IP1

Analytic Methods in Graph Theory

The theory of graph limits provides analytic tools to study large graphs. Such tools have found applications in various areas of computer science and mathematics; they are also closely linked to the flag algebra method, which changed the landscape of extremal combinatorics. We will present an introduction to this rapidly developing area of graph theory and survey some of the recent results obtained in the area.

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IP2

Interpolation Polynomials, Operator Method, and Theory of Enumeration

Goncarov Polynomials are the basis of solutions of the classical Goncarov Interpolation Problem, which have been studied extensively by analysts due to their significance in the interpolation theory of smooth and analytic functions. These Polynomials also play an important role in combinatorics due to their close relations to parking functions. This is not just a coincidence. In this talk we will present the interpolation problems with delta-operators, develop the algebraic and analytic theory of delta-Goncarov polynomials, and apply these results to problems in binomial enumeration and order statistics.

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IP3

A Simply Exponential Upper Bound on the Maximum Number of Stable Matchings

Stable matching is a classical combinatorial problem that has been the subject of intense theoretical and empirical study since its introduction in 1962 in a seminal paper by Gale and Shapley. In this talk, we describe a new upper bound on $f(n)$, the maximum number of stable matchings that a stable matching instance with n men and nwomen can have. It has been a long-standing open problem to understand the asymptotic behavior of f(n) as n goes to infinity, first posed by Donald Knuth in the 1970s. Until now the best lower bound was approximately 2.28^n, and the best upper bound was $2^{n \log n - O(n)}$. In this work, we show that for all n, $f(n)$ is at most c^n for some universal constant c. This matches the lower bound up to the base of the exponent. Joint work with Shayan Oveis Gharan and Robbie Weber.

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IP4

Waiter-Client Games

Waiter-Client games (also called Picker-Chooser games) is a type of positional games that gained popularity recently. When played on the edge set of a graph G (typically a complete graph K_n, or a random graph drawn from G(n,p)), the game goes as follows. For a positive integer q (the so called game bias), in each round Waiter offers to Client q+1 previously unoffered edges of G. Client chooses one of the edges offered, the rest go to Waiter. Waiter wins the game if by the time every edge of G has been claimed, Client's graph possesses a given graph theoretic property P, Client wins otherwise. We will present several recent results about Waiter-Client games played on complete and random graphs and discuss the role of the so called probabilistic intuition in their analysis. Based on joint works with M. Bednarska-Bzdega, D. Hefetz, T. Luczak, W. E. Tan, N. Trumer.

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IP5

New Developments in Hypergraph Ramsey Theory

The Ramsey number $r_k(s, n)$ is the minimum integer N, such that for any red/blue coloring of the k-tuples of $\{1, 2, ..., N\}$, there are s integers such that every k-tuple among them is red, or there are n integers such that every k-tuple among them is blue. In this talk, I will discuss new lower bounds for $r_k(s, n)$ which nearly settles a question of Erdos and Hajnal from 1972. I will also discuss a more general function introduced by Erdos and Hajnal, and several interesting open problems in the area. This is joint work with Dhruv Mubayi.

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IP6

Random Graph Processes

When dealing with random objects, it is often useful to reveal the randomness gradually, rather than all at once; that is, to turn a static random object into a random process. In this talk we will describe some classical proofs of this type, and a few more recent applications, for example to Ramsey numbers, and to determining sharp thresholds in G(n,p) and in random sets of integers. Various parts of the talk are based on joint work with Paul Balister, Béla Bollobás, Asaf Ferber, Gonzalo Fiz Pontiveros, Simon Griffiths, Oliver Riordan, Wojciech Samotij, and Paul Smith.

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IP7

Deciphering Cellular Networks: From Normal Functioning to Disease

Each cell in our body accomplishes its functions via a complex network of molecular interactions. Analyses of these networks are thus key to understanding cellular functioning (and, in the case of disease, malfunctioning). I will overview what has been discovered about the basic structure and organization of cellular networks, and present frameworks and algorithms that leverage these properties in order to gain a better understanding of diseases such as cancer.

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IP8

Algorithms for the Asymmetric Traveling Salesman Problem

The traveling salesman problem is one of the most fundamental optimization problems. Given n cities and pairwise distances, it is the problem of finding a tour of minimum distance that visits each city once. In spite of significant research efforts, current techniques seem insufficient for settling the approximability of the traveling salesman problem. The gap in our understanding is especially large in the general asymmetric setting where the distance from city i to j is *not* assumed to equal the distance from j to i. In this talk, we will give an overview of old and new approaches for settling this question. We shall, in particular, talk about our new approach that gives the first constant-factor approximation algorithm for the asymmetric traveling salesman problem. This is based on joint work with Jakub Tarnawski and László Végh.

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SP1

2018 Dnes Knig Prize Lecture: Pseudorandom Graphs and the Green-Tao Theorem

The celebrated Green-Tao theorem states that there are arbitrarily long arithmetic progressions in the primes. I will explain some of the main ideas of the proof from a graph theoretic perspective, with a focus on the role of pseudorandomness in the proof. (Based on joint work with David Conlon and Jacob Fox)

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SP2

Hot Topics Session

Abstract Not Available At Time Of Publication.

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CP1

Robust Maximal Independent Sets

A maximal independent set (MIS) in a simple connected graph G is robust if it remains maximal in every spanning connected subgraph of G. We refer to such a set as an RMIS. The notion of robustness was introduced by Casteigts et al. as a means of studying highly dynamic networks. They characterized the class of graphs in which every MIS is robust, calling this class $RMIS^\forall$, and raised the question of whether the corresponding graph class $RMIS^\exists$ (graphs which contain some RMIS) admits a mathematically natural characterization. Towards a resolution of this question, we show that every graph $G \in RMIS^\exists$ has at most $\frac{n^2}{4}$ edges, and that this bound is tight if and only if n is even and G is a balanced complete bipartite graph. This is joint work with Arnaud Casteigts and Luis Goddyn.

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CP1

Algebraic Analysis of Spiking Neural Networks for Graph Partitioning

Spiking neural networks (SNNs) are weighted graphs of logistical units which are used for event-based computation. Understanding the discrete spiking dynamics of these systems is integral to designing algorithms for neuromorphic hardware. Recently, we have shown how systems of deterministic leaky-integrate and fire neurons can be incorporated into label propagation for community detection using a fully connected SNN with static edge weights [K.E. Hamilton and T.S. Humble, "Spiking spin-glass models for label propagation and community detection" arXiv: 1801.03571]. However, deploying spiking label propagation on neuromorphic hardware requires sparse representations. In this talk we explore how sparsity affects our spiking label propagation method. We focus on how sparse can a SNN be in order to be used for label propagation and how the sparsity of the underlying graph affects the resolution limit of spike-based label propagation.

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CP1

Large Degree Asymptotics and the Reconstruction Threshold of Asymmetric Ising Model on Regular D-Ary Trees

Determining the reconstruction threshold of a broadcast models on on d-ary regular tree, as the interdisciplinary subject, has attracted more and more attention from probabilists, statistical physicists, biologists, etc. It is known that the Kesten-Stigum reconstruction bound is tight for roughly symmetric binary channels. However, rigorous reconstruction thresholds have only been established in a small number of models. By means of a refined analysis of moment recursion on a weighted version of the magnetization, concentration investigation, and large degree asymptotics, we establish the exact reconstruction threshold of the asymmetric Ising model on regular d-ary trees, when the Kesten-Stigum bound is not tight for the asymmetric channel. Furthermore, we figure out the critical asymmetry threshold to keep the tightness of Kesten-Stigum reconstruction bound, and develop an algorithm of determining the concrete reconstruction threshold when the degree d is large enough.

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CP1

Approximating Sparse Graphs: the Random Overlapping Communities Model

What is the limit of a sequence of sparse graphs (with average degree unbounded and $o(n)$)? We consider convergence in the first k moments of the graph spectrum (equivalent to the numbers of closed k-walks) appropriately normalized. We introduce a simple, easy to sample, random graph model that captures the limiting spectra of many sequences of interest, including the sequence of hypercube graphs. The Random Overlapping Communities (ROC) model is specified by a distribution on pairs (s, q), $s \in \mathbb{Z}_+, q \in (0, 1]$. A graph on n vertices with average degree d is generated by repeatedly picking pairs (s, q) from the distribution, adding an Erdős-Rényi random graph of edge density q on a subset of vertices chosen by including each vertex with probability s/n, and repeating this process so that the expected degree is d. Our proof of convergence to a ROC random graph is based on the Stieltjes moment condition. We also show that the model is an effective approximation for individual graphs. For almost all possible triangle-to-edge and four-cycle-to-edge ratios, there exists a pair (s, q) such that the ROC model with this single community type produces graphs with both desired ratios, a property that cannot be achieved by stochastic block models of bounded description size. Moreover, ROC graphs exhibit an inverse relationship between degree and clustering coefficient, a characteristic of many real-world networks.

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CP1

Dynamical Stability Despite Time-Varying Network Structure

Dynamic processes on real-world networks are inherently time-delayed due to finite processing speeds, the need to transmit data over distances, or other interruptions in the network's dynamics. These time-delays, which correspond to bisecting edges in the network's underlying graph of interactions, can and often do have a destabilizing effect on the network's dynamics. We demonstrate that networks whose underlying graph of interactions satisfy the criteria which we refer to as *intrinsic stability* are able to maintain their stability even in the presence of time-varying time-delays. These time-varying delays can be of any form, e.g. deterministic, stochastic, etc. Furthermore, determining whether a network is intrinsically stable is straightforward and can be implemented on large-scale networks.

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CP2

Proper Orientations of Planar Bipartite Graphs

An orientation of a graph G is *proper* if any two adjacent vertices have different indegrees so that the values of the indegrees define a coloring of G. The *proper orientation number* of a graph G is the minimum of the maximum indegree, taken over all proper orientations of G. The problem of determining the proper orientation number is hard: deciding if a graph G has proper orientation number equal to 2 is NP-complete even if G is a planar graph. The question about which classes of graphs have bounded proper orientation number is still open, including the case of planar graphs. It has been shown that classes like trees, cacti and claw-free planar graphs have bounded proper orientation number. In this talk, we present a proof that 3-connected planar bipartite graphs have bounded proper orientation number.

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CP2

A Matrix Approach to p-Competition Graphs

For a positive integer p, the p-competition graph of a digraph D is a graph which has the same vertex set as D and an edge between distinct vertices x and y if and only if u and v have at least p common out-neighbors in D. A graph is said to be a p-competition graph if it is the p-competition graph of a digraph. In this talk, we introduce the notion of p-row graph of a matrix to study p-competition graphs. Utilizing these notions, we extend results given by Kim *et al.* [p-competition graphs, *Linear Algebra Appl.* **217** (1995) 167–178] and identity the n-competition graphs and the $(n-1)$-competition graphs among the graphs with n vertices. Furthermore, we completely characterize the caterpillars which are p-competition graphs and the spiked cycles with exactly one pendant vertex adjacent to each vertex of an n-cycle which are p-competition graphs. This work was supported by the National Research Foundation of Korea(NRF) funded by the Korea government(MEST) (No. NRF-2015R1A2A2A01006885, No. NRF-2017R1E1A1A03070489) and by the Korea government(MSIP) (No. 2016R1A5A1008055).

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CP2

On 1-Factors with Prescribed Lengths in Tournaments

About 50 years ago, Camion proved that every strongly connected tournament is Hamiltonian, and Moon proved that for any strongly connected n-vertex tournament T with a vertex v and any integer $3 \leq \ell \leq |V(T)|$, there is a cycle of length ℓ containing v. We prove the following extension of both classical results of Camion and Moon. For positive integers $n, t, \ell_1, \ldots, \ell_t$ with $\ell_1, \ldots, \ell_t \geq 3$ and $\sum_{i=1}^{t} \ell_i = n$, every strongly $10^{50}t$-connected n-vertex tournament T with t distinct vertices $x_1, \ldots, x_t \in V(T)$ contains t vertex-disjoint cycles $C_1, \ldots, C_t$ such that $x_i \in V(C_i)$ and $|V(C_i)| = \ell_i$ for $1 \leq i \leq t$. The connectivity is best possible up to constant. We also prove an analogous result on partitioning highly connected tournaments into highly connected subtournaments with prescribed sizes and vertices. In particular, the result implies that there exists a constant $C > 0$ such that for integers $n, t \geq 1$ and $\ell_1, \ldots, \ell_t \geq n/100t$ with $\sum_{i=1}^{t} \ell_i = n$, every strongly Ct-connected tournament T with $2t$ distinct vertices $x_1, \ldots, x_t, y_1, \ldots, y_t \in V(T)$ admits t vertex-disjoint paths $P_1, \ldots, P_t$ so that P_i is a path from x_i to y_i with length ℓ_i for $1 \leq i \leq t$. This is joint work with Jaehoon Kim (University of Birmingham).

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CP2

Cyclic Triangle Factors in Regular Tournaments

A tournament is an orientation of a complete graph. A tournament on n vertices is regular if the indegree and the outdegree of every vertex is $(n-1)/2$, and a cyclic triangle factor is a collection of $n/3$ vertex-disjoint cyclic triangles. We prove that when n is sufficiently large and an odd multiple of 3, every regular tournament on n vertices contains a cyclic triangle factor. For large tournaments, this resolves a conjecture made independently by Cuckler and Yuster.

