well-quasi-ordering of graphs or matroids admitting good tree-like decompositions; (1) Robertson and Seymour's theorem for graphs of bounded tree-width, (2) Geelen, Gerards, and Whittle's theorem for matroids representable over a fixed finite field having bounded branch-width, and (3) Oum's theorem for graphs of bounded rank-width with respect to pivot-minors.

Sang-Il Oum
 KAIST
 sangil@kaist.edu

CP9

Applications of the Traveling Salesman Problem and Perfect B-Matching for Finding Genomic Medians

Genomic medians model an ancestor of several species. There has been extensive research on finding medians. We study the Breakpoint Median Problem (BMP) and present a novel and successful approach in which the NP-hard problem of BMP for linear multichromosomal genomes is transformed into a variation of the Traveling Salesman Problem. We also use perfect b-matchings to show, for the first time, that BMP for circular or mixed unsigned genomes is solvable in polynomial time.

Maryam Haghghi, Sylvia Boyd
 University of Ottawa
 mhagh051@uottawa.ca, sylvia@eecs.uottawa.ca

CP9

A Branch, Bound, and Remember Algorithm for the Simple Assembly Line Balancing Problem

A new exact algorithm is presented for the assembly line balancing problem, which finds and verifies the optimal solution for every problem in the benchmarks of Hoffmann, Talbot, and Scholl one-half second per problem, on average, including one problem that has remained open for over ten years. The previous best known algorithm solved 257 of the 269 benchmarks. The new algorithm is based on a branch and bound method using memory to eliminate redundant subproblems.

Sheldon H. Jacobson
 University of Illinois
 Dept of Computer Science
 shj@uiuc.edu

Edward Sewell
 Southern Illinois University Edwardsville
 esewell@siue.edu

CP9

An Approximation Algorithm for the Multilevel Bottleneck Assignment Problem

We deal with the multilevel bottleneck assignment problem. The multilevel bottleneck assignment problem is NP-complete, and some approximation algorithms have been proposed. We propose an approximation algorithm that uses the element's rank in each set sorted in the ascending order. We show the effectiveness of our algorithm by numerical experiments for the case that elements' values follow the normal distribution. Also we present the idea of our algorithm's extension to multidimensional case.

Yuusaku Kamura
 Tokyo A&T University
 kamura@cc.tuat.ac.jp

Mario Nakamori
 Tokyo University of Agriculture and Technology
 nakamori@cc.tuat.ac.jp

CP9

Greedy Is Good to Approximate Minimum Rainbow Subgraphs

We consider the MINIMUM RAINBOW SUBGRAPH problem (MRS): Given a graph G , whose edges are coloured with p colours. Find a subgraph $F \subseteq G$ of minimum order and with p edges such that each colour occurs exactly once. In this talk we will show that the Greedy algorithm for the MRS problem has an approximation ratio of $\frac{\Delta}{2} + \frac{\ln \Delta + 1}{2}$ for graphs with maximum degree Δ . If the average degree d of a minimum rainbow subgraph is known, then the approximation ratio is $\frac{d}{2} + \frac{\ln[d]+1}{2}$.

Ingo Schiermeyer
 Technische Universität Bergakademie Freiberg
 Institut fuer Diskrete Mathematik und Algebra
 Ingo.Schiermeyer@tu-freiberg.de

CP10

Constructing Self-Dual Graph Embeddings in Surfaces

A cellular automorphism of a surface S is a 2-cell graph embedding G in S together with an automorphism of the cellular structure given by G . We detail methods which allow one, given a catalog of all cellular automorphisms in any particular surface S (such as we have produced for five surfaces), to construct all self-dual graph embeddings in S . Our methods account for all free and all non-free automorphisms, of all possible orders.

Lowell Abrams
 Department of Mathematics
 The George Washington University
 labrams@gwu.edu

Daniel Slilaty
 Department of Mathematics and Statistics
 Wright State University
 daniel.slilaty@wright.edu

CP10

k -Metric Dimension of Graphs

Let $G(V, E)$ be a connected graph. A subset S of V is said

to be k -resolving set of G , if for every pair of distinct vertices $u, v \in V - S$, there exists a vertex $w \in S$ such that $|d(u, w) - d(v, w)| \geq k$, for some $k \in \mathbb{Z}^+$. Among all k -resolving sets of G , the set having minimum cardinality is called a k -metric basis of G and its cardinality is called the k -metric dimension of G , denoted by $\beta_k(G)$. In this paper, we characterize the graphs with prescribed k -metric dimensions and also extend some of the earlier known results on metric dimension of graphs.

Sooryanarayana B

Dr. Ambedkar Institute of Technology, Bangalore
dr_bsnrao@yahoo.co.in

CP10

Almost Empty Monochromatic Triangles in Planar Point Sets

For positive integers $c, s \geq 1$, let $M_\Delta(c, s)$ be the least integer such that any set of at least $M_\Delta(c, s)$ points in the plane, no three on a line and colored with c colors, contains a monochromatic triangle with at most s interior points. The case $s = 0$, which corresponds to empty monochromatic triangles, has been studied extensively over the last few years. In particular, it is known that $M_\Delta(1, 0) = 3$, $M_\Delta(2, 0) = 9$ and $M_\Delta(c, 0) = \infty$, for $c \geq 3$. In this paper we extend these results when $c \geq 4$ and $s \geq 1$. We prove that the least integer $\lambda(c)$ such that $M_\Delta(c, \lambda(c)) < \infty$ satisfies:

$$\frac{\lfloor c \rfloor_p - 1}{2} \leq \lambda(c) \leq c - 2,$$

where $c \geq 2$ and $\lfloor c \rfloor_p$ is the largest prime number less than or equal to c . We also show that $M_\Delta(c, c - 2) \leq (c + 1)^2$, for $c \geq 2$. Finally, we determine the exact values of $M_\Delta(c, s)$ for several small values of c and s , and discuss related problems for general convex polygons.

Bhaswar B. Bhattacharya

Department of Statistics
Stanford University
bhaswar.bhattacharya@gmail.com

Deepan Basu

Indian Statistical Institute, Kolkata
sudhudeepan@gmail.com

Sandip Das

ISI, Calcutta, India
sandipdas@isical.ac.in

CP10

On The Metric Dimension Of Generalized Wheel And Other Graphs

For an ordered set $W = \{w_1, w_2, \dots, w_k\}$ of vertices and a vertex v in a connected graph G , the representation of v with respect to W is the ordered k -tuple $r(v | W) = (d(v, w_1), d(v, w_2), \dots, d(v, w_k))$, where $d(x, y)$ represents the distance between the vertices x and y . The set W is called a resolving set for G if every two vertices of G have distinct representations. A resolving set containing a minimum number of vertices is called a basis for G . The elements of a metric basis are called land marks and the metric dimension of G , denoted by $\beta(G)$, is the number of vertices in a basis of G .

A generalized wheel graph is $W_{mn} = C_m + \overline{K_n}$. In this Paper we determine the metric dimensions of Generalized Wheel graphs. We also obtain the metric dimension of

some cellular network graphs and their dual graphs.

Shreedhar K

KVG College of Engineering, Sullia
shreedhar.k@rediffmail.com

Sooryanarayana B

Dr. Ambedkar Institute of Technology, Bangalore
dr_bsnrao@yahoo.co.in

CP10

Latin Squares and Competition Numbers

In this talk we show how latin squares are used to find bounds on the competition numbers of complete multipartite graphs. Let G be a graph and let I_k denote the graph on k isolated vertices. The minimum k such that $G \cup I_k$ is the competition graph of an acyclic digraph is called the competition number of G . We show that if $n \geq 5$ is odd, then $k(K_n^4) \in \{n^2 - 4n + 7, n^2 - 4n + 8\}$. For the general case, we show that if n is a prime integer and $m \leq n$, then $k(K_n^m) \leq n^2 - 2n + 3$.

Jaromy S. Kuhl

University of West Florida
jkuhl@uwf.edu

CP10

Metric Dimension of Amalgamation of Graphs

A set of vertices S resolves a graph G if every vertex is uniquely determined by its vector of distances to the vertices in S . The metric dimension of G is the minimum cardinality of resolving set of G . Let $\{G_1, G_2, \dots, G_n\}$ be a finite collection of graphs and each G_i has a fixed vertex v_{0_i} called a terminal. The amalgamation $Amal\{G_i; v_{0_i}\}$ is formed by taking all the G_i 's and identifying their terminals. Here we study the metric dimension of $Amal\{G_i; v_{0_i}\}$ for $\{G_1, G_2, \dots, G_n\}$ a finite collection of arbitrary graphs. We give lower and upper bounds for the dimension, show that the bounds are tight, and construct infinitely many graphs for each possible value of dimensions.

Rinovia Simanjuntak, SALADDIN Uttungadewa, Suhadi Wido Saputro

Institut Teknologi Bandung
rino@math.itb.ac.id, s_uttungadewa@math.itb.ac.id,
suhadi@math.itb.ac.id

CP11

The Periodicity of Winning/Losing States in Subtraction Games

A subtraction game is a game involving a pile of tokens and a finite set S of positive integers. Two players move alternately, each removing some m tokens provided that m is an element in S . The player who makes the last move wins. We introduce an observation on the periodicity of the winning/losing positions of subtraction games which have a connection to the periodicity of the nim-sequences.

Nhan Bao Ho

La Trobe University
nbho@students.latrobe.edu.au

CP11

Towards a De Bruijn-Erdos Theorem in the L_1 -

Metric

In 1948, de Bruijn and Erdős proved that every set of n points in the plane is either collinear, or it induces at least n lines. The notion of a line can be extended in a natural way to an arbitrary metric space as follows. If δ is a metric, we say that the point x is *between* the points a and b if $\delta(a, b) = \delta(a, x) + \delta(x, b)$. The *line* induced by the points a and b consists of the points a , b , and all points x such that one of a, b, x is between the other two. With the usual Euclidean, or L_2 , metric, this is equivalent to the usual definition of a line. Chen and Chvátal conjectured in 2006 that a statement analogous to the de Bruijn–Erdős theorem holds in any finite metric space. Despite several partial results, this question is still open. We prove that with the L_1 (also called Manhattan) metric, every set of n points in the plane is either collinear, or it induces at least $\Omega(n^{6/7-o(1)})$ lines.

Ida Kantor

Charles University
ida@kam.mff.cuni.cz

Balázs Patkós

Alfr
{e}d R
{e}nyi Institute of Mathematics, Budapest
patkos@renyi.hu

CP11

Radio Number of k^{th} Power of a Path

Let G be a connected graph. For any two vertices u and v , let $d(u, v)$ denotes the distance between u and v in G . The maximum distance between any pair of vertices is called the *diameter* of G and is denoted by $\text{diam}(G)$. A radio labeling of a connected graph G is an assignment of distinct positive integers to the vertices of G , with $x \in V(G)$ labeled $f(x)$, such that $|f(u) - f(v)| + d(u, v) \geq 1 + \text{diam}(G)$ for all $u, v \in V, u \neq v$. The radio number $rn(f)$ of a radio labeling f of G is the maximum label assigned by f to a vertex of G . The radio number $rn(G)$ of G is the $\min\{rn(f)\}$ over all radio labeling f of G . The k^{th} power of a graph G , denoted by G^k , is the graph on the vertices of G with two vertices u and v are adjacent in G^k , whenever $d(u, v) \leq k$ in G . In this paper, we completely determine the radio number of the graph P_n^k for positive integers n, k with $k \geq 2$.

P. Devadas Rao

Srinivas Institute of Technology
devadasrao@yahoo.co.in

Sooryanarayana B

Dr. Ambedkar Institute of Technology, Bangalore
dr_bsnr Rao@hotmail.com

Chandru Hegde

PES Institute of Technology, Bangalore
chandruhg@gmail.com

CP11

Discrete Operators Applied to Further Generalize the Integral Image Algorithm

The "Integral Image" algorithm was extended to continuous and more general domains by Wang, Doretto et al in 2007. Their theorem will be abbreviated the "Antideriva-

tive Formula" in this talk. The main results are: (1) a more rigorous formulation (via a discretization of the derivative) to a parameter at the antiderivative formula, and (2) an extension of the antiderivative formula to more general types of domains, via a (novel) discrete integration method over curves in the plane.

Amir Shachar

Mathematical Institute, Hebrew University, Jerusalem, Israel
amir.shachar@mail.huji.ac.il

CP11

Graphs with Minimum Identifying Code and Minimum Size

In a graph G , let $B(u)$ be the set of u with all its neighbors in G . A subset S of vertices is called an identifying code of G if, for every pair of distinct vertices u and v , both $B(u) \cap S$ and $B(v) \cap S$ are nonempty and distinct. A minimum identifying code of a graph G is an identifying code of G with minimum cardinality and $M(G)$ is the cardinality of a minimum identifying code for G . A minimum identifying code graph G of order n is a graph with $M(G) = \lceil \log_2(n+1) \rceil$ having the minimum number of edges. Moncel constructed minimum identifying code graphs of order $2^m - 1$ for $m \geq 2$ and left the same problem, for arbitrary order, to be open. In this talk, we proposed the construction of connected minimum identifying code graphs to solve this problem.

Li-Da Tong

National Sun Yat-sen University, Taiwan
ldtong@math.nsysu.edu.tw

CP12

Eulerian Circuits with No Monochromatic Transitions.

Let G be an eulerian digraph with a fixed edge coloring (not necessarily a proper edge coloring). A compatible circuit T is an eulerian circuit of G such that no consecutive edges in the circuit have the same color. We provide sufficient conditions for the existence of a compatible circuit, strengthening results of Fleischner and Isaak. We also show several examples of digraphs that do not have compatible circuits.

James Carraher

University of Nebraska
s-jcarrah1@math.unl.edu

Stephen Hartke

Department of Mathematics
University of Nebraska - Lincoln
hartke@math.unl.edu

CP12

Labeled Embeddings of Graphs

We present a recent variant of the graph embedding problem on labeled graphs. Given a graph $G = (V, E)$, a k -labeled embedding of G is a labeling $f : V \rightarrow \{1..k\}$ such that there exists an edge-disjoint placement of two copies of G into the complete graph $K_{|V|}$ preserving f . The objective consists in maximizing the number of labels k . We give upper bounds in the general case, exact values for some families of graphs, and extensions for the placement

of more than two copies of G .

Eric Duchene, Hamamache Kheddouci
Lyon 1 University
eric.duchene@univ-lyon1.fr,
hamamache.kheddouci@univ-lyon1.fr

Richard Nowakowski
Department of Mathematics and Statistics
Dalhousie University
rjn@mathstat.dal.ca

Amine Tahraoui
Lyon 1 University
mohammed.tahraoui@gmail.com

CP12 Dynamic Coloring and List Dynamic Coloring of Planar Graphs

A *dynamic chromatic number* $\chi_d(G)$ of a graph G is the least number k such that G has a proper k -coloring of the vertex set $V(G)$ so that for each vertex of degree at least 2, its neighbors receive at least two distinct colors. We show that $\chi_d(G) \leq 4$ for every planar graph except C_5 . The *list dynamic chromatic number* $ch_d(G)$ of G is the least number k such that for any assignment of k -element lists to the vertices of G , there is a dynamic coloring of G where the color on each vertex is chosen from its list. Based on Thomassen's result that every planar graph is 5-choosable, an interesting question is whether the list dynamic chromatic number of every planar graph is at most 5 or not. We answer this question by showing that $ch_d(G) \leq 5$ for every planar graph.

Seog-Jin Kim
Konkuk University
skim12@konkuk.ac.kr

Sang June Lee
Emory University, USA
slee242@emory.edu

Won-Jin Park
Seoul National University, Korea
wonjin96@snu.ac.kr

CP12 The Competition Graphs of Powers of Digraphs

The *competition graph* $C(D)$ of a digraph D has the same vertex set as D and has an edge between vertices u and v if and only if there exists a common prey of u and v in D . Given a digraph D , the convergence of the sequence $\{C(D^m)\}_{m=1}^{\infty}$ has been studied by several researches that are related to the notion of competition index. In this paper, given a digraph D , we focus on the limit graph of the sequence $\{C(D^m)\}_{m=1}^{\infty}$ if it converges. We find the limit graph of $\{C(D^m)\}_{m=1}^{\infty}$ when D has at most two strongly connected components, and then we give a sufficient and necessary condition for its limit graph consisting of only complete connected components.

Boram Park
DIMACS
Rutgers University
boramp@dimacs.rutgers.edu

Woongbae Park, Suh-Ryung Kim
Seoul National University
ubmpark@hanmail.net, srkim@snu.ac.kr

CP12 Flow-Continuous Mappings – Influence of the Group

Mapping $f : E(G) \rightarrow E(H)$ is M -flow-continuous if for every flow ϕ on H using values in M the composition $\phi \circ f$ is a flow on G . This notion was introduced by Jaeger to approach flow-related conjectures (like CDC). We discuss the influence of the group on flow-continuous mappings. On one hand, groups for which this mapping exists exhibit nice structure. On the other hand, in the important case of snarks we can restrict to Z_2 , Z_3 or Z .

Robert Samal
Charles University
samal@iuuk.mff.cuni.cz

Jaroslav Nesetril
department of Applied Mathematics
Charles University
nesetril@kam.mff.cuni.cz

CP12 Total Weight Choosability of Cartesian Product of Graphs

A graph $G = (V, E)$ is called (k, k') -choosable if the following is true: For any total list assignment L which assigns to each vertex x a set $L(x)$ of k real numbers, and assigns to each edge e a set $L(e)$ of k' real numbers, there is a mapping $f : V \cup E \rightarrow \mathbf{R}$ such that $f(y) \in L(y)$ for any $y \in V \cup E$ and for any two adjacent vertices x, x' , $\sum_{e \in E(x)} f(e) + f(x) \neq \sum_{e \in E(x')} f(e) + f(x')$. In this talk, we will show that if G is the Cartesian product of an even number of even cycles, or the Cartesian product of an odd number of even cycles and at least one of the cycles has length $4n$ for some positive integer n , then G is $(1, 3)$ -choosable.

Jiaojiao Wu, Tsai-Lien Wong
Department of Applied Mathematics
National Sun Yat-sen University
wujj0007@gmail.com, tlwong@math.nsysu.edu.tw

Xuding Zhu
Zhejiang Normal University, China
xudingzhu@gmail.com

CP13 Counting Minimal Sturmian Words

The subword complexity $p_w(n)$ of a word w is the number of distinct subwords of length n of w . We call a word w *Sturmian of order N* , if $p_w(n) = n + 1$ for $n = 1, \dots, N$. It is *minimal* if it has minimal length among all Sturmian words of order N . Equivalently, it is minimal if it has length $2N$. Recently, Blanchet-Sadri and Lemsire considered such words and provided an algorithm for generating all of them using techniques from graph theory. In this paper, we exploit their approach in order to count the number of minimal Sturmian words of order N and we show that this number is connected to Euler's totient function from number theory. We also present some other results that come from applying this graph theoretical framework to

subword complexity.

Francine Blanchet-Sadri
University of North Carolina
blanchet@uncg.edu

Sean Simmons
MIT
seanken@math.mit.edu

Bob Chen
University of California at San Diego
b2chen@ucsd.edu

CP13 Recurrence in Infinite Partial Words

The *recurrence function* $R_w(n)$ of an infinite word w was introduced by Morse and Hedlund in relation to symbolic dynamics. It is the size of the smallest window such that, wherever its position on w , all length n subwords of w will appear at least once inside that window. The *recurrence quotient* $\rho(w)$ of w , defined as \limsup of the quotient of $R_w(n)$ and n , is useful for studying the growth rate of $R_w(n)$. It is known that if w is periodic, then $\rho(w) = 1$, while if w is not, then $\rho(w) \geq 3$. A long standing conjecture from Rauzy states that the latter can be improved to $\rho(w) \geq (2.5 + .5\sqrt{5}) \sim 3.618$, this bound being true for each Sturmian word and being reached by the Fibonacci word. In this paper, we study in particular the spectrum of values taken by the recurrence quotients of infinite partial words, which are sequences that may have some undefined positions. In this case, we determine exactly the spectrum of values, which turns out to be 1, every real number greater than or equal to 2, and ∞ . More precisely, if an infinite partial word w is “ultimately factor periodic”, then $\rho(w) = 1$, while if w is not, then $\rho(w) \geq 2$, and we give constructions of infinite partial words achieving each value.

Francine Blanchet-Sadri
University of North Carolina
blanchet@uncg.edu

Bob Chen
University of California at San Diego
b2chen@ucsd.edu

Sinziana Munteanu
Princeton University
munteanu@princeton.edu

CP13 Unavoidable Sets

Partial words are sequences over a finite alphabet that may contain some undefined positions called holes. We first consider unavoidable sets of partial words of equal length. We compute the minimum number of holes in sets satisfying some conditions (summed over all partial words in the sets). We also construct sets that achieve this minimum. This is a step towards the difficult problem of fully characterizing all unavoidable sets of partial words. We are next concerned with the complexity of deciding the avoidability of sets of partial words over an arbitrary alphabet. Towards this, we investigate the minimum size of unavoidable sets of partial words with a fixed number of holes. Additionally, we analyze the complexity of variations on the decision problem when placing restrictions on the number of holes

and length of the words.

Francine Blanchet-Sadri
University of North Carolina
blanchet@uncg.edu

Laure Flapan
Yale University
laure.flapan@yale.edu

Steven Ji
MIT
zyji@mit.edu

Elizabeth Reiland
Harvey Mudd College
ereiland@hmc.edu

Stephen Watkins
Vanderbilt University
stephen.d.watkins@vanderbilt.edu

CP13 Solving Wilf’s Sigma-Tau Problem

We honor Herb Wilf (1931-2012) by solving Exercise 6 from his textbook *Combinatorial Algorithms* with Albert Nijenhuis (1975). The symmetric group S_n is generated by $\sigma = (1\ 2\ \dots\ n)$ and $\tau = (1\ 2)$, and Wilf asks if S_n can be sequenced “so that each is obtained from its predecessor” by σ or τ . We settle Wilf’s open problem with a cyclic sequence when n is odd, and a non-cyclic sequence when n is even.

Aaron M. Williams
University of Victoria
Department of Computer Science
haron@uvic.ca

CP14 Monotone Path Systems in Regions with Holes

A monotone path system (MPS) is a finite set of pairwise disjoint paths (polygonal arcs) in the plane such that every horizontal line intersects each of the paths in at most one point. Consider a simple polygon in the xy -plane which bounds the polygonal region D . Let T and B be two finite, disjoint, equicardinal sets of points of D . Cameron and Sachs gave a polytime algorithm for finding a MPS joining T with B . We consider polygonal regions with holes.

Kathie Cameron
Wilfred Laurier University, Canada
kcameron@wlu.ca

Katie Tsuji
Wilfrid Laurier University
tsuj0590@mylaurier.ca

CP14 Lattice-point Generating Functions for Free Sums of Convex Sets

The join of two convex sets in Euclidean space is the convex hull of their union. This join is called a free sum under certain conditions on the convex sets. We present a multivariate generating function that gives information about the lattice points in the free sum. This work is motivated by

(and recovers) a product formula of Braun for the Ehrhart series of the free sum of certain lattice polytopes.

Pallavi Jayawant
Bates College
pjayawan@bates.edu

Matthias Beck
San Francisco State University
mattbeck@sfsu.edu

Tyrrell B. Mcallister
University of Wyoming
tmcallis@uwyo.edu

CP14

A New Lower Bound Based on Gromov's Method of Selecting Heavily Covered Points

Classical theorem of Bárány states that there exists $c_d > 0$ such that for every n -set P of points in \mathbf{R}^d in general position, there exists a point of \mathbf{R}^d contained in at least $c_d \binom{n}{d+1}$ $(d+1)$ -simplices with vertices at the points of P . Gromov improved the known lower bound on c_d by topological means. Using methods from extremal combinatorics, we improve one of the quantities appearing in Gromov's approach and thereby provide a new stronger lower bound on c_d for arbitrary d .

Lukas Mach
Computer Science Institute of Charles University (IUK)
Lesser Town Square, no. 25, Prague
lukas.mach@gmail.com

Daniel Král
Computer Science Institute of Charles University (IUK)
kral@kam.mff.cuni.cz

Jean-Sébastien Sereni
CNRS (LIAFA)
sereni@kam.mff.cuni.cz

CP14

On Structures of Geometrically Realizable Triangulations on the Möbius Band

Let G be a graph embedded in to a surface F^2 . A geometric realization of G is an embedding of F^2 into a Euclidian 3-space with no self-intersection such that each face of G is a flat polygon. In 1983, Brehm found a Möbius triangulation (i.e., a triangulation on the on the Möbius band) which has no geometric realization. In this talk, we characterize geometrically realizable Möbius triangulations.

Shoichi Tsuchiya
Tokyo University of Science
s-s-t-b@mail.goo.ne.jp

CP14

Grid Representation for the Triangulations of the Torus

William Thurston describes all triangulations of the sphere such that each vertex has degree six or less. In this talk, we present a grid representation for the triangulations of the torus with at most two odd vertices where each vertex has degree five or more. We also discuss the motivation

behind studying this family, and some applications of our description. This is a joint work with Luis Goddyn.

Maryam Verdian Rizi
Simon Fraser University
mverdian@gmail.com

CP15

n -Tournaments That Have n -Integer Signatures

A compact representation for many digraphs is defined in a "labeled graph" context. Each positive integer of an n -element subset S (called the signature of the digraph) of $Z_m \setminus \{0\}$, is assigned to a vertex of a digraph with n vertices. An arc from a vertex x to another vertex y exists if and only if $(y - x) \bmod m$ is an element of the signature. A digraph defined by such a signature is called a *mod difference digraph*. In this presentation, we discuss the n -Tournaments T_n having uniquely defined n -Integer signatures.

Vasudeva Acharya
Srinivas Institute of Technology, Mangalore
vasudevanitk@gmail.com

Suresh M. Hegde
National Institute of Technology Karnataka
Surathkal
smhegde59@yahoo.com

CP15

New Characterizations of Proper Interval Bigraphs

The class of proper interval bigraphs was introduced and characterized by Sen and Sanyal in terms of monotone consecutive arrangement of adjacency matrix. In this paper we define astral triple of edges in a bigraph and characterize proper interval bigraph in terms of this and other notions. Tucker characterized proper circular arc graphs in terms of circularly compatible 1's of adjacency matrices. We have shown an inter-relation between monotone consecutive arrangement and circularly compatible 1's.