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CP3

On Generalized Quadrangles and Girth Eight Algebraically Defined Graphs

For a field F and polynomials $f, g \in F[x, y]$, the partite sets P and L of a three-dimensional algebraically defined (bipartite) graph are each copies of F^3, and $(p_1, p_2, p_3) \in P$ and $[\ell_1, \ell_2, \ell_3] \in L$ are adjacent if and only if $p_2 + \ell_2 = f(p_1, \ell_1)$ and $p_3 + \ell_3 = g(p_1, \ell_1)$. Of interest is whether for a particular field there exist nonisomorphic girth eight algebraically defined graphs; this question was originally motivated by the study of generalized quadrangles. In this talk, we will discuss results over several fields of interest.

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CP3

Many k-Neighborly Polytopes from Quivers

A d dimensional polytope on n vertices, P, is said to be k-neighborly if every set of k vertices spans a face of P. Such polytopes provide interesting extremal objects in discrete geometry; for example, $\lfloor d/2 \rfloor$-neighborly polytopes have the largest number of faces of any d-polytope on n-vertices, according to McMullen's Upper Bound Theorem. On the other hand, in recent work Donoho and Tanner ignited an interest in the Compressive Sensing community in k-neighborly polytopes and showed that, in some sense, most polytopes are k-neighborly, provided d and n are large enough relative to k. However, explicit examples remain scarce. In this talk we will discuss how one can verify the k-neighborliness of polytopes explicitly constructed from weighted directed graphs, also known as quivers, using tools from the geometry of toric varieties.

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CP3

Solving Tropical Linear Systems in Terms of the Shortest Path Problem

Min-Plus algebra(or tropical semiring) is the set of real numbers and an extra element infinity ∞ endowed with the two operations $\oplus$ and $\otimes$: $\oplus$ stands for the conventional "min' operation and $\otimes$ stands for the conventional "+' operation. Min-Plus algebra has its origin in the shortest path problem. In this talk, we present a new approach for giving a solution of linear systems on Min-Plus algebra in the sense of tropical geometry. It is the tropical analogue of the Jacobi iterative method; this iteration converges in finite number of steps under the assumption that the coefficient matrix is diagonally dominant. Validity of our algorithm is proved in the framework of networks associated with Min-Plus matrices. It is also proved that the tropical solution by our approach is proved to be identical to the solution by tropical Cramer's rule. In view of computational complexities, our approach needs $O(n^3)$ steps to solve tropical linear systems, where n is the size of the coefficient matrix. This fact is easily derived from Floyd-Warshall algorithm. Hence we see that the computation by our algorithm is superior to that by tropical Cramer's rule which requires $O(n^4)$ steps.

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CP3

Topology and Holomorphic Invariants Using the Application of Combinatorics

In this research 3-manifolds such as Heegaard Floer homology and embedded contact homology were studied. These invariants are based on holomorphic curves and moduli spaces, but in the simplest cases, some of their structure reduces to some elementary combinatorics and algebra which may be of interest in its own right. Further highlight which is essentially a light-hearted exposition of some previous work of the author, we give a brief introduction to some of the ideas of contact topology and holomorphic curves, discuss some of these elementary results, and indicate how they arise from holomorphic invariants.

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CP4

Polynomial Time Solution to the Domino Puzzle

Consider a puzzle in which one is given a bag of dominoes. The two ends of each domino can be labeled with any integer values, positive or negative. The objective of the puzzle is to line up the dominoes end-to-end in a circle, such that at each adjacent pair of domino ends, the sum of the numbers is non-negative. For a given arrangement of dominoes, it is trivial to check whether the condition is satisfied, but a brute force approach would yield $O(2^n(n-1)!)$ possible distinct arrangements to check. This talk will describe a polynomial time approach which will produce a solution to an arbitrary instance of the domino puzzle. The domino puzzle is motivated as a partial solution to the problem of efficiently finding an embedding of a tree with minimal distance between adjacent leaves. Given a set of subtrees with common root and known in distances and out distances, consider determining an order for the subtrees such that the sum of the out distance of one subtree and the in distance of its neighbor exceed some constant k. The problem just described can be easily transformed into an instance of the domino puzzle.

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CP4

Optimizing Order Picking Problem By a New Scalable Method

For a generalized order picking problem consisting of N orders and M pickers, where the orders are dynamically specified as a sub-graph of a non-symmetric graph $G(V;E)$, a solution is proposed using a three-stage method. In the first step, the sub-graph $G_0(V;E)$ corresponding to N picking destinations is extracted from $G(V;E)$ using Dijkstra's algorithm. In the second stage, a multilevel graph partitioning algorithm is utilized to decompose the problem into M balanced partitions with maximum locality. The picking points in each subpartition are initially marked from 1 to N_p. In the last stage, a variant of classic Breadth First Search known as the Cuthill-McKee algorithm is used to reorder the picking points such that the traveled distance by each picker is near minimal. Each step is a polynomial method thus reducing the complexity of the NP problem to a polynomial. Additionally, each partition is independent of others which makes this algorithm to be scalable and suitable for larger problem sizes. An application in the municipal recycling collection service is illustrated.

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CP4

The Fullerene Project

A *fullerene* models a pure carbon molecule and is a 3-regular plane graph with only hexagonal and pentagonal faces. A *Kekulé structure* is a perfect matching of the edges, and corresponds to a double bond structure of the molecule. The *Clar number* of a fullerene is the maximum number of independent resonant hexagons over all Kekulé structures (the maximum size of an independent set of hexagons with 3 of their bounding edges in the perfect matching). A higher Clar number is correlated with higher molecular stability. We have begun a "Fullerene Project" with the goal of finding the Clar number for all highly symmetric fullerenes. Results will be discussed, as will opportunities for research, including at the undergraduate level.

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CP4

Efficient Methods for Enforcing Contiguity in Ge-

ographic Districting Problems

Every ten years, United States Congressional Districts must be redesigned in response to a national census. While the size of practical political districting problems is typically too large for exact optimization approaches, heuristics such as local search can help stakeholders quickly identify good (but suboptimal) plans that suit their objectives. However, enforcing a district contiguity constraint during local search can require significant computation; tools that can reduce contiguity-based computations in large practical districting problems are needed. This talk introduces the geo-graph framework for modeling geographic districting as a graph partitioning problem, discusses two geo-graph contiguity algorithms, and applies these algorithms to the creation of United States Congressional Districts from census blocks in several states. The experimental results demonstrate that the geo-graph contiguity assessment algorithms reduce the average number of edges visited during contiguity assessments by at least three orders of magnitude in every problem instance when compared with simple graph search, suggesting that the geo-graph model and its associated contiguity algorithms provide a powerful constraint assessment tool to political districting stakeholders.

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CP4

Leximax and Leximin Rank-Ordered Rules on the Power Set with Discrete Categories

The objective of this study is to characterize the *leximax* and *leximin rank-ordered rules* on the power set of the finite set of categorized alternatives with a rearrangement method. By applying the method, each *null* alternative, meaning "choosing not to choose each alternative," is added to each subset if it does not include the alternative, and a cardinality of every transformed subset becomes equal to a cardinality of the set of alternatives. Then, all alternatives and null alternatives in every transformed subset are rearranged in descending or ascending order for each category. The major result is a characterization of the *leximax* (*leximin*) *rank-ordered rule* by *extended responsiveness* for each category and *priority of the best* (*worst*) based on an order of categories. The latter axiom requires that a preference order of any two subsets be in accordance with a preference order of the best (worst) alternatives within them while considering the order of categories.

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CP4

The Solution Attractor Theory of Local Search System: The Traveling Salesman Problem Case

Although both the TSP and local search have huge literature, there is still a variety of open problems. The study of local search for the TSP continues to be an interesting research problem in computational mathematics and computer science. In our study, a local search algorithm is treated as a discrete dynamical system, and its search behavior is studied from the perspective of dynamical systems. The attractor theory in dynamical systems provides the necessary and sufficient theoretical foundation to study the search behavior of local search systems. We will introduce the solution-attractor theory of local search system, using the TSP as study problem. In a local search system, search trajectories converge into a small region (solution attractor) in the solution space. This solution-attractor theory not only provides a model to describe the search behavior of a local search system, but also offers an important method to solve the TSP efficiently with optimality guarantee. The novel search system, the attractor-based search system, will be described. We also present some empirical results on the important properties of the solution attractor. So far there exist no efficient algorithms to solve the NP-complete TSP, only the brute-force search can provide a solution. The general question our study attempts to answer is The TSP can be solved by a brute-force search algorithm efficiently?

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CP5

The Saturation Number, Extremal Number, Spectral Radius, and Family of k-Edge-Connected Graphs

Given a family of graphs $\mathcal{F}$, a graph G is **$\mathcal{F}$-saturated** if no member of $\mathcal{F}$ is a subgraph of G, but for any $e \in E(\overline{G})$, some member of $\mathcal{F}$ is a subgraph of $G+e$. The **saturation number** and **extremal number** of $\mathcal{F}$, denoted $sat(n,\mathcal{F})$ and $ex(n,\mathcal{F})$, respectively, is the minimum and maximum number of edges in an n-vertex $\mathcal{F}$-saturated graph, respectively. For a given positive integer k, let $\mathcal{F}_k$=$\{H|H$ is a k-vertex-connected graph$\}$ and $\mathcal{F}'_k$=$\{H|H$ is a k-edge-connected graph$\}$. Wenger determined $sat(n,\mathcal{F}_k)$. In this talk, we provide $sat(n,\mathcal{F}'_k)$ and $ex(n,\mathcal{F}'_k)$; we characterize when equality holds. Furthermore, we give a necessary condition related to the spectral radius for $\mathcal{F}_k$-saturated and $\mathcal{F}'_k$-saturated graphs.

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CP5

Decomposition of Random Hypergraphs

For an r-uniform hypergraph H, let $f(H)$ be the minimum number of complete r-partite r-uniform subhypergraphs of H whose edge sets partition the edge set of H. In this talk, we will prove that if $(\log n)^{2.001}/n \leq p \leq 1/2$ and $H \in H^{(r)}(n,p)$, then with high probability $f(H) = (1-\pi(K_r^{(r-1)})+o(1))\binom{n}{r-1}$, where $\pi(K_r^{(r-1)})$ is the Turán density of $K_r^{(r-1)}$.

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CP5

The Zarankiewicz Problem in 3-Partite Graphs

Bipartite Turán problems are some of the most interesting problems in extremal graph theory. They have a rich history dating back to an early paper of Erdős from 1938. While much progress has been made, many questions have not been answered. The case when the forbidden graph is a complete bipartite graph is closely related to the famous Zarankiewicz problem. In this talk, we will discuss a variation of the bipartite Turán problem where the host graph must be 3-partite. The Zarankiewicz problem corresponds to the case when the host graph is 2-partite. We also present some bounds on the maximum number of edges in a 3-partite graph with no subgraph isomorphic to $K_{s,t}$. This is joint work with Michael Tait.

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CP6

An Algorithm to Find Maximum Area Polygons Circumscribed About a Convex Polygon

A convex polygon Q is *circumscribed* about a convex polygon P if every vertex of P lies on at least one side of Q. The aim of this talk is finding maximum area polygons circumscribed about a given convex n-gon P. In the first part of the talk, after collecting some geometric properties of these polygons, we present an algorithm with $O(n^3)$ running time that finds both the maximum area, and the polygons with maximum area circumscribed about P. Suppose that Q is circumscribed about P, and let $S_1, \ldots, S_n$ be sides of P in counterclockwise order. We say that S_i is "used' by Q if it is on the boundary of Q, and "not used' otherwise. We can assign a sequence from $\{U, N\}^n$ to Q such that the ith term is U if S_i is used and N otherwise. In the second part of the talk we investigate the following problem: which sequences can be assigned to a maximum area circumscribed polygon, for some P. In particular, we disprove a conjecture of Farris. Finally, we sum up what is known about higher dimensional generalizations of this problem. This is a joint work with M. Ausserhofer, S. Dann and G. Tóth.

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CP6

Circular Repetition Thresholds for Small Alphabets

A word w is called a β-power if we can write $w = x^\beta$ for some word x. For example, the English word `onion` $=$ $(\texttt{oni})^{5/3}$ is a 5/3-power. If we treat `onion` as a *circular word*, then it also contains the 2-power `onon` $= (\texttt{on})^2$. The *strong circular repetition threshold* for k-ary words, denoted CRT(k), is the infimum of the set of all β such that there are β-power free circular words of any length on k letters. It is known that $\mathrm{CRT}(2) = 5/2$ [Aberkane and Currie, 2004], $\mathrm{CRT}(3) = 2$ [Shur 2011], and $\mathrm{CRT}(k) = (\lceil k/2\rceil + 1)/(\lceil k/2\rceil)$ for all $k \geq 6$ [Gorbunova, 2012]. We prove that $\mathrm{CRT}(4) = 3/2$, confirming a conjecture of Gorbunova, and also explore the last remaining open case for 5 letters. We briefly discuss the related weak and intermediate circular repetition thresholds.

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CP7

Extremal Collections of k-Uniform Vectors

Extremal combinatorics is a field where we wish to optimize a discrete parameter for some family of large combinatorial objects. Most such questions have parallels in probabilistic combinatorics, where one is more concerned with the statistical behaviour of a randomly chosen object in this family. Consider the particular context of a representable matroid (i.e. the columns of a matrix) over $\mathbb{F}_2$ of rank $\leq n$. Here, one well-studied distribution is to fix a small k and large m and randomly generate m columns with k 1's. Indeed, when $k = 2$, this is the graphic matroid of the Erdős-Rényi random graph $G_{n,m}$. We explore the corresponding extremal question. What is the maximum number of weight-k columns a matrix of rank $\leq n$ can have?

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CP7

Coloring Vertex-minor-free Graphs with No Short Cycles

Geelen conjectured that every proper vertex-minor closed class $\mathcal{G}$ of graphs is χ-bounded, i.e., there exists a function

f such that $\chi(G) \leq f(\omega(G))$ for every graph $G \in \mathcal{G}$. Motivated by this conjecture, we show that for every proper vertex-minor closed class $\mathcal{G}$, there exists K such that every graph $G \in \mathcal{G}$ with girth at least 10 has chromatic number at most K.

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CP7

On the Excluded Minors for Represented Frame Matroids

Recently, Chen gave an infinite family of excluded minors for frame matroids. This family features matroids with arbitrarily long sequences of nested 3-separations. We show that for each integer k, there exists n such that no excluded minors for represented frame matroids have n nested k-separations. This implies that the excluded minors with branch-width k have bounded size. We conjecture that there are finitely many excluded minors for the class. This is joint work with Jim Geelen.

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CP7

On Group Divisible Designs with Two Associate Classes and Larger Second Index

A group divisible design $\mathsf{GDD}(m, n; \lambda_1, \lambda_2)$ is an ordered pair $(V, \mathcal{B})$ where V is an $(m+n)$-set of symbols while $\mathcal{B}$ is a collection of 3-subsets (called blocks) of V satisfying the following properties: the $(m+n)$-set is divided into 2 groups of sizes m and n; each pair of symbols from the same group occurs in exactly λ_1 blocks in $\mathcal{B}$; and each pair of symbols from different groups occurs in exactly λ_2 blocks in $\mathcal{B}$. λ_1 and λ_2 are referred to as the first index and second index, respectively. When $\lambda_1 \geq \lambda_2$, the existence problem of $\mathsf{GDD}(m, n; \lambda_1, \lambda_2)$ is completely solved for $m, n \neq 2$ by N. Pabhapote et al. in 2009-2012 using Steiner triple systems and related designs. Later on, in 2013, J. Chaffee and C. Rodger provided the complete solution of the problem for $m = 2$ or $n = 2$ using a classic result of Colbourn and Rosa on quadratic leaves. Recently, some progress has been made for the case $\lambda_1 < \lambda_2$ when $\lambda_1 = 1, 2$ and 3. This paper discusses on the existence problem of GDDs when $4 \leq \lambda_1 < \lambda_2$. We obtain the necessary conditions and prove that these conditions are sufficient for most of the cases. Our construction uses various graph decomposition techniques including the result from Alspach's problem, which is a problem on the decomposition of complete graphs into cycles.

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CP8

Tools for Enumerating Graphs with Prescribed Degree Sequences

To detect statistical anomalies in networks, we compare empirically observed networks with realizations from a realistic random graph model. Since many real world networks exhibit degree heterogeneity, we consider some challenges in randomly constructing graphs with a given bidegree sequence in an unbiased way. In particular, we propose a novel method for the asymptotic enumeration of directed graphs that realize a bidegree sequence, $\mathbf{d}$, with maximum degree $d_{max} = O(S^{\frac{1}{2}-\tau})$ for an arbitrarily small positive number τ , where S is the number of edges specified by d; the previous best results from Greenhill et al. allow for $d_{max} = o(S^{\frac{1}{3}})$. Our approach is based on two key steps, graph partitioning and degree preserving switches. The former allows us to relate enumeration results to degree sequences that are easy to handle, while the latter facilitates expansions based on numbers of shared neighbors of pairs of nodes.

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CP8

Garden-of-Eden States and Fixed Points of Monotone Systems

Finding all fixed points in monotone systems is known to be NP-complete. We present a mechanism to identify a subset of states based on which we can search a portion of Garden-of-Eden states and fixed points of a given monotone system. As one of the applications, the problem of constructing a sequential equivalent of a parallel monotone system is discussed. We also connect these results to the Knaster-Tarski theorem and the LYM inequality.

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CP8

A Randomized Algorithm for Approximating Zonotopes

We propose a randomized algorithm for enumerating the vertices of a zonotope, which is a low-dimensional linear projection of a hypercube. The algorithm produces a pair of the zonotope's vertices by sampling a random linear combination of the zonotope generators, where the combination's weights are the signs of the product between the zonotope's generator matrix and random vectors with normally distributed entries. We study the probability of recovering particular vertices and relate it to the vertices' normal cones. This study shows that if we terminate the randomized algorithm before all vertices are recovered, then the convex hull of the resulting vertex set approximates the zonotope. In high dimensions, we expect the enumeration algorithm to be most appropriate as an approximation algorithm, particularly for cases when existing methods are not practical.

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CP8

Enumeration of Unsensed Orientable Maps on Surfaces of a Given Genus

In this work we enumerate unlabelled maps on genus g surfaces up to all homeomorphisms of these surfaces, including both orientation-preserving and orientation-reversing. Using the theory of NEC groups we describe all periodic orientation-reversing symmetries admissible for a given genus g surface. We use the concept of a quotient map on an orbifold and reduce the problem of enumerating symmetric maps to enumeration of maps of a special kind (quotient maps) on orientable and non-orientable surfaces, possibly having a boundary and a certain number of branch points. We develop a technique to enumerate such maps. Combining these results with the result of Mednykh and Nedela regarding enumerating maps up to orientation-preserving homeomorphisms, we enumerate genus g maps up to all possible symmetries.

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CP8

Some Partitions Identities Between $P(n,m) - P(n-1,m)$ and $p(n,m-1)$

Previous work establishes partition identities between $\Delta(n,3)$, partitions of n into at most 3 parts with no parts of size 1, and $p(n,2)$, partitions of n into at most 2 parts as well as partition identities between $\Delta(n,4)$ and $p(n,3)$. When $lcm(1,...,m) \neq lcm(1,...,m-1)$, we establish new partition identities between $\Delta(n,m)$ and $p(n,m-1)$ using quasipolynomials. Furthermore, we extend these identities to partitions generated by Gaussian polynomials.

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CP9

Properly Colored Connections in Graphs

For a connected graph, we define the proper-walk connection number as the minimum number of colors needed to color the edges of a graph so that there is a walk between every pair of vertices without two consecutive edges having the same color. The proper-trail and proper-path connection numbers are defined similarly. We show that the proper-walk connection number is at most three for all cyclic graphs, and at most two for bridgeless graphs. We also characterize the bipartite graphs that have proper connection number equal to two. We show that the proper-path [proper-trail] connection number is nearly determined by the maximum number of bridges incident with a vertex [with a vertex not in a cycle].

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CP9

A k-Partite Generalization of Chordal Bipartite Graphs

The traditional development of chordal bipartite graph theory is largely by analogy with chordal graph theory. But chordal bipartite graphs can be viewed as a special case of "chordally k-partite graphs,' defined to be the k-partite graphs in which every minimal vertex separator induces a complete k-partite subgraph. The traditional chordal bipartite graphs are precisely the chordally 2-partite graphs. The following new characterization of a graph G being chordally k-partite emphasizes the graphs being properly k-colored: If each color c determines the subgraph G_c of all edges of G that have a color-c endpoint, then G is chordally k-partite if and only if each G_c is chordal bipartite and every induced nontriangular cycle of G is in exactly two G_c subgraphs.

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CP9

An Asymptotic Bound for the Strong Chromatic Number

The strong chromatic number $\chi_s(G)$ of a graph G on n vertices is the least number r with the following property: after adding $r\lceil n/r \rceil - n$ isolated vertices to G and taking the union with any collection of spanning disjoint copies of K_r in the same vertex set, the resulting graph has a proper vertex-colouring with r colours. We show that for every $c > 0$ and every graph G on n vertices with $\Delta(G) \geq cn$, $\chi_s(G) \leq (2 + o(1))\Delta(G)$, which is asymptotically best possible.

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CP10

A Local Chordalization Approach to the Hadwiger Conjecture and the Erdős-Faber-Lovász Conjecture

In this talk, we work out a way called the "local chordalization of G' for a non-chordal graph G to obtain a specific chordal spanning supergraph G^* of G. If G satisfies so-called the "NC property', then G^* has a nice property that $\omega(G^*) \leq \omega(G) + 1$, which implies $\chi(G) \leq \omega(G^*) = \chi(G^*) \leq \omega(G) + 1$ and so gives a good upper bound of the chromatic number $\chi(G)$ of G in terms of the clique number $\omega(G)$ of G. We also utilize the local chordalization of a graph to partially answer the Hadwiger conjecture and the Erdős-Faber-Lovász conjecture, both of which concern a chromatic number, for the graphs satisfying the NC property. This work was supported by the National Research Foundation of Korea(NRF) funded by the Korea government(MEST) (No. NRF-2015R1A2A2A01006885, No. NRF-2017R1E1A1A03070489) and by the Korea government(MSIP) (No. 2016R1A5A1008055).

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CP10

On Essentially 4-Edge-Connected Cubic Bricks

Lovasz (1987) proved that every matching covered graph may be uniquely decomposed into a list of bricks (nonbipartite) and braces (bipartite). Carvalho, Lucchesi and Murty (2002) proved a conjecture of Lovasz which states that every brick G, distinct from K_4, the triangular prism $\overline{C_6}$ and the Petersen graph, has a b-invariant edge e — that is, an edge e such that $G - e$ is a matching covered graph with exactly one brick. A cubic graph is essentially 4-edge-connected if it is 3-edge-connected and if the only 3-cuts are the trivial ones. A brick G is near-bipartite if it has a pair of edges $\{e, f\}$ such that $G - \{e, f\}$ is bipartite matching covered; for instance, K_4 and $\overline{C_6}$. We prove that every essentially 4-edge-connected cubic graph G is either a brick or a brace; furthermore, if G is a brick that is not near-bipartite and is not the Petersen graph, then G has at least $\frac{|V(G)|}{2}$ b-invariant edges.

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CP10

Vertex Disjoint Paths Covers of Rectangular Grids, Tori, and Hypertori

Let G be a graph and let $W_{2k} = \{u_1, v_1, u_2, v_2, \ldots, u_k, v_k\}$ be a set of $2k$ distinct vertices in G. A k-to-k vertex disjoint path cover of G is a collection of k vertex disjoint paths $\{P_1, P_2, \ldots, P_k\}$ such that the endpoints of P_i are u_i and v_i, and the vertices of $\cup P_i$ are all the vertices in G. We say that G is paired k-to-k vertex disjoint path coverable if a k-to-k vertex disjoint path cover exists for all choices W_{2k} in G (there is a similar definition if G is bipartite). Such definitions are the generalizations of Hamiltonian connected graphs and Hamiltonian laceable graphs. In this talk, we will discuss the vertex disjoint path coverabilty of rectangular grids, tori (obtained by connecting the vertices on opposite sides of rectangular grids), and hypertori (obtained by connecting the vertices on opposite faces of higher-dimensional rectangular grids).

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CP10

Limited Broadcast Domination and Multipacking

A k-limited dominating broadcast is a function $f : V(G) \to \{0, 1, 2, \ldots, k\}$ such that every vertex v in the graph has $d(v, u) \leq f(u)$ for some vertex u. A optimal k-limited dominating broadcast is one that minimize the cost $\sum_{v \in V(G)} f(v)$. Algorithmic, complexity, and other results for k-limited dominating broadcasts, and the dual problem of k-limited multipackings, will be described. Both problems are shown to be NP-complete for all $k \geq 1$, and Polynomial for strongly chordal graphs.

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MS1

Hereditary Semiorders and Enumeration of Semiorders by Dimension (Part I)

In 2010, Bousquet-Mélou et al. defined sequences of nonnegative integers called ascent sequences and showed that the ascent sequences of length n are in one-to-one correspondence with the interval orders, i.e., the posets not containing the poset $\mathbf{2}+\mathbf{2}$. Through the use of generating functions, this provided an answer to the longstanding open question of enumerating the (unlabeled) interval orders. A semiorder is an interval order having a representation in which all intervals have the same length. The number of unlabeled semiorders on n points has long been known to be the n^{th} Catalan number. However, describing the ascent sequences that correspond to the semiorders under the bijection of Bousquet-Mélou et al. has proved difficult. A major part of the difficulty in this area is that the ascent sequence corresponding to a semiorder may have an initial subsequence that corresponds to an interval order that is not a semiorder. We define the hereditary semiorders to be those corresponding to an ascent sequence for which every initial subsequence also corresponds to a semiorder. We provide a structural result that characterizes the hereditary semiorders in terms of what we call blocks and boundaries. This talk will discuss the bijection of Bousquet-Mélou et al. and our structural description of the hereditary semiorders. See Part II for enumerative applications of this work.

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MS1

A Simple Proof Characterizing Interval Orders

with Interval Lengths between 1 and k

A poset $P = (X, \prec)$ is an *interval order* if it has a representation in which each $x \in X$ is assigned a real interval I_x so that $x \prec y$ in P if and only if I_x is completely to the left of I_y. Fishburn proved that for any positive integer k, an interval order has a representation in which all interval lengths are between 1 and k if and only if the order does not contain $(k+2)+1$ as an induced poset. In this talk we give a simple proof of this result using potential functions and directed graphs.

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MS1

A Note on the Size of $\mathcal{N}$-free Families

The $\mathcal{N}$ poset consists of four distinct sets W, X, Y, Z such that $W \subset X$, $Y \subset X$, and $Y \subset Z$ where W is not necessarily a subset of Z. A family $\mathcal{F}$, considered as a subposet of the n-dimensional Boolean lattice $\mathcal{B}_n$, is $\mathcal{N}$-free if it does not contain $\mathcal{N}$ as a subposet. Let $\mathrm{La(n,\mathcal{N})}$ be the size of a largest $\mathcal{N}$-free family in $\mathcal{B}_n$. Katona and Tarján proved that $\mathrm{La(n,\mathcal{N})} \geq \binom{\mathrm{n}}{\mathrm{k}} + \mathrm{A(n,4,k+1)}$, where $k = \lfloor n/2 \rfloor$ and $A(n,4,k+1)$ is the size of a single-error-correcting code with constant weight $k+1$. In this note, we prove for n even and $k = n/2$, $\mathrm{La(n,\mathcal{N})} \geq \binom{\mathrm{n}}{\mathrm{k}} + \mathrm{A(n,4,k)}$, which improves the bound on $\mathrm{La(n,\mathcal{N})}$ in the second order term for some values of n and should be an improvement for an infinite family of values of n, depending on the behavior of the function $A(n,4,\cdot)$.