Ashok K. Das
Dept. of Pure Mathematics, University of Calcutta, India
ashokdas.cu@gmail.com

CP15

House of Graphs: a Database of Interesting Graphs

In this talk we will present a new searchable database of graphs. Next to complete lists of some graph classes (such as fullerenes or snarks), also a list of graphs that already turned out to be *interesting* and *relevant* in the study of graph theoretic problems is offered. We will demonstrate how users can perform queries on this database and how they can add new *interesting* graphs to it. House of Graphs is accessible at <http://hog.grinvin.org>

Jan Goedgebeur
Ghent University
jan.goedgebeur@ugent.be

Gunnar Brinkmann
University of Ghent,
Belgium
gunnar.brinkmann@ugent.be

Kris Coolsaet
Ghent University
kris.coolsaet@ugent.be

Hadrien Melot
Universite de Mons
hadrien.melot@umons.ac.be

CP15

Immersion of Complete Graphs in Graphs with Minimum Degree $n - 1$

In 2003, F. Abu-Khazam and M. Langston conjectured that an n -chromatic graph contains an immersion of a complete graph on n vertices. We will look at an attempt to prove this by looking at a stronger statement involving minimum degree. We will consider examples that show a graph with minimum degree $n - 1$ need not contain an immersion of a complete graph on n vertices for n greater than or equal to 8.

Megan Heenehan, Karen Collins
Wesleyan University
mheenehan@wesleyan.edu, kcollins@wesleyan.edu

CP15

Fat Hoffman Graphs with Smallest Eigenvalue at Least $-1 - \tau$

In this talk, we show that all fat Hoffman graphs with smallest eigenvalue at least $-1 - \tau$, where τ is the golden ratio, can be described by a finite set of fat $(-1 - \tau)$ -irreducible Hoffman graphs. In the terminology of Woo and Neumaier, we mean that every fat Hoffman graph with smallest eigenvalue at least $-1 - \tau$ is an \mathcal{H} -line graph, where \mathcal{H} is the set of isomorphism classes of maximal fat $(-1 - \tau)$ -irreducible Hoffman graphs.

Yoshio Sano
National Institute of Informatics
sano@nii.ac.jp

Akihiro Munemasa
Tohoku University
munemasa@math.is.tohoku.ac.jp

Tetsuji Taniguchi
Matsue College of Technology
tetsuzit@matsue-ct.ac.jp

CP15

Finding 1-Factors in Realizations of Degree Sequences

Kundu proved a necessary and sufficient condition for a degree sequence to have a realization containing a k -factor. Brualdi and independently Busch, Ferrara, Hartke, Jacobson, Kaul and West conjectured that the same condition could yield much more: a realization of the sequence containing k edge-disjoint 1-factors. In this talk, we describe two results making partial progress towards this conjecture.

Tyler Seacrest
University of Nebraska – Lincoln
t_seacrest@umwestern.edu

CP16

Cayley Factorization and the Area Method

Given a bracket polynomial B , i.e. a polynomial in formal determinants. Assume B is homogenous and has integer coefficients. Let $e(B, C)$ be the evaluation of B for a point configuration C . The Cayley factorization problem asks for a synthetic construction for testing $e(B, C) = 0$. We give an explicit algorithm that generates a bracket monomial M and a construction which tests $e(M \cdot B, C) = 0$. This construction is more geometrically motivated and compact than the one of Sturmfels and Whiteley. M has lower degree.

Susanne Apel
Technische Universitaet Muenchen
apel@ma.tum.de

CP16

Variations on the Erdos Discrepancy Problem

The Erdos Discrepancy Problem asks if there exists a sequence $\{t_i\}_{i>0}$ over $\{-1, 1\}$ and a constant c such that $|\sum_{i=1}^k t_{id}| < c$ for all $k, d \in \mathbf{N}$. We examine variations on this problem where the values of d are restricted to certain subsets of \mathbf{N} and certain values of c are fixed. We count the number of sequences satisfying these conditions, find the lexicographically least such sequence, and present a number theory conjecture that arises.

Alexander Leong
University of Waterloo
School of Computer of Science
aleong@uwaterloo.ca

Jeffrey Shallit
University of Waterloo
School of Computer Science
shallit@cs.uwaterloo.ca

CP16

$1\frac{1}{2}$ -Designs Arising from Group Rings

Let $T = (\mathcal{P}, \mathcal{B}, \mathcal{I})$ be a tactical configuration with parameters (v, b, k, r) . For every point $x \in \mathcal{P}$ and every block $B \in \mathcal{B}$, let $\phi(x, B)$ be the number of flags $(y, C) \in \mathcal{I}$ such that $y \in B \setminus \{x\}$, $x \in C$ and $C \neq B$. A $1\frac{1}{2}$ -design with parameters $(v, b, k, r; \alpha, \beta)$ is a tactical configuration T such that

$$\phi(x, B) = \begin{cases} \alpha, & x \notin B; \\ \beta, & x \in B. \end{cases}$$

Examples of $1\frac{1}{2}$ -designs include 2-designs, complete bipartite graphs $K_{n,n}$, transversal designs, and partial geometries. In this talk, we introduce a method which can be viewed as a generalization of difference sets to construct symmetric $1\frac{1}{2}$ -designs. We also give non-existence results on symmetric $1\frac{1}{2}$ -designs in connection to directed strongly regular graphs.

Oktay Olmez
Iowa State University
oolmez@iastate.edu

CP16

On Iterated Functions, Directed Graphs, and Re-

cursion

In this presentation, we show how enumerations of the backwards iterates of certain piecewise defined functions lead to general second order linear recurrence relations. In particular, for each integer $k \geq 2$, we provide a piecewise function f_k that acts on k equal subdivisions of the unit interval $[0, 1]$, and the recurrence relation that results from counting the solutions of $f_k(x) = \psi$ for some ψ in $(0, 1)$.

Christopher Raridan, Elliot Krop
Clayton State University
ChristopherRaridan@clayton.edu, elliotkrop@clayton.edu

CP17**Universal H -Colourable Graphs**

Rado constructed a (simple) denumerable graph R with the positive integers as vertex set with the following edges: For given m and n with $m < n$, m is adjacent to n if n has a 1 in the m 'th position of its binary expansion. It is well known that R is a universal graph in the set \mathcal{I}_c of all countable graphs (since every graph in \mathcal{I}_c is isomorphic to an induced subgraph of R) and that it is a homogeneous graph (since every isomorphism between two finite induced subgraphs of R extends to an automorphism of R). In this talk we discuss a graph $U(H)$ which is H -universal in $\rightarrow H_c$, the induced-hereditary hom-property of H -colourable graphs consisting of all (countable) graphs which have a homomorphism into a given (countable) graph H . If H is the (finite) complete graph K_k , then $\rightarrow H_c$ is the property of k -colourable graphs. The universal graph $U(H)$ is characterised by showing that it is, up to isomorphism, the unique denumerable, H -universal graph in $\rightarrow H_c$ which is H -homogeneous in $\rightarrow H_c$. The graphs H for which $U(H) \cong R$ are also characterised.

Izak Broere
University of Pretoria
izak.broere@up.ac.za

Johannes Heidema
University of South Africa
johannes.heidema@gmail.com

CP17**A Generalization of Menger's Theorem**

Consider an acyclic directed network G with sources S_1, S_2, \dots, S_l and distinct sinks R_1, R_2, \dots, R_l . For $i = 1, 2, \dots, l$, let c_i denote the min-cut between S_i and R_i . Then, by Menger's theorem, there exists a group of c_i edge-disjoint paths from S_i to R_i , which will be referred to as a group of Menger's paths from S_i to R_i in this paper. Although within the same group they are edge-disjoint, the Menger's paths from different groups may have to merge with each other. In this paper, we prove that by choosing Menger's paths appropriately, the number of mergings among different groups of Menger's paths is always bounded by a constant, which is independent of the size and the topology of G . The tightest such constant for the all the above-mentioned networks is denoted by $\mathcal{M}(\lfloor_\infty, \lfloor_\epsilon, \dots, \lfloor_\epsilon)$ when all S_i 's are distinct, and by $\mathcal{M}^*(\lfloor_\infty, \lfloor_\epsilon, \dots, \lfloor_\epsilon)$ when all S_i 's are in fact identical. It turns out that \mathcal{M} and \mathcal{M}^* are closely related to the network encoding complexity for a variety of networks. Computation of these two functions, however, appears to be rather difficult; so far there are no explicit formulas for $\mathcal{M}(\lfloor_\infty, \lfloor_\epsilon, \dots, \lfloor_\epsilon)$ and $\mathcal{M}^*(\lfloor_\infty, \lfloor_\epsilon, \dots, \lfloor_\epsilon)$ for a generic

parameter c_1, c_2, \dots, c_l . We also derive exact values of and tighter bounds on \mathcal{M} and \mathcal{M}^* for some parameters. See <http://arxiv.org/abs/0805.4059> for the full manuscript.

Guangyue Han
Department of Mathematics
University of Hong Kong
ghan@hku.hk

CP17**Another Proof for Lovász's Cathedral Theorem**

A graph with perfect matchings is saturated if addition of any complement edges creates new perfect matchings. Cathedral theorem, which is originally investigated by Lovász (1986) and later given another proof by Szigeti (1993), is a constructive characterization of saturated graphs and appears in proving the theorem on totally- k -covered graphs. Here, we gave the third proof for Lovász's Cathedral theorem by revealing the ordered structure of graphs with perfect matchings.

Nanao Kita
Keio University
kita@a2.keio.jp

CP17**Graphs of Small Rank-Width Are Pivot-Minors of Graphs of Small Tree-Width**

We prove that every graph of rank-width k is a pivot-minor of a graph of tree-width at most $2k$. We also prove that graphs of rank-width at most 1, equivalently distance-hereditary graphs, are exactly vertex-minors of trees, and graphs of linear rank-width at most 1 are exactly vertex-minors of paths.

O-Joung Kwon
Department of Mathematical Sciences, KAIST
ilkof@kaist.ac.kr

Sang-Il Oum
KAIST
sangil@kaist.edu

CP17**Saturation Numbers for Families of Graph Subdivisions**

For a family \mathcal{F} of graphs, a graph G is \mathcal{F} -saturated if G contains no member of \mathcal{F} but the addition of any edge in \bar{G} results in one. The minimum number of edges in an \mathcal{F} -saturated graph of order n is denoted $sat(n, \mathcal{F})$. For a graph H , $\mathcal{S}(\mathcal{H})$ denotes the family of graphs resulting from replacing the edges of H with internally disjoint paths. We determine $sat(n, \mathcal{S}(\mathcal{C}_t))$ for small t , and provide a bound when t is arbitrarily large. We also examine $sat(n, \mathcal{S}(\mathcal{K}_t))$ in light of a result of Wagner's on minors.

Craig Tennenhouse
University of New England
ctennenhouse@une.edu

Michael Ferrara
University of Colorado Denver
michael.ferrara@ucdenver.edu

Michael Jacobson

University of Colorado, Denver
=
michael.jacobson@ucdenver.edu

Kevin Milans
University of South Carolina
milans@math.sc.edu

Paul Wenger
University of Colorado Denver
paul.wenger@ucdenver.edu

MS1

Variations on the Majorization Order

The key role played by the majorization (aka dominance) order on integer partitions as a tool in both pure and applied mathematics has been widely recognized and documented. Recently, variants of the classical majorization order have appeared in the study of posets defined by certain symmetric function inequalities. We will describe these variants, focusing on differences and similarities between these posets and the classical majorization order.

Curtis Greene
Haverford College
cgreene@haverford.edu

MS1

Linear Extension Diameter and Reversal Ratio

Define the distance between two linear extensions L_1 and L_2 of a poset \mathbf{P} as the number of incomparable pairs x, y with $x <_{L_1} y$ and $y <_{L_2} x$. The *linear extension diameter* of \mathbf{P} , $\text{led}(\mathbf{P})$ is the maximum distance over all pairs of linear extensions. We introduce the *reversal ratio* of \mathbf{P} as the ratio of $\text{led}(\mathbf{P})$ to the total number of (unordered) incomparable pairs of \mathbf{P} . We provide a family of posets with reversal ratio tending to 0 with the number of points and investigate questions involving bounding the reversal ratio for posets of fixed width and posets of fixed dimension.

Mitchel T. Keller
London School of Economics
mitch@rellek.net

Graham Brightwell
Department of Mathematics
London School of Economics
g.r.brightwell@lse.ac.uk

MS1

Forbidden Structures for Efficient First-Fit Chain Partitioning

Using natural numbers for identifying chains, First-Fit algorithm processes elements of a poset P in some order and for each element it assigns the smallest natural number such that all elements with the same number form a chain. Let \mathcal{P} be a class of posets with bounded-width, closed under taking induced subposets. We prove that there is a constant c such that all posets from \mathcal{P} are partitioned by First-Fit into at most c chains if and only if there is a width 2 poset not in \mathcal{P} .

Bartłomiej E. Bosek
Jagellion University, Poland
bosek@tcs.uj.edu.pl

Tomasz Krawczyk, Grzegorz Matecki
Jagiellonian University
krawczyk@tcs.uj.edu.pl, matecki@tcs.uj.edu.pl

MS1

Forbidden Induced Posets in the Boolean Lattice

The induced Turán number $\text{La}^*(n, P)$ is the maximum size of a family of elements in the n -dimensional Boolean lattice that does not contain P as an *induced* subposet. Not much is known about $\text{La}^*(n, P)$ when the Hasse diagram of P contains cycles. We present bounds on $\text{La}^*(n, P)$ for some such posets. This is joint work with Linyuan Lu.

Linyuan Lu, Kevin Milans
University of South Carolina
lu@math.sc.edu, milans@math.sc.edu

MS1

Title Not Available at Time of Publication

Abstract not available at time of publication

William T. Trotter
School of Mathematics
Georgia Institute of Technology
trotter@math.gatech.edu

MS2

Lie Theory for Hyperplane Arrangements

There is a well-known isomorphism of representations between the homology of the partition lattice and the multilinear part of the free Lie algebra. This is a result of Hanlon, Joyal, and Stanley. Rich combinatorics underlies this fact, as shown by subsequent work of several authors, including Barcelo, Bergeron, Bjorner, Garsia, Reutenauer and Wachs. In this talk we propose an extension of this and other classical results to real linear hyperplane arrangements. A central role is played by the notion of Hopf monoid. We develop a Lie theory for these objects which includes the Cartier-Milnor-Moore and Poincaré-Birkhoff-Witt theorems. The classical results are obtained by specializing to the case of braid arrangements. This is joint work in progress with Swapneel Mahajan.

Marcelo Aguiar
Texas A&M
maguiar@math.tamu.edu

Swapneel Mahajan
IIT Mumbai
swapneel@math.iitb.ac.in

MS2

Tesler Matrices, Parking Functions, and Diagonal Harmonics

We show how the Hilbert series of the space of Diagonal Harmonics can be expressed in terms of combinatorial objects called Tesler matrices. This leads to some open positivity questions involving what we call “colored parking functions”. This is joint work with D. Armstrong, A. Garsia, B. Rhoades, and B. Sagan.

Jim Haglund
University of Pennsylvania
Department of Mathematics

jhaglund@math.upenn.edu

MS2

Combinatorial Ergodicity in Products of Chains

Many cyclic actions τ on a finite set S of combinatorial objects, along with many natural statistics ϕ on S , exhibit “combinatorial ergodicity”: the average of ϕ over each τ -orbit in S is the same as the average of ϕ over the whole set S . This phenomenon was first noticed by Panyushev in 2007 in the context of antichains in root posets; Armstrong, Stump, and Thomas proved his conjecture in 2011. We describe a theoretical framework for results of this kind, and discuss old and new results for products of chains.

Tom Roby

University of Connecticut/MIT
tom.robby@uconn.edu

James Propp

U Mass Lowell
jamespropp@gmail.com

MS2

Classical and Quasi Symmetric Hall-Littlewood Polynomials and Transition Matrices

An interesting property of Hall-Littlewood polynomials is that they interpolate between the Schur and monomial symmetric functions at $t = 0$ and 1, respectively. Hivert has constructed a family of quasisymmetric functions with a parameter t , which interpolate in a similar way between the fundamental and monomial quasisymmetric functions. In this talk we present a combinatorial interpretation for the expansion of Hall-Littlewood polynomials in terms of Hivert functions, as well as other transition matrices between the latter and other families of quasisymmetric functions.

Nicholas Loehr

Virginia Tech
nloehr@math.vt.edu

Luis Serrano

LACIM
serrano@lacim.ca

Gregory Warrington

University of Vermont
gregory.warrington@uvm.edu

MS2

Demazure Crystals, Kirillov-Reshetikhin Crystals, and the Energy Function

I will discuss a paper with Anne Schilling which surveys and expands upon some relationships between Demazure crystals of non-exceptional affine Kac-Moody algebras and Kirillov-Reshetikhin (KR) crystals. In particular, certain Demazure crystals are isomorphic as classical crystals to tensor products of KR crystals, and we show that this isomorphism intertwines the natural affine grading on the Demazure crystals with a combinatorially defined energy function. This leads to a formula for the Demazure character in terms of the energy function, and has applications to symmetric function theory since certain specializations of Macdonald polynomials are equal to specializations of

Demazure characters.

Peter Tingley

MIT
ptingley@math.mit.edu

MS3

Conjectures Equivalent to the Borodin-Kostochka Conjecture that a Priori Seem Weaker

Borodin and Kostochka conjectured that every graph G with maximum degree $\Delta \geq 9$ satisfies $\chi \leq \max\{\omega, \Delta - 1\}$. We carry out an in-depth study of minimum counterexamples to the Borodin-Kostochka conjecture. Our main tool is the classification of graph joins $A * B$ with $|A| \geq 2$, $|B| \geq 2$ that are f -choosable, where $f(v) := d(v) - 1$ for each vertex v . Since such a join cannot be an induced subgraph of a vertex critical graph with $\chi = \Delta$, we have a wealth of structural information about minimum counterexamples to the Borodin-Kostochka conjecture. Our main result is to prove that certain conjectures that a priori seem weaker than the Borodin-Kostochka Conjecture are in fact equivalent to it. One such equivalent conjecture is the following: Any graph with $\chi \geq \Delta = 9$ contains $K_3 * \overline{K_6}$ as a subgraph.

Daniel Cranston

Virginia Commonwealth University
Department of Mathematics and Applied Mathematics
dcranston@vcu.edu

MS3

List-coloring on Surfaces with Some Small Lists

C. Thomassen’s celebrated 5-list-coloring theorem for planar graphs proves more. Among its consequences are the results that 1) a planar graph with one vertex with a 1-list and the rest with 5-lists and 2) a planar graph with 3-lists on the vertices of one face and 5-lists elsewhere can be list-colored. We study generalizations of these two variations for graphs on nonplanar surfaces. We obtain initial results for graphs on the projective plane and torus and begin a study for surfaces with larger Euler genus.

Alice M. Dean

Skidmore College
Mathematics and Computer Science Department
adean@skidmore.edu

Joan P. Hutchinson

Macalester College
Department of Mathematics
hutchinson@macalester.edu

MS3

Fractional Colorings of Cubic Graphs

Fractional coloring is a relaxation of classical graph coloring. Each independent set is assigned weight and each vertex is required to be in independent sets of weight at least one. The goal is to minimize the total weight of independent sets. In the talk, we present two recent results: The fractional chromatic number of any triangle-free cubic graph is at most $32/11$ and the fractional chromatic number of any cubic graph with sufficiently large girth is smaller than $23/10$.

David Ferguson

London School of Economics

davidgferguson@gmail.com

Tomas Kaiser
University of West Bohemia
kaisert@kma.zcu.cz

Frantisek Kardos
INRIA Sophia-Antipolis
frantisek.kardos@upjs.sk

Daniel Kral
Charles University
kral@iuuk.mff.cuni.cz

Jan Volec
IUUK Charles University
janv@kam.mff.cuni.cz

MS3

4-critical Graphs on Surfaces without Contractible Cycles of Length at Most 4

We show that every 4-critical graph G embedded in a fixed surface Σ so that every contractible cycle has length at least 5 can be expressed as $G = G' \cup G_1 \cup G_2 \cup \dots \cup G_k$, where $|V(G')|$ and k are bounded by a constant (depending linearly on the genus of Σ) and G_1, \dots, G_k are graphs (of unbounded size) whose structure we describe exactly. The proof is computer-assisted—we use computer to enumerate all plane 4-critical graphs of girth 5 with a precolored cycle of length at most 16, that are used in the basic case of the inductive proof of the statement.

Zdenek Dvorak
Department of Applied Mathematics
Charles University, Prague
rakdver@kam.mff.cuni.cz

Bernard Lidicky
University of Illinois, Urbana, IL
lidicky@illinois.edu

MS3

Extending Graph Choosability Results to Paintability

Introduced independently by Schauz and by Zhu, the *Marker/Remover game* is an on-line version of list coloring. The resulting graph parameter, *paintability*, is at least the list chromatic number (the *choosability*). We strengthen several choosability results to paintability. We study paintability of joins with complete graphs and determine bounds on the paintability of complete bipartite graphs. We characterize 3-paint-critical graphs and show that claw-free perfect graphs with $\omega(G) \leq 3$ have paintability equal to chromatic number. Finally, we introduce and study *sum-paintability*, the analogue of sum-choosability.

James Carraher
University of Nebraska
s-jcarrah1@math.unl.edu

Sarah Loeb, Thomas Mahoney, Gregory Puleo, Mu-Tsun Tsai
University of Illinois
sloeb2@illinois.edu, tmahone2@illinois.edu,
gpuleo@gmail.com, tsai39@illinois.edu

Douglas B. West
University of Illinois, Urbana
Department of Mathematics
west@math.uiuc.edu

MS4

Title Not Available at Time of Publication

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Hamed Hatami
Department of Mathematics
Princeton Univ.
hatami@gmail.com

MS4

On a Problem of Erdős and Rothschild on Edges in Triangles

Erdős and Rothschild asked to estimate the maximum number $h(n, c)$ such that every n -vertex graph with at least cn^2 edges, each of which is contained in at least one triangle, must contain an edge that is in at least $h(n, c)$ triangles. In 1987, Erdős asked whether for every $c > 0$, there is $\epsilon > 0$ such that $h(n, c) > n^\epsilon$. We prove $h(n, c) = n^{O(1/\log \log n)}$ for every fixed $c < 1/4$, the first improvement over an old construction of Alon and Trotter.

Jacob Fox
MIT
fox@math.mit.edu

Po-Shen Loh
Department of Mathematical Sciences
Carnegie Mellon University
ploh@cmu.edu

MS4

Turan's Brickyard Problem and Flag Algebras

Recently, Razborov developed a "flag algebra" calculus which captures in pure form many of the techniques used in extremal combinatorics. This calculus has been successfully used in the last few years to improve the best known bounds on many of the long-standing open problems in extremal graph theory. In this talk we describe an application to the Turán's brickyard problem: the problem of determining the crossing number of the complete bipartite graph $K_{m,n}$. Beas on joint work with Yori Zwols.

Sergey Norin
McGill University
snorine@gmail.com

MS4

Turán Densities of Hypergraphs Related to K_{k+1}^k

Let $B_i^{(k)}$ be the k -uniform hypergraph on the vertex set $S \cup T$ with $|S| = i$ and $|T| = k - 1$ with the edges consisting of all k -sets containing S or T . We derive upper and lower bounds for the Turán density of $B_i^{(k)}$ that are close to each other as $k \rightarrow \infty$. We also obtain asymptotically tight bounds for the Turán density of several other infinity families of hypergraphs. The construction that supports the lower bounds is derived from elementary number theory by probabilistic arguments. The upper bounds are derived

from the results of de Caen, Sidorenko, and Keevash.

Yi Zhao

Georgia State University
yzhao6@gsu.edu

József Balogh
University of Illinois
jobal@math.uiuc.edu

Tom Bohman
Carnegie Mellon
tbohman@math.cmu.edu

Béla Bollobás
Trinity College, Cambridge
University of Memphis
b.bollobas@dpmms.cam.ac.uk

MS4

Extremal results in sparse pseudorandom graphs

Szemerédi's regularity lemma is a fundamental tool in extremal combinatorics. However, the original version is only helpful in studying dense graphs. In the 1990s, Kohayakawa and Rödl proved an analogue of Szemerédi's regularity lemma for sparse graphs as part of a general program toward extending extremal results to sparse graphs. Many of the key applications of Szemerédi's regularity lemma use an associated counting lemma. In order to prove analogues of these results for sparse graphs, it remained a well-known open problem to prove a counting lemma in sparse graphs. The main advance of this paper lies in a new counting lemma, proved following the functional approach of Gowers, which complements the sparse regularity lemma of Kohayakawa and Rödl, allowing us to count small graphs in regular subgraphs of a sufficiently pseudorandom graph. We use this to prove analogues of several well-known combinatorial theorems, including the graph removal lemma, the Erdős-Stone-Simonovits theorem, and Ramsey's theorem, for subgraphs of sparse pseudorandom graphs. These results extend and improve upon a substantial body of previous work.

David Conlon
University of Oxford
david.conlon@maths.ox.ac.uk

Jacob Fox
MIT
fox@math.mit.edu

Yufei Zhao

Massachusetts Institute of Technology
yufeiz@mit.edu

MS5

On the Directed Oberwolfach Problem

The Oberwolfach problem asks whether the K_n (or $K_n - I$ if n is even) admits a 2-factorization in which each factor is isomorphic to a specified 2-factor F . We consider a directed variant of this problem, in which we are now required to factorize the complete symmetric digraph K_n^* . In particular, we consider the question of determining necessary and sufficient conditions for the existence of a resolvable decomposition of K_n^* into directed m -cycles, and present

some results towards its solution.

Andrea Burgess

Ryerson University
andrea.burgess@ryerson.ca

Patrick Niesink
.
patrick.niesink@rogers.com

Mateja Sajna
University of Ottawa
msajna@uottawa.ca

MS5

Defining Sets in Combinatorial Arrays

A defining set in a combinatorial array is a partially filled-in array with a unique completion. We compare what is known about the defining sets of $(0, 1)$ -matrices and Latin squares. While these arrays on the surface seem quite different, for certain cases the minimum possible size for a defining set appears to be the same.