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MS1

Better Bounds for Poset Dimension and Boxicity

The *dimension* of a poset P is the minimum number of total orders whose intersection is P. We prove that the dimension of every poset whose comparability graph has maximum degree Δ is at most $\Delta \log^{1+o(1)} \Delta$. This result improves on a 30-year old bound of Füredi and Kahn, and is within a $\log^{o(1)} \Delta$ factor of optimal. We prove this result via the notion of boxicity. The *boxicity* of a graph G is the minimum integer d such that G is the intersection graph of d-dimensional axis-aligned boxes. We prove that every graph with maximum degree Δ has boxicity at most $\Delta \log^{1+o(1)} \Delta$, which is also within a $\log^{o(1)} \Delta$ factor of optimal. We also show that the maximum boxicity of graphs with Euler genus g is $\Theta(\sqrt{g \log g})$, which solves an open problem of Esperet and Joret and is tight up to a $O(1)$ factor. arXiv:1804.03271.

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MS1

Hereditary Semiorders and Enumeration of Semiorders by Dimension (Part II)

This talk builds on the structural description of the hereditary semiorders described in Part I (talk by M.T. Keller). Once the structure of hereditary semiorders is understood, it is possible to construct a generating function to enumerate them. This involves considering the ascent sequences that correspond to the blocks that can appear in a hereditary semiorder. We are also able to enumerate the semiorders by dimension. In 1978, Rabinovitch showed that if P is a semiorder, then $\dim(P) \leq 3$ with equality if and only if P contains one of three subposets on seven points. We use these subposets and our characterization of hereditary semiorders to give an alternate characterization of the semiorders of dimension at most 2. From this characterization, we are able to construct the ordinary generating function for the semiorders of dimension at most 2. Since the number of semiorders on n points is given by the n^{th} Catalan number, this also leads to an enumeration of the semiorders of dimension 3.

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MS2

Large Independent Sets in Triangle-free Graphs Avoiding a Clique-minor

The celebrated Hadwiger's conjecture says that for all $t \geq 1$, every graph with no K_{t+1} minor can be t-colored. If the conjecture is true, it would in particular imply that the independence number of such a graph with n vertices is at least n/t; and in 1982, Duchet and Meyniel proved that this bound holds within a factor 2 (later improved by Fox, and by Balogh and Kostochka). Forbidding triangles sometimes leads to better bounds on chromatic number, and indeed, it is natural to conjecture that the chromatic number of triangle-free graphs with no K_t minor is sublinear in t. We show a bound on the independence number of such graphs that supports this conjecture; more precisely, for sufficiently large t, every triangle-free n-vertex graph with no K_t minor has independence number at least $n/t^{26/27}$. This answers a question by Sergey Norin.

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MS2

Polynomial-time Algorithm for Maximum Weight

Independent Set on P6-free Graphs

In the problem of Maximum Weight Independent Set, the task is to find an independent set of maximum possible weight in a given graph with non-negative weights on vertices. While the problem is NP-hard in general, it becomes solvable in polynomial time when restricted to many special graph classes. We give a polynomial-time algorithm for the class of P_6-free graphs, that is, graphs that do not contain a path on 6 vertices as an induced subgraph. This extends previous results of Lokshtanov, Vatshelle and Villanger (SODA 2014) who gave a polynomial-time algorithm for P_5-free graphs and of Lokshtanov, Pilipczuk and van Leeuwen (SODA 2016) who gave a quasipolynomial-time algorithm for P_6-free graphs. Our algorithm is based on enumerating all maximal cliques appearing in a suitable family of minimal chordal completions of the graph.

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MS2

Erdős-Pósa Property of Chordless Cycles and its Applications

A chordless cycle in a graph G is an induced subgraph of G which is a cycle of length at least four. We prove that the Erdős-Pósa property holds for chordless cycles, which resolves the major open question concerning the Erdős-Pósa property. Our proof for chordless cycles is constructive: in polynomial time, one can find either $k+1$ vertex-disjoint chordless cycles, or $ck^2 \log k$ vertices hitting every chordless cycle for some constant c. It immediately implies an approximation algorithm of factor $\mathcal{O}(\mathsf{opt} \log \mathsf{opt})$ for Chordal Vertex Deletion. We complement our main result by showing that chordless cycles of length at least ℓ for any fixed $\ell \geq 5$ do not have the Erdős-Pósa property.

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MS2

The Grid Theorem for Rank-Width

The grid theorem is a fundamental result in graph minor theory. It is a starting point for extending structural and algorithmic results on graphs of bounded tree-width to graphs without a K_t minor. The grid theorem states that a family of graphs has unbounded tree-width if and only if it contains every planar graph as a minor. We prove that a family of graphs has unbounded rank-width if and only if it contains every circle graph as a vertex-minor.

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MS2

Hereditary Families with Atypical Structure

Investigation of the typical structure of graphs in a specific hereditary family is a classical direction of research in graph theory, going back to pioneering work of Erdős, Kleitman and Rothschild, and Prömel and Steger. In this talk, we discuss constructions of graphs H such that almost all graphs in the hereditary family of H-free graphs exhibit unexpected behaviour. In particular, we construct infinitely many graphs H such that almost all H-free graphs do not contain a homogeneous set of linear size, answering a question of Loebl et al. Additionally, we disprove a related conjecture of Reed and Scott.

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MS3

Distributed Coloring with Fewer Colors

In the distributed setting, each vertex needs to decide which color to receive so that the group decision results in a proper graph coloring. With the model we are considering ('the LOCAL model'), in a single round, each vertex can exchange information with its neighbors. The goal is to minimize the number of rounds of information exchanges that are necessary for a good global decision to be taken. In a way, this value encapsulates how local the target property is. There is a stark difference of complexity between this setting and the centralized one. For example, computing the chromatic number of a graph of small diameter is easy here, while computing a 2-coloring of a path is hard. A much-studied question is that of the complexity of k-coloring a graph with no vertex of degree k or higher, which is easily solved by a simple greedy algorithm in the centralized setting. Here we discuss what happens when fewer colors are allowed. This is joint work with Pierre Aboulker, Nicolas Bousquet and Louis Esperet.

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MS3

Characterization of Cycle Obstruction Sets for Improper Coloring Planar Graphs

For nonnegative integers $k, d_1, \ldots, d_k$, a graph is $(d_1, \ldots, d_k)$-colorable if its vertex set can be partitioned into k parts so that the ith part induces a graph with maximum degree at most d_i for all $i \in \{1, \ldots, k\}$. A class $\mathcal{C}$ of graphs is *balanced k-partitionable* and *unbalanced k-partitionable* if there exists a nonnegative integer D such that all graphs in $\mathcal{C}$ are $(D, \ldots, D)$-colorable and $(0, \ldots, 0, D)$-colorable, respectively, where the tuple has length k. A set X of graphs is an *obstruction set* of a graph class $\mathcal{C}$ if containing none of the graphs in X as a subgraph guarantees membership of $\mathcal{C}$. In other words, a graph G is a member of $\mathcal{C}$ if G does not contain any graph in X as a subgraph. This paper characterizes all cycle obstruction sets of planar graphs to be balanced k-partitionable and unbalanced k-partitionable for all k; namely, we identify all inclusion-wise minimal cycle obstruction sets for all k. This is joint work with Chun-Hung Liu and Sang-il Oum.

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MS3

Acyclic Edge-coloring of Planar Graphs: Delta Colors Suffice when Delta is Large

An *acyclic edge-coloring* of a graph G is a proper edge-coloring of G such that the subgraph induced by any two color classes is acyclic. The *acyclic chromatic index*, $\chi'_a(G)$, is the smallest number of colors allowing an acyclic edge-coloring of G. Clearly $\chi'_a(G) \geq \Delta(G)$ for every graph G. Cohen, Havet, and Müller conjectured that there exists a constant M such that every planar graph with $\Delta(G) \geq M$ has $\chi'_a(G) = \Delta(G)$. We prove this conjecture.

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MS3

Vertex Partition with Average Degree Constraint

A classical result, due to Stiebitz in 1996, states that a graph with minimum degree $s + t + 1$ contains a vertex partition (A, B), such that $G[A]$ has minimum degree at least s and $G[B]$ has minimum degree at least t. Motivated by this result, it was conjectured that for any non-negative real number s and t, such that if G is a non-null graph with average degree at least $s + t + 2$, then there exist a vertex partition (A, B) such that $G[A]$ has average degree at least s and $G[B]$ has average degree at least t. Earlier, we claimed a weaker result of the conjecture that there exist two disjoint vertex set A and B (for which the union may not be all the vertices) that satisfy the required average degree constraints. Very recently, we fully proved the conjecture. This is joint work with Yan Wang at Facebook.

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MS3

Vector Coloring the Categorical Product of Graphs

Vector t-coloring of a graph G is an assignment of unit vectors to vertices of G such that vectors assigned to adjacent vertices are far apart – they have inner product $\leq -\frac{1}{t-1}$. I will present recent progress on vector coloring of graph products, in particular a new proof of vector-coloring version of the Hedetniemi conjecture and characterization of all optimal colorings of the product. Joint work with C. Godsil, D.E. Roberson, B. Rooney, A. Varvitsiotis.

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MS4

The Bipartite $K_{2,2}$ -Free Process and Ramsey Numbers

The smallest n such that every red-blue edge-coloring of $K_{n,n}$ contains a red $K_{2,2}$ or a blue $K_{t,t}$ is known as the two color bipartite Ramsey number, $br(2, t)$. In the bipartite $K_{2,2}$-free process, beginning with an empty graph on vertex set $A \cup B$ where $|A| = |B| = n$, random edges from A to B are sequentially added under the restriction that no $K_{2,2}$ is formed. We use the technique of dynamic concentration to analyze this process and show how the resulting graph can be used to improve the best known lower bound on $br(2, t)$. This is joint work with Deepak Bal.

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MS4

The Size of the Giant Component in the D-Process

Graph processes $(G(i), i \geq 0)$ are usually defined as follows. Starting from the empty graph on n vertices, at each step i a random edge is added from a set of available edges. For the d-process, edges are chosen uniformly at random among all edges joining vertices of current degree at most $d - 1$. The fact that, during the process, vertices become *saturated* when reaching degree d makes the process depend heavily on its history. However, it shares several qualitative properties with the classical Erdos-Rényi graph process. For example, there exists a critical time t_c at which a giant component emerges, whp (that is, the largest component in $G(tn)$ goes from logarithmic to linear order). In this talk we consider $d \geq 3$ fixed and describe the growth of the size of the giant component. In particular, we show that whp the largest component in $G((t_c + \varepsilon)n)$ has asymptotic size cn, where $c \sim c_d\varepsilon$ is a function of time ε as $\varepsilon \to 0+$. The growth, linear in ε, is a new common qualitative feature shared with the Erdos-Rényi graph process and can be generalized to hypergraph processes with different max-allowed degree sequences. This is work in process jointly with Lutz Warnke and builds on work by Warnke and Wormald (in preparation).

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MS4

A Probabilistic Approach Towards the Aharoni-Berger Conjecture on Rainbow Matchings

Let G be a properly edge coloured multigraph with m colours and let $\mathcal{M} = \{M_1, \ldots, M_m\}$ be the set of m matchings induced by each colour in G. Assume that every matching in $\mathcal{M}$ has size n. Aharoni and Berger conjectured that if G is bipartite and $m = n-1$ then G contains a full rainbow matching, i.e. a matching that contains exactly one edge from each M_i for each $1 \leq i \leq m$. We prove an approximate version of this conjecture. We show that if $m \leq n - n^c$, where $c > 9/10$, and G is simple, or is a multigraph with low multiplicity, whereas not necessarily bipartite, then G contains a rainbow matching if n is sufficiently large. Our proof proceeds by analysing a randomised algorithm. This is collaborated work with Reshma Ramadurai, Ian Wanless and Nick Wormald.

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MS4

Domination in Random Regular Graphs and in Graphs with Large Girth

We devise probabilistic local algorithms to produce dominating sets in random regular graphs, for different notions of domination. This leads to new upper bounds on the size of a minimum dominating set. The structure of the algorithms allows us to translate our results into deterministic bounds for regular graphs with sufficiently large girth.

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MS4

Packing Edge-disjoint Spanning Trees in Random Geometric Graphs

We consider the problem of packing edge-disjoint spanning trees in the random geometric graph $G(n, r)$. This was inspired by some earlier work on the $G(n, p)$ model, in which we proved that (with high probability) $G(n, p)$ contains exactly $\min(\delta, \lfloor m/(n-1) \rfloor)$ edge-disjoint spanning trees, where m is the number of edges and delta is the minimum degree. This result has been recently extended to the random geometric setting for all r such that $\delta < \epsilon \log n$. In particular we show that, for r in that range, $G(n, r)$ contains (with high probability) δ edge-disjoint spanning trees, and obtain the corresponding hitting-time result for the random graph process in which edges are added one by one in increasing order of length.

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MS5

Three Colour Bipartite Ramsey Number of Cycles and Paths

The *k-colour bipartite Ramsey number* of a bipartite graph H is the least integer n for which every k-edge-coloured complete bipartite graph $K_{n,n}$ contains a monochromatic copy of H. The study of bipartite Ramsey numbers was initiated, over 40 years ago, by Faudree and Schelp and, independently, by Gyárfás and Lehel, who determined the 2-colour Ramsey number of paths. In this paper we determine asymptotically the 3-colour bipartite Ramsey number of paths and (even) cycles.

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MS5

A Stability Theorem for Small Cycle Covers

Kouider and Lonc proved that every graph with n vertices and minimum degree at least n/k contains k-1 cycles that together cover all the vertices of the graph. Note that the case k=2 is Dirac's Theorem for Hamilton cycles. I will talk about the structure of the graphs that have minimum degree nearly n/k and yet cannot be covered by k-1 cycles. Our main result shows that every such graph must be close to one of a number of extremal examples, and it can be used to give a different proof of the above theorem of Kouider and Lonc. This is joint work with Jozsef Balogh and Jozef Skokan.

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MS5

Rainbow Trees

A subgraph of an edge-coloured graph is called rainbow if all its edges have distinct colours. The study of rainbow subgraphs goes back to the work of Euler on Latin squares. Since then, rainbow structures were focus of extensive research and found applications in design theory and graph decompositions. In this talk we discuss how probabilistic reasoning can be used to attack several old problems in this area. In particular we show that well known conjectures of Andersen, Ringel, and Graham-Sloane hold asymptotically. This is joint work with Richard Montgomery and Benny Sudakov.

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MS5

Linear Cycles of Consecutive Lengths in Linear Hypergraphs

In this talk we consider the following question. Under which density assumptions can one find a set of cycles of a given number of consecutive lengths in a hypergraph? For graphs, this can be traced back to a question of Erdős and later a theorem of Bondy and Vince that any graph with minimum degree at least three contains two cycles whose lengths differ by at most two. Hăggkvist and Scott later showed that every graph with minimum degree $\Omega(k^2)$ contains k cycles of consecutive even lengths. This quadratic bound was first improved to a linear one by Verstraete, who proved that average degree at least $8k$ will ensure the existence of k cycles of consecutive even lengths. We establish an analogue (stronger) result to for linear hypergraphs (i.e. no pair of vertices is contained in more than one edge). We show that for every $r \geq 3$ there exists a constant $c = c(r)$, such that for all $k \geq 2$, every r-uniform linear hypergraph of average degree at least ck contains a set of k linear cycles of consecutive lengths. This is joint work with Tao Jiang and Jie Ma.

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MS6
Dimension and Subdivision of K_4 Free Posets

Take a poset whose cover graph lacks a K_4 minor and subdivide edges of the cover graph. This talk will demonstrate bounds for the dimension of the poset induced by this subdivision.

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MS6
Local Dimension is Unbounded for Planar Posets

In 1981, Kelly showed that planar posets can have arbitrarily large dimension. However, the posets in Kelly's example have bounded Boolean dimension and bounded local dimension, leading naturally to the questions as to whether either Boolean dimension or local dimension is bounded for the class of planar posets. The question for Boolean dimension was first posed by Nešetřil and Pudlák in 1989 and remains unanswered today. The concept of local dimension is quite new, introduced in 2016 by Ueckerdt. In just the last year, researchers have obtained many interesting results concerning Boolean dimension and local dimension, contrasting these parameters with the classic Dushnik-Miller concept of dimension, and establishing links between both parameters and structural graph theory, path-width and tree-width in particular. We show that local dimension is not bounded on the class of planar posets. Our proof also shows that the local dimension of a poset is not bounded in terms of the maximum local dimension of its blocks, and it provides an alternative proof of the fact that the local dimension of a poset cannot be bounded in terms of the tree-width of its cover graph, independent of its height.

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MS6
A Random Version of the r-fork-free Theorem

Let $\mathcal{P}(n)$ denote the set of all subsets of $[n]$ and let $\mathcal{P}(n,p)$ be the set obtained from $\mathcal{P}(n)$ by selecting elements independently at random with probability p. The r-fork poset is the family of distinct sets $F, G_1, ..., G_r$ such that $F \subset G_i$ for all i. De Bonis and Katona showed that, for fixed r, any $(r+1)$-fork-free family in $\mathcal{P}(n)$ has size at most $(1+o(1))\binom{n}{\lfloor n/2 \rfloor}$. In this talk, I will discuss a similar result for $(r+1)$-fork-free families in $\mathcal{P}(n,p)$. In particular, if $pn \to \infty$, then with high probability, the largest $(r+1)$-fork-free set in $\mathcal{P}(n,p)$ has size at most $(1+o(1))p\binom{n}{\lfloor n/2 \rfloor}$. This result is influenced by the work of Balogh, Mycroft and Treglown, who proved a random version of Sperner's theorem using the hypergraph container method.

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MS6
Partially Ordered Sets and Finite Topologies

Finite partially ordered sets and finite topologies are known to be equivalent in some way, but it seems that there is more to the story. In this talk I will explain this equivalence, discuss additional combinatorial structures like hypergraphs and abstract simplicial complexes, and other classes of finite set systems, and show how they can all be studied through the lens of posets.

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MS6
Fractional Local Dimension

The original notion of dimension for posets was introduced by Dushnik and Miller in 1941 and has been studied extensively in the literature. In 1992, Brightwell and Scheinerman developed the notion of fractional dimension as the natural linear programming relaxation of the Dushnik-Miller concept. Recently, there has been considerable interest in a new variation of dimension called *local dimension*. For a poset P, both the fractional dimension and the local dimension of P are both bounded from above by the dimension of P and can be considerably less. However, neither of the two parameters is bounded in terms of the other. In this paper, we introduce and study a common generalization which we call *fractional local dimension*. For a pair (n, d) with $2 \leq d < n$, we consider the poset $P(1, d; n)$ consisting of all 1-element and d-element subsets of $\{1, 2, \ldots, n\}$ partially ordered by inclusion. This poset has fractional dimension $d + 1$, but for fixed $d \geq 2$, its local dimension goes to infinity with n. On the other hand, we show that as n tends to infinity, the fractional local dimension of $P(1, d; n)$ tends to a value $f(d) \sim d/\log d$. In fact, for a given value of $d \geq 2$, we will be able to determine $f(d)$ within an additive error of 1. This is joint work with F. Barrera-Cruz, T. Prag and H. C. Smith.

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MS7

The Genus of a Random Bipartite Graph

Archdeacon and Grable (1995) proved that the genus of the random graph $G \in \mathcal{G}(n,p)$ is almost surely close to $pn^2/12$ if $p = p(n) \gg 3(\ln n)^2 n^{-1/2}$. We prove an analogous result for random bipartite graphs in $\mathcal{G}(n_1, n_2, p)$. If $n_1 \geq n_2 \gg 1$, phase transitions occur for every positive integer i when $p = \Theta((n_1 n_2)^{-\frac{i}{2i+1}})$. A different behavior is exhibited when one of the bipartite parts has constant size, $n_1 \gg 1$ and n_2 is a constant. In that case, phase transitions occur when $p = \Theta(n_1^{-1/2})$ and when $p = \Theta(n_1^{-1/3})$.

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MS7

On the Genus of the Complete 3-uniform Hypergraph

In 1968, Ringel and Youngs confirmed the last open case of the Heawood Conjecture by determining the genus of every complete graph K_n. We determine the (non-orientable) genus of the complete 3-uniform hypergraph $K_n^{(3)}$ for every even n and discuss differences with the odd case. This problem was motivated by the last open case in the study of the genus of random bipartite graphs. It is also proved that the number of minimum genus embeddings of $K_n^{(3)}$ when n is even, is more than exponential in n.

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MS7

Half-integral Linkages in Highly Connected Directed Graphs

We study the half-integral k-Directed Disjoint Paths Problem (1/2 kDDPP) in highly strongly connected digraphs. The integral kDDPP is NP-complete even when restricted to instances where $k = 2$, and the input graph is L-strongly connected, for any $L \geq 1$. We show that when the integrality condition is relaxed to allow each vertex to be used in two paths, the problem becomes efficiently solvable in highly connected digraphs (even with k as part of the input). Specifically, we show that there is an absolute constant c such that for each $k \geq 2$ there exists $L(k)$ such that 1/2 kDDPP is solvable in time $O(|V(G)|^c)$ for a $L(k)$-strongly connected directed graph G. As the function $L(k)$ grows rather quickly, we also show that 1/2 kDDPP is solvable in time $O(|V(G)|^{f(k)})$ in $(36k^3 + 2k)$-strongly connected directed graphs. We show that for each $\epsilon < 1$, deciding half-integral feasibility of kDDPP instances is NP-complete when k is given as part of the input, even when restricted to graphs with strong connectivity epsilon k.

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MS7

Scattered Classes of Graphs

For a class $\mathcal{C}$ of graphs G equipped with functions f_G defined on subsets of $E(G)$ or $V(G)$, we say that $\mathcal{C}$ is k-*scattered* with respect to f_G if there exists a constant ℓ such that for every graph $G \in \mathcal{C}$, the domain of f_G can be partitioned into subsets of size at most k so that the union of every collection of the subsets has f_G value at most ℓ. We present structural characterizations of graph classes that are k-scattered with respect to several graph connectivity functions. In particular, our theorem for cut-rank functions provides a rough structural characterization of graphs having no $mK_{1,n}$ vertex-minors, which allows us to prove that such graphs have bounded linear rank-width.

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MS8

Bounding the Chromatic Number by a Fraction of the Maximum Degree for Graphs with no Large Cliques

Greedy coloring yields an upper bound on the chromatic number χ of $\Delta + 1$ for graphs of maximum degree at most Δ, which is tight for cliques. Much attention has been devoted to improving this "greedy bound' for graphs without large cliques. Brooks famously proved it can be improved by one for graphs with no clique of size $\Delta + 1$ if $\Delta \geq 3$. Reed conjectured it can be improved by k for graphs with no clique of size larger than $\Delta + 1 - 2k$. Johansson improved the greedy bound by a factor of $\Omega(\ln \Delta)$ or $\Omega(\ln \Delta / \ln \ln \Delta)$ for graphs without triangles or cliques of any fixed size, respectively. Notably missing is a *linear* improvement on the greedy bound. We prove that for sufficiently large Δ, for graphs with no clique of size ω,

$$\chi \leq 72\Delta \sqrt{\frac{\ln \omega}{\ln \Delta}}.$$

Thus, for large Δ, if $\omega^{(72c)^2} \leq \Delta$ then $\chi \leq \Delta/c$. This bound actually holds for the list-chromatic and even the correspondence (a.k.a. DP)-chromatic number. In fact, we prove a "local version' of it, a result about the existence of a coloring when the number of available colors for each vertex depends on local parameters, like its degree and the clique number of its neighborhood. Our result simultaneously implies the linear improvement over the "greedy bound' and the two aforementioned results of Johansson. Joint work with Marthe Bonamy, Peter Nelson, and Luke Postle.

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MS8

Coloring $(2K_2, W_4)$-Free Graphs

Coloring $2K_2$-free graphs has received considerable attention in the past few years, in particular trying to find the tightest χ-binding function for this class or for some subclasses of it. We show that $(2K_2, W_4)$-free graphs are $\omega+1$-colorable, where $2K_2$ is the disjoint union of two edges, and W_4 is the wheel of length 4 (a C_4 with a universal vertex). This result is tight for any value of ω at least 2, for instance on a C_5 compete to a clique. This improves the previous bound of $5\omega+5$. Our technique, based on graph decomposition, immediately implies that the clique number together with an optimal coloring can be found in polynomial time on $(2K_2, W_4)$-free graphs.

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MS8

Circular Flow and Circular Coloring of Graphs

A circular k/d-flow is a flow that takes values from $\{\pm k, \pm(k+1), \ldots, \pm(k-d)\}$. Extending Tutte's flow conjectures, Jaeger proposed the circular flow conjecture that every $4p$-edge-connected graph admits a circular $(2+1/p)$-flow. This conjecture has been verified for $6p$-edge-connected graphs, but however, disproved for every $p \geq 3$ recently. We suggest a modified conjecture on planar graph. Planar Circular Flow Conjecture: Every $2k$-edge-connected planar graph admits a circular $(2+2/k)$-flow.The $k = 1, 2$ cases are known as the 4CT and Grotzsch's theorem(3CT). It is open for $k \geq 3$. In this talk, for $k = 4$, we present a concise proof that every 10-edge-connected planar graph admits a circular 5/2-flow. Note that the dual theorem is previously obtained by Dvorak-Postle (Combinatorica 2017) that every girth 10 planar graph is circular 5/2-colorable.

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MS8

Clustered Coloring, Hajos' Conjecture and Gerards-Seymour Conjecture

Hajos (and Gerards and Seymour, respectively) conjectured that every graph with no K_{t+1}-topological minor (and with no odd K_{t+1}-minor, respectively) is properly t-colorable. A weakening of these conjectures is to consider clustered coloring which only requires every monochromatic component having bounded size. In joint work with David Wood, we prove a series of tight results about clustered coloring on graphs with no subgraph isomorphic to a fixed complete bipartite graph. These results have a number of applications. In particular, they imply that K_{t+1}-topological minor free graphs of bounded tree-width or with any odd minor excluded are clustered t-list-colorable or (t+1)-colorable, respectively. They also lead to the first linear bound for the clustered coloring version of Hajos' conjecture and the currently best bound for the clustered coloring version of Gerards and Seymour's conjecture. More applications will be discussed in this talk.