Nicholas Cavenagh

University of Waikato
nickc@waikato.ac.nz

MS5

Graph Decompositions and Convexity

One of the most interesting conjectures in the area of graph decompositions is due to Nash-Williams. It states that the edge set of any sufficiently large graph with all even degrees, $3m$ edges, v vertices and minimum degree of at least $3/4v$ can be partitioned into triangles. We discuss a new approach for exploring this problem using the inclusion matrix of the Johnson scheme and the facets of the convex cone it generates.

Kseniya Garaschuk

University of Victoria
kgarasch@gmail.com

Peter Dukes
Assistant Professor
dukes@uvic.ca

MS5

Extending the Bruck-Ryser-Chowla Theorem to Coverings

The celebrated Bruck-Ryser-Chowla theorem rules out the existence of various balanced incomplete block designs, including projective planes of infinitely many orders. In this talk I will discuss how (parts of) the Bruck-Ryser-Chowla theorem can be extended to establish the nonexistence of various covering designs and, consequently, the nonexistence of certain decompositions of a complete graph into copies of a smaller complete graph minus an edge.

Daniel Horsley

Memorial University, Newfoundland, Canada
danhorsley@gmail.com

Darryn Bryant, Melinda Buchanan, Barbara Maenhaut,
Victor Scharaschkin
University of Queensland

db@maths.uq.edu.au, mjb@maths.uq.edu.au,
bmm@maths.uq.edu.au, victors@maths.uq.edu.au

MS5

Trinal Decompositions of Steiner Triple Systems

Let $STS(n)$ be a Steiner triple system of order n . A *triangle* T is a set of three pairwise intersecting triples of an $STS(n)$ whose intersection is empty. Z. Füredi posed a question whether the set of triples of any $STS(n)$ can be decomposed into triangles. This question remains largely unanswered, although examples of such decomposition are known for every admissible order $n \equiv 1$ or $9 \pmod{18}$. A triangle $T = \{\{a, b, c\}, \{c, d, e\}, \{e, f, a\}\}$ in an $STS(n)$ is sometimes called a *hexagon triple* because the outer edges ab, bc, cd, de, ef, fa form a hexagon. Depending on a graph-theoretic or geometric representation, respectively, that triangle determines naturally two more triples: the *inner* triple $\{a, c, e\}$ and the *midpoint* triple $\{b, d, f\}$. In either case, the number of inner triples (called *type 1*) or that of midpoint triples (*type 2*) equals one third of the total number of triples in an $STS(n)$. A problem which will be discussed concerns the existence of three distinct decompositions of an $STS(n)$ into triangles such that the union of three collections of type 1 triples (type 2, respectively) from these three decompositions form a set of triples of a Steiner triple system of the same order n . Such decompositions are called *trinal* decompositions of type 1 and type 2, respectively. Solutions to the existence question for trinal decompositions of type 1 and type 2 will be presented.

Mariusz Meszka

AGH University of Science and Technology
meszka@agh.edu.pl

Charles C. Lindner
Auburn University
lindncc@auburn.edu

Alexander Rosa
Department of Mathematics
McMaster University
rosa@mcmaster.ca

MS6

Structural Requirements for RNA Elements

RNA plays a major role in many regulatory circuits of cells, and new and often surprising function are discovered continuously. The structure of RNA elements determines the associated function for many ncRNAs. Clustering by similarity on the level of sequence and structure is now an accepted approach for annotating ncRNAs and for determining new ncRNA classes. The problem, however, is the large number of RNAs to be clustered (e.g., up to 450,000 predicted ncRNAs in human), and the complexity of the similarity test. We have introduced a new alignment-free method for clustering that avoids the complex all-against-all pairwise comparisons, and is still able to cluster according to sequential and structural properties. Furthermore, we will discuss application problems like the bacterial adaptive immunessystem called CRISPR that is based on RNA.

Rolf Backofen

University of Freiburg
backofen@informatik.uni-freiburg.de

MS6

Understanding SHAPE-directed RNA Secondary Structure Prediction

We investigate the interplay between experimental data and thermodynamic model via stochastic simulations. RNA prediction under the NNTM is a discrete optimization problem whose accuracy can be improved by the incorporation of auxiliary information. However, our results demonstrate that improvements in SHAPE-directed predictions are non-uniform and correlated with original MFE accuracies. This analysis suggests that further advances in computational molecular biology are needed to reliably predict RNA secondary structures.

Zsuzsanna Sukosd
Nanoscience Center
Aarhus University
zs@mb.au.dk

Christine E. Heitsch

School of Mathematics
Georgia Tech
heitsch@math.gatech.edu

MS6

Detecting SNP-Induced Structural Changes in RNA: Application to Disease Studies

Single Nucleotide Polymorphisms (SNPs) are often linked to critical phenotypes such as diseases. However, the specific molecular mechanisms by which a causal SNP acts is usually not obvious. Changes in RNA secondary structure emerge as a possible explanation. We introduce *remuRNA*, an efficient method to compute the distance between the native and mutant RNA structure Boltzmann ensembles. We applied *remuRNA* to determine which of the disease-associated non-coding SNPs are potentially related to RNA structural changes.

Raheleh Salari

Stanford University
rahelehs@stanford.edu

Teresa Przytycka
NCBI
przytyck@ncbi.nlm.nih.gov

MS6

Efficient Algorithms to Explore the RNA Mutational Landscape

Understanding the relationship between RNA sequences and structures is essential to decipher evolutionary processes, predict deleterious mutations and design synthetic molecules. We introduce RNAmutants, the first algorithm for exploring complete RNA sequence-structures maps in polynomial time and space. Using statistical mechanics and importance sampling techniques, we estimate the thermodynamical pressure applied on sequences and explore regions of the mutational landscape preserving the nucleotide composition. We show that C+G-contents influence the evolutionary accessible structural ensembles.

Jerome Waldispuhl

McGill University
jeromew@cs.mcgill.ca

Bonnie Berger

Applied Mathematics, MIT
bab@mit.edu

Srinivas Devadas
CSAIL, MIT
devadas@mit.edu

Peter Clote
Biology, Boston College
clote@bc.edu

Yann Ponty
LIX, Ecole Polytechnique
yann.ponty@lix.polytechnique.fr

MS7

Path Graphs, PR-trees, and Split Decomposition

In this work we present new characterizations of (directed) path graphs*. First, we describe a new data structure (*PR-trees*) which captures the set of path-tree models of a path graph (generalizing *PQ-trees*). This allows us to characterize and recognize (directed) path graphs via *split decomposition*. The recognition algorithm runs in $\mathcal{O}(|\mathcal{V}| * |\mathcal{E}|)$ for both directed path graphs and path graphs. * The intersection graphs of (directed) paths in (directed) trees.

Steven Chaplick
Department of Computer Science,
University of Toronto
chaplick@cs.toronto.edu

MS7

Algorithms for Unipolar and Generalized Split Graphs

$G=(V_1 \cup V_2, E)$ is *unipolar* when V_1 is a clique and V_2 induces the disjoint union of cliques. A *generalized split graph* is either unipolar or its complement is unipolar. We present an $\mathcal{O}(nm')$ -time recognition algorithm for unipolar graphs, where m' is the number of edges in a minimal triangulation of the given graph. We efficiently solve four classic optimization problems on unipolar and generalized split graphs and prove that perfect code is NP-complete for unipolar graphs.

Elaine M. Eschen
Lane Department of CSEE
West Virginia University
Elaine.Eschen@mail.wvu.edu

Xiaoqiang Wang
West Virginia University
xiaoqiang.wang.wvu@gmail.com

MS7

Recognizing Even-Cycle Matroids

A matroid M is an even-cycle matroid if the cycles of M correspond to the even cycles of a signed graph. The problem of recognizing whether a binary matroid (represented by a 0,1 matrix) is an even-cycle matroid is open. Progress on this problem has been hampered by the fact that even cycle matroids can have an arbitrary number of pairwise inequivalent representations (two signed graphs are equivalent if they are related by a sequence of Whitney-flips and signature exchanges). We discuss how to proceed for the recognition problem for the case where we are given a fixed

size minor that is not a projection of a graphic matroid.

Bertrand Guenin
University of Waterloo
bguenin@math.uwaterloo.ca

Irene Pivotto
Simon Fraser University, BC
ipivotto@sfu.ca

Paul Wollan
Department of Mathematics
University of Hamburg
paul.wollan@gmail.com

MS7

Fixed Weight De Bruijn Graphs

Let S be the set of all binary strings of length n with weight (number of 1s) w and $w-1$. The *de Bruijn graph* for S is a directed graph $G(S)$ whose nodes are the length $n-1$ prefixes and suffixes of the strings in S . There is an arc labeled $x \in \{0, 1\}$ from $\alpha = a_1 \cdots a_{n-1}$ to $\beta = a_2 \cdots a_{n-1}x$ if $\alpha x \in S$. In addition to considering constructions of fixed weight de Bruijn cycles, we consider the problem of determining the diameter of the de Bruijn graph $G(S)$.

Joe Sawada
University of Guelph
Dept. of Computer Science
jsawada@uoguelph.ca

MS7

Induced and Distance- k Matchings and Some Related Min-Max Relations

A distance- k matching in a graph is a matching such that the distance between any two edges of the matching is at least k . Computing the size of a largest induced matching (distance-2 matching) in a graph is NP-hard. We consider finding a largest distance- k matching in certain classes of graphs. In some cases, along comes a relation between the size of a largest distance- k matching and the size of a smallest appropriate cover.

R Sritharan, Arthur Busch
The University of Dayton
rsritharan1@udayton.edu, art.busch@udayton.edu

Feodor F. Dragan
Kent State University
Dept. of Computer Science
dragan@cs.kent.edu

Chandra Krishnamurthy
The University of Dayton
chandrum50@gmail.com

MS8

Q_2 -Free Families in the Boolean Lattice

For a family of subsets of $\{1, \dots, n\}$, ordered by inclusion and a partially-ordered set P , we say that the family is P -free if it does not contain a subposet isomorphic to P . We are interested in finding $\text{ex}(n, P)$, the largest size of a P -free family of subsets of $[n]$. It is conjectured that, for any fixed P , this quantity is $(k+o(1))\binom{n}{2}$ for some fixed integer

k , depending only on P . Recently, Boris Bukh has verified the conjecture for P which are in a “tree shape”. There are some other small posets P for which the conjecture has been verified. The smallest for which it is unknown is Q_2 , the Boolean lattice on two elements. We will discuss improvements of the bounds of Griggs, Li, and Lu. This is joint work with Ryan Martin, Iowa State University and Michael Young, Iowa State University.

Lucas J. Kramer, Ryan R. Martin, Michael Young
Iowa State University
ljramer@iastate.edu, rymartin@iastate.edu,
myoung@iastate.edu

MS8

First-Fit Coloring of Ladder-Free Posets

Bosek and Krawczyk provided a subexponential bound for the on-line chain partitioning of posets of width w and observed the problem could be reduced to First-Fit chain partitioning of $2w^2$ -ladder-free posets of width w . We provide a subexponential upper bound (in terms of w with m fixed) for the performance of First-Fit chain partitioning on m -ladder-free posets. With the Bosek-Krawczyk observation, this yields a slightly improved upper bound for the general problem.

Matt E. Smith
Arizona State University
mattearlsmith@gmail.com

H. A. Kierstead
Mathematics Department
Arizona State University
hal.kierstead@gmail.com

MS8

Dimension and Height for Posets with Planar Cover Graphs

Planar posets can have arbitrarily large dimension. However, we show that the dimension of a planar poset is bounded as a function of its height. More precisely, we show that for each integer $h \geq 2$, there exists a least positive integer c_h so that if P is a poset with a planar cover graph and height h , then the dimension of P is at most c_h . Trivially, $c_1 = 2$. Felsner, Li and Trotter showed that $c_2 = 4$, but their proof techniques do not seem to apply when $h \geq 3$. In this paper, we establish the existence of c_h , although we suspect that the upper bound provided by our proof is far from best possible. From below, a construction of Kelly is modified to show that c_h is at least $h + 2$.

Noah Streib
Georgia Institute of Technology
nstreib3@math.gatech.edu

William T. Trotter
School of Mathematics
Georgia Institute of Technology
trotter@math.gatech.edu

MS8

The Width of the Family of Maximum Antichains

Felsner, Krawczyk and Micek conjectured in 2010 that the maximum possible width of the family of maximum an-

tichains in a $(k+k)$ -free poset of width w is $(k-1)^{w-1}$. This is easily shown to be true for $w \leq 2$. We give the proof for $w = 3$ and present several different constructions attaining the conjectured extremal value for $w \geq 3$. Despite this support we still feel to be far away from the proof for all w .

Michał Lasoń, Piotr Micek
Jagiellonian University
lason@tcs.uj.edu.pl, micek@tcs.uj.edu.pl

Noah Streib
Georgia Institute of Technology
nstreib3@math.gatech.edu

William T. Trotter
School of Mathematics
Georgia Institute of Technology
trotter@math.gatech.edu

Bartosz Walczak
Jagiellonian University
walczak@tcs.uj.edu.pl

MS8

The Dimension of Posets with Planar Cover Graphs

We study the conditions that bound the dimension of posets with planar cover graphs. We show that if P is a poset with a planar comparability graph, then the dimension of P is at most four. We also show that if P has an outerplanar cover graph, then the dimension of P is at most four. Finally, if P has an outerplanar cover graph and the height of P is two, then the dimension of P is at most three. These three inequalities are all best possible.

Stefan Felsner
Technical University of Berlin
Institute for Mathematics
felsner@math.tu-berlin.de

William T. Trotter
School of Mathematics
Georgia Institute of Technology
trotter@math.gatech.edu

Veit Wiechert
TU - Berlin
veit416@hotmail.com

MS9

Tropisms, Surfaces and the Puiseux Series

We present a polyhedral method to develop Puiseux series expansions for surfaces, defined by a system of polynomials. Our starting point is the construction of cones of normal vectors to the Newton polytopes, associated with the system of polynomials. Generating vectors of the normal cone, which lead to an initial form system with regular, isolated solutions are considered pretropisms. When the generating vectors of the normal cone lead to an exact, finite representation of the surface or to its Puiseux series expansion, then they are referred to as tropisms.

Danko Adrovic, Jan Vershelde
Department of Mathematics, Statistics and Computer Science

University of Illinois at Chicago
 adrovic@math.uic.edu, jan@math.uic.edu

MS9**Divisors on Tropical Varieties**

I will present notions of divisors, linear equivalence, and rank on tropical models. A tropical model is a simplicial complex together with some numerical data telling how the affine linear structures relate. Although the motivations come from algebraic varieties, I will discuss the combinatorial aspects.

Dustin Cartwright
 Department of Mathematics
 Yale University
 dustin.cartwright@yale.edu

MS9**Orbits of Projective Point Configurations**

Given an $r \times n$ matrix, thought of as representing n points in projective $(r-1)$ -space, we consider the closure of the orbit of all projectively equivalent matrices. I will discuss the equations cutting out this variety, its finely graded Hilbert series, and their relation to the matroid of the point configuration.

Alex Fink
 North Carolina State University
 arfink@ncsu.edu

Andrew Berget
 University of California, Davis
 berget@math.ucdavis.edu

MS9**Log-concavity of Characteristic Polynomials and Tropical Intersection Theory**

In a recent joint work with June Huh, we proved the log concavity of the characteristic polynomial of a realizable matroid by relating its coefficients to intersection numbers on an algebraic variety and applying an algebraic geometric inequality. In this talk, we outline that proof which involves algebraic geometric positivity.

Eric Katz
 University of Texas Austin
 eekatz@math.uwaterloo.ca

MS9**Tropical Torelli Space and Tropical Period Mapping**

I will discuss the Teichmüller type approach to the moduli of tropical curves. We also define the tropical period mapping and investigate the injectivity of this map on the Torelli space (i.e. the generalized Torelli problem). We will describe the image of the period map (i.e. the Schottky locus). To better understand the Torelli problem and the Schottky locus, we consider the (marked) moduli of “metric” regular matroids. Various compactifications of the moduli of tropical curves will be obtained from this point of view.

Farbod Shokrieh
 Georgia Institute of Technology

shokrieh@math.gatech.edu

MS10**Globally Fair Stable Matchings**

Stable marriage instances generally have many stable matchings. In spite of this, Gale and Shapley’s famous algorithm for computing stable matchings can only output two kinds: the man-optimal/woman-pessimal or the woman-optimal/man-pessimal stable matchings. This has motivated the study of fair stable matchings. This talk is about stable matchings whose fairness is derived from the fact that they are “good” representatives of the distributive lattice of stable matchings of the instance.

Christine T. Cheng
 University of Wisconsin-Milwaukee
 ccheng@cs.uwm.edu

MS10**Stable Matching as a Heuristic for Cost-Based Matching Problems**

Minimum-cost assignment problems arise in many situations in practice. The optimal solution of such problems usually requires network flow techniques, which can be computationally taxing for very large problem instances. Here, we discuss potential heuristics for minimum-cost assignment problems based on stable matchings, which can generally be computed much more efficiently. A number of approaches will be discussed, along with the results of empirical testing to assess their viability in practice.

Brian C. Dean, John Dabney
 Clemson University
 bcdean@cs.clemson.edu, jdabney@clemson.edu

MS10**Some Open Problems in Matchings with Preferences**

Matching problems involving preferences have been studied for many years, and have a range of real-world applications. The stable marriage problem is perhaps the most famous such problem, but many variants of it have been studied, involving extensions and variations of the basic model. Despite the extensive literature in this area, many challenging (and fascinating) open problems remain. I will survey some of these open problems that have connections with discrete mathematics, algorithms and complexity.

David F. Manlove
 University of Glasgow
 david.manlove@glasgow.ac.uk

MS10**A Unified Approach to Equivalence Results in Object Allocation**

We consider probabilistic mechanisms that allocate indivisible objects to agents by hierarchical exchange using the top-trading cycles algorithm. The main result is a general technique for proving that seemingly different probabilistic mechanisms are in fact equivalent. This approach simplifies and unifies several equivalence results in the literature. The same technique is used to generalize these results to mechanisms in which the priority structure for each object is given by a tree (instead of a linear ordering of the

agents).

Jay Sethuraman
Columbia University
jay@ieor.columbia.edu

Thiam Lee
Columbia
thl2102@columbia.edu

MS11

Homeomorphically Irreducible Spanning Trees

Let G be a graph. A spanning tree of G is called a *homeomorphically irreducible spanning tree* (HIST) if it does not contain vertices of degree 2. In 1979, Albertson, Berman, Hutchinson, and Thomassen asked the following two questions:

1. Does every triangulation of a surface contain a HIST except the triangle?
2. Does every graph with every edge on two triangles contain a HIST?

We have confirmed both questions positively. The outlines of the proofs will be given in this talk.

Guantao Chen
Department of Mathematics and Statistics
Georgia State University
gchen@gsu.edu

Songling Shan
Georgia State University
sshan2@gsu.edu

MS11

Decompositions of (Hyper)Graphs into Cliques or Bicliques

This talk will be a brief survey of recent results regarding edge-decompositions of (hyper)graphs into cliques or bicliques. These include various extensions of De Bruijn-Erdos Theorem and Graham-Pollak Theorem. Despite recent progress, many problems remain open.

Sebastian Cioaba
University of Delaware at Newark
cioaba@math.udel.edu

MS11

Multipartite Version of the Alon-Yuster Theorem

In this talk, we prove the asymptotic multipartite version of the Alon-Yuster theorem. That is, if $k \geq 3$ is an integer, H is a k -colorable graph and $\gamma > 0$ is fixed, then for sufficiently large n and for every balanced k -partite graph G on kn vertices with each of its corresponding $\binom{k}{2}$ bipartite subgraphs having minimum degree at least $\frac{k-1}{k}n + \gamma n$, the graph G has a subgraph consisting of $\lfloor n/|V(H)| \rfloor$ vertex-disjoint copies of H .

Ryan R. Martin
Iowa State University
rymartin@iastate.edu

Jozef Skokan
London School of Economics
j.skokan@lse.sc.uk

MS11

An Erdos-Stone Theorem for Hypergraphs

This talk is about complete k -partite subgraphs in hypergraphs with sufficiently many k -cliques. These results generalize the Erdős-Stone theorem for 2-graphs.

Vladimir Nikiforov
Department of Mathematical Sciences, University of Memphis
Memphis, TN 38152-3240, United States
vnikifrv@memphis.edu

MS11

On Independent Sets in Steiner Systems

For a hypergraph H , let $\alpha(H)$ denote the largest set of vertices containing no edge of H . In this talk we give near-optimal bounds on the size of a largest independent set in Steiner systems on n points. We conjecture that the minimum value of $\alpha(H)$ over all Steiner systems H on n vertices is asymptotic to $\sqrt{3n \log n}$ as $n \rightarrow \infty$. The methods are a combination of spectral techniques and probabilistic combinatorics, which are useful for various other problems on independent sets in hypergraphs.

Jacques Verstraete
University of California-San Diego
jverstra@math.ucsd.edu

MS12

Graph Homomorphisms: Mixing and Homotopies

Given a k -colouring of a graph, consider the process of recolouring a single vertex to obtain a new k -colouring. Provided k is sufficiently large, one can generate all k -colourings of the graph. We study circular colourings giving bounds on how large k/q must be to ensure all circular colourings can be generated by recolouring. We connect our work to discrete homotopies of graph homomorphisms and pre-colourings of graphs.

Richard Brewster
Department of Mathematics and Statistics
Thompson Rivers University
rbrewster@tru.ca

Jon Noel
McGill University
jonathan.noel@mail.mcgill.ca

MS12

Defective Colorings and Colorings that Avoid Large Monochromatic Components

We consider two types of colorings. Those that avoid monochromatic graphs with large degree and those that avoid monochromatic graphs with large components. We discuss relations between these two parameters and make several remarks on issues of computational complexity.

John Gimbel
University of Alaska Fairbanks
jggimbel@alaska.edu

MS12

Kempe-equivalence Classes for 3-edge-colored Cu-

bic Graphs

An edge-Kempe change switches the colors in a maximal two-colored chain in a proper edge coloring of a graph. Two proper edge colorings of a graph are called Kempe equivalent if you can get from one to the other by a sequence of edge-Kempe changes. This work examines Kempe equivalence in 3-edge colorable cubic graphs. Not all proper edge colorings of a 3-edge colorable cubic graph are Kempe equivalent. We give results about the number of non-equivalent proper edge colorings there can be for certain classes of cubic graphs.

Ruth Haas
Smith College
rhaas@smith.edu

Sarah-Marie Belcastro
Smith College
Hampshire College Summer Studies in Mathematics
smbelcas@toroidalsnark.net

MS12**Distinguishing Edge Colourings of Graphs**

An edge colouring of a graph G is *distinguishing* provided that the identity is the only automorphism of G that preserves the edge colours. The minimum number of colours required to produce such a colouring is the *edge distinguishing chromatic number* of G . In this talk I will describe results that we have obtained concerning the edge distinguishing chromatic number and the more general edge distinguishing number of a graph.

Karen Seyffarth
Mathematics and Statistics
University of Calgary
kseyffar@math.ucalgary.ca

Richard Brewster
Department of Mathematics and Statistics
Thompson Rivers University
rbrewster@tru.ca

Stacey Lamont
Department of Mathematics and Statistics
University of Calgary
swlamont@math.ucalgary.ca

MS12**Obstructions to Homomorphisms Involving the Graft Extension**

Let H_1 be a digraph that has an \underline{X} -enumeration, say $\{h_1, h_2, \dots, h_n\}$. Let H_2 be a digraph such that H_2 -colouring is polynomial. Form a new digraph H by deleting the vertex h_n from H_1 and replacing it by the digraph H_2 : every vertex $h_i \in V(H_1)$ that is adjacent to (from) h_n is now adjacent to (from) every vertex in H_2 . The digraph H is denoted by $\text{graft}(H_1, H_2)$. Given a digraph H , a dual (or obstruction) of H is a digraph F such that $G \not\rightarrow H$ if and only if $F \rightarrow G$. In this talk we aim to identify the obstructions of H in the case where $H = \text{graft}(H_1, H_2)$.

Jacobus Swarts
Mathematics
Vancouver Island University
cobus@math.uvic.ca

Gary Macgillivray
Mathematics and Statistics
University of Victoria
gmacgill@math.uvic.ca

MS13**TBD on Genome Assembly Algorithms**

Abstract not available at time of publication.

Max Alekseyev
University of South Carolina
maxal@cse.sc.edu

MS13**De Bruijn Graph Based Genome Assembly for Single Cells**

Characterization of environmental bacteria, the vast majority of which elude cultivation, is necessary for many applications including discovery of rare novel species. The ability to generate high-quality draft genome assemblies that support annotation of the majority of genes will drive advances in characterizing such uncultured organisms. Recent advances in DNA amplification technology have enabled whole genome sequencing directly from individual cells without requiring growth in culture. These methods amplify femtograms of DNA extracted from a single bacterial cell into micrograms of DNA needed for current sequencing platforms. Based on these advances, we developed a specialized software tool for assembling sequencing reads from single cells and applied it to assembly of two known genomes, *E. coli* and *S. aureus*, and an unknown marine genome, SAR324 Deltaproteobacterium. These draft de novo single cell assemblies, with no efforts to close gaps and resolve repeats, identify more than 90% of genes. DNA amplification using Multiple Displacement Amplification (MDA), however, creates serious coverage bias and chimeric fragments. Our algorithm successfully deals with these errors. Our assembler is based on the celebrated de Bruijn graph in which nodes are $(k-1)$ -mers and edges are k -mers. We present the general de Bruijn graph sequence assembly algorithm as well as our modifications to it.

Hamidreza Chitsaz
Wayne State University
chitsaz@wayne.edu

MS13**Quantifying Uniformity of Mapped Reads**

We describe a tool for quantifying the uniformity of mapped reads in high-throughput sequencing experiments. Our statistic directly measures the uniformity of both read position and fragment length, and we explain how to compute a p-value that can be used to quantify biases arising from experimental protocols and mapping procedures. Our method is useful for comparing different protocols in experiments such as RNA-Seq.