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MS8

4-coloring P_6-free Graphs

The result in this talk is motivated by the following question: Given k and t, what is the complexity of deciding if a given graph G with no induced t-vertex path is k-colorable? This had been solved in all cases except when $k = 3$ and $t \geq 8$ and when $k = 4$ and $t = 6$. We give an algorithm that, for any graph G with no six-vertex induced path, and for precoloring $f : S \to \{1, 2, 3, 4\}$ of a subset $S \subseteq V(G)$, decides in polynomial time if f can be extended to a 4-coloring of G. Joint work with Maria Chudnovsky and Mingxian Zhong.

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MS9

Homomorphic Secret Sharing, or: Locally Decodable Codes for Functions (Part 2)

A homomorphic secret sharing (HSS) scheme is a secret sharing scheme that allows mapping each share of a secret s to a compact share of f(s) for a given function f. This mapping can be viewed as a succinctly described locally decodable encoding of the truth-table of f. This two-part talk will survey the state of the art on HSS, applications, open questions, and connections with problems from other domains. The first part will include a brief introduction to the topic and cover results on HSS schemes with information-theoretic secrecy. The second part will cover HSS schemes with secrecy against computationally bounded parties, which can offer lightweight alternatives to fully homomorphic encryption in several application scenarios.

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MS9

Staircase Codes for Secret Sharing and Private Information Retrieval

I will describe the communication efficient secret sharing (CESS) problem and introduce explicit constructions of CESS schemes, called Staircase Codes, that achieve optimal communication an read costs. Time permitting, I will talk about two applications of Staircase codes: (1) on minimizing latency against stragglers in secure distributed computing; and (2) on constructing universally-robust private information retrieval schemes with optimal download cost. Joint work with my PhD student Rawad Bitar.

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MS9

Homomorphic Secret Sharing, or: Locally Decod-

able Codes for Functions (Part 1)

A homomorphic secret sharing (HSS) scheme is a secret sharing scheme that allows mapping each share of a secret s to a compact share of f(s) for a given function f. This mapping can be viewed as a succinctly described locally decodable encoding of the truth-table of f. This two-part talk will survey the state of the art on HSS, applications, open questions, and connections with problems from other domains. The first part will include a brief introduction to the topic and cover results on HSS schemes with information-theoretic secrecy. The second part will cover HSS schemes with secrecy against computationally bounded parties, which can offer lightweight alternatives to fully homomorphic encryption in several application scenarios.

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MS9

Coding for Private Function Computation

We study the problem of private function retrieval (PFR) in a distributed storage system. In PFR the user wishes to compute a linear combination of M messages stored in non-colluding (N,K) coded databases while revealing no information about the coefficients of the intended linear combination to any of the individual databases. We present an achievable scheme for linearly coded PFR with a rate that matches the capacity for MDS coded private information retrieval derived recently, $R = (1 + R_c + R_c^2 + \cdots + R_c^{M-1})^{-1} = \frac{1-R_c}{1-R_c^M}$, where $R_c = \frac{K}{N}$ is the rate of the code. We show that based on the information sets of a linear code and by exploiting code automorphisms the PFR code does not need to have the MDS property. For example, cyclic codes and Reed-Muller codes achieve the PFR rate R. We also show that this achievable rate is tight in some special cases.

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MS9

Secure Distributed Storage and Its Connections to Communication-efficient Secret Sharing

Large-scale distributed storage systems are susceptible to various security and privacy threats due to valuable and confidential nature of the information hosted on these systems. In this talk, I'll present the results on characterizing the secrecy capacity of repair-efficient distributed storage systems. The secrecy capacity of the system measures the maximum amount of information that can be stored on the system without leaking any useful information to a passive eavesdropper. I'll then discuss how these results allow us to construct communication-efficient secret sharing schemes, where given access to redundant shares, a legitimate user can reduce the amount of data downloaded during the reconstruction of the secret. Joint work with O. Ozan Koyluoglu and Sriram Vishwanath

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MS10

Minimizing the Number of 5-cycles in Graphs with Given Edge-density

Motivated by the work of Razborov about the minimal density of triangles in graphs we study the minimal density of cycles C_5. We show that every graph of order n and size $\left(1-\frac{1}{k}\right)\binom{n}{2}$, where $k \geq 3$ is an integer, contains at least

$$\left(\frac{1}{10}-\frac{1}{2k}+\frac{1}{k^2}-\frac{1}{k^3}+\frac{2}{5k^4}\right)n^5+o(n^5)$$

copies of C_5. This bound is optimal. The proof is based on the flag algebras framework. This is a joint work with Patrick Bennett and Bernard Lidický.

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MS10

Packing Nearly Optimal Ramsey R(3,t) Graphs

In 1995 Kim famously proved the Ramsey bound $R(3,t) \geq ct^2/\log t$ by constructing an n-vertex graph that is triangle-free and has independence number at most $C\sqrt{n \log n}$. We extend this celebrated result, which is best possible up to the value of the constants, by approximately decomposing the complete graph K_n into a packing of such nearly optimal Ramsey $R(3,t)$ graphs. More precisely, for any $\epsilon > 0$ we find an edge-disjoint collection $(G_i)_i$ of n-vertex graphs $G_i \subseteq K_n$ such that (a) each G_i is triangle-free and has independence number at most $C_\epsilon\sqrt{n \log n}$, and (b) the union of all the G_i contains at least $(1-\epsilon)\frac{n(n-1)}{2}$ edges. Our algorithmic proof proceeds by sequentially choosing the graphs G_i via a semi-random (i.e., Rödl nibble type) variation of the triangle-free process. As an application, we prove a conjecture in Ramsey theory by Fox, Grinshpun, Liebenau, Person, and Szabó (concerning a Ramsey-type parameter introduced by Burr, Erdős, Lovász in 1976). Namely, denoting by $s_r(H)$ the smallest minimum degree of r-Ramsey minimal graphs for H, we close the existing logarithmic gap for $H = K_3$ and establish that $s_r(K_3) = \Theta(r^2 \log r)$. The talk is based on joint work with Lutz Warnke.

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MS10

Assessing Significance in a Markov Chain Without Mixing

We will describe a new statistical test to demonstrate outlier status for a state of any reversible Markov Chain. Remarkably, the test can rigorously demonstrate outlier status without any bounds on the mixing time of the chain. We will show how this test can be applied to detect gerrymandering of political districtings. This is joint work with Maria Chikina and Alan Frieze.

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MS10

Embedding the Uniform Random Graph into the Bipartite Regular Random Graph

In 2004 Kim and vu conjectured that if d grows faster than $\log n$, then with high probability one can "sandwich" a random d-regular graph $G(n,d)$ between two binomial random graphs $G(n,p_1)$ and $G(n,p_2)$, both of which have expected degrees asymptotically equal to d. By "sandwiching" we mean a joint distribution of the three random graphs such that with high probability $G(n,p_1)$ is a subgraph of $G(n,d)$ and $G(n,d)$ is a subgraph of $G(n,p_2)$. Recently Dudek, Frieze, Rucinski and Sileikis proved the lower embedding, i.e., that $G(n,p_1)$ is a subgraph of $G(n,d)$ with high probability, provided $d=o(n)$. We extend this result to random bipartite graphs using a new approach that also works for $d \sim cn$, $0<c<1$.

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MS11

Incomplete Tilings

Let T be a tile, meaning a finite subset of $[2]^d$ for some d. Does T tile $[2]^n$ for large n, meaning that the latter set admits a partition into isometric copies of T? An obvious necessary condition is that $|T|$ is a power of 2, which turns out to be sufficient. In this talk we consider the case when $|T|$ has prime factors other than 2, and we aim to pack disjoint copies of T into $[2]^n$, leaving as few gaps as possible. We show that it is always possible to cover all but at most $O(n^C)$ elements of $[2]^n$, where $C=C(T)$ is a constant depending on T. We also demonstrate a tile T for which one has to leave at least $\Omega(\log n)$ gaps. This talk is based on joint work with Shoham Letzter.

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MS11

Path Partitions of Regular Graphs

The well-known theorem of Dirac (1952) states that a graph on n vertices with minimum degree at least n/2 contains a Hamilton cycle. As a possible generalisation of Dirac's result, Magnant and Martin (2009) conjectured that every k-regular graph on n vertices can be partitioned into at most n/(k+1) paths, a bound which is attained by a disjoint union of k+1 cliques. Note that the regularity assumption is needed in order to allow for a partition into a small number of paths, as otherwise a sufficiently unbalanced bipartite graph is a counter example. We prove this conjecture in the case where k is linear in n and n is large. This talk is based on joint work with Vytautas Gruslys.

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MS11

Maximising the Number of Induced Cycles in a Graph

How many induced cycles can a graph on n vertices contain? For sufficiently large n, we determine the maximum number of induced cycles and the maximum number of even or odd induced cycles. We also characterize the graphs achieving this bound in each case. This answers a question of Tuza, and a conjecture of Chvátal and Tuza from 1988. Joint work with Alex Scott.

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MS11

Generalized Turan Problem for Trees

A natural generalization of the classical Turán question is the following. For two fixed graphs T and H and an integer n, let $ex(n,T,H)$ be the maximum number of copies of T in an H-free graph on n vertices. In this talk we present the solution to this question for the case where both T and H are trees. If time allows we will also discuss the case where T is a general bipartite graph and H is a tree. Joint work with Noga Alon.

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MS12

On the Dimension of Random Posets

We study the dimension of random bipartite partially ordered sets, where there are fixed sets of maximal and minimal elements, and they are related with probability p. In this talk we focus on the range $1/2 \leq p < 1$, and we find upper and lower bounds on the dimension of the resulting poset.

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MS12

The Width of Down Sets in Boolean Lattices

Our original motivation is a problem of Daykin and Frankl that dates from the early 1980's: what is the minimum width of a convex subset of specified size in a Boolean lattice B_n. We address this problem for down sets of B_n (with a little success). We fully characterize the down sets that maximize width (again, of fixed size). Several other problems of similar flavor are considered.

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MS12

Whitney Duals of Graded Posets

For a graded poset P, let $w_k(P)$ be its kth Whitney number of the first kind and let $W_k(P)$ be its kth Whitney number of second kind. We say posets P and Q are Whitney duals if $|w_k(P)| = W_K(Q)$ and $|w_k(Q)| = W_k(P)$ for all k. In this talk, we will describe a method to construct Whitney duals. This method uses edge labelings and quotient posets. We will also discuss some examples of posets which have Whitney duals.

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MS12

Minimum Saturated Families of Sets

We call a family $\mathcal{F}$ of subsets of $[n]$ s-saturated if it contains no s pairwise disjoint sets, and moreover no set can be added to $\mathcal{F}$ while preserving this property (here $[n] = \{1, \ldots, n\}$). More than 40 years ago, Erdős and Kleitman conjectured that an s-saturated family of subsets of $[n]$ has size at least $(1 - 2^{-s+1})2^n$. It is easy to show that every s-saturated family has size at least $\frac{1}{2} \cdot 2^n$, but, as was mentioned by Frankl and Tokushige, even obtaining a slightly better bound of $(1/2 + \epsilon)2^n$, for some fixed $\epsilon > 0$, seems difficult. In this note, we prove such a result, showing that every s-saturated family of subsets of $[n]$ has size at least $(1 - 1/s)2^n$. This lower bound is a consequence of a multipartite version of the problem, in which we seek a lower bound on $|\mathcal{F}_1| + \ldots + |\mathcal{F}_s|$ where $\mathcal{F}_1, \ldots, \mathcal{F}_s$ are families of subsets of $[n]$, such that there are no s pairwise disjoint sets, one from each family $\mathcal{F}_i$, and furthermore no set can be added to any of the families while preserving this property. We show that $|\mathcal{F}_1| + \ldots + |\mathcal{F}_s| \geq (s-1) \cdot 2^n$, which is tight e.g. by taking $\mathcal{F}_1$ to be empty, and letting the remaining families be the families of all subsets of $[n]$.

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MS13

Unavoidable Minors in 2-connected Graphs of Large Pathwidth

We prove the conjecture of Seymour (1993) that for every apex-forest H_1 and outerplanar graph H_2 there is an integer p such that every 2-connected graph of pathwidth at least p contains H_1 or H_2 as a minor. An independent proof was recently obtained by Dang and Thomas.

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MS13

Caterpillars and the Strong Erdos-Hajnal Property

A class $\mathcal{C}$ of graphs has the "strong Erdős-Hajnal property" if there is a constant $c > 0$ with the following property: In every graph in $\mathcal{C}$, with n vertices say, there are two disjoint sets of vertices A and B with $|A|, |B| > cn$, and either every vertex in A is adjacent to every vertex in B, or there are no edges between A and B. Liebenau and Pilipczuk conjectured that for every tree T, the class of graphs containing neither T nor its complement as induced subgraphs has the strong Erdos-Hajnal property. I will talk about some progress towards this conjecture, and related results.

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MS13

Coloring Graphs with No Clique Immersion

Hadwiger's conjecture states that if a graph has no K_t minor, then the graph is properly $t-1$ colorable. Lescure and Meynial made the analogous conjecture for graph immersions - if a graph has no K_t immersion, then the graph can be properly colored with $t-1$ colors. Recent work by Dvorak and Norin has shown that if a graph does not contain K_t as a minor, then the graph can be (possibly improperly) colored with $t-1$ colors so that every connected component of the induced subgraph of a single color class has bounded size. We consider the analogous question for graph immersions and show that if a graph has no K_t immersion, then it can be colored with colors $1, 2, \ldots, t-1$ such that the color classes $3, 4, \ldots, t-1$ each induce an independent set and every connected component of the subgraph induced by vertices of color 1 or 2 has bounded size. We also show that a minimal counterexample to the immersion variant of Hadwiger's conjecture must have bounded size.

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MS13

Attacking Hadwigers Conjecture via Chordal Partitions

Hadwiger's Conjecture asserts that every graph with no K_t-minor is $(t-1)$-colourable. This is widely considered to be one of the most important conjectures in graph theory. It is even open whether every graph with no K_t-minor is $O(t)$-colourable. This talk will describe four results, each of which can be considered as a step in the direction of Hadwiger's conjecture. These results state that graphs with no K_t-minor:

- have stable sets of size at least $\frac{n}{2t-1}$ [Duchet and Meyniel],
- are fractionally $(2t-1)$-colourable [Reed and Seymour],
- are $(t-1)$-colouable with bounded defect, and $(2t-2)$-colourable with bounded clustering [Van den Heuvel and Wood].

The unifying theme of these proofs is the use of chordal partitions. The take-home message is that chordal partitions provide an approach for studying K_t-minor-free graphs that is much simpler than the graph minor structure theorem.

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MS13

Obstructions for Three-Coloring and List Three-Coloring H-Free Graphs

A graph is H-free if it has no induced subgraph isomorphic to H. We characterize all graphs H for which there are only finitely many minimal non-three-colorable H-free graphs. Such a characterization was previously known only in the case when H is connected. This solves a problem posed by Golovach *et al.* As a second result, we characterize all graphs H for which there are only finitely many H-free minimal obstructions for list 3-colorability.

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MS14

The Distinguishing Cost of Graph Products

The *distinguishing number* of a graph is the smallest number of colors necessary to color the vertices so that no nontrivial automorphism preserves the color classes. If a graph can be distinguished with two colors, the *distinguishing cost* is the smallest possible size of the smaller color class. This talk will cover background as well as new results in the distinguishing cost of certain graph products.

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MS14

Distinguishing Numbers of Partially Ordered Sets

In this talk, we introduce the distinguishing chromatic number and the distinguishing number of a poset. The former is equal to the width, but the latter concept is more interesting. We prove that every distributive lattice has distinguishing number equal to two, and characterize those distributive lattices with distinguishing number equal to one. We also consider the distinguishing number for planar, ranked, Cohen-Macaulay posets.

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MS14

On Uniquely k-List Colorable Graphs

A graph is called *uniquely k-list colorable* if there exists a set of lists of k-colors, one for each vertex, for which there is a unique proper list coloring; this concept was introduced independently by M. Mahdian and E. S. Mahmoodian and by J. H. Dinitz and W. J. Martin. Conversely, a graph is said to have *property $M(k)$* if for every assignment of k-lists to its vertices for which there is a list coloring, then there is more than one list coloring; this property is named for

Marshall Hall, who studied systems of distinct representatives and their multiplicities. For classes of graphs, we look for the least k for which these graphs have property $M(k)$. We establish bounds on k for graphs embedded on surfaces with property $M(k)$ - e.g., planar graphs satisfy property $M(4)$. We also study these parameters in general for regular graphs and for graphs with varying list sizes. This work is co-authored with M. Abdolmaleki, S. Gh. Ilichi, N. Matsumoto, and M. A. Shabani (*Graphs and Combinatorics*, accepted 2018).

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MS14

Acyclic Colouring of Graphs on Surfaces

An acyclic k-colouring of a graph G is a proper k-colouring of G with no bichromatic cycles. In 1979, Borodin proved that planar graphs are acyclically 5-colourable, an analog of the Four Colour Theorem. Kawarabayashi and Mohar proved in 2010 that "locally' planar graphs are acyclically 7-colourable, an analog of Thomassen's result that "locally' planar graphs are 5-colourable. We say that a graph G is *critical* for (acyclic) k-colouring if G is not (acyclically) k-colourable, but all proper subgraphs if G are. In 1997, Thomassen proved that for every $k \geq 5$ and every surface S, there are only finitely many graphs that embed in S that are critical for k-colouring. Here we prove the analogous result that, for each surface S and large enough k, there are finitely many graphs embeddable on S that are critical for acyclic k-colouring. This result implies that there exists a linear time algorithm that, given a surface S and large enough k, decides whether a graph embedded in S is acyclically k-colourable.

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MS14

Arithmetic Progressions in Graphs

In this talk arithmetic progressions on the integers and the integers modulo n are extended to graphs. This allows for the definition of the anti-van der Waerden number of a graph. Much of the focus of this paper is on 3-term arithmetic progressions. A 3-term arithmetic progression of a graph G is a subset of vertices $\{u, v, w\}$ such that $dist_G(u, v) = dist_G(v, w)$. With general results, bounds obtained using distance parameters, and determining exact values for classes of graphs, including trees and cartesian products of graphs.

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MS15

Random Walk Methods and Their Application to Biological Networks

Many of the computational methods that seek to leverage high-throughput information currently being generated about genes and genetic modules driving disease deal with a representation of some of that information in the form of a massive graph, where there are vertices for each gene or protein, and two genes or proteins are connected by an edge if there is evidence that there is some form of association. For example, in the PPI network, vertices are proteins, and two proteins are connected by an edge if there is experimental evidence that they physically bind in the cell. Like many other graphs that arise from applications in biological or social sciences, these graphs tend to be organized according to the principle that the social scientists call homophily, the tendency of vertices to share similarities with their direct connections. Applications that perform inference or other general machine learning tasks to mine such graph data, typically encode the similarity (or disimilarity, in the case of a distance metric), according to some measure of graph proximity. Finding the right network-based measure of dissimilarity, customized for the application at hand, can lead to valuable new insights. We survey some of the methods based on random walks on graphs that have been applied to biological network applications and discuss open problems in both the application domain, and in the underlying mathematical theory.

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MS15

Synthesizing Signaling Pathways from Temporal Phosphoproteomic Data

We present a method for automatically discovering signaling pathway structures from time-resolved phosphoproteomic data. The Temporal Pathway Synthesizer (TPS) algorithm uses constraint-solving techniques first developed in the context of formal verification to explore paths in a graph of protein-protein interactions. It systematically eliminates all candidate structures for a signaling pathway in which a protein node is activated or inactivated before its upstream regulators. These temporal rules can be combined with other discrete constraints derived from the graph topology or prior knowledge. The TPS algorithm can model over one hundred thousand dynamic phosphosites and can discover pathway members that are not differentially phosphorylated. Applied to the human epidermal growth factor and yeast osmotic stress responses, it recovers known pathways and proposes new pathway connections. Independent kinase mutant studies validate predicted substrates in the TPS osmotic stress pathway.

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MS15

Denoising Large Scale Molecular Profiling Data Using Network Filters

Noise is ubiquitous in large scale transcriptomic and proteomic datasets due to biological factors such as cell cycle asynchronicity and technical issues like variations in sample preparation protocols. These types of noise make combining independent data sets difficult and impedes making robust predictions from large data sets for personalized medicine. In this talk, I will describe the network-based filters we recently developed to reduce the noise in large systems biology data sets. These filters combine noisy data measurements using molecular interaction networks to reveal the underlying denoised signal. Depending on the setting, a single filter can be applied to the entire system, or the technique can be combined with module-detection algorithms to apply different filters to different regions of the network. Applied to synthetic data with known network structure and signal, these filters significantly reduce externally introduced noise across different levels of measurement assortativity and modular network structures. Finally, we applied these filters to human protein expression data to predict changes in expression between healthy and cancerous tissues. Using the network filters to clean the data before applying a machine learning algorithm significantly increased the prediction accuracy compared to using the raw data. These results demonstrate the utility of these network filters to denoise real world systems biology data sets.

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MS15

A Multi-Species Functional Embedding Integrating Sequence and Network Structure

Computational methods for transferring knowledge across species are key for leveraging experimental datasets from model organisms for understanding human genetics. Standard approaches to this problem rely on genetic homology, but these approaches suffer from limitations. First, not all genes have homologs, limiting the amount of knowledge that can be transferred, and second, genes change or repurpose functions, complicating the transfer of knowledge. To address these challenges, researchers have expanded the notion of homology using high-throughput genomic and proteomic measurements, such as through network alignment. We take a new approach to transferring knowledge with our kernel-based method, HANDL, that integrates sequence and network structure to embed proteins from different species in the same vector space. The key insight behind our approach is that we can use homologous pairs of cross-species proteins as "landmarks," through which we can relate all proteins in one species with the proteins in a second species. We show that inner products in the HANDL-space and the embeddings themselves capture functional similarity across species. We also show that the embeddings are useful for a variety of functional tasks, including predicting "orthologous phenotypes" (phenologs), and predicting pairwise gene function such as synthetic lethality. Software for the HANDL algorithm is available at https://github.com/lrgr/HANDL.

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MS15

Integration and Dissection of Molecular Networks for Functional Analysis and Disease Modeling

Recent advances in biotechnology have enabled large-scale measurements of molecular interactions, alterations, and expression that occur in human cells. Identifying connections, patterns and deeper functional annotations among such heterogeneous measurements will potentially enhance our capability to identify biological processes underlying diseases, useful biomarkers, and novel drugs. In this talk, I will describe algorithms that use existing molecular interactions to integrate functional genomic data into molecular networks that uncover novel disease-related pathways. First, I will introduce Mashup, a machine learning algorithm that integrates multiple heterogeneous networks into compact topological features for functional inference. Second, I will discuss extensions of Mashup for discovering new disease factors and subnetworks in neurodegeneration and cancer. Finally, I will briefly introduce our most recent work on network-based gene-set functional analysis that extends the reach of current methods in functional enrichment analysis.

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MS16

Counting with Borel's Triangle

Borel's triangle is an array of integers closely related to the classical Catalan numbers. In this talk we study combinatorial statistics counted by Borel's triangle. We present various combinatorial interpretations of Borel's triangle in terms of lattice paths, binary trees, and pattern avoiding permutations and matchings, and derive a functional equation that is useful in analyzing the involved structures.

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MS16

Barely Set-valued Tableaux and Nonintersecting Paths in Young Diagrams

Let λ be an integer partition and k be a positive integer, and let $\mathrm{BSSYT}(\lambda, k)$ represent the set of barely set-valued semistandard Young tableaux of shape λ such that the values in row i cannot exceed $k+i$. When λ is the rectangular staircase shape $\delta_d(b^a)$, Reiner, Tenner and Yong posed a conjecture on the cardinality of $\mathrm{BSSYT}(\delta_d(b^a), k)$. In this talk, we show that the cardinality of $\mathrm{BSSYT}(\lambda, k)$ is equal to the number of left turns or the number of right turns over k-tuples of nonintersecting paths in λ. The latter number has been computed by Chan, Haddadan, Hopkins and Moci using probabilistic techniques. When $\lambda = \delta_d(b^a)$, we are led to a proof of the conjecture of Reiner, Tenner and Yong. We also construct two bijections between the set of k-tuples of nonintersecting paths in λ and the set of fillings of λ with nonnegative integers such that the length of any southeast chain cannot exceed k. These two bijections imply that the number of left turns and the number of right turns are equidistributed over k-tuples of nonintersecting paths in λ. When $k = 1$ and λ is the staircase shape, such an equidistribution has been proved by Deutsch by constructing an involution on Dyck paths.

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MS16
Mahonian-Stirling Statistics on Labeled Trees

It is a classical result of MacMahon that the number of inversions and the major index have the same distribution over permutations and words and in his honor the permutation/word statistics with the same distribution are called Mahonian. Even stronger result is that the pairs (inversions, right-to-left minima) and (major index, right-to-left minima) have the same distribution over S_n. An analogue of MacMahon's result has been proven for (signed and unsigned) labeled rooted forests. Here we present how one can generalize the sorting index, another Mahonian statistic, to the setting of labeled trees. We also discuss what happens when we consider so called Stirling partners (analogues of right-to-left minima) for each of these three statistics and give some open questions.

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MS16
Log-behavior of Partition Function

The Turán inequalities and the higher order Turán inequalities arise in the study of Maclaurin coefficients of an entire function in the Laguerre-Pólya class. A real sequence $\{a_n\}$ is said to satisfy the Turán inequalities if for $n \geq 1$, $a_n^2 - a_{n-1}a_{n+1} \geq 0$. It is said to satisfy the higher order Turán inequalities if for $n \geq 1$, $4(a_n^2 - a_{n-1}a_{n+1})(a_{n+1}^2 - a_n a_{n+2}) - a_n a_{n+1} - a_{n-1}a_{n+2})^2 \geq 0$. A sequence satisfying the Turán inequalities is also called log-concave. For the partition function $p(n)$, DeSalvo and Pak showed that for $n > 25$, the sequence $\{p(n)\}_{n>25}$ is log-concave and proposed a conjecture on the upper bound for the 2-order difference of $\log p(n)$. We proved this conjecture and gave the bounds for any finite difference of $\log p(n)$. Then, by using the Hardy-Ramanujan-Rademacher formula to derive an upper bound and a lower bound for $p(n+1)p(n-1)/p(n)^2$ we prove that $p(n)$ satisfies the higher order Turán inequalities for $n \geq 95$, which was conjectured by Chen. Consequently, for $n \geq 95$, the Jensen polynomials $g_{3,n-1}(x) = p(n-1) + 3p(n)x + 3p(n+1)x^2 + p(n+2)x^3$ have only real zeros. Furthermore, we show that $p(n)$ satisfies the double Turán inequalities for $n \geq 222$.

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MS16
Parking Distributions on Trees

We consider a generalization of parking functions to parking distributions on trees and study the unordered version and a q-analogue. We give an efficient way to form generating functions to compute these values and establish the positivity and log-concavity of a related polynomial, which replies on the structure of the underlying trees. We present various enumerative results, including the number of total parking distributions and prime parking distributions, and the connections to lattice paths.