Valerie Hower, Richard Starfield, Adam Roberts
University of California, Berkeley
vhower@math.miami.edu, rstarfield@gmail.com, adarob@eecs.berkeley.edu

Lior Pachter
University of California, Berkeley
Dept. of Mathematics

lpachter@math.berkeley.edu

MS13

Combinatorial Designs for Sequencing Pooled Samples

Rare variants account for missing heritability that cannot be explained by common variants. DNA Pooling is a cost effective method to sequence a large number of samples and to discover rare variants. In this talk, I will present two new combinatorial designs for overlapped pooling strategies and show their effectiveness in discovering rare variants and in identifying variant carriers.

Wenhui Wang, Xiaolin Yin, Matthew Hayes, Yoon Soo Pyon, Jing Li
Case Western Reserve University
wxw134@case.edu, xiao.yin@case.edu, meh52@case.edu, yoon.pyon@case.edu, jingli@cwru.edu

MS13

Spaced Seeds and their Application in Next Generation Sequencing

We will briefly overview the spaced seeds technique for improving the speed and sensitivity of homology search. Then, a variation of spaced seeds is introduced to provide full sensitivity reads mapping for next generation sequencing analysis.

Bin Ma
University of Waterloo
binma1@gmail.com

MS14

The Pebbling Threshold of Graph Sequences

A pebbling threshold for a family of graphs is a function $g(n)$ such that any pebbling configuration of size much larger than $g(n)$ is almost surely solvable and of size much less than $g(n)$ is almost surely unsolvable. We will discuss pebbling threshold for an arbitrary graph family and present the results for particular families of graphs and discuss open problems. We will also introduce a probabilistic version of Graham's pebbling conjecture for the threshold.

Airat Bekmetjev
Mathematics Department
Hope College
bekmetjev@hope.edu

MS14

Complexity of Diameter Two Graph Pebbling

We present tight bounds on the number of vertices with two and three pebbles that can exist in an unsolvable configuration on a diameter two graph in terms of the size of the graph. We use the construction from this result to prove that determining reachability of a vertex is NP-complete, even in graphs of diameter two.

Charles Cusack, Timothy Lewis, Daniel Simpson
Department of Mathematics
Hope College
cusack@hope.edu, timothy.lewis@hope.edu, daniel.simpson@hope.edu

Samuel Taggart

Department of Mathematics
Oberlin College
samuel.taggart@oberlin.edu

MS14

Graph Pebbling: Past, Present, Future

In this talk we aim to give a gentle introduction to the subject of graph pebbling, including its history from combinatorial number theory, its growth as a purely graph theoretic topic, and its development into an area of combinatorial optimization. We shall describe some of its variations as well, such as optimal pebbling, cover pebbling, fractional pebbling, pebbling thresholds, and rubbling, along with its connections to computer science. Lastly, we will present a few of the major techniques in the field and offer some tantalizing open problems for further research.

Glenn Hurlbert
Arizona State University
hurlbert@mingus.la.asu.edu

MS14

Graph Rubbling

Graph rubbling is a version of graph pebbling where an additional move is allowed. The new move adds one pebble at vertex u in exchange for removing one pebble each from two vertices that are neighbors of u . Rubbling numbers are defined analogously to pebbling numbers. The purpose of this talk is to give a summary of what is known about rubbling and optimal rubbling and to present a set of unanswered questions.

Nandor Sieben
Department of Mathematics
Northern Arizona University
nandor.sieben@nau.edu

MS14

Pebbling Graphs of Diameter Three and Four

Given a configuration of pebbles on the vertices of a connected graph G , a pebbling move is defined as the removal of two pebbles from some vertex and the placement of one of these on an adjacent vertex. The pebbling number of a graph G is the smallest integer k such that for each vertex v and each configuration of k pebbles on G there is a sequence of pebbling moves that places at least one pebble on v . We improve on a bound of Bukh by showing that the pebbling number of a graph of diameter three on n vertices is at most $\lfloor 3n/2 + 2 \rfloor$, and this bound is best possible. Further, we will describe an asymptotic bound for graphs of diameter four and an asymptotic bound for pebbling graphs of arbitrary diameter obtained via discharging.

Carl Yerger
Department of Mathematics
Davidson College
cayerger@davidson.edu

Noah Streib
Georgia Institute of Technology
nstreib3@math.gatech.edu

Luke Postle
Georgia Tech
ljpostle@math.gatech.edu

MS15**Phase Transition in Random Graph Processes through the Lens of PDE and Singularity Analysis**

Erdős and Rényi show that in the standard random graph on n vertices, a phase transition takes place when the number of edges reaches $n/2$ and a giant component emerges. Since this seminal work, various random graph processes have been studied. In this talk we discuss new approaches to study the size and structure of components near the critical point of random graph processes: key techniques are a quasi-linear PDE and its singularity analysis.

Mihyun Kang

Technische Universität Graz
Institut für Optimierung und Diskrete Mathematik
kang@math.tugraz.at

MS15**Self-similarity of Graphs**

An old problem of Jacobson and Schönheim asks for the maximum s such that every m -edge graph contains a pair of edge-disjoint isomorphic subgraphs with s edges. We prove that every m -edge graph contains a pair of edge-disjoint isomorphic subgraphs with at least $c(m \log m)^{2/3}$ edges. We also construct graphs that show this estimate is correct up to a constant factor. Our results improve bounds of Erdős, Pach, and Pyber from 1987.

Choongbum Lee
University of California, Los Angeles
choongbum.lee@gmail.com

Po-Shen Loh

Department of Mathematical Sciences
Carnegie Mellon University
ploh@cmu.edu

Benny Sudakov
Department of Mathematics
UCLA
bsudakov@math.ucla.edu

MS15**Hunting the k -SAT Threshold**

We prove that the threshold for the existence of solutions in random k -NAESAT is $2^{k-1} \ln 2 - (\frac{\ln 2}{2} + \frac{1}{4}) + \varepsilon_k$, where $|\varepsilon_k| \leq 2^{-(1-o_k(1))k}$. According to deep but non-rigorous arguments from statistical mechanics, the insufficiency of current methods to prove such results is due to a change in the geometry of the set of solutions called *condensation* that occurs shortly before the actual threshold for the existence of solutions. In the talk I will describe a new method that is inspired by the sophisticated but non-rigorous formalism called Survey Propagation.

Konstantinos Panagiotou

Max-Planck-Institute for Informatics
kpanagio@mpi-inf.mpg.de

Amin Coja-Oghlan
University of Warwick
aminco@me.com

MS15**The Fractal Nature of the Abelian Sandpile**

The Abelian sandpile is a diffusion process for configurations of chips on the integer lattice; a vertex with at least 4 chips *topples*, distributing one chip to each of its neighbors. One of the most striking unexplained features of the sandpile is that it appears to produce terminal configurations converging to a peculiar fractal pattern when begun from increasingly large stacks of chips at the origin. We will present a mathematical explanation for this phenomenon.

Wesley Pegden

Courant Institute
pegden@math.nyu.edu

Charles Smart
Massachusetts Institute of Technology
smart@math.mit.edu

Lionel Levine

Cornell University
levine@math.cornell.edu

MS15**Achlioptas Processes: Recent Results and New Problems**

Recent results have shown that the phase transition of a large class of Achlioptas processes looks qualitatively similar to that of the Erdos-Renyi random graph process. I will describe these results and pay particular attention to one technique involved in the proofs, combining the differential equation method with Flajolet-Sedgewick singularity analysis. I will then propose some open questions about Achlioptas processes related to both random graphs and random constraint satisfaction problems.

Will Perkins

Georgia Tech
wperkins3@math.gatech.edu

Mihyun Kang

Technische Universität Graz
Institut für Optimierung und Diskrete Mathematik
kang@math.tugraz.at

Joel Spencer

New York University
spencer@cims.nyu.edu

MS16**Rational Noncrossing Partitions**

For each positive rational number α/β in lowest terms we define a poset of noncrossing partitions $NC(\alpha/\beta)$ with the property that

$$|NC(\alpha/\beta)| = \frac{1}{2\alpha + \beta} \binom{2\alpha + \beta}{\alpha}.$$

For the rational number $\alpha/\beta = n/(kn - n + 1)$ we obtain the poset of " k -divisible" noncrossing partitions of the cycle $(1, 2, \dots, kn)$, in which the size of each block of a partition is divisible by k . For $k = 1$ we obtain the "good old" $NC(n) = NC(n/1)$.

Drew Armstrong

University of Miami
drewarmstrong@gmail.com

Nathan Williams
University of Minnesota
will3089@umn.edu

MS16

Separation Probabilities for Products of Permutations

We study the mixing properties of permutations obtained as product of two uniformly random permutations of fixed types. For instance, we give an exact formula for the probability that elements $1, 2, \dots, k$ are in distinct cycles of the random permutation of $\{1, 2, \dots, n\}$ obtained as product of two uniformly random n -cycles.

Olivier Bernardi
MIT
bernardi@math.mit.edu

Rosena Du
East China Normal University
rxdu@math.ecnu.edu.cn

Alejandro Morales
MIT
ahmorales@math.mit.edu

Richard Stanley
Massachusetts Institute of Technology
rstan@math.mit.edu

MS16

Bijections for Lattice Paths Between Two Boundaries

We prove that on the set of lattice paths with north and east (unit) steps that lie between two boundaries B and T , the statistics ‘number of east steps shared with B ’ and ‘number of east steps shared with T ’ have a symmetric joint distribution. We give an involution that switches these statistics, and a generalization to paths that contain south steps. We show that a similar result relates to the Tutte polynomial of a matroid. Finally, we extend our main theorem to k -tuples of paths, and we provide connections to flagged semistandard Young tableaux and to k -triangulations.

Sergi Elizalde
Department of Mathematics
Dartmouth
sergi.elizalde@dartmouth.edu

Martin Rubey
-
martin.rubey@math.uni-hannover.de

MS16

Tableaux and Plane Partitions of Truncated Shapes

We consider a new kind of straight and shifted plane partitions/Young tableaux — ones whose diagrams are no longer of partition shape, but rather Young diagrams with boxes erased from their upper right ends. We find formulas for the number of standard tableaux in certain cases,

namely a shifted staircase without the box in its upper right corner, i.e. truncated by a box, a rectangle truncated by a staircase and a rectangle truncated by a square minus a box. The proofs involve finding the generating function of the corresponding plane partitions using interpretations and formulas for sums of restricted Schur functions and their specializations. The number of standard tableaux is then found as a certain limit of this function.

Greta Panova
UCLA
panova@math.ucla.edu

MS16

The Möbius Function of Generalized Subword Order

Let P be a poset and let P^* be the set of all finite length words over P . Generalized subword order is the partial order on P^* obtained by letting $u \leq w$ if and only if there is a subword u' of w having the same length as u such that each element of u is less than or equal to the corresponding element of u' in the partial order on P . Classical subword order arises when P is an antichain, while letting P be a chain gives an order on compositions. For any finite poset P , we give a simple formula for the Möbius function of P^* in terms of the Möbius function of P . This permits us to rederive in an easy and uniform manner previous results of Björner, Sagan and Vatter, and Tomie. We are also able to determine the homotopy type of all intervals in P^* for any finite P of rank at most 1. This is joint work with Peter McNamara

Bruce Sagan
Michigan State University
Department of Mathematics
sagan@math.msu.edu

MS17

Closed 2-cell Embeddings Under Partial Duality

In 2009 Chmutov introduced a partial duality operation, using only a subset of the edges, for graph embeddings. The topological consequences of this operation have not yet been intensively investigated. One important property of embeddings is being *closed 2-cell*, when the boundary of every face is a cycle in the graph. We present a necessary and sufficient condition for a closed 2-cell embedding to remain closed 2-cell after taking a partial dual.

Mark Ellingham
Department of Mathematics
Vanderbilt University
mark.ellingham@vanderbilt.edu

Xiaoya Zha
Middle Tennessee State University
xzha@mtsu.edu

MS17

Biembedding Designs and Minimum Genus Embeddings

In this presentation I will discuss results establishing, for $n \equiv 3 \pmod{36}$, that K_n has a face 2-colourable, blue and green say, nonorientable embedding in which there are $(n-1)/2$ blue faces each of which have a Hamilton cycle as their facial walk and $n(n-1)/6$ green faces each of which have a

triangle as their facial walk. By adapting the construction results on minimum genus embeddings of $K_n + \overline{K_m}$ are also obtained.

Tom McCourt
University of Bristol
tom.mccourt@bristol.ac.uk

MS17

Genus Distribution of Path-like Graphs: Transfer Matrix Method

The Transfer Matrix approach is taken for computing the genus distribution of graphs whose structure is repeated in a way of a long path or a cycle. As an example we provide explicit solutions for genus distributions of the Cartesian product of various small graphs with a long path or a cycle.

Bojan Mohar
Simon Fraser University
mohar@sfu.ca

MS17

Polychromatic Coloring of Graphs on Surfaces

Let G be a graph on a surface. A polychromatic k -coloring of G is a vertex- k -coloring of G such that each face of G receives all the k colors. Recently, Horev et al. proved that every cubic bipartite plane graph admits a polychromatic proper 4-coloring, where “4” is best possible, and the cubicity and bipartiteness cannot be omitted in the theorem. In my talk, we discuss a recent progress on polychromatic colorings of graphs on surfaces.

Atsuhiko Nakamoto
Yokohama National University
Japan
nakamoto@ynu.ac.jp

MS17

Obstructions for Embeddings of Graphs in Surfaces

Only for two surfaces, the sphere and the projective plane, the complete list of obstructions (forbidden minors) for embedding graphs into the surface is known. We present our general results about the obstructions of connectivity 2. As a consequence, we obtain all obstructions for the torus of connectivity 2.

Bojan Mohar, Petr Skoda
Simon Fraser University
mohar@sfu.ca, pskoda@sfu.ca

MS18

The Δ^2 Conjecture for Graph Labellings with Separation Conditions

In 1988 Roberts described a problem posed to him by Lanfear concerning the efficient assignment of channels to a network of transmitters in the plane. To understand this problem, Griggs and Yeh introduced the theory of integer vertex λ -labellings of a graph G . To prevent interference, labels for nearby vertices must be separated by specified amounts k_i depending on the distance i , $1 \leq i \leq p$. One seeks the minimum span of such a labelling. The $p = 2$ case with $k_1 = 2$ and $k_2 = 1$ has attracted the most attention, particularly the tantalizing conjecture that for such “ $L(2, 1)$ -labellings”, if G has maximum degree $\Delta \geq 2$, then

the minimum span is at most Δ^2 . It has now been proven for all sufficiently large Δ , but remains open for small Δ , even for $\Delta = 3$.

Jerry Griggs
University of South Carolina, Columbia
griggs@math.sc.edu

MS18

Backbone Coloring: Tree Backbone in Planar Graphs

Backbone coloring is a variation of channel assignment problem. For a graph G and a subgraph H (called *backbone*) of G , a *backbone k -coloring of G over H* is a proper vertex coloring of G using colors from $\{1, 2, \dots, k\}$, such that the colors for any two adjacent vertices in H differ by at least two. The *backbone chromatic number of G over H* , $\text{BBC}(G, H)$, is the smallest k of a backbone k -coloring admitted by G over H . Broesma et al. showed that $\text{BBC}(G, H) \leq 2\chi(G) - 1$ holds for every G and H . This implies that if G is planar, then $\text{BBC}(G, H) \leq 7$ for all H . They conjecture that if G is planar and T is a tree, then $\text{BBC}(G, H) \leq 6$. We prove this conjecture when T is a tree of diameter at most 4.

Victor Campos
Universidade Federal do Ceara
campos@lia.ufc.br

Frederic Havet
INRIA Sophia-Antipolis, France
fhavet@sophia.inria.fr

Rudini Sampaio, Ana Shirley Ferreira Silva
Universidade Federal do Ceara
rudinims@gmail.com, shirleyfsilva@gmail.com

MS18

$L(2,1,1)$ -Labeling Is NP-complete for Trees

An $L(p_1, p_2, p_3)$ -labeling of a graph G with span λ is a mapping f that assigns each vertex u of G an integer label $0 \leq f(u) \leq \lambda$ such that $|f(u) - f(v)| \geq p_i$ whenever vertices u and v are of distance i for $i \in \{1, 2, 3\}$. We show that testing whether a given graph has an $L(2, 1, 1)$ -labeling with some given span λ is even -complete for the class of trees.

Petr A. Golovach
Durham University
petr.golovach@durham.ac.uk

Bernard Lidicky
University of Illinois, Urbana, IL
lidicky@illinois.edu

Daniel Paulusma
Durham University
daniel.paulusma@durham.ac.uk

MS18

Backbone Colorings of Graphs with Large Girths

Backbone coloring is a variation of the channel assignment problem. For a graph G and a subgraph H (called *backbone*) of G , a *backbone k -coloring of G over H* is a proper vertex coloring of G using colors from $\{1, 2, \dots, k\}$, such

that the colors of adjacent vertices in H differ by at least two. The *backbone chromatic number of G over H* , $\text{BBC}(G, H)$, is the smallest k of a backbone k -coloring of G over H . Broersma, Fomin, Golovach, and Woeginger showed that $\text{BBC}(G, H) \leq 2\chi(G) - 1$ holds in general. Miškuf, Škrekovski, and Tancer proved that for any n there exists a triangle-free graph G with a spanning tree T such that $\chi(G) = n$ and $\text{BBC}(G, T) = 2n - 1$. We generalize this result: For any n there exists a graph G with arbitrarily large girth and a tree $T \subseteq G$ with $\chi(G) = n$ and $\text{BBC}(G, H) = 2n - 1$. Moreover, we prove that if T is a tree with degrees bounded by a given constant, and G is a subgraph of the square of T , then $\text{BBC}(G, T)$ can be determined in polynomial time.

Yuehua Bu
Zhejiang Normal University, China
yhbu@zjnu.edu.cn

Daphne D. Liu
California State University, Los Angeles
Department of Mathematics
dliu@calstatela.edu

Xuding Zhu
Zhejiang Normal University, China
xudingzhu@gmail.com

MS18

Distance Three Labellings of Graphs

Let h be a positive integer. An $L(h, 1, 1)$ -labelling of a (finite or infinite) graph is an assignment of nonnegative integers (labels) to its vertices such that adjacent vertices receive labels with difference at least h , and vertices distance two or three apart receive distinct labels. The span of such a labelling is the difference between the maximum and minimum labels used. Motivated by applications in frequency assignment, the $L(h, 1, 1)$ -labelling problem seeks for the minimum span over all $L(h, 1, 1)$ -labellings of a graph together with an optimal $L(h, 1, 1)$ -labelling. In this talk I will review recent results on the $L(h, 1, 1)$ -labelling problem.

Sanmaing Zhou
The University of Melbourne
sanming@unimelb.edu.au

MS19

Cycle Extension Property in BIBD Block-Intersection Graphs

A cycle C in a graph G is said to be extendible if there exists a cycle C' such that $V(C) \subseteq V(C')$ and $|V(C')| = |V(C)| + 1$. A graph G is said to be cycle extendible if every non-Hamiltonian cycle of G is cycle extendible. A balanced incomplete block design $\text{BIBD}(v, k, \lambda)$ consists of a set of blocks, each of which is a k -subset of a point set V of cardinality v , such that each pair of points occurs in precisely λ of the blocks of the design. The block-intersection graph of a design D is the graph having the block set of D as its vertex set, and in which two vertices are adjacent if and only if their corresponding blocks have non-empty intersection. We show that for integers $k \geq 2$ and $\lambda \geq 1$, the block-intersection graph of a $\text{BIBD}(v, k, \lambda)$ is cycle extendible. This is joint work with David Pike.

Atif Abueida
The University of Dayton

atif.abueida@notes.udayton.edu

David Pike
Memorial University of Newfoundland
dapike@mun.ca

MS19

Schröder Quasigroups and Related Combinatorial Designs

Schröder quasigroups have been studied quite extensively over the years. Apart from corresponding to self-orthogonal Latin squares with the Weisner property, Schröder quasigroups are known to be associated with other combinatorial configurations such as orthogonal arrays with interesting conjugate invariant properties, a class of edge-colored designs with block size 4, and triple tournaments. The purpose of this talk is to survey known existence results for various aspects of these associations and to mention some open problems.

Frank Bennett
Mount Saint Vincent University
Frank.Bennett@msvu.ca

MS19

Decompositions of Complete Graphs into Cycles and Related Problems

In 1981, Alspach posed the problem of proving that the obvious necessary conditions for a decomposition of a complete graph into cycles of specified lengths are also sufficient. In this talk I will briefly outline a solution to Alspach's problem and discuss other similar problems.

Darryn Bryant
University of Queensland
db@maths.uq.edu.au

MS19

Friendship 3-hypergraphs

Let (X, \mathcal{B}) be a set system in which \mathcal{B} is a set of 3-subsets of X . Then (X, \mathcal{B}) is a *friendship 3-hypergraph* if it satisfies the following property: for distinct elements $u, v, w \in X$, there exists a unique fourth element $x \in X$ such that $\{u, v, x\}, \{u, w, x\}, \{v, w, x\} \in \mathcal{B}$. If a friendship 3-hypergraph contains an element $f \in X$ such that $\{f, u, v\} \in \mathcal{B}$ for all $u, v \in X \setminus \{f\}$, then it is called a *universal friend 3-hypergraph* and the element f is called a *universal friend* of the hypergraph. In this presentation, we will show that if (X, \mathcal{B}) is a friendship 3-hypergraph with $|X| = n$, then $|\mathcal{B}| \geq \lceil (n-1)(n-2)/3 \rceil$. In addition, we will also show that if $n \equiv 2, 4 \pmod{6}$, then this bound is met if and only if (X, \mathcal{B}) is a universal friend 3-hypergraph.

Ben Li
University of Manitoba
lipakc@cs.umanitoba.ca

MS19

Broadcast Systems

A broadcast system of order n is a decomposition of the complete directed graph D_n into n minimum broadcast trees, one rooted at each node. I will show that broadcast systems exist for all orders, and discuss some partial results

on uniform broadcast systems where all of the broadcast trees are isomorphic.

Matthew Walsh

Indiana-Purdue University, Fort Wayne
walshm@ipfw.edu

MS20

Graph Theoretical Design Strategies for DNA Self-assembly

Recent advances in DNA self-assembly have resulted in nanoscale graphs: cubes, octahedrons, truncated octahedra, and even buckyballs, as well as ultra-fine meshes, lidded boxes and 2D figures. These constructs serve emergent applications in biomolecular computing, nanoelectronics, biosensors, drug delivery systems, and organic synthesis. One construction method uses k-armed branched junction molecules, called tiles, whose arms are double strands of DNA with one strand extending beyond the other, forming a 'sticky end' at the end of the arm that can bond to any other sticky end with complementary Watson-Crick bases. A vertex of degree k in the target graph is formed from a k-armed tile, and joined sticky ends form the edges. Another construction method 'threads' a single strand of DNA through the graphical structure and then uses short 'staple' strands for an origami folding of the DNA into the desired geometric realization of the graph. A third method uses circular single strands of DNA to trace the faces of a topological embedding of the graph. We use graph theory to determine optimal design strategies for biologists producing these nanostructures, and conclude with a discussion of how the same mathematics, on the macroscale now, may be adapted to space applications. This is joint work with Greta Pangborn, with an undergraduate research component.

Joanna Ellis-Monaghan

Saint Michaels College
Department of Mathematics
jellis-monaghan@smcvt.edu

MS20

Fluid Models for Self-organized Microtubule Arrays

In plant cells, microtubules self-organize into ordered arrays from an initially isotropic system as a result of their interactions. We develop a mean-field model which is used to derive sufficient conditions for self-organization by conducting a stability analysis. Considering parameter regions that satisfy conditions for organization, we develop predictive methodologies for expected number and average length of microtubules over time using fluid models for microtubule dynamics and approximations. Results are tested using computer simulations.

Ezgi Eren

Industrial and Systems Engineering
Texas A&M University
ezgieren@neo.tamu.edu

Natarajan Gautam
Texas A&M University
gautam@tam.u.edu

Ram Dixit
Biology Department
Washington University in St. Louis

ramdixit@wustl.edu

MS20

Specification and Optimization of Synthetic Multi-cell Behaviors

The process by which a single cell develops into a multi-celled organism is complicated. A combination of internal logic, control of growth and division, and cell-cell communication must coordinate the behaviors of the growing organism so that it differentiates correctly in time and space, in spite of environmental perturbations, and intrinsic or extrinsic noise. Although several formalisms have been defined to describe development to produce CGI plants using L-systems for example the relationship between high level programs and the possible biochemical implementation of those programs in micro-organisms is tenuous. Said differently, it is unknown whether the basic mechanisms available to the synthetic biologist are sufficient to implement the pattern formation algorithms defined at higher levels. Here, we introduce a formal specification and programming language, called gro, that allows the programmer to write distributed algorithms at a variety of different levels of abstraction. For example, the programmer may specify that a cell changes from one state to another, of that cell state is defined at the level of a multi-stable gene network with all of the low-copy number noise that would accompany it. The programs can be simulated in an environment that models the basic geometry of micro-colony growth and division, as one might see under a microscope, and also models the production, degradation, and diffusion of signaling molecules. In this talk, we illustrate gro with a variety of examples; focus on the example of symmetry-breaking in particular; and discuss a notion abstraction for gro programs using Wasserstein pseudometrics. The result is a tool that may someday allow the molecular programmer to specify a developmental process at a high level, and refine it, step-by-step, into a low level description of how an implementation would work, and finally to formally compare the specification to an actual experimental implementation.

Eric Klavins

Department of Electrical Engineering
University of Washington
klavins@ee.washington.edu

MS20

Inferring Physical Parameters and Assembly Pathways from Indirect Measures of Viral Self-assembly

Virus capsids have inspired many theoretical studies of assembly mechanisms and pathways accessible to a simple set of self-assembling components. It has generally proven impossible, though, to determine where any particular virus falls in this universe of possibilities. We have combined discrete assembly models with continuous optimization over rate parameters to infer assembly kinetics and pathways from bulk measures of assembly progress. Application to real viruses suggests a diversity of mechanisms in use in nature.

Russell Schwartz

Biological Sciences and Computer Science Departments
Carnegie Mellon University
russells@andrew.cmu.edu

Lu Xie
Joint Ph.D. Program in Computational Biology

Carnegie Mellon University
firexl@gmail.com

Gregory Smith
Department of Biological Sciences
Carnegie Mellon University
grsmith@andrew.cmu.edu

Xian Feng
Department of Biological Sciences
Carnegie Mellon University
arionfxh@gmail.com

MS20

Modelling the Co-operative Roles of Genomic RNA during Virus Assembly

We demonstrate that the genomes of ssRNA viruses impact on the assembly of the viral protein containers that package them. For a test virus, bacteriophage MS2, we show that its genomic sequence has evolved specific patterns that play important functional roles in the assembly process. We quantify these via kinetic modelling and a computation of the assembly pathways and, in combination with graph theory, predict unprecedented details concerning the organisation of the packaged genome.

Reidun Twarock

Departments of Mathematics and Biology
University of York
rt507@york.ac.uk

Eric Dykeman, Nick Grayson
Department of Biology
University of York
ecd502@york.ac.uk, neg100@york.ac.uk

Peter Stockley
Astbury Centre for Structural Molecular Biology
University of Leeds
p.g.stockley@leeds.ac.uk

MS21

Egerváry LPs and Fractional Vertex Packing

We treat relations of Egerváry (i.e. Hungarian) type algorithms to various early results on fractional vertex packings and coverings by Nemhauser and Trotter, Picard and Queranne, Bourjolly and Pulleyblank, Lovász, Korach, Deming, Sterboul, and Kayll, including that, for any vertex weighted graph G , every maximal set of vertices with 0s and 1s, rather than halves, in an optimum weight fractional vertex packing is the same. It can be extended to an optimum integer vertex packing of G . It provides an easy way to test whether G is K-E since, with all weights one, some optimum fractional vertex packing has no fractions if and only if G is K-E.

Jack Edmonds

Kitchener
jedmonds@math.uwaterloo.ca

MS21

König-Egerváry Graphs: Introduction and a Warm-up Result

K-E graphs are those for which the maximum size of a matching coincides with the minimum size of a covering

(bipartite graphs being a basic example). Edmonds (1965) characterized the perfect matching polytope $PM(G)$ of a graph $G = (V, E)$ as the set of nonnegative $\mathbf{x} \in \mathbb{R}^E$ satisfying two families of constraints: ‘vertex saturation’ and ‘blossom’. When the blossom constraints are redundant for determining $PM(G)$, the graph is *non-Edmonds*. After discussing some early results on K-E graphs, we’ll show that these graphs are non-Edmonds.

Mark Kayll

University of Montana
mark.kayll@umontana.edu

MS21

Fractional Independence Number and König-Egerváry Graphs

The *fractional independence number* α_f of a graph is the maximum value of $\sum w(v_i)$, where $w(v_i) \in [0, 1]$, for each vertex v_i of the graph, and $w(v_i) + w(v_j) \leq 1$ for each pair $\{v_i, v_j\}$ of adjacent vertices in the graph. This is the linear programming relaxation of the integer programming formulation for the independence number α of the graph. α_f is an upper bound for α and can be computed efficiently. We show that $\alpha = \alpha_f$ for a graph if, and only if, the graph is König-Egerváry, and discuss connections to the work of Nemhauser, Trotter, Bourjolly, Pulleyblank, and the theory of critical independent sets.

Craig E. Larson

Virginia Commonwealth University
clarson@vcu.edu

MS21

Independent Sets in almost König-Egerváry Graphs

Let $\alpha(G)$ denote the cardinality of a maximum independent set and $\mu(G)$ the size of a maximum matching in $G = (V, E)$. If $\alpha(G) + \mu(G) = |V| - 1$, then G is an *almost König-Egerváry graph*. Let $\text{core}(G)$ ($\text{corona}(G)$) be the intersection (union, respectively) of all maximum independent sets, and $\text{ker}(G)$ be the intersection of all critical independent sets. In this talk we prove that if G is an almost König-Egerváry unicyclic graph, then: (i) $\text{ker}(G) = \text{core}(G)$ and (ii) $|\text{corona}(G)| + |\text{core}(G)| = 2\alpha(G) + 1$.

Vadim E. Levit

Ariel University Center of Samaria and Holon Inst. of Tech.

Dept. of Computer Science & Mathematics
levitv@ariel.ac.il

Eugen Mandrescu

Department of Computer Science
Holon Institute of Technology
eugen_m@hit.ac.il

MS22

Phase Transition in Random Integer Programs

We consider integer programs on random polytopes in R^n with m facets whose normal vectors are chosen independently from any spherically symmetric distribution. We show a phase transition phenomenon: a transition from integer infeasibility to integer feasibility happens within a constant factor increase in the radius of the largest inscribed ball. Our main tools are: a new connection between

integer programming and matrix discrepancy, a bound on the discrepancy of random Gaussian matrices and Lovett-Meka's algorithm for finding low discrepancy solutions.

Karthekeyan Chandrasekaran
Georgia Institute of Technology
karthe@gatech.edu

MS22

The Game Chromatic Number of Sparse Random Graphs

Given a graph G and an integer k , two players properly color the vertices of G using k colors. The first player wins iff when the game ends all the vertices are colored. The game chromatic number $\chi_g(G)$ is the minimum k for which the first player has a winning strategy. We present results regarding the asymptotic behavior of this parameter for random graphs with constant average degree and for random regular graphs.

Simi Haber
Tel Aviv University
habbersi@post.tau.ac.il

Alan Frieze, Mikhail Lavrov
Carnegie Mellon University
alan@random.math.cmu.edu, mlavrov@andrew.cmu.edu

MS22

Connectivity and Giant Components in Stochastic Kronecker Graphs

A stochastic Kronecker graph is a random graph model wherein each vertex is represented by a string in an alphabet Γ , and the probability that two vertices are adjacent is determined by comparing their corresponding strings. We use matrix concentration inequalities to develop conditions under which a stochastic Kronecker graph is asymptotically connected, and under which it has a giant component.

Mary Radcliffe
UC San Diego
mradcliffe@math.ucsd.edu

MS22

The Power and Weakness of Two Choices: Unbalanced Allocations

The "power of two choices" (generating several random options and choosing among them) has been used successfully in load balancing algorithms, queuing theory, and Achlioptas processes. Here an allocation algorithm for generating an unbalanced distribution using this technique is presented and analyzed. This type of algorithm has connections to physics, biology, and economics, and arose originally from a real-world cost-minimization question. Its analysis uses ideas from differential equations, random walks, and some new concepts.

Amanda Redlich
Rutgers
aredlich@math.rutgers.edu

MS23

Symmetric chain decomposition for necklace posets

and relation to cyclic crystals

The quotient of a Boolean algebra by a cyclic group is proven to have a symmetric chain decomposition. This generalizes earlier work of Griggs, Killian and Savage on the case of prime order, giving an explicit construction for any order, prime or composite. The combinatorial map specifying how to proceed downward in a symmetric chain is shown to be a natural cyclic analogue of Kashiwara's sl_2 lowering operator in the theory of crystal bases. This is joint work with Anne Schilling.

Patricia L. Hersh
North Carolina State University
plhersh@ncsu.edu

MS23

Volume Bounds for Shadow Covering

Suppose that K and L are compact convex subsets of Euclidean space such that, for every direction u , the orthogonal projection of L onto the subspace u^\perp contains a translate of the corresponding projection of the body K . In spite of these covering conditions, it is possible for K to have *greater volume* than L . The question then turns to bounds: How large can the volume ratio $\frac{V(K)}{V(L)}$ be? And what other valid comparisons can be made? While these questions are posed in the setting of convex geometric analysis, a fundamental role in their resolution is played by Helly's Theorem.

Dan Klain
UMass Lowell
daniel.klain@uml.edu

Christina Chen
Newton North High School
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Tanya Khovanova
MIT
tanya@math.mit.edu

MS23

Perturbation of Transportation Polytopes

We introduce a perturbation method that can be used to reduce the problem of finding the multivariate generating function (MGF) of a non-simple cone to computing the MGF of simple cones. We then give a universal perturbation that works for any transportation polytope. We apply this perturbation to the family of central transportation polytopes of order $kn \times n$, and obtain formulas for the MGFs of the feasible cones of vertices of the polytope and the MGF of the polytope. The formulas we obtain are enumerated by combinatorial objects. A special case of the formulas recovers the results on Birkhoff polytopes given by the author and De Loera and Yoshida.

Fu Liu
UC Davis
fuliu@math.ucdavis.edu

MS23

Monotone Hurwitz Numbers: Polynomiality and Explicit Forms

Monotone Hurwitz numbers are a desymmetrized version

of the classical Hurwitz numbers from enumerative algebraic geometry. They appeared recently in the context of random matrix theory. In this talk I will focus on the algebraic and combinatorial structure of monotone Hurwitz numbers, which is to a surprising extent similar to the classical case. In particular, I will discuss polynomiality and Toda equations for monotone Hurwitz numbers, as well as low-genus formulas. This is joint work with I. Goulden and M. Guay-Paquet (Waterloo).

Jonathan I. Novak
MIT
jnovak@math.mit.edu

MS23 Orientations, Semiorders, Arrangements, and Parking Functions

It is known that the Pak-Stanley labeling of the Shi hyperplane arrangement provides a bijection between the regions of the arrangement and parking functions. For any graph G , we define the G -semiorder arrangement and show that the Pak-Stanley labeling of its regions produces all G -parking functions.

David Perkinson
Reed College
davidp@reed.edu

MS24 Distances Between Evolutionary Trees

Phylogenetic (leaf-labelled) trees are used in computational biology to show the evolutionary relationships within a collection of species. A common way to measure the dissimilarity between phylogenetic trees with identical leaf sets is the minimum number of certain tree rearrangement operations that is necessary to transform one tree into the other. In other words, we use the graph distance of the graph where the vertices are all phylogenetic trees with given leaf set and two trees are adjacent if they are a single rearrangement operation apart. I will summarize recent results on the tree bisection and reconnection (tbr) and the subtree prune and regraft (spr) distances.

Stefan Gruenewald
PICB
Shanghai
stefan@picb.ac.cn

MS24 On t -Path Closed Graphs

A t -path closed is a graph with girth $t+1$ such that for each pair of distinct vertices there is a path of length t connecting them. In this talk we will give several constructions of such graphs. Also we will give relations with cages and Moore graphs.

Jacobus Koolen
Korea Advanced Institute of Science and Technology
Dept Mathematics,POSTECH,
jhk@amath.kaist.ac.kr

Hwang Rae Lee
Dept Math
POSTECH
meso@postech.ac.kr

Stefan Gruenewald
PICB
Shanghai
stefan@picb.ac.cn

MS24 Switchings, Extensions, and Reductions in Central Digraphs

A directed graph is called *central* if, for each ordered pair u, v of (not necessarily distinct) vertices, there is a unique vertex z such that the digraph contains the arcs uz, zv . Equivalently, the adjacency matrix A satisfies the matrix equation $A^2 = J$, where J is the matrix with a 1 in each entry. It has been conjectured that every central directed graph can be obtained from a standard example by a sequence of simple operations called switchings, and also that it can be obtained from a smaller one by an extension. We disprove these conjectures and present a general extension result which, in particular, shows that each counterexample extends to an infinite family of central digraphs.

Andre Kundgen
California State University, San Marcos
akundgen@csusm.edu

Gregor Leander
Technical University of Denmark
g.leander@mat.dtu.dk

Carsten Thomassen
Technical University of Denmark
c.thomassen@mat.dtu.dk

MS24 Greedy Trees and the Extremal Distances

We show a “universal property” of the greedy tree with a given degree sequence, namely that the number of pairs of vertices whose distance is at most k is maximized by the greedy tree for all k . This rather strong assertion immediately implies, and is equivalent to, the minimality of the greedy trees with respect to graph invariants of the form $W_f(T) = \sum_{\{u,v\} \subseteq V(T)} f(d(u,v))$ for any nonnegative, nondecreasing function f . With different choices of f , one directly solves the minimization problems of distance-based graph invariants including the classical Wiener index, the Hyper-Wiener index and the generalized Wiener index.

Nina Schmuck
Technische Universität
”at Graz
nina.schmuck@tugraz.at

Stephan Wagner
Stellenbosch University
swagner@sun.ac.za

Hua Wang
Georgia Southern University, GA
hwang@georgiasouthern.edu

MS24 Walks and homomorphisms of digraphs

In this talk we try to discuss some connections between

symbolic dynamics and digraph homomorphisms and then apply them to some problems on walks in digraphs posed by Delorme, Tvrdik, Harbane and Heydemann et al.

Yaokun Wu

Shanghai Chiao Tong Univ.,
Shanghai, China
ykwu@sjtu.edu.cn

Yaokun Wu

Shanghai Jiao Tong University
Shanghai, China
ykwu@sjtu.edu.cn

MS25

Title Not Available at Time of Publication

Abstract not available at time of publication.

Andreas Brandstädt

FB Informatik, University of Rostock, Germany
ab@informatik.uni-rostock.de

MS25

Convexity and Graph Classes

We survey graph classes that arise from convexity in graphs with emphasis on convex geometries.

Ortrud R. Oellermann

The University of Winnipeg
o.oellermann@uwinnipeg.ca

MS25

Atomic Structure, Hyperbolicity, and Recognition of AT-free Graphs with no Induced 4-cycles

An atom of a graph is a maximal induced subgraph with no clique cutset. We characterize atoms of C_4 -free AT-free graphs. This class of graphs is of interest as it coincides with 1-hyperbolic AT-free graphs while all other AT-free graphs are 2-hyperbolic. Based on the structure of atoms, we describe an efficient algorithm for the recognition of the class.

Derek Corneil

University of Toronto
dgc@cs.utoronto.ca

Juraj Stacho

University of Warwick
j.stacho@warwick.ac.uk

MS25

Polygon Numbers of Circle Graphs

Circle graphs and k -polygon graphs are intersection graphs of chords of a circle and chords of a convex k -sided polygon where each chord has its endpoints on distinct sides, respectively. Determining $\psi(G)$, the minimum number of sides in a polygon representation of a circle graph G , is NP-hard, whereas determining whether G is a k -polygon graph for fixed k can be done in polynomial time. We give bounds on $\psi(G)$ when G is an arbitrary circle graph and identify graph classes for which $\psi(G)$ can be computed in polynomial time.

Lorna Stewart, Richard Valenzano

University of Alberta

lorna.stewart@ualberta.ca, valenzan@ualberta.ca

MS25

Unit Interval Graphs of Mixed Intervals

The class of unit interval graphs has a lovely characterization as those interval graphs with no induced claw $K_{1,3}$. The characterization remains the same whether the intervals used in the intersection representation are all open intervals or all closed intervals. In recent work, Rautenbach and Szwarcfiter characterize the broader class that arises when both open and closed intervals of unit length are permitted. In this talk we consider the same problem when unit length mixed intervals of the form $(x, x + 1]$ and $[x, x + 1)$ are also allowed. We give a structural characterization of this class of graphs.

Ann N. Trenk

Wellesley College
atrenk@wellesley.edu

Alan Shuchat

Mathematics Department
Wellesley College
ashuchat@wellesley.edu

Randy Shull

Department of Computer Science
Wellesley College
rshull@wellesley.edu

Lee West

Wellesley College
awest@wellesley.edu

MS26

The Cost of 2-Distinguishing Cartesian Powers

A graph is said to be *2-distinguishable* if there is a vertex labeling with two labels so that only the trivial automorphism preserves the labels. Define the *cost of 2-distinguishing* G , denoted $\rho(G)$, to be the minimum size of a label class in such a labeling. A *determining set* is a subset of vertices with trivial pointwise stabilizer; its minimum size is denoted $\text{Det}(G)$. The main result of this talk is that under mild hypotheses, $\rho(G^k) \in \{\text{Det}(G^k), \text{Det}(G^k) + 1\}$.

Debra L. Boutin

Hamilton College
dboutin@hamilton.edu

MS26

Groups That Are Transitive on All Partitions of a Finite Set

We study the question of which subgroups of S_n are transitive on the set of all ordered partitions of the set $[n] = \{1, \dots, n\}$ and all unordered partitions of $[n]$. This work can be considered a generalization of well known work in which subgroups of S_n that are transitive on the set of all subsets of $[n]$ of size k were determined. As an application of our results, we determine which Johnson graphs are Cayley graphs.

Ted Dobson

Mississippi State University
dobson@math.msstate.edu

Aleksander Malnic
University of Ljubljana
aleksander.malnic@guest.arnes.si

MS26

Decomposing Hypergraphs on Finite Fields

We examine edge decompositions of complete uniform hypergraphs whose parts are permuted transitively by some permutation of the vertex set. We present an algebraic method for constructing such a hypergraph decomposition on a finite field which is related to the Paley graph construction and is derived from a partition of the cosets of the multiplicative group of units of the field. We discuss the symmetry and other properties of the hypergraphs we obtain.

Shonda Gosselin

University of Winnipeg
Department of Mathematics and Statistics
s.gosselin@uwinnipeg.ca

MS26

Infinite Motion and Distinguishing Number 2

Given a group A acting faithfully on a set X , define the *motion* (also known as minimal degree) of A , to be $m(A) = \min_{a \neq 1} |\{x : x^a \neq x\}|$. A general principle for finite A is that if $m(A) \gg |A|$, then the action has distinguishing number 2, that is, there is a subset Y whose set-wise stabilizer is trivial. For infinite A and countable X , we make the *Infinite Motion Conjecture*: if $m(A)$ is infinite, then the action has distinguishing number 2. We consider various contexts for the conjecture in the case of locally finite graphs.

Thomas Tucker

Colgate University
ttucker@colgate.edu

Wilfried Imrich
University of Leoben
wilfried.imrich@unileoben.ac.at

Simon Smith, Mark E. Watkins
Syracuse University
smsmit13@syr.edu, mewatkin@syr.edu

MS26

Finite Subgraphs of d -Distinguishable, Locally Finite Graphs

It is known (M.E. Watkins and X. Zhou, 2007) that every infinite, locally finite tree T with finite distinguishing number $d(T) = d_0$ contains a finite subtree with distinguishing number d_0 . It is not difficult to prove more generally that if every finite subgraph Φ of an infinite, locally finite graph Γ satisfies $d(\Phi) \leq d_0$, then $d(\Gamma) \leq d_0 + 1$. We investigate conditions subject to which this bound may be sharp.

Mark E. Watkins, Simon Smith
Syracuse University
mewatkin@syr.edu, smsmit13@syr.edu

MS27

Fast Algorithms for Phylogenetic Reconstruction

We present two recent very fast algorithms to infer phylogenetic trees in $o(n^2)$ time when the input consists of data from n species. Our first algorithm uses a search tree much like a randomly balanced binary search tree to place each new species into its correct place. Our second algorithm uses nearest-neighbour search to speedily find roughly where each new taxon goes, and then uses more robust methods to exactly place the new species correctly.

Dan Brown

Cheriton School of Computer Science
University of Waterloo
dan.brown@uwaterloo.ca

MS27

Gene Family Evolution by Duplication and Loss - Reconciliation and Species Tree Inference

Almost all genomes which have been studied contain genes that are present in two or more copies. They are usually identified through sequence similarity, and grouped into a single ‘Gene Family’. From a functional point of view, such grouping is not sufficient to infer a common function for genes. Indeed, it is important to distinguish between ‘orthologs’ which are copies in different species related through speciation, and thus likely to have similar functions, and ‘paralogs’, which are copies that have evolved by duplication, and more likely to have acquired new functions. Understanding the evolution of gene families through speciation, duplication, and loss is thus a fundamental question in functional genomics, and also in evolutionary biology and phylogenomics. Reconciliation is the commonly used method for inferring the evolutionary scenario for a gene family. It consists in ‘embedding’ inferred gene trees into a species tree. When a species tree is not known, a natural algorithmic problem is to infer a species tree from a set of gene trees, such that the corresponding reconciliation minimizes the number of duplications and/or losses. The main drawback of reconciliation is that the inferred evolutionary scenario is strongly dependent on the considered gene trees, as few misplaced leaves may lead to a completely different history. In this talk, we will clarify several theoretical questions and present various algorithmic issues related to reconciliation and species tree inference. In particular, we will present a strategy for ‘correcting’ or preprocessing a gene tree prior to reconciliation or species tree inference, and give various complexity results and algorithmic solutions, in both cases of a known and an unknown species tree.

Nadia S. El-Mabrouk

Département d’informatique et de recherche
opérationnelle
Université de Montréal
mabrouk@iro.umontreal.ca

MS27

Tree Compatibility, Character Compatibility, and Graph Triangulation

We consider two classic NP-complete problems in phylogenetic tree construction, tree compatibility and character compatibility. In each case, the ‘yes’ instances are precisely those for which a specific kind of triangulation exists for a certain graph. The relationship between triangulations and character compatibility has been known for over

three decades (Buneman, 1974); an analogous relationship with tree compatibility was identified more recently (Vakati and Fernández-Baca, 2011). We use these characterizations to gain insight into the fundamental differences in tractability between the two problems.

David F. Fernandez-Baca
Computer Science
Iowa State University
fernande@iastate.edu

Sudheer Vakati
Department of Computer Science
Iowa State University
svakati@iastate.edu

MS27

Aspects of Fractionation; A Fundamental Evolutionary Process

In the evolutionary history of virtually all eukaryotic species is at least one whole genome duplication (WGD). Each WGD event is followed by a period of fractionation whereby only one of the copies of almost all gene pairs is shed, sometimes on one of the two homeologous chromosomes, and sometimes on the other. This effectively scrambles the gene order on chromosomes and introduces an extreme level of noise into gene order comparisons between genomes descending from the WGD and those that diverged before this event, and also between genomes in sister lineages descending from the event radiating soon after the WGD. In these cases, fractionation is responsible for more gene order disruption than rearrangements such as inversion and translocation. We discuss three aspects of fractionation:

- the time course of fractionation on scales of tens to hundreds of millions of years,
- a recurrence for the run lengths of deleted and undeleted genes on a chromosome, and
- a model for gene family size, where a genome originates from more than one successive WGD or other polyploidization event.

David Sankoff, Chunfang Zheng
Department of Mathematics and Statistics
University of Ottawa
sankoff@uottawa.ca, chunfang313@gmail.com

MS27

Reconstruction of Certain Phylogenetic Networks from the Tree-Additive Distances Between Their Leaves

Suppose N is a rooted directed graph and each leaf corresponds to an extant biological species. Suppose each arc of N has a nonnegative weight and inheritance of a character at a hybrid vertex occurs with a certain probability from each parent. The tree-additive distance between two leaves is the expected value of their distances in the displayed trees. Sufficient conditions are investigated so that, given the tree-additive distances between all leaves, it is possible to reconstruct the network.

Stephen J. Willson
Iowa State University
swillson@iastate.edu

MS28

Quotients of the Boolean Lattice by Wreath Products

Rod Canfield has asked if all quotients of a Boolean lattice B_n induced by subgroups of its automorphism group, essentially S_n , are symmetric chain orders. K. Jordan verified this in the special case of a subgroup generated by an n -cycle, answering a question raised earlier by Griggs, Killian and Savage. In earlier work we found an especially straightforward proof of Jordan's result based on the Greene-Kleitman symmetric chain decomposition. Hersh and Schilling, and Dhand have presented other proofs of the same result, and the latter has the substantial generalization that P^n/Z_n is an SCO whenever P is an SCO. Here we continue in the same vein as our earlier work, describing circumstances under which subgroups G of the symmetric group which are wreath products are guaranteed to induce quotients that are symmetric chain orders. This is done by carefully winnowing Greene-Kleitman SCDs.

Dwight Duffus
Emory University
Mathematics and Computer Science Department
dwight@mathcs.emory.edu

Kyle Thayer
Emory University
kthayer@emory.edu

MS28

Poset-free Families of Sets

Given a finite poset P , we consider the largest size $La(n, P)$ of a family F of subsets of $[n] := \{1, \dots, n\}$ that contains no (weak) subposet P . For fixed P it can be very difficult to determine $La(n, P)$, even asymptotically. We continue to believe that $\pi(P) := \lim_{n \rightarrow \infty} La(n, P) / \binom{n}{\lfloor n/2 \rfloor}$ exists for general posets P , and, moreover, it is an integer that we can predict. The existence of the limit remains open, for instance, for the four-element diamond poset and the six-element crown. However, we are developing methods that allow us to solve the asymptotic problem, and sometimes even the exact problem for all n , for increasingly many posets P . These methods involve studying the Lubell function of a family F , which is the average number of times a random full chain meets F .

Jerry Griggs
University of South Carolina, Columbia
griggs@math.sc.edu

Wei-Tian Li
Department of Mathematics
University of South Carolina
weitianli@math.sinica.edu.tw

Linyuan Lu
University of South Carolina
lu@math.sc.edu

MS28

Chopping Celery and the Lattice of Integer Partitions

The *chop vector* of a set S of celery sticks of positive integer lengths is the infinite vector $\mathbf{v}_S = (v_1, v_2, v_3, \dots)$, where each v_w is the minimum number of cuts needed to chop S

into unit pieces, using a knife that can cut up to w sticks at a time. In this talk we see a connection (found jointly with Thao Do) between the set of chop vectors and the lattice of integer partitions.

Bill Sands, Thao Do
University of Calgary
sands@ucalgary.ca, thao10@gmail.com

MS28

Diamond-Free Collections of Subspaces

Let V be a finite-dimensional vector space over a finite field, and let A, B, C , and D be subspaces of V . We say that $\{A, B, C, D\}$ is a diamond if A is a subspace of both B and C which in turn are subspaces of D . Inspired by the recent work on the Boolean Lattices, we ask: What is the size of the largest collection of diamond-free subspaces of V ? The corresponding question in the Boolean Lattices has not been completely settled and neither is the question in the Linear Lattices. We report on partial progress. Joint work with Ghassan Sarkis and the undergraduate math research circle at Pomona College.

Shahriar Shahriari
Pomona College
SShahriari@pomona.edu

MS28

Linear Discrepancy of Partially Ordered Sets

The *linear discrepancy* of a P , denoted $\text{ld}(P)$, is the minimum over all linear extensions of the maximum difference between the positions of two incomparable elements. Tanenbaum, Trenk, and Fishburn conjectured that always $\text{ld}(P) \leq \lfloor (3r - 1)/2 \rfloor$, where r is the maximum number of elements incomparable to any single element. We disprove this conjecture by showing that appropriately randomized bipartite posets have linear discrepancy asymptotic to the trivial upper bound, $2r - 1$. On the other hand, we show that the conjecture does hold for posets having width 2.

Jeong Ok Choi
GIST College
Gwangju Institute of Science and Technology
jeong.choi@trincoll.edu

Kevin Milans
University of South Carolina
milans@math.sc.edu

Douglas B. West
University of Illinois, Urbana
Department of Mathematics
west@math.uiuc.edu

MS29

Roots of Combinatorial Polynomials

Polynomials arise in a variety of ways in combinatorics, from applications like graph colourings and network reliability, to theoretical investigations of sequences related to independent sets of graphs and open sets of finite topologies. We discuss some recent results about the roots of such polynomials, both in terms of location and nature, as well as some connections to fractals.

Jason Brown

Dalhousie University, Canada
Dept of Maths, Stats, & CS
brown@mathstat.dal.ca

MS29

Graph Colouring and the Topological Penrose Polynomial

The Penrose polynomial of a plane graph first appeared implicitly in Roger Penrose's 1971 work on diagrammatic tensors, but was discovered to have a number of remarkable graph theoretical properties, particularly with respect to graph colouring. We now extend the Penrose polynomial, originally defined only for plane graphs, to graphs embedded in arbitrary surfaces. This leads to new identities and relations for the Penrose polynomial which cannot be realized within the class of plane graphs. In particular, by exploiting connections with the transition polynomial and the ribbon group action, we find a deletion-contraction-type relation for the Penrose polynomial and its relation to the ribbon graph polynomial of Bollobas and Riordan. We relate the Penrose polynomial of an orientable checkerboard colourable graph to the circuit partition polynomial of its medial graph and use this to find new combinatorial interpretations of the Penrose polynomial. We also show that the Penrose polynomial of a plane graph G can be expressed as a sum of chromatic polynomials of twisted duals of G . This allows us to obtain a new reformulation of the Four Colour Theorem.

Joanna Ellis-Monaghan
Saint Michaels College
Department of Mathematics
jellis-monaghan@smcvt.edu

Iain Moffatt
University of South Alabama
imoffatt@jaguar1.usouthal.edu

MS29

Matroids, Greedoids and the Tutte Polynomial

We present some conjectures and counterexamples related to the greedoid generalization of the Tutte polynomial of a matroid. In particular, we give simple examples to show the Tutte polynomial does not distinguish greedoids. We also study the affine relations satisfied by the coefficients of the Tutte polynomial in this more general setting.

Gary Gordon
Lafayette College
Department of Mathematics
gordong@mail.lafayette.edu

MS29

Some Recent Results on Chromatic and Tutte Polynomials for Families of Graphs

We discuss some recent results on chromatic and Tutte polynomials (equiv. to Potts model partition functions in statistical physics) and some generalizations for various families of graphs. These include weighted-set chromatic and Tutte polynomials, lower bounds on Potts ground-state entropy, and chromatic polynomials for one- and multi-parameter families of planar triangulation graphs. References include S.-C. Chang and R. Shrock, *J. Phys. A (JPA)* 42, 385004 (2009); *J. Stat. Phys. (JSP)* 138, 496 (2010); R. Shrock and Y. Xu, *JSP* 139, 27 (2010); *JSP*

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Robert Shrock

SUNY at Stony Brook
C. N. Yang Institute for Theoretical Physics
robert.shrock@sunysb.edu

MS29

Peck orders and LYM orders

Abstract not available at time of publication.

David Wagner

University of Waterloo, Canada
Dept. of Combin. and Opt.
dgwagner@uwaterloo.ca

MS30

Edge-coloring 8-regular Planar Graphs

In 1974 Seymour made the following conjecture:

Let G be a k -regular planar graph, such that if X is an odd set of vertices of G , then at least k edges of G have one end in X and the other in $V(G) \setminus X$. Then G is k -edge colorable.

For $k = 3$ this is equivalent to the Four Color Theorem. The cases of $k = 4, 5$ were solved by Guenin, the case of $k = 6$ by Dvorak, Kawarabayashi and Kral, and the case of $k = 7$ by Edwards and Kawarabayashi. In joint work with Edwards and Seymour, we now seem to have a proof for the case $k = 8$, and that is the topic of this talk.

Maria Chudnovsky

Columbia
mchudnov@columbia.edu

Katherine Edwards, Paul Seymour

Princeton University
ke@princeton.edu, pds@math.princeton.edu

MS30

Graph Stirling Numbers

For a graph G and an integer k , the graph Stirling number $S(G, k)$ is the number of partitions of $V(G)$ into k non-empty independent sets. Equivalently it is the number of proper colourings of G using exactly k colours, with two colourings identified if they differ only on the names of the colours. If G is the empty graph on n vertices then $S(G, k)$ is just $S(n, k)$, the familiar Stirling number of the second kind. In this talk, we look at the Stirling numbers of families and forests and cycles. Among other results, we generalize Harper's theorem on the asymptotic normality of the ordinary Stirling numbers.

David J. Galvin, Do Trong Thanh

University of Notre Dame
dgalvin1@nd.edu, dtrongth@nd.edu

MS30

Recent Results on Grundy number

A k -coloring of a graph $G = (V, E)$ is a function $f : V \rightarrow$

$\{1, \dots, k\}$ such that $f(v) \neq f(w)$ for all $vw \in E$. The Grundy number of a graph is the largest integer k such that there is a k -coloring f of G such that if $1 \leq i < j \leq k$ and $f(v) = j$ then there exist $w \in N(v)$ such that $f(w) = i$. It is well known that the Grundy number of G is equal to the worst case performance of First-Fit on G . I will discuss many recent results concerning Grundy number.

H. A. Kierstead

Mathematics Department
Arizona State University
hal.kierstead@gmail.com

MS30

Bounding the Fractional Chromatic Number of K_Δ -free Graphs

In this talk I will discuss recent work in bounding the difference between the maximum degree and the fractional chromatic number in graphs for which the answer is not obvious, i.e. for graphs whose clique number is less than the maximum degree. This work has interesting ties to the Borodin-Kostochka conjecture and Reed's conjecture.

Andrew D. King

Columbia University
andrew.d.king@gmail.com

Linyuan Lu, Xing Peng

University of South Carolina
lu@math.sc.edu, pengx@mailbox.sc.edu

MS30

Multicolor and Directed Edit Distance

For the edit distance problem, simple graphs on the same vertex set are elements in a metric space defined by the normalized edit distance. The primary question is the maximum distance of a graph from some fixed hereditary property.

In this talk, we generalize this concept to other kinds of graphs. We consider multicolorings of the edges of complete graphs as well as simple directed graphs. The same question – the maximum distance of an element from a hereditary property – is considered in these settings and we provide bounds for this quantity.

Ryan R. Martin, Maria Axenovich

Iowa State University
rymartin@iastate.edu, axenovic@iastate.edu

MS31

Two Extensions of Ramsey's Theorem

Ramsey's theorem states that every 2-colouring of the edges of the complete graph on $\{1, 2, \dots, n\}$ contains a monochromatic clique of order roughly $\log n$. We prove new bounds for two extensions of Ramsey's theorem, each demanding extra structure within the monochromatic clique. In so doing, we answer a question of Erdős and improve upon results of Rödl and Shelah.

David Conlon

University of Oxford
david.conlon@maths.ox.ac.uk

Jacob Fox

MIT
fox@math.mit.edu

Benny Sudakov
Department of Mathematics
UCLA
bsudakov@math.ucla.edu

MS31

On Restricted Ramsey Numbers

A classical Ramsey theorem states that in any 2-coloring of the edges of a sufficiently large complete graph, one will always find a monochromatic complete subgraph. In 1970, Folkman extended this result showing that for any graph G there exists a graph H with the same clique number as G such that any 2-coloring of the edges of H yields a monochromatic copy of G . In this talk, we present some old and recent developments concerning Folkman-type results for vertex colorings.

Andrzej Dudek
Department of Mathematics
Western Michigan University
andrzej.dudek@wmich.edu

MS31

Ramsey Problems on Non-Complete Graphs

A typical question in Ramsey Theory is, for given graphs G and H , to determine the Ramsey number $R(G, H)$: the smallest integer N such that, in every colouring of the edges of the complete graph K_N on N vertices with red and blue, we either find a red copy of G or a blue copy of H . One naturally wonders whether the complete graph K_N in the above definition can be replaced by some other graph F on N vertices. It would be naive to think we can take *any* graph on N vertices, therefore, we put some restrictions on such a graph F . In this we shall discuss the following problem: For given graphs G and H , is there a constant $0 < c < 1$ such that if a graph F on $N = R(G, H)$ vertices has minimum degree at least $(1 - c)N$, then in every colouring of the edges of F with red and blue, we either find a red copy of G or a blue copy of H . It is not even clear why such c should even exist. We determine the maximum c when G and H are cycles or paths, and show that c exists for a rather large class of pairs (G, H) .

Jozef Skokan
London School of Economics
jozef@member.ams.org

MS31

Title Not Available at Time of Publication

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TBA TBA
IBM Corporation
TBA

MS31

Diagonal Forms for Incidence Matrices and Zero-Sum (mod 2) Ramsey Theory

Let H be a t -uniform hypergraph on k vertices, with $a_i \geq 0$ denotes the multiplicity of the i -th edge, $1 \leq i \leq \binom{k}{t}$. Let

$\mathbf{h} = (a_1, \dots, a_{\binom{k}{t}})^\top$, and $N_t(H)$ the matrix whose columns are the images of \mathbf{h} under the symmetric group S_k . We determine a diagonal form (Smith normal form) of $N_t(H)$ for a very general class of H . Motivated by Y. Caro's results, we show that if H is simple, the zero-sum Ramsey number (mod 2) of H is almost surely k as $k \rightarrow \infty$.

Wing Hong Tony Wong, Richard Wilson
California Institute of Technology
tonywong@caltech.edu, rmw@caltech.edu

MS32

Non-extendible Latin Cuboids

There is a celebrated result due to Marshall Hall that every latin rectangle is completable to a latin square. However, the equivalent statement in higher dimensions is not true. A 3-dimensional array has lines of cells in three directions, called *rows*, *columns* and *stacks*. An $n \times n \times k$ latin cuboid is a 3-dimensional array containing n different symbols positioned so that every symbol occurs exactly once in each row and column and at most once in each stack. An $n \times n \times n$ latin cuboid is a *latin cube* of order n . An $n \times n \times k$ latin cuboid is *extendible* if it is contained in some $n \times n \times (k+1)$ latin cuboid and it is *completable* if it is contained in some latin cube of order n . In this talk I will present some results on non-extendible and non-completable $n \times n \times k$ latin cuboids where k is approximately half of n .

Darryn Bryant
University of Queensland
db@maths.uq.edu.au

Nicholas Cavenagh
University of Waikato
nickc@waikato.ac.nz

Barbara Maenhaut
University of Queensland
bmm@maths.uq.edu.au

Kyle Pula
University of Denver
jpula@math.du.edu

Ian Wanless
Monash University
ian.wanless@monash.edu

MS32

Block Colourings of Designs Revisited

Block colourings of designs, both classical and its variants, and also the so-called specialized block colourings, offer an extensive variety of interesting problems. We will discuss some old and new concepts, results and open problems in colourings of block designs, mostly for Steiner triple systems and Steiner systems $S(2, 4, v)$.

Alexander Rosa
Department of Mathematics
McMaster University
rosa@mcmaster.ca

MS32**Skolem and Rosa Rectangles and Related Designs**

A *Skolem sequence of order n* is a sequence $S = (s_1, s_2, \dots, s_{2n})$ of $2n$ integers such that (1) for all $k = 1, \dots, n$ there are exactly two terms s_i, s_j such that $s_i = s_j = k$, and (2) if $s_i = s_j = k$ and $i < j$, then $j - i = k$. Two Skolem sequences S, S' are disjoint if $s_i = s_j = k = s'_t = s'_u$ implies that $\{i, j\} \neq \{t, u\}$, for all $k = 1, 2, \dots, n$. For example, the two Skolem sequences of order four 1, 1, 4, 2, 3, 2, 4, 3 and 2, 3, 2, 4, 3, 1, 1, 4 are disjoint. A set of m pairwise disjoint Skolem sequences forms a Skolem rectangle of strength m . The above sequences then form a Skolem rectangle of strength two: 1,1,4,2,3,2,4,3 2,3,2,4,3,1,1,4. We introduce several new and powerful constructions for Skolem and Rosa rectangles then we apply them to generate simple cyclic triple systems and cyclic disjoint triple systems.

Nabil Shalaby

Memorial University of Newfoundland
nshalaby@mun.ca

Vaclav Linek

University of Winnipeg
v.linek@uwinnipeg.ca

MS32**Cyclic Block Designs with Block Size 3 from Skolem-Type Sequences**

A Skolem-type sequence is a sequence (s_1, \dots, s_t) of positive integers $i \in D$ such that for each $i \in D$ there is exactly one $j \in \{1, \dots, t - i\}$ such that $s_j = s_{j+i} = i$. Positions in the sequence not occupied by integers $i \in D$ contain null elements. In 1939, Pelsesohn solved the existence problem for cyclic Steiner triple systems for $v \equiv 1, 3 \pmod{6}, v \neq 9$. Using the same technique in 1981, Colbourn and Colbourn extended the solution to all admissible $\lambda > 1$. It is known that Skolem-type sequences may be used to construct cyclic Steiner triple systems as well as cyclic triple systems with $\lambda = 2$. The main result of this talk is an extension of former results onto cyclic triple systems with $\lambda > 2$. In addition we introduce a new kind of Skolem-type sequence. This is joint work with my supervisor, Dr. Nabil Shalaby.

Daniela Silvesan, Nabil Shalaby

Memorial University of Newfoundland
danielas@mun.ca, nshalaby@mun.ca

MS33**Combinatorics of Splice Graphs**

Splice graphs compactly represent the possible isoforms of a gene which undergoes multiple splicing. I will talk about the combinatorics of splice graphs and how this relates to the problem of inferring them from RNA-Seq data.

Dustin Cartwright

Yale University
dustin.cartwright@yale.edu

MS33**Bayesian Centroid Estimation for Genome-Wide Association Studies**

Genome-Wide Association Studies (GWAS) attempt to identify a (possibly small) subset of single nucleotide poly-

morphisms (SNPs) from a large number of measured candidates that are associated with a specific observable trait. Identification of associated genetic variants is particularly hard due to very large genotype sizes in comparison to case-control group sizes. We formally frame this problem as Bayesian variable selection in a logistic regression model with spike-and-slab priors in the coefficients. To help overcome the curse of dimensionality, we set a hierarchical model that groups SNPs according to gene proximity and further explore a co-dependency structure between SNPs and genes by adopting an Ising hyper-prior on the space of possible SNP associations to trait. We introduce and derive centroid and graph centroid estimators and contrast them to the classical MAP estimators in this setup. We illustrate this approach with a toy example and a larger simulated dataset based on HapMap. Finally, we offer a few concluding remarks and directions for future work.

Luis Carvalho

Dept. of Mathematics and Statistics
Boston University
lecarval@math.bu.edu

MS33**Encoding Memories in Neuronal Networks**

Various mechanisms for encoding memories in networks of neurons have been studied in the past few decades, most notably since Hopfield's famous papers in the early 1980s. Given a prescribed list of memory patterns, however, it is still an unsolved problem how to arrange connections between neurons in a recurrent network such that these - and only these - memories are encoded via stable fixed points of the dynamics. I will discuss some recent progress on this problem, which exploits connections to discrete geometry.

Carina Curto

Department of Mathematics
University of Nebraska-Lincoln
ccurto2@math.unl.edu

MS33**Assembling Helices in RNA Junctions by Using 3D Graphs**

The structure of RNA junctions is important to understand its function. A novel 3D tree graph approach is introduced to predict the geometrical helical arrangements of junctions in space. Tree graphs are implemented to represent junctions, and biological assumptions combined with graph combinatorics are used to study the geometrical/topological configurations of native-like junctions. For a given target junction, statistical analysis is then used to predict the tree graph that best resemble its RNA native structure.

Christian Laing

Departments of Biology, Mathematics and Computer Science
Wilkes University
christian.laing@wilkes.edu

MS33**Asymptotic Distribution of Substructures in a Stochastic Context-free Grammar Model of RNA Folding**

Some recent methods for predicting RNA secondary structures are based on stochastic context-free grammars

(SCFGs). We analyze one of the most notable SCFGs which is used in the prediction program Pfold. In particular, we show that the distribution of base pairs, helices and various types of loops in RNA secondary structures generated by this SCFG is asymptotically Gaussian, for a generic choice of the grammar probabilities. Our proofs are based on singularity analysis of probability generating functions.

Svetlana Poznanovikj
School of Mathematics
Georgia Institute of Technology
svetlana@math.gatech.edu

Christine E. Heitsch
School of Mathematics
Georgia Tech
heitsch@math.gatech.edu

MS34

Improving Christofides' Algorithm for the Metric s - t Path Traveling Salesman Problem

The Metric s - t Path Traveling Salesman Problem (TSP) asks for a minimum-cost Hamiltonian path with specified start and end points in a finite metric space. Christofides' $3/2$ -approximation algorithm for the Metric TSP was shown by Hoogeveen in 1993 to be a $5/3$ -approximation for the Metric s - t Path TSP. We present a polynomial-time ϕ -approximation algorithm for the s - t Path TSP, where ϕ is the golden ratio, the first improvement upon Christofides' algorithm in general metrics.

Hyung-Chan An, Robert Kleinberg, David Shmoys
Cornell University
anhc@cs.cornell.edu, rdk@cs.cornell.edu,
shmoys@cs.cornell.edu

MS34

Electrical Flows, Laplacian Systems, and Faster Approximation of Maximum Flow in Undirected Graphs

In this talk, I'll describe a new technique for approximating the maximum flow in capacitated, undirected graphs. I'll then use this technique to develop the asymptotically fastest-known algorithm for solving this problem. Our approach is based on treating the graph as a network of resistors and solving a sequence of electrical flow problems with varying resistances on the edges. Each of these may be reduced to the solution of a system of linear equations in a Laplacian matrix, which can be solved in nearly-linear time.

Paul Christiano, Jonathan Kelner
MIT
paulfchristiano@gmail.com, kelner@mit.edu

Aleksander Madry
Microsoft Research New England
madry@mit.edu

Daniel Spielman
Yale University
spielman@cs.yale.edu

Shang-Hua Teng
USC
shanghua@usc.edu

MS34

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Prasad Raghavendra
Georgia Tech
raghavendra@cc.gatech.edu

MS34

The Entropy Rounding Method in Approximation Algorithms

Let A be a matrix and x be a fractional vector, say an LP solution to some discrete optimization problem. We give a new randomized rounding procedure for obtaining an integral vector y such that $Ay \approx Ax$, provided that A has *bounded Δ -approximate entropy*. This property means that for uniformly chosen random signs $\chi(j) \in \{\pm 1\}$ on any subset of the columns, the outcome $A\chi$ can be approximately described using at most $\frac{m}{5}$ bits in expectation (with m being the number of selected columns). To achieve this result, we modify well-known techniques from the field of *discrepancy theory*, especially we rely on *Beck's entropy method*. We demonstrate our procedure by providing an $OPT + O(\log^2 OPT)$ approximation for Bin Packing With Rejection.

Thomas Rothvoss
Massachusetts Institute of Technology
Department of Mathematics
rothvoss@math.mit.edu

MS34

Semidefinite Programming Hierarchies and the Unique Games Conjecture

We survey recent results about semidefinite programming (SDP) hierarchies in the context of the Unique Games Conjecture. This conjecture has emerged as a unifying approach towards settling many central open problems in the theory of approximation algorithms. It posits the hardness of a certain constraint satisfaction problem. We show both upper and lower bounds on the complexity of this problem within restricted computational models defined by SDP hierarchies.

David Steurer
Microsoft Research New England, USA
dsteur@cs.princeton.edu

MS35

Some Problems and Results on the On-line Chain Partitioning of Posets

On-line chain partitioning of posets has been a widely researched topic since Kierstead's seminal paper on the subject in 1981. In this talk we describe a generalization of Kierstead's auxiliary order, and we prove many powerful properties, in hopes of providing a linear algorithm for the chain partitioning problem.

Csaba Biro
University of Louisville
csaba.biro@louisville.edu

Linyuan Lu
University of South Carolina
lu@math.sc.edu

MS35**News About Semiantichains and Unichain Coverings**

Saks and West ask if for any product of posets the size of the minimum unichain covering equals of the size of a maximum semiantichain, which would be a nice generalization of Greene–Kleitman Theorem. We found several new classes of posets for which the conjecture is true. However, we found an example showing that in general this min-max relation is false. This finally disproofs 30 year old conjecture.

Bartłomiej E. Bosek
Jagellion University, Poland
bosek@tcs.uj.edu.pl

Stefan Felsner
Technical University of Berlin
Institute for Mathematics
felsner@math.tu-berlin.de

Kolja Knauer
TU-Berlin
knauer@math.TU-Berlin.de

Grzegorz Matecki
Jagiellonian University
matecki@tcs.uj.edu.pl

MS35**An Improved Bound for First-Fit on Posets Without Two Long Incomparable Chains**

It is known that the First-Fit algorithm for partitioning a poset P into chains uses relatively few chains when P does not have two incomparable chains each of size k . In particular, if P has width w then Bosek, Krawczyk, and Szczyrpka (*SIAM J. Discrete Math.*, 23(4):1992–1999, 2010) proved an upper bound of ckw^2 on the number of chains used by First-Fit for some constant c , while Joret and Milans (*Order*, 28(3):455–464, 2011) gave one of ck^2w . We prove an upper bound of the form ckw , which is best possible up to the value of c .

Vida Dujmovic
Carleton University
vida@cs.mcgill.ca

Gwenaël Joret
Universite Libre de Bruxelles
gjoret@ulb.ac.be

David R. Wood
University of Melbourne
woodd@unimelb.edu.au

MS35**First-Fit Coloring of Interval Graphs**

Let $FF(k)$ be the maximum number of colors to be used when we adopt the First-Fit algorithm to color an interval graph with maximum clique size k . We will discuss the estimate of $FF(k)$ in this talk. Especially, we show that $4k - 5 \leq FF(k) \leq 8k - 11$ when $k > 1$, improving a little bit the current known best record. The upper bound is obtained basically by the column construction method

invented by Pemmaraju, Raman, Varadarajan et al.

Peng Li
Shanghai Jiao Tong University
lidetiansjtu@sjtu.edu.cn

Yaokun Wu
Shanghai Chiao Tong Univ.,
Shanghai, China
ykwu@sjtu.edu.cn

Yaokun Wu
Shanghai Jiao Tong University
Shanghai, China
ykwu@sjtu.edu.cn

MS35**Semiororders and Ascent Sequences**

We analyze the recent bijection of Bousquet-Mélou, Claesson, Dukes and Kitaev between interval orders and ascent sequences restricted the the case of semiororders, resulting in a new structural result on the canonical representation of semiororders.

Stephen J. Young, Jeff Remmel
University of California, San Diego
s7young@math.ucsd.edu, jremmel@ucsd.edu

MS36**Algorithms and Existential Polytime?**

An EP theorem asserts the existence of something for which any instance is ‘easy’ to recognize. Often an EP theorem can be proved by a polytime algorithm for finding an instance of what is asserted to exist. We discuss favorite open problems about the following two EP theorems: (1) If there is a Hamiltonian cycle H containing edge e in graph G such that G minus the edges of H is connected, then there is another one H' , different from H . (2) If a surface triangulation S contains a set T of triangles which partition the vertices of S , then S contains another such set T' , different from T .

Jack Edmonds
Kitchener
jedmonds@math.uwaterloo.ca

MS36**Some Graph Theory Problems I Would Like to See Solved**

I will describe a number of open graph theory problems which arise primarily out of questions in Ramsey theory.

Ron Graham
UCSD
graham@ucsd.edu

MS36**Euler’s Rigidity Conjecture**

In 1766, Euler conjectured that every polyhedron was rigid. Connelly finally disproved the conjecture in 1977. The investigations of the conjecture and rigidity in general included many other interesting conjectures; perhaps the

most interesting has yet to be formulated.

Jack Graver

Mathematics Department
Syracuse University
jegraver@mailbox.syr.edu

MS36

Ringel and Kotzig after Fifty Years

Next year will mark the 50th anniversary of the first truly large international graph theory conference which took place in Smolenice, Czechoslovakia. Many outstanding problems were posed there, including the celebrated Ringel's problem on decomposing the complete graph into isomorphic trees, and Kotzig's problem on perfect one-factorizations of the complete graph. We will discuss some developments related to these problems which remain still wide open today.

Alexander Rosa

Department of Mathematics
McMaster University
rosa@mcmaster.ca

MS37

Cops and Robbers on Geometric Graphs

In the game of cops and robbers, one robber is pursued by a set of cops on a graph G . In each round, these agents move between vertices along the edges of the graph. The cop number $c(G)$ denotes the minimum number of cops required to catch the robber in finite time. We study the cop number of geometric graphs. For points $x_1, x_2, \dots, x_n \in R^2$, and $r \in R^+$, the geometric graphs $G(x_1, \dots, x_n; r)$ is the graph on these n points, with x_i, x_j adjacent when $\|x_i - x_j\| \leq r$. We prove that $c(G) \leq 9$ for any connected geometric graph $G \in R^2$. We improve on this bound for random geometric graphs that are sufficiently dense. Let $G(n, r)$ denote the probability space of geometric graphs with n vertices chosen uniformly and independently from $[0, 1]^2$. For $G \in G(n, r)$, we show that with high probability (whp), if $nr^4 \gg \log n$ then $c(G) \leq 2$ and if $nr^4 \gg \log n$ then $c(G) = 1$. Finally, we provide a lower bound near the connectivity regime of $G(n, r)$: if $nr^2 \ll \log^2 n$ then $c(G) > 1$ whp.

Andrew J. Beveridge

Department of Mathematics, Statistics and Computer Science
Macalester College
abeverid@macalester.edu

Andrzej Dudek

Department of Mathematics
Western Michigan University
andrzej.dudek@wmich.edu

Alan Frieze

Department of Mathematical Sciences
Carnegie Mellon University
alan@random.math.cmu.edu

Tobias Mueller

Centrum voor Wiskunde en Informatica
tobias@cwi.nl

MS37

Seepage in Directed Acyclic Graphs

Seepage is a vertex-pursuit game played on directed acyclic graphs (or dags), introduced by Nowakowski et al. We consider applications of Seepage to the modelling of hierarchical social networks. A stochastic model is introduced which generates dags with a prescribed degree sequence. We play a variant of Seepage on the model, and contrast results on the green number in the case of a constant versus a power law degree sequence.

Anthony Bonato

Ryerson University
abonato@ryerson.ca

MS37

Ambush Cops and Robbers

A variation of the game with two robbers is introduced. The cops win by moving onto the same vertex as *one* of the robbers after a finite number of moves. The robbers win by avoiding capture indefinitely or by both moving onto the same vertex as the cop. (Otherwise, the robbers are on distinct vertices.) We present a recognition theorem (and cop strategy) for graphs on which one cop can guarantee a win. (Joint work with M. Creighton)

Nancy E. Clarke

Acadia University
nancy.clarke@acadiau.ca

MS37

Cops and Scared Robber

In a traditional game of Cops and Robber, the cops and robber move alternately on a graph, where each player can elect to move to an adjacent vertex or remain at his current position. In this case, the Scared Robber has the restriction that he can not move closer to any cop. The motivation for adding this restriction is to gain insight into the robber's strategy in the traditional game, and determine when moving toward a cop would actually be to the robber's advantage.

Shannon L. Fitzpatrick

University of Prince Edward Island
sfitzpatrick@upeil.ca

Stephen Finbow

Math, Stats, and CS
St. Francis Xaxier University
sfinbow@stfx.ca

MS37

Chasing Cops on Random Graphs

In the game of cops and robber, the cops try to capture a robber moving on the vertices of the graph. The minimum number of cops required to win on a given graph G is called the cop number of G . The biggest open conjecture in this area is the one of Meyniel, which asserts that for some absolute constant C , the cop number of every connected graph G is at most $C\sqrt{|V(G)|}$. We show that Meyniel's conjecture holds asymptotically almost surely for a random d -regular graph, $d \geq 3$, as well as in the standard random graph model $G(n, p)$. (Joint work with Nick Wormald.) We also investigate the game played on a (percolated) random

geometric graph. (Joint work with Noga Alon.)

Pawel Pralat
Ryerson University
pralat@ryerson.ca

Nick Wormald
Department of Combinatorics and Optimization
University of Waterloo, Waterloo
nickwor@math.uwaterloo.ca

Noga Alon
Schools of Mathematics and Computer Science
Tel Aviv University
nogaa@post.tau.ac.il

MS38 An Analogue of the Harer-Zagier Formula for General Surfaces

We consider the different ways of gluing the edges of a $2n$ -gon in pairs so as to create a surface without boundary. Up to homeomorphism, the surface obtained is characterized by its genus and by its orientability. The Harer-Zagier formula characterizes the generating function of the genus of the orientable surfaces obtained from the gluings of the $2n$ -gon. In this work we give an analogue of the Harer-Zagier for general (locally orientable) surfaces. The proof is bijective.

Olivier Bernardi
MIT
bernardi@math.mit.edu

MS38 Rooted $K_{2,4}$ Minors in Planar Graphs

Given 3 terminal vertices in a graph G , Robertson and Seymour characterized whether we could find a rooted $K_{2,3}$ minor in G using the terminals for the larger side of the bipartition. We provide a characterization for when G has 4 terminals and is planar.

Lino Demasi
Simon Fraser University
lmd14@sfu.ca

MS38 Coloring Graphs on Surfaces

We will review new progress on coloring and list-coloring embedded graphs. This talk is based on works with Ken-ichi Kawarabayashi, Bernard Lidicky, Bojan Mohar, Luke Postle and Robin Thomas.

Zdenek Dvorak
Department of Applied Mathematics
Charles University, Prague
rakdver@kam.mff.cuni.cz

MS38 Clique Immersion in Digraphs

Immersion is a containment relation between graphs (or digraphs) which is defined similarly to the more familiar notion of minors, but is incomparable to it. This talk will begin with a gentle introduction, and eventually show that every Eulerian digraph with minimum degree at least

$t(t-1)$ contains a bidirected clique of order t as an immersion. Joint work with Matt DeVos, Bojan Mohar and Diego Scheide.

Jessica McDonald
Simon Fraser University
jessica_mcdonald@sfu.ca

MS38 Hamiltonicity of Graphs on Surfaces

In 1956, Tutte proved that every 4-connected plane graph has a hamiltonian cycle. Beginning with the result by Tutte, many results on the hamiltonicity of graphs on surfaces were shown. However, the following conjecture by Grünbaum and Nash-Williams has been unsolved for more than 40 years; every 4-connected graph on the torus has a hamiltonian cycle. In this talk, we will mention recent results around the conjecture by Grünbaum and Nash-Williams.

Ken-ichi Kawarabayashi, Kenta Ozeki
National Institute of Informatics, Japan
k_keniti@nii.ac.jp, ozeki@nii.ac.jp

MS39 Distinguishing Numbers and Regular Orbits

For a group G acting on a set X , the *distinguishing number* is the least number of parts in a partition of X which is preserved only by the identity element of G . Various results about distinguishing numbers can be expressed in terms of orbits of G on the power set of X . We survey some known results from the group theory literature, and consider some problems of a combinatorial nature.

Robert Bailey
University of Regina
robert.bailey@uregina.ca

MS39 On the Orders of Symmetric Graphs

In this talk I will describe some recent developments concerning finite symmetric (arc-transitive) graphs. The first is the computer-assisted determination of all cubic (3-valent) symmetric graphs on up to 10000 vertices, which produced some new large graphs with given degree and diameter. The second is a new approach for classifying all connected symmetric cubic graphs of given orders, showing for example that for any fixed k and any integer $s > 1$, there are only finitely many s -arc-transitive cubic graphs of order kp where p is prime. In turn, these results have led to some further new discoveries about the orders of symmetric graphs of higher valency (in some recent joint work with Caiheng Li and Primož Potocnik).

Marston Conder
University of Auckland, New Zealand
m.conder@auckland.ac.nz

MS39 A Catalog of Self-Dual Plane Graphs with Max Degree 4

In this paper, we produce a catalog of self-dual plane graphs with maximum degree 4 (self-dual spherical grids). Based on their automorphism groups, self-dual spherical

grids fall into a finite number of parameterized, infinite families. The individual self-dual spherical grids in a family have the same basic shape, differing only in size.

Elizabeth Hartung
Massachusetts College of Liberal Arts
e.hartung@mcla.edu

Jack Graver
Mathematics Department
Syracuse University
jegraver@mailbox.syr.edu

MS39

Hamiltonian Cycles in Cayley Graphs

I will provide an overview of general results on hamiltonian cycles in Cayley graphs, focusing on some recent work that deals with graphs whose order has few prime factors. Some of this is based on work produced jointly in various combinations with Steve Curran, Klavdija Kutnar, Dragan Marušič, Dave Witte Morris, and Primož Šparl.

Joy Morris
Mathematics and Computer Science
University of Lethbridge
joy@cs.uleth.ca

MS40

Title Not Available at Time of Publication

Abstract not available at time of publication.

Joel S. Bader
Johns Hopkins University
Department of Biomedical Engineering
joel.bader@jhu.edu

MS40

Network Archaeology: Uncovering Ancient Networks from Present-Day Interactions

Abstract not available at time of publication.

Carl Kingsford
Department of Computer Science
University of Maryland, College Park
carlk@cs.umd.edu

MS40

Understanding Phenome-genome Association by Co-clustering and Graph Matching

Graph algorithms are playing an increasingly important role in studying phenotype-gene relations in the context of systems biology and phenome (the whole collection of phenotypes) analysis. I will introduce two methods that utilize network information in phenome network and gene-relation network to study phenome-genome associations, a random-walk based graph-matching algorithm (Bi-RW) for unveiling associations between phenome and genes, and a regularized NMF algorithm (R-NMTF) to co-cluster phenotypes and genes, and detect associations between phenotype clusters and gene clusters.

Rui Kuang
Dept Computer Science
University of Minnesota

kuang@cs.umn.edu

MS40

Sensitive Graph-theoretic Approaches for Extracting Function from Biological Networks

Sequence-based computational approaches have revolutionized our understanding of biology. Since proteins aggregate to perform function instead of acting in isolation, the connectivity of a protein interaction network (PIN) will deepen biological insights over and above sequences of individual proteins. The advancement relies on developing sensitive graph-theoretic methods for extracting biological knowledge from PINs. Analogous to sequence alignment, alignment of PINs will impact biological understanding. Network alignment maps nodes of different networks with the goal of "fitting" one network into the other well to identify topologically similar network regions and transfer function between them. Since network alignment is computationally infeasible, owing to the NP-completeness of the underlying subgraph isomorphism problem, heuristic algorithms are sought. We designed a sensitive measure of the topological position of a node in the network, graphlet degree vector (GDV), to measure the number of 2-5-node graphlets (induced subgraphs) that the node participates in. Hence, GDV of a node is a detailed topological descriptor of its extended network neighborhood. Our GDV-similarity measure compares GDVs of two nodes to quantify similarity of their extended networks neighborhoods. Using these measures, we developed two network alignment algorithms: a greedy "seed and extend" approach that quickly finds approximate alignments and an approach that finds optimal alignments by using the "expensive" Hungarian algorithm. Their alignments expose surprisingly large regions of network and functional similarity even in distant species, suggesting broad similarities in cellular wiring across all life on Earth. Also, we used these measures to show that aging, cancer, pathogen-interacting, drug-target and genes involved in signaling pathways are "central" in the network, occupying dense network regions and "dominating" other genes in the network.

Tijana Milenkovic
Department of Computer Science and Engineering
University of Notre Dame
tmilenko@nd.edu

MS40

Biological Networks in Three Dimensions

Two studies are highlighted where three-dimensional modeling of protein networks provides insights into the biophysics and evolution of biological systems. First, a structural analysis of the yeast protein-protein interaction network reveals that protein evolution is constrained by the biophysics of protein folding, the mutational robustness of proteins, and the biophysics and function of protein-protein interactions. Second, a structural analysis of human-virus protein-protein interaction networks reveals distinct principles governing antagonism versus cooperation in host-pathogen interactions.

Yu (Brandon) Xia
Bioinformatics Program & Dept. of Chemistry
Boston University
yuxia@bu.edu

MS41

Advances on Quantifier Elimination and Applications

In this talk, we present a new approach for computing cylindrical algebraic decomposition of real space via triangular decomposition of polynomial systems. Based on it, a general quantifier elimination method is proposed. The usage of our method is illustrated by several application examples.

Changbo Chen
University of Western Ontario
changbo.chen@gmail.com

Marc Moreno Maza
Computer Science Department
University of Western Ontario
moreno@csd.uwo.ca

MS41

Automatic Quantifier Elimination Proves a Key Result in Submodular Function Minimization

We show how symbolic computation can automatically prove an important and well-known result in combinatorial optimization. Specifically, we address the question “Which objective functions can be minimized by reduction to s - t min cut?” This question has been answered by a number of highly-cited papers in discrete mathematics and computer vision. By posing this same question to a computer algebra system, we automatically identify *submodularity* as being the key condition for reduction to s - t min cut.

Andrew Delong
The University of Western Ontario, Canada
andrew.delong@gmail.com

MS41

On Newton Polytopes, Tropisms, and Puiseux Series to Solve Polynomial systems

Sparse polynomial systems in several variables are characterized by a set of exponents of monomials that appear with nonzero coefficient. The convex hull of this set of exponents is the Newton polytope. To a system of sparse polynomial equations corresponds a tuple of Newton polytopes. Vectors perpendicular to a tuple of edges of all polytopes are tropisms when they define the leading powers of a Puiseux series development for a solution of the polynomial system. In this talk we outline a polyhedral approach to solve polynomial systems by means of Puiseux series. On standard benchmark problems as the cyclic n -roots systems we obtained exact representations for surfaces of solutions.

Jan Verschelde, Danko Adrovic
Department of Mathematics, Statistics and Computer Science
University of Illinois at Chicago
jan@math.uic.edu, adrovic@math.uic.edu

MS41

Algebraic Representations of Branches of Functions

Apparently-simple function definitions may hide subtleties from branch cuts in the complex plane. Hence formulae that initially seem correct may fail for various values. One

remedy is to consider the complement of the branch cuts, decomposing this space by Cylindrical Algebraic Decomposition and checking validity on each connected component. This process will be discussed and how it is possible to improve this algorithm’s efficiency with pre-conditioning and choice of variable order.

David J. Wilson, Russell Bradford, James Davenport
University of Bath
D.J.Wilson@bath.ac.uk, r.j.bradford@bath.ac.uk,
j.h.davenport@bath.ac.uk

MS41

A Solver for Linear Algebraic Systems Resulting from Selecting Discrete Structures

A computer algebra program LSSS (Linear Selective Systems Solver) has been developed to solve linear systems efficiently that are sparse, overdetermined and have many variables that take the value zero in the solution. Applications include the determination of first integrals and Lie-symmetries of systems of non-commutative ODEs requiring the solution of linear systems with over one billion equations, the computation of Poisson homologies and co-homologies of Poisson algebras and the study of compatible Poisson structures.

Thomas Wolf
Department of Mathematics
Brock University
twolf@brocku.ca

MS42

A De Bruijn - Erdős Theorem in Connected Graphs?

De Bruijn and Erdős proved that every noncollinear set of n points in the plane determines at least n distinct lines. Chen and Chvátal suggested that this might generalize to all finite metric spaces with appropriately defined lines. As for metric spaces defined by connected graphs, the analogue of the De Bruijn - Erdős theorem is known to hold for all bipartite graphs, all chordal graphs, and all graphs of diameter two.

Vasek Chvatal
Concordia University
chvatal@encs.concordia.ca

MS42

Matthews Sumner Conjecture on Claw-Free Graphs

The Matthews Sumner Conjecture is that every 4-connected claw-free graph is Hamiltonian. There are a large number of conjectures, some seemingly weaker and some seemingly stronger, that are equivalent to this conjecture that will be discussed. For example, the Carsten Thomassen Conjecture that every 4-connected line graph is Hamiltonian is an equivalent conjecture.

Ralph Faudree
University of Memphis
Department of Math Sciences
rfaudree@memphis.edu

MS42**How to Recognize a Good Conjecture**

The speaker will present some challenges in dealing with open problems and conjectures. He may discuss some specific graph theory conjectures and demonstrate some rationale behind the Open Problem Garden.

Bojan Mohar
Simon Fraser University
mohar@sfu.ca

MS42**Some of my favorite Conjectures**

We will present and briefly discuss some open questions in two areas: (1) *Cyclic* Coloration of plane graphs and (2) Well-covered graphs.

Michael D. Plummer
Department of Mathematics
Vanderbilt University
michael.d.plummer@vanderbilt.edu

MS42**The Implicit Representation of Graphs Conjecture**

A class of graphs \mathcal{P} is called a *hereditary property* if it is closed under taking induced subgraphs and isomorphism. Common examples include being acyclic, being planar, and being bipartite. Given a hereditary property \mathcal{P} , we seek a method of labeling the vertices of graphs in \mathcal{P} with short labels [that is, $O(\log n)$ bits for each vertex] such that we can determine adjacency of two vertices just by considering their labels. Formally, a property \mathcal{P} admits an *implicit representation* provided there is a function $A : \mathbf{Z}^+ \times \mathbf{Z}^+ \rightarrow \{0, 1\}$ and a positive integer k such that for every $G \in \mathcal{P}$ with there is a mapping $\ell : V(G) \rightarrow [n^k]$ (where $n = |V(G)|$) such that $u \sim v$ if and only if $A(\ell(u), \ell(v)) = 1$. It is easy to create such a labeling for acyclic graphs: Pick a root vertex in each component, number the vertices from 1 to n , and label vertex v as (v, w) where w is the unique neighbor of v on a path from v to the root (or use the label (v, v) if v is the root). However, bipartite graphs admit no such representation simply because there are too many. That is, for a property \mathcal{P} , the *speed* of \mathcal{P} is a function that gives for each n the number of labeled graphs in \mathcal{P} with $V = [n]$. If a property has an implicit representation, then necessarily its speed is bounded by an expression of the form n^{cn} for a positive constant c . The *Implicit Representation Conjecture* of Kannan, Naor, and Rudich posits that this necessary condition is also sufficient.

Ed Scheinerman
Johns Hopkins University
ers@jhu.edu

MS43**Ramsey Classes Defined by Forbidden Homomorphisms**

I will talk about Ramsey properties of classes of digraphs (or more generally, relational structures) defined by forbidding homomorphisms from a fixed set of digraphs. Cases with infinitely many forbidden structures are of particular interest. These classes have several interesting applica-

tions.

Jan Foniok
Queen's University
foniok@mast.queensu.ca

MS43**A Randomized Version of Ramsey's Theorem**

For every integer $r \geq 2$ we call a k -uniform hypergraph H on n vertices r -Ramsey-forcing if every r -edge-coloring of K_n contains a monochromatic copy of K_k whose vertices form a hyperedge in H . We determine the threshold for a random k -uniform hypergraph on n vertices and edge probability q to be r -Ramsey-forcing. Further we discuss common features of the above problem with the more classical Ramsey's theorem for random (hyper-)graph $G(n, p)$.

Luca Gugelmann
Institute of Theoretical Computer Science ETH Zurich
8092 Zurich, Switzerland
lgugelmann@inf.ethz.ch

Yury Person
Freie Universitat, Berlin
person@math.fu-berlin.de

Angelika Steger
Institute of Theoretical Computer Science
ETH, Zürich
steger@inf.ethz.ch

Henning Thomas
Institute of Theoretical Computer Science ETH Zurich
8092 Zurich, Switzerland
hthomas@inf.ethz.ch

MS43**General Deletion Lemmas via the Harris Inequality**

For a given graph H let X_H denote the random variable that counts the number of copies of H in a random graph $G_{n,p}$. In order to control the upper tail of X_H , Rödl and Ruciński showed that with 'Janson-like' probability, deleting a small fraction of all edges suffices to reduce the number of copies of H to at most $(1+\varepsilon)E[X_H]$. This approach is known as the 'deletion method' and appears in many proofs of Ramsey properties of random structures. In this talk I will present a variant of the deletion method that is based on the Harris inequality and extends to more general graph properties.

Reto Spöhel
Max-Planck-Institut für Informatik
Saarbrücken
rspoehel@mpi-inf.mpg.de

Angelika Steger
Institute of Theoretical Computer Science
ETH, Zürich
steger@inf.ethz.ch

Lutz Warnke
University of Oxford
lutz.warnke@merton.ox.ac.uk

MS43**On Ramsey Multiplicities of Graphs Containing Triangles**

A graph G is k -common ($k > 1$) if the minimum number of monochromatic copies of G over all k edge colorings of K_n is asymptotic to the expected number of monochromatic copies of G in a random k edge coloring. Jagger, Šťovíček and Thomason defined the class of k -common graphs, and showed among other results that every graph containing K_4 as a subgraph is not 2-common. We prove that every graph containing K_3 as a subgraph is not 3-common.

Michael Young
Iowa State University
myoung@iastate.edu

James Cummings
Carnegie Mellon University
jcumming@andrew.cmu.edu

MS44**Multidimensional Algorithmic Mechanism Design**

In his seminal paper, Myerson [1981] provides a revenue-optimal auction for a seller who is looking to sell a single item to multiple bidders. Extending this auction to simultaneously selling multiple heterogeneous items has been one of the central problems in Mathematical Economics. We provide such an extension that is also computationally efficient.

Costis Daskalakis
Massachusetts Institute of Technology
costis@csail.mit.edu

MS44**Combinatorial Walrasian Equilibria**

One way to resolve a combinatorial auction is via Walrasian equilibrium: setting a price for each item so that, when bidders take their most demanded sets, each object is chosen by exactly one bidder. Such equilibria have desirable properties, but they exist only in special cases. In this work we introduce the alternative notion of combinatorial Walrasian equilibrium, in which one first partitions the objects into indivisible bundles and then sets a price for each bundle. We design mechanisms that generate combinatorial Walrasian equilibria for various classes of bidder valuations, with the goal of maximizing social welfare. Our study also touches upon revenue and truthfulness in such mechanisms.

Brendan Lucier
Microsoft Research New England
brlucier@microsoft.com

Michal Feldman
Hebrew University of Jerusalem
mfeldman@huji.ac.il

MS44**Knightian Auctions**

In an auction, a player may not exactly know his own valuation, or its distribution. We thus study single-good auctions whose players know their own valuations only within a multiplicative factor (e.g., 10%). The notions of im-

plementation in dominant and undominated strategies are naturally extended to this setting, but their power is vastly different. Namely, (1) We prove that no dominant-strategy mechanism can guarantee more social welfare than by assigning the good at random; but (2) We prove a much better performance can be obtained via undominated-strategy mechanisms, and actually provide tight upper and lower bounds for the fraction of the maximum social welfare guaranteeable by such mechanisms, whether deterministic or probabilistic.

Silvio Micali
Massachusetts Institute of Technology
silvio@csail.mit.edu

Alessandro Chiesa, Zeyuan Zhu
MIT
alexch@csail.mit.edu, zeyuan@csail.mit.edu

MS44**Online Procurement**

We present results for online procurement markets. We introduce mechanisms with desirable approximation guarantees in various models of online procurement. We also present new models of strategic bidding in such markets, and discuss new mechanism design frameworks for these bidding models.

Yaron Singer
University of California at Berkeley
yaron@cs.berkeley.edu

MS44**Bayesian Multi-Parameter Scheduling**

We study the makespan minimization problem with unrelated selfish machines. Specifically, our goal is to schedule a given set of jobs on m machines; the machines are strategic agents who hold the private information of the run-time of each job on them. The goal is to design a mechanism that minimizes makespan — the time taken for the last job to complete. In the strategic setting, strong impossibility results are known that show that no truthful (anonymous) mechanism can achieve better than a factor m approximation. We show that under mild Bayesian assumptions it is possible to circumvent such negative results and obtain a constant approximation.

Balasubramanian Sivan
University of Wisconsin-Madison
balu2901@cs.wisc.edu

Shuchi Chawla
Department of Computer Sciences
University of Wisconsin-Madison
shuchi@cs.wisc.edu

Jason Hartline
Northwestern U
hartline@eecs.northwestern.edu

David Malec
University of Wisconsin-Madison
dmalec@cs.wisc.edu

MS45**Graph Homomorphism Counts Mod M**

I will talk about the numbers $\text{hom}(F, G) \pmod m$ as the graphs F and G vary.

Swastik Kopparty
Massachusetts Institute of Technology
swastik.kopparty@gmail.com

MS45**Frozen Vertices in Colourings of a Random Graph**

Over the past decade, much of the work on random k -SAT, random graph colouring, and other random constraint satisfaction problems has focussed on some foundational unproven hypotheses that have arisen from statistical physics. Some of the most important such hypotheses concern the ‘clustering’ of the solutions. It is believed that if the problem density is sufficiently high then the solutions can be partitioned into clusters that are, in some sense, both well-connected and well-separated. Furthermore, the clusters contain a linear number of ‘frozen variables’, whose values are fixed within a cluster. The density where such clusters arise corresponds to an algorithmic barrier, above which no algorithms have been proven to solve these problems. In this talk, we prove that frozen vertices do indeed arise for k -colourings of a random graph, when k is a sufficiently large constant, and we determine the exact density threshold at which they appear.

Michael Molloy
University of Toronto
molloy@cs.toronto.edu

MS45**Colorings and Homomorphisms of Sparse Graphs**

chromatic number and low tree-width / low tree-depth colorings. Dichotomy of sparsity by means of chromatic numbers. Applications to distance coloring, circular chromatic number of large girth graphs with sub-exponential expansion, etc.

Jaroslav Nešetřil
department of Applied Mathematics
Charles University
nesetřil@kam.mff.cuni.cz

Patrice Ossona de Mendez
CNRS Paris
Centre d'Analyse et de Mathématiques Sociales
pom@ehess.fr

MS45**Fast Algorithms for Sparse Graphs**

Algorithms for sparse graphs: subgraph isomorphism problem, connection with bounded local tree-width. Low Tree Depth Decomposition and first-order properties. Application to graph invariants.

Patrice Ossona de Mendez
CNRS Paris
Centre d'Analyse et de Mathématiques Sociales
pom@ehess.fr

Jaroslav Nešetřil

department of Applied Mathematics
Charles University
nesetřil@kam.mff.cuni.cz

MS45**Semilattice and NU Polymorphisms on Reflexive Graphs**

The structures H for which arc-consistency solves H -COL are exactly those that admit TSI polymorphisms. The two main sources of TSI polymorphisms are *near unanimity* (NU) and *semilattice* (SL) polymorphisms. Much has been done to understand the nature of NU polymorphisms, but SL polymorphisms are not so well understood. In this talk we describe the structure of symmetric reflexive graphs admitting various types of SL polymorphisms. Further we relate the existence of SL polymorphisms on these graphs to the existence of NU polymorphisms of various types, and to related classes of graphs. This is preliminary work in understanding SL polymorphisms, and includes joint work with Pavol Hell.

Mark Siggers
Kyungpook National University
Daegu, Republic of Korea
mhsiggers@knu.ac.kr

MS46**Near Factorisations of the Complete Graph**

A w -near k -factor of a graph G on n vertices is a spanning subgraph of G with w vertices of degree 0 and $n - w$ vertices of degree k . In this talk, we introduce the concept of a w -near k -factorization of a graph G , which is a decomposition of G into w -near k -factors. Thus, for example, a k -factorization is equivalent to a 0-near k -factorization, and a near 1-factorization is equivalent to a 1-near 1-factorization. We focus on w -near 2-factorizations of the complete graph K_n and $K_n - I$; in the case that the partial 2-factors are required to be pairwise isomorphic, this may be viewed as a generalization of the Oberwolfach problem. We discuss some constructions of w -near 2-factorizations in which all cycles in the near-factors have the same length.

Peter Danziger, Andrea Burgess
Ryerson University
danziger@ryerson.ca, andrea.burgess@ryerson.ca

MS46**Bounds for Covering Arrays with Row Limit**

Covering arrays with row limit (*CARLs*) are a generalization of covering arrays. They have a new parameter **row weight**, w , representing the number of non-empty cells in a row. Considering w as a function of the number of columns, k , there are two extremal cases: when w is a constant, *CARLs* are equivalent to group divisible covering designs and we know their optimal size; when $w = k$, *CARLs* are covering arrays, and their optimal size is still unknown in most cases. We present two probabilistic models to determine the upper bounds on the size of a *CARL* when $w = f(k)$ and we look into critical points where the change in the behaviour occurs.

Nevena Francetic
University of Toronto
nevena.francetic@utoronto.ca

Peter Danziger
Ryerson University
danziger@ryerson.ca

Eric Mendelsohn
University of Toronto
Department of Mathematics
mendelso@math.utoronto.ca

MS46

A new construction of strength-3 covering arrays using primitive polynomials over finite fields

In this talk, we present a new construction of covering arrays based on Linear Feedback Shift Register (LFSR) sequences constructed using primitive polynomials over finite fields. For any prime power q , this construction gives a covering array of strength 3 with $q^2 + q + 1$ factors/columns over q levels/symbols that has size $2q^3 - 1$ (number of rows). The construction can be extended to non-prime powers v by dropping levels from a larger prime power. This results in significant reductions on known upper bounds for covering array sizes in most cases covered by this construction. In particular, for the values of $v \leq 25$ kept in Colbourn's covering array tables, this construction improves upper bounds for all $v \neq 2, 3, 6$.

Lucia Moura
University of Ottawa
Information Technology
lucia@site.uottawa.ca

Sebastian Raaphorst
University of Ottawa
mraap046@site.uottawa.ca

Brett C. Stevens
Carleton University
School of Mathematics and Statistics
brett@math.carleton.ca

MS46

New Areas in Covering Arrays

In recent years, with Gary Bazdell, I have had increased communication and collaboration with industrial users of combinatorial designs, predominantly covering arrays. Coming out of their needs and interests, Gary and I have been motivated to think about new generalisations of covering arrays, specifically ones that introduce order to the rows and columns. I will discuss these definitions, the mathematics and their connections to applications.

Brett C. Stevens
Carleton University
School of Mathematics and Statistics
brett@math.carleton.ca

MS46

Nonincident Points and Blocks in Designs

We study the problem of finding the largest possible set of s points and s blocks in a balanced incomplete block design, such that that none of the s points lie on any of the s blocks. We investigate this problem for two types of BIBDs: projective planes and Steiner triple systems. For a projective plane of order q , we prove that $s \leq 1 + (q + 1)(\sqrt{q} - 1)$ and we also show that equality can be

attained in this bound whenever q is an even power of two. For a Steiner triple system on v points, we prove that $s \leq (2v + 5 - \sqrt{24v + 25})/2$ and we determine necessary and sufficient conditions for equality to be attained in this bound.

Douglas R. Stinson
University of Waterloo
David R. Cheriton School of Computer Science
dstinson@uwaterloo.ca

MS47

Optimality of the Neighbor Joining Algorithm and Faces of the Balanced Minimum Evolution Polytope

Balanced minimum evolution (BME) is a statistically consistent distance-based method to reconstruct a phylogenetic tree from an alignment of molecular data. In 2000, Pauplin showed that the BME method is equivalent to optimizing a linear functional over the BME polytope, the convex hull of the BME vectors obtained from Pauplin's formula applied to all binary trees. The BME method is related to the popular Neighbor Joining (NJ) algorithm, now known to be a greedy optimization of the BME principle. In this talk I will elucidate some of the structure of the BME polytope and strengthen the connection between the BME method and NJ Algorithm. I will show that any subtree-prune-regraft move from a binary tree to another binary tree corresponds to an edge of the BME polytope. Moreover, I will describe an entire family of faces parametrized by disjoint clades. Finally, given a phylogenetic tree T , I will show that the BME cone and every NJ cone of T have intersection of positive measure.

David Haws
University of Kentucky
dchaws@gmail.com

Terrell Hodge
Western Michigan University
terrell.hodge@wmich.edu

Ruriko Yoshida
University of Kentucky
ruriko.yoshida@uky.edu

MS47

Finding the Max Cut of the Genetic Interactions Graph in Yeast Finds Compensatory Pathways.

By using a randomized local search method to find the max cut in the graph of genetic interactions in yeast we generate potential compensatory networks. Unlike other methods, this method works solely on genetic interaction data from epistatic miniarray profiles (E-MAP) and synthetic genetic array analysis (SGA), this enables us to use physical interactions as an additional validation source. We finish with some open questions regarding the behavior of our technique on different graphs and weights.

Benjamin Hescott
Tufts University
hescott@cs.tufts.edu

Mark Leiserson
Brown University
mdml@cs.brown.edu

Andrew Gallant, Diana Tatar
Tufts University
jamslam@gmail.com, dtatar01@cs.tufts.edu

Lenore Cowen
Dept. of Computer Science
Tufts University
cowen@cs.tufts.edu

MS47
Statistics and Applications of Tree Space

The space of metric n -trees is a polyhedral complex, in which each polyhedron corresponds to a different tree topology. Under the construction of Billera, Holmes, and Vogtmann, this space is non-positively curved, so there is a unique geodesic (shortest path) between any two trees. We will look at what it means to do statistics on this space, as well as some biological applications.

Megan Owen
Fields Institute
mowen@fields.utoronto.ca

MS47
Comparing Biological and Mathematical Approaches to Modeling Tissue Development in *C. elegans*

Gene networks are often inferred from experimental data using single-method approaches; however, an individual method may not sufficiently recover the network. We developed a modeling pipeline that combines statistical and algebraic methods. We built a mathematical model of tissue development from wildtype *C. elegans* data. We compared it to an existing biological model on a gold-standard network. While both models identified many interactions, the mathematical model was enriched for positive predictions compared to biological model.

Brandilyn Stigler
Southern Methodist University
bstigler@smu.edu

MS47
Profiling RNA Secondary Structures

Efficient methods for sampling from the Boltzmann distribution have led to an emergence of ensemble-based approaches to RNA secondary structure prediction. We present a novel combinatorial method, RNA structure profiling, for identifying patterns in structural elements across a Boltzmann sample. Our approach is based on classifying structures according to features chosen from well-defined structural units called helix classes. We show that combinatorial profiling is straightforward, stable and surprisingly comprehensive.

Emily Rogers, M. Shel Swenson
School of Mathematics
Georgia Institute of Technology
erogers8@mail.gatech.edu, mswenson@math.gatech.edu

Christine E. Heitsch
School of Mathematics
Georgia Tech
heitsch@math.gatech.edu

MS48
New Results on D-Optimal Matrices

D-optimal matrices are $2v \times 2v$ $(-1,+1)$ -matrices that have maximal determinant among all $2v \times 2v$ $(-1,+1)$ -matrices, where v is an odd positive integer. The value of the maximal determinant is given by Ehlich's bound. We present new theoretical and computational results on D-optimal matrices of circulant type. Such D-optimal matrices are constructed via two circulant submatrices of orders v each. In particular, we construct new D-optimal matrices of orders 206, 242, 262, 482. Joint work with D. Z. Djokovic.

Ilias S. Kotsireas
Wilfrid Laurier University
Department of Computing
ikotsire@wlu.ca

MS48
Matroid Base Polytope Decomposition and Applications

Let $P(M)$ be the matroid base polytope of a matroid M . A matroid base polytope *decomposition* of $P(M)$ is a decomposition of the form $P(M) = \bigcup_{i=1}^t P(M_i)$ where each $P(M_i)$ is also a matroid base polytope for some matroid M_i , and for each $1 \leq i \neq j \leq t$, the intersection $P(M_i) \cap P(M_j)$ is a face of both $P(M_i)$ and $P(M_j)$. In this talk, we shall present some new results on the above decomposition. We give sufficient conditions on M in order that $P(M)$ has a *hyperplane split* (that is, a decomposition with $t = 2$) and show that $P(M)$ has not a hyperplane split if M is binary. We finally discuss an application in relation with Tutte and Ehrhart polynomials.

Jorge L. Ramirez Alfonsin
Montpellier 2, France
jramirez@math.univ-montp2.fr

MS48
Generating Program Invariants via Interpolation

This talk focuses on automatically generating polynomial equations that are inductive loop invariants of computer programs. A new method which is based on polynomial interpolation is proposed. Though the proposed method is not complete, it is efficient and can be applied to a broader range of problems compared to existing methods targeting similar problems. The efficiency of our approach is testified by experiments on a large collection of programs.

Rong Xiao
University of Western Ontario
rong@csd.uwo.ca

Marc Moreno Maza
Computer Science Department
University of Western Ontario
moreno@csd.uwo.ca

MS48
Parallel Computation of the Minimal Elements of a Poset and Applications

Computing the minimal elements of a partially ordered finite set (poset) is a fundamental problem in combinatorics

with numerous applications. In a previous work, we have developed for this task a divide-and-conquer algorithm which is also cache-efficient and which can be efficiently parallelized free of determinacy races. We adapted this technique to questions arising in computer algebra (polynomial expression optimization) and combinatorics (transversal hypergraph generation). In this talk, we present new applications in both computer algebra (coprime factorization) and combinatorics (orthogonal hypergraph generation). We have implemented the corresponding algorithms in Cilk++ targeting multi-cores. For our test problems of sufficiently large input size our code demonstrates a linear speedup on 32 cores.

Yuzhen Xie

University of Western Ontario
yxie@csd.uwo.ca

Marc Moreno Maza
Computer Science Department
University of Western Ontario
moreno@csd.uwo.ca

MS49

Conjectures on Thickness, Connectivity, and Other Things

Various conjectures that I've found intriguing will be discussed. These will include a conjecture on thickness and chromatic number, a mixed-connectivity conjecture, and the total graph conjecture.

Lowell Beineke

Indiana University - Purdue University Fort Wayne
beineke@ipfw.edu

MS49

Snarks and Their Relation to Conjectures about Graphs

In this talk I will shortly discuss the role of snarks in proving or refuting conjectures and sketch an algorithm that was used to generate large lists of snarks. The results of these computations and some of the published conjectures that could be refuted by the snarks generated will be presented. This research is joint work with Jan Goedgebeur, Jonas Hägglund and Klas Markström

Gunnar Brinkmann

University of Ghent,
Belgium
gunnar.brinkmann@ugent.be

MS49

On Conjectures of Graffiti.pc

This talk will begin with a brief description of how the conjecture-making computer program, Graffiti.pc, generates graph theoretical conjectures. Then, I will talk about some of my favorite Graffiti.pc conjectures.

Ermelinda DeLaVina

University of Houston
DelavinaE@uhd.edu

MS49

Title Not Available at Time of Publication

Abstract not available at time of publication.

Fan Chung Graham

University of California, San Diego
fan@ucsd.edu

MS51

On Metric Dimension of Functigraphs

A set S of vertices in a graph G is called a *resolving set* for G if for every pair of vertices $x, y \in V(G)$, there is a vertex $s \in S$ such that $d(x, s) \neq d(y, s)$. The minimum number of vertices in a resolving set for G is the *metric dimension* $dim(G)$ of G . Given two copies G_1 and G_2 of a graph G and a function $f : V(G_1) \rightarrow V(G_2)$, the *functigraph* $C(G, f)$ is the graph with vertices $V(G_1) \cup V(G_2)$ and edges $E(G_1) \cup E(G_2) \cup \{xy | y = f(x)\}$. In this talk, we give bounds on the metric dimension of functigraphs, particularly in the cases when G is a cycle or path and when the function f is a constant function or permutation.

Linda Eroh

Department of Mathematics
University of Wisconsin at Oshkosh
eroh@uwosh.edu

Cong Kang, Eunjeong Yi

Texas A&M University at Galveston
kangc@tamug.edu, yie@tamug.edu

MS51

Closed K-Stop Distance in Graphs.

The Traveling Salesman Problem (TSP) is still one of the most researched topics in computational mathematics, and we introduce a variant of it, namely the study of the closed k -walks in graphs. We search for a shortest closed route visiting k cities in a non complete graph without weights. This motivates the following definition. Given a set of k distinct vertices $\mathcal{S} = \{v_1, v_2, \dots, v_k\}$ in a simple graph G , the k -circuit-distance of set \mathcal{S} is defined to be

$$d_k(\mathcal{S}) = \min_{\theta \in \mathcal{P}(\mathcal{S})} \left(d(\theta(x_1), \theta(x_2)) + d(\theta(x_2), \theta(x_3)) + \dots + d(\theta(x_k), \theta(x_1)) \right),$$

where $\mathcal{P}(\mathcal{S})$ is the set of all permutations from \mathcal{S} onto \mathcal{S} . That is the same as saying that $d_k(\mathcal{S})$ is the length of the shortest circuit through the vertices $\{x_1, \dots, x_k\}$. Recall that the Steiner distance $sd(\mathcal{S})$ is the number of edges in a minimum connected subgraph containing all of the vertices of \mathcal{S} . We note some relationships between Steiner distance and circuit distance. The 2-circuit distance is twice the ordinary distance between two vertices. We conjecture that $rad_k(G) \leq diam_k(G) \leq \frac{k}{k-1} rad_k(G)$ for any connected graph G for $k \geq 2$. For $k = 2$, this formula reduces to the well-known classical result $rad(G) \leq diam(G) \leq 2rad(G)$. We prove the conjecture in the cases when $k = 3$ and $k = 4$ for any graph G and for $k \geq 3$ when G is a tree.

Raluca M. Gera

Naval Postgraduate School
rgera@nps.edu

Grady Bullington, Linda Eroh, Steve Winters
University of Wisconsin Oshkosh
bullington@uwosh, eroh@uwosh, winters@uwosh

MS51**Distance in Rainbow Connected Graphs**

A path (not necessarily a shortest one) between two vertices in a connected graph is rainbow-colored if each edge of the path is labeled with a distinct color. A connected graph is rainbow-connected if the edges of the graph are assigned colors so that a rainbow-colored path exists between every pair of vertices. In this paper, I discuss the recent work on methods for determining rainbow-colored paths in a given rainbow-connected graph.

Garry L. Johns
Saginaw Valley State University
glj@svsu.edu

MS51**Using Graphs for Facility Location Problems**

The eccentricity of a vertex v in a connected graph G is the distance from v to a vertex farthest from v in G . The distance of a vertex v in a connected graph G is the sum of the distances from v to the vertices of G . In this talk, we will consider subgraphs induced by these concepts for facility location problems.

Steven J. Winters
University of Wisconsin Oshkosh
winters@uwosh.edu

MS52**Near-Unanimity Graphs and Absolute Retracts**

We describe a generating set for the variety of reflexive graphs that admit a k -ary near-unanimity operation; we further delineate a very simple subset that generates the variety of *absolute retracts* with respect to j -holes; in particular we show that every reflexive graph with a 4-NU operation is an absolute retract for 3-holes. Our results generalise and encompass several results on NU-graphs and absolute retracts from the past 30 years.

Tomas Feder
Stanford University
tomas@theory.stanford.edu

Pavol Hell
School of Computer Science
Simon Fraser University
pavol@sfu.ca

Benoit Larose
Concordia University
larose@mathstat.concordia.ca

Cynthia Loten
Fraser Valley
cynthia.loten@ufv.ca

Mark Siggers
Kyungpook National University
Daegu, Republic of Korea
mhsiggers@knu.ac.kr

Claude Tardif
Department of Mathematics and Computer Science
Royal Military College
Claude.Tardif@rmc.ca

MS52**Graph Partitions**

We consider partitions of the vertices of a graph into a fixed number of labelled cells such that (i) the subgraph induced by each cell belongs to a family that depends on the cell, and (ii) edges joining vertices in different cells are allowed only if the cells correspond to adjacent vertices in a given pattern graph H . Both polynomiality and NP-completeness results are presented.

Gary Macgillivray
Mathematics and Statistics
University of Victoria
gmacgill@math.uvic.ca

Peter Dukes
University of Victoria, Canada
dukes@math.uvic.ca

Steve Lowdon
Mathematics and Statistics
University of Victoria
slowdon@math.uvic.ca

MS52**Graph Partitions With Emphasis on $2K_2$ -Partition**

Pavol Hell will present some recent progress and some open questions on the problem of partitioning a graph, or digraph, according to a prescribed pattern of adjacencies. Both classifications by complexity and characterizations by forbidden induced subgraphs will be discussed. Then Daniel Paulusma will describe a recent solution (joint with Barnaby Martin) of the problem of complexity of the disconnected cut, or equivalently the problem of $2K_2$ -partition. Specifically, for a connected graph $G = (V, E)$, a subset U of V is called a disconnected cut if both U and V disconnect G . The problem to decide whether a graph has a disconnected cut is shown to be NP-complete. This problem is polynomially equivalent to the following problems: testing if a graph has a $2K_2$ -partition, testing if a graph allows a vertex-surjective homomorphism to the reflexive 4-cycle and testing if a graph has a spanning subgraph that consists of at most two bicliques. Hence, as an immediate consequence, these three decision problems are NP-complete as well.

Pavol Hell
School of Computer Science
Simon Fraser University
pavol@sfu.ca

Barnaby Martin, Daniel Paulusma
Durham University
barnaby.martin@durham.ac.uk,
daniel.paulusma@durham.ac.uk

MS52**Bipartite Graphs and Approximation of Minimum Cost Homomorphisms**

For a fixed target graph H , the minimum cost homomorphism problem, $\text{MinHOM}(H)$, asks, for a given graph G with integer costs $c_i(u)$, $u \in V(G)$, $i \in V(H)$, and an integer k , whether or not there exists a homomorphism of G to H of cost not exceeding k . When the target graph H is a bipartite graph, a dichotomy classification is known: $\text{MinHOM}(H)$ is solvable in polynomial time if and only

if H is a proper interval bigraph (i.e., a bipartite permutation graph). We suggest an integer linear program (ILP) formulation for $\text{MinHOM}(H)$, and by rounding the ILP solution, we obtain a 2-approximation algorithm for $\text{MinHOM}(H)$, when H is a doubly convex bipartite graph. If time permits, we explain how to modify the rounding procedure to obtain a $|V(H)|$ -approximation algorithm for $\text{MinHOM}(H)$ when the complement of the bipartite graph H is a circular arc graph.

Arash Rafiey
Simon Fraser University
arash.rafiey@ii.uib.no

MS52

Adjoint Functors in Graph Theory

Functors in graph theory are essentially constructions that make new graphs out of input graphs. Two functors L, R are respectively right and left adjoint to the other if there is a correspondence between the homomorphisms of $L(G)$ to H and the homomorphisms of G to $R(H)$. There are various places where adjoint functors arise naturally without necessarily being noticed: - Viewing lexicographic products by complete graphs as right adjoints naturally defines Kneser graphs as (cores of) left adjoints of complete graphs. - Reformulating the question of Harvey and Murty on the existence of k -chromatic graphs with strongly independent colour classes in terms of adjoint functors naturally leads to the approach taken by Gyarfas, Jensen and Stiebitz to answer it affirmatively. In the case of directed graphs and constraint satisfaction problems, the adjoint functors arise in the arc graph construction, and they preserve tree duality and many Maltsev-type operations related to complexity classifications. All of this suggests that the power and limitations of adjoint functors in graph theory should be better understood.

Claude Tardif
Department of Mathematics and Computer Science
Royal Military College
Claude.Tardif@rmc.ca

Jan Foniok
Queen's University
foniok@mast.queensu.ca

MS53

New Results and Open Problems on Random Geometric Graphs

Abstract not available at time of publication.

Josep Diaz
Departament de Llenguatges i Sistemes Informatics
Universitat Politecnica de Catalunya, Spain
diaz@lsi.upc.edu

MS53

Modelling Interference in Wireless Networks using Geometric Graphs

Given a set of positions for wireless nodes, the interference minimization problem is to assign a transmission radius (equivalently, a power level) to each node such that the resulting communication graph is connected, while minimizing the maximum interference. In this talk I will discuss recent geometric graph models for representing interfer-

ence in ad hoc and sensor wireless networks, along with corresponding algorithmic and complexity results for the interference minimization problem.

Stephane Durocher
University of Manitoba
durocher@cs.umanitoba.ca

MS53

On the Treewidth of Random Geometric Graphs

We give asymptotically exact values for the treewidth $tw(G)$ of a random geometric graph in $[0, \sqrt{n}]^2$. More precisely, we show that there exists some $c_1 > 0$, such that for any constant $0 < r < c_1$, $tw(G) = \Theta(\frac{\log n}{\log \log n})$, and also, there exists some $c_2 > c_1$, such that for any $r = r(n) \geq c_2$, $tw(G) = \Theta(r\sqrt{n})$. Our proofs show that for the corresponding values of r the same asymptotic bounds also hold for the pathwidth and treedepth of a random geometric graph.

Dieter Mitsche
Ryerson University
Toronto
dmitsche@ryerson.ca

Guillem Perarnau
Universitat Politecnica de Catalunya
guillem.perarnau@ma4.upc.edu

MS53

On the 2-Edge Connectivity of Geometric Planar Graphs With Bounded Edge Length

Abstract not available at time of publication.

Oscar Morales Ponce
Carleton University
Ottawa, Canada
oscarmponce@gmail.com

MS53

Some Results about Disk Graphs and Pseudocircle Arrangements

Abstract not available at time of publication.

Tobias Mueller
Centrum voor Wiskunde en Informatica
tobias@cwi.nl

MS54

Generating Trees for Partitions and Permutations with No k -nestings

We describe a generating tree approach to the enumeration and exhaustive generation of set partitions and permutations with no k -nestings. Unlike previous work in the literature using connections of these objects with Young tableaux and restricted lattice walks, our approach deals directly with partition and permutation diagrams. We detail a generation algorithm that uses only labels to describe these set partitions and permutations with no k -nestings, and provide explicit functional equations for the generating functions, with k as a parameter, getting valuable series results.

Sophie Burrill

Simon Fraser University
srb7@sfu.ca

Sergi Elizalde
Dartmouth College
sergi@gauss.dartmouth.edu

Marni Mishna
Simon Fraser University
mmishna@sfu.ca

Lily Yen
Capilano University
Simon Fraser University
lyen@capilanou.ca

MS54

Bijections Between Truncated Affine Arrangements and Valued Graphs

We present some constructions on the set of nbcs (No Broken Circuit sets) of some deformations of the braid arrangement. This leads us to some new bijective proofs for Shi, Linial and similar hyperplane arrangements.

David Forge
Université de Paris-Sud
david.forge@lri.fr

veronique ventos
Universite Paris 11
ventos@lri.fr

sylvie corteel
Universite Paris 7
corteel@liafa.jussieu.fr

MS54

What Computer Algebra Systems Can Offer to Tackle Realizability Problems of Matroids

In his PhD dissertation, Hiroki Nakayama establishes a connection between oriented matroids and mathematical programming, by applying polynomial optimization techniques to the realizability problem of oriented matroids. In this talk, I will discuss what are the tools that computer algebra systems offer today to implement realizability algorithms, such as the one of Nakayama.

Marc Moreno Maza
Computer Science Department
University of Western Ontario
moreno@csd.uwo.ca

MS54

Stochastic Ptri Nets and Symbolic Calculus

Abstract not available at time of publication.

Michel Petitot
Université des Sciences et Technologies de Lille I
michel.petitot@lifl.fr

MS54

The Interplay Between Finite Fields and Computer

Algebra

Finite fields display erratic behavior when the field size is small and for large finite fields memory usage and processor power become bottlenecks. I will outline the computer algebra packages containing finite fields implementations and will list drawbacks and advantages to each. I will illustrate this with examples from my research including an exhaustive search algorithm for normal bases as well as data sets obtained for a section of the forthcoming "Handbook of Finite Fields".

David Thomson
Carleton University
dthomson@math.carleton.ca

MS55

A Theoretical Foundation for Neural Sensor Networks

Multiple recent multi-neuron recordings have uncovered structure in the statistics of mammalian retinal output that is well-captured by a probabilistic model from statistical physics called the Ising model. Guided by these findings and motivated by classical ideas in theoretical neuroscience, we have developed a model of neural sensor networks. Our approach incorporates a recently developed Ising model parameter fitting technique called Minimum Probability Flow (MPF). Although a theoretical explanation for network processing of sensory stimuli, our model can also be used to uncover structure in many highly noisy datasets. We discuss several such applications to neuroscience, behavioral genetics, and machine learning. In addition, we discuss how our network can learn an exponential number of combinatorial structures (cliques in graphs) from only a small number of training samples.

Christopher Hillar
University of California, Berkeley
chillar@msri.org

Kilian Koepsell
UC Berkeley
kilian@berkeley.edu

MS55

Neural Code Topology Imposes Constraints on the Network Architecture

There are two complementary perspectives on what controls neural activity in sensory systems: receptive fields, and neural network dynamics. Receptive fields largely determine the representational function of a neuronal network, while network dynamics stem from the network structure. We propose a mathematical framework where the structure of neuronal networks can be related to combinatorial properties of receptive fields, and demonstrate how this can be used to relate network structure to homotopy invariants of represented stimuli.

Vladimir Itskov
Department of Mathematics
University of Nebraska, Lincoln
vitskov2@math.unl.edu

MS55

Stable Exponential Storage in Hopfield Networks

A Hopfield auto-associative neural network on n nodes can

store a random collection of at most $2n$ binary patterns as memories. However, it has been observed experimentally that random networks are typically capable of exponential storage in the form of *spurious memories*, which emerge mysteriously from the random network coupling. We give for the first time a parameterized family of Hopfield networks that stably store exponential numbers of binary patterns. Moreover, we give experimental evidence suggesting that these memories are attractors for the clean-up dynamics of the Hopfield network with large basins of attraction. We also present some applications.

Kilian Koepsell
UC Berkeley
kilian@berkeley.edu

Ngoc Tran, Christopher Hillar
University of California, Berkeley
tran@stat.berkeley.edu, chillar@msri.org

MS55

Noise-Induced Dynamics in Electrically Coupled Neuronal Networks

Electrically coupled networks of excitable neurons forced by small noise are analyzed in this work, using techniques from dynamical systems and algebraic graph theories. The results are presented from two complementary perspectives of variational analysis of spontaneous network dynamics and the slow-fast analysis of synchronization. The former yields geometric interpretation of various dynamical regimes, while the latter highlights the contribution of the network architecture to the stability of the synchronous state.

Georgi S. Medvedev
Drexel University
Department of Mathematics
medvedev@drexel.edu

MS55

Simplex Packings of Marginal Polytopes and Mixtures of Exponential Families

A combinatorial approach to the representational power of mixtures of discrete exponential families is presented based on combinatorics of convex polytopes and coding theory. The number of mixtures of a hierarchical model which contain another hierarchical model can be bounded by the cardinality of simplex face packings of their marginal polytope lattices. A bound for such packings is presented for the k -way interaction exponential families.

Guido F. Montufar
Pennsylvania State University
gfm10@psu.edu