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MS17
Homomorphism Duals for 2-Edge-Coloured Paths

Homomorphisms of digraphs to transitive tournaments can be characterized by the well-known duality result with directed paths: a digraph $G \to \overrightarrow{T_n}$ if and only if $\overrightarrow{P}_{n+1} \not\to G$. For the general situation, such duality results are fully characterized by the work of Nešetřil and Tardif. In this work we study duality results for 2-edge-coloured paths in attempt to find analogues of transitive tournaments in the class of 2-edge-coloured graphs. We present a direct construction producing much smaller graphs than the Nesetril-Tardif *bear construction*. We also discuss attempts to generalize Minty's Theorem.

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MS17
The Selective Coloring Problem

The Selective Graph Coloring Problem (SelCol), also known as partition coloring, is a generalization of the standard graph coloring problem; given a graph with a partition of its vertex set into clusters, the objective is to choose exactly one vertex per cluster so that, among all possible selections, the number of colors necessary to color the vertices in the selection is minimum. We first present some applications that can be modeled using SelCol and emphasize the flexibility carried out by this model in comparison with the classical graph coloring. We will note that each one of these applications motivates the study of SelCol in a different class of graphs and sometimes with particular types of clusters. Consequently we investigate the complexity of SelCol in those special cases. In particular, we show that although SelCol is NP-hard in (linear) interval graphs, it becomes polynomially solvable under some assumptions on the clustering. Subsequently, we introduce a related problem, SelCol+, which corresponds to evaluating the cost of the worst selection. By revisiting some models for SelCol, we emphasize that solving SelCol+ can be helpful when one does not have full control over the selection process. In such a context, we compare the complexities of SelCol and SelCol+ in graph classes motivated by applications. If time permits, we will also very briefly mention the principles of our decomposition based exact solution framework for SelCol.

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MS17
Fractional Cocolorings of Graphs

The cochromatic number of a graph is the fewest number of colors needed to color the vertices so that each color class induces a complete or empty graph. In this talk we consider the fractional counterpart, defined as follows. In a fractional cocoloring we assign a non-negative number to each clique and independent set in such a manner that for each vertex v, when we sum the values on all cliques and independent sets containing v, we get a sum of at least one. The value of such a fractional coccoloring is the sum of the labels on each clique and independent set. The fractional cochromatic number is the minimum value from all fractional cocolorings. We compare chromatic numbers and fractional cochromatic numbers..

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MS17
Frugal Colourings and Homomorphisms

A k-colouring of a graph G is t-frugal if, for every vertex x of G, at most t vertices in the neighbourhood of x have the same colour. We give a dichotomy theorem for the complexity of deciding whether a given graph has a t-frugal k-colouring, and bounds on the number of colours required to t-frugally colour a graph of given maximum degree. We also discuss restricting the problem to some special graph classes, and the more general topic of t-frugal homomorphisms.

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MS17
The Slow-Coloring Game

The *slow-coloring game* is played by Lister and Painter on a graph G. Initially, all vertices of G are uncolored. In each round, Lister marks a non-empty set M of uncolored vertices, and Painter colors a subset of M that is independent in G. The game ends when all vertices are colored. The score of the game is the sum of the sizes of all sets marked by Lister. The goal of Painter is to minimize the score, while Lister tries to maximize it; the score under optimal play is the *cost*. A greedy strategy for Painter keeps the cost of G to at most $\chi(G)n$ when G has n vertices, which is asyptotically sharp for Turan graphs. On various classes Painter can do better. For n-vertex trees the maximum cost is $\lfloor 3n/2 \rfloor$. There is a linear-time algorithm and inductive formula to compute the cost on trees, and we characterize the extremal n-vertex trees. Also, Painter can keep the cost to at most $(1 + 3k/4)n$ when G is k-degenerate, $7n/3$ when G is outerplanar, and $3.9857n$ when G is planar. These results involve various subsets of Grzegorz Gutowski, Tomasz Krawczyk, Thomas Mahoney, Gregory J. Puleo, Hehui Wu, Michal Zajac, and Xuding Zhu.

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MS18
The Language of RNA Base Pairings

An RNA sequence folds into a 3d structure via a set of (canonical, noncrossing) pairings/matchings between complementary nucleotide bases. Although thermodynamic optimization is the dominant base pairing prediction paradigm, formal languages are an important alternative. Here we consider the asymptotic distribution of substructures in the best stochastic context free grammar (SCFG) model of RNA base pairings. We also give preliminary results on the challenge of identifying multimodal structural distributions under the best practice of incorporating auxiliary experimental data into the base pairing predictions.

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MS18
Network-based Investigation of Mutational Profiles Reveals Cancer Genes

Cancer is a genetic disease where a body's own cells acquire mutations that allow them to grow uncontrollably. To uncover the genetic determinants of cancer, the genomes of thousands of tumors across tens of cancer types have been sequenced. Initial analyses have revealed that each individuals tumor typically contains numerous mutations, only a subset of which are cancer-relevant, and that the mutations across tumors can differ vastly. Thus, identifying the alterations that give rise to cancer is extremely challenging. Networks provide a unifying framework to uncover genes causal for cancers, as specific functions tend to be disrupted in cancers, and functionally related genes tend to be proximal in interaction networks. I will introduce a network-based method that identifies small connected subnetworks of genes that, while not individually frequently mutated, together are perturbed across (i.e., "cover") a large fraction of the individuals. We devise an intuitive objective function for this task and solve the problem optimally, using integer linear programming, and efficiently with a fast heuristic. We apply our method to 24 cancer types and uncover both well-known cancer genes as well as new potential cancer-related genes. Overall, our work demonstrates the power of combining per-individual mutational information with interaction networks in order to uncover genes functionally relevant in cancers, and especially those genes that are less frequently mutated.

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MS18
New Directions in Deconvolving Genomic Mixtures of Copy Number Variation Data

We examine a problem motivated by cancer genomics: deconvolving mixtures of genomic copy number data to infer subpopulations of cells making up a heterogeneous sample. We focus on the evolution of a basic mixed membership model formulation to encompass continuing advances in the experimental data sources available for this work. We specifically consider model extensions to take better advantage of multi-regional sampling in which one has samples from distinct subregions of a mixture, structural variant information describing large-scale rearrangements in cellular genomes, and single-cell sequencing data providing noisy partial data on isolated cells. In each case, we consider how models can be extended to accommodate the novel data sources and how we can then solve the associated optimization problems to fit models to real data.

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MS18
Two Problems on Tree-based Networks

Tree-based networks, which may be roughly defined as leaf-labeled networks built by adding arcs only between edges of its base tree, have elegant properties for modeling evolutionary histories. They were developed to answer the question: how tree-like is evolution? Francis and Steel showed that determining if a network is tree-based can be decided in polynomial time via a reduction to 2SAT. We show that it is NP-hard to determine if a network is based on a specific tree by reduction from 3-Dimensional Matching (3DM). We also show that the question of how far a network is from being tree-based is NP-hard via a reduction from Max-2SAT. This is joint work with Katherine St. John (Hunter College) and our Research Experience for Undergraduates (REU) students from Fall 2015 and Fall 2017.

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MS18
Multi de Bruijn Sequences

We generalize the notion of a de Bruijn sequence to a “multi de Bruijn sequence”: a cyclic or linear sequence that contains every k-mer over an alphabet of size q exactly m times. For example, over the binary alphabet $\{0,1\}$, the cyclic sequence (00010111) and the linear sequence 000101110 each contain two instances of each 2-mer $00, 01, 10, 11$. We derive formulas for the number of such sequences. The formulas and derivation generalize classical de Bruijn sequences (the case $m = 1$). We also determine the number of multisets of aperiodic cyclic sequences containing every k-mer exactly m times; for example, the pair of cyclic sequences (00011)(011) contains two instances of each 2-mer listed above. This uses an extension of the Burrows-Wheeler Transform due to Mantaci et al., and generalizes a result by Higgins for the case $m = 1$.

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MS19
Enumeration on Row-increasing Tableaux of Shape $2 \times n$

In this talk I will present some recent results on counting major and amajor index of increasing and row-increasing tableaux. In 2014 O. Pechenik studied the cyclic sieving of increasing tableaux of shape $2 \times n$, and obtained a polynomial on the major index of these tableaux, which is a q-analogue of refined small Schröder numbers. We define row-increasing tableaux and study the major and amajor index of row-increasing tableaux of shape $(2 \times n)$. The resulting polynomials are both q-analogues of refined large Schröder numbers. For both results we give bijective proofs. This is joint work with Xiaojie Fan and Yue Zhao.

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MS19
Two Types of Quasisymmetric Power Sums

Symmetric functions (SYM) have a number of well known bases: the monomials are dual to the complete homogeneous functions, the elementary basis is dual to the forgotten basis, while the Schur functions and the power sums (up to rescaling) are each self dual. Two related spaces, the quasisymmetric functions (QSYM) and the noncommutative symmetric functions (NSYM) are dual as combinatorial Hopf algebras, and most of these well known bases of SYM have analogues in one of QSYM and NSYM (or both, if the basis was self dual in SYM). In Gelfand et. als 1995 paper, they define not just one but two analogues of the power sum basis in NSYM using generating functions. The duals of their bases, up to scaling, are naturally the quasisymmetric power sums, the subject of this talk. In contrast to the simplicity of the symmetric power sums, or the other well known bases of the quasisymmetric functions, the quasisymmetric power sums have a more complex combinatorial description. Thus, although symmetric function proofs often translate directly to quasisymmetric analogues, this is not the case for quasisymmetric power sums. We discuss joint work with Ballantine, Daugherty, Mason, and Niese which explores the properties of these two families of quasisymmetric power sums.

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MS19

CLT for Descents in Matchings and Derangements

The distribution of descents in certain conjugacy classes of S_n have been previously studied, and it is shown that its moments have interesting properties. We use a symmetry of descents in matchings to prove a central limit theorem for the number of descents in matchings by a generating function approach. We then extend this result to derangements.

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MS19

New Duals of MacMahon's Theorem on Plane Partitions

The enumeration of tilings dates back to the early 1900s when MacMahon proved his classical theorem on the number of boxed plane partitions. The theorem is equivalent to an exact enumeration of lozenge tilings of a region restricted by a hexagonal contour. Recently Ciucu and Krattenthaler introduced 'duals' of MacMahon's theorem. Intuitively, instead of considering the number of tilings inside a given hexagonal contour as in MacMahon's enumeration, they considered the asymptotic tiling number of a region outside a given contour. They found a couple of striking asymptotic patterns of this type, that are similar to the formula in MacMahon's theorem. In this talk, we investigate several new duals of MacMahon's theorem. We also present q-analogs of these results, which enumerate the corresponding plane-partition-like structures by their volume.

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MS20

The Normalized Laplacian Matrix and Qualitative Properties of Graphs Including Random Walks

The normalized Laplacian matrix for a graph can yield important (qualitative) information about a graph, including things such as connectivity, and expansion, but struggles in some (quantitative) information about a graph, including things such as number of edges. We look at what is known about the normalized Laplacian, how we can understand the spectrum, including examples for cospectral constructions. We also give connections to random walks and show how the normalized Laplacian can be used to understand Kemeny's constant.

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MS20

Forbidden Subgraphs and Equiangular Lines

The spectral radius of a graph is the largest eigenvalue of its adjacency matrix. For every λ, let $\mathcal{F}(\lambda)$ be the family of graphs of spectral radius $\leq \lambda$. It is well known that $\mathcal{F}(\lambda)$ is closed under taking subgraphs. For which λ can $\mathcal{F}(\lambda)$ be defined by a finite set of forbidden subgraphs? In this talk, I will give an answer to this question and illustrate its connection with the problem of estimating the maximum cardinality of equiangular lines in the n-dimensional Euclidean space — a family of lines through the origin such that the angle between any pair of them is the same. Joint work with Alexandr Polyanskii.

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MS20

Graphs Whose Distance Matrices Have the Same Determinant

In 1971, Graham and Pollak introduced an addressing scheme for communication where each vertex is labeled with a string in $\{1, 0, *\}$ such that the distance of every pair of vertices is the same as the Hamming distance of their labels. In the same paper, they showed the inertia of the distance matrix can be used to lower bound the length of such strings; they also proved that the determinant of the distance matrix of a tree only depends on the order, but not the structure of the tree. Later in 1977, Graham, Hoffman, and Hosoya extended this result by showing that the distance determinant only depends on the blocks of a graph but not how the blocks attach to each other. In this talk, we will introduce another family of graphs such that the distance determinant is independent of the structure. For these graphs, we compute the determinant, the cofactor, and the inertia of the distance matrix; and the formulas only depends on the input parameters but not the structure.

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MS20

Rainbow Spanning Trees in General Graphs

A rainbow spanning tree in an edge-colored graph is a spanning tree in which each edge is a different color. Carraher, Hartke, and Horn showed that for n and C large enough, if G is an edge-colored copy of K_n in which each color class has size at most $n/2$, then G has at least $\lfloor n/(C \log n) \rfloor$ edge-disjoint rainbow spanning trees. Here we strengthen this result by showing that if G is *any* edge-colored graph with n vertices in which each color appears on at most $\delta \cdot \lambda_1/2$ edges, where $\delta \geq C \log n$ for n and C sufficiently large and λ_1 is the second-smallest eigenvalue of the normalized Laplacian matrix of G, then G contains at least $\left\lfloor \frac{\delta \cdot \lambda_1}{C \log n} \right\rfloor$ edge-disjoint rainbow spanning trees.

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MS20

Balanced Set Type Conditions

In Paul Terwilliger's papers "A characterization of P- and Q-polynomial association schemes' and "Balanced sets and Q-polynomial association schemes,' he introduced certain conditions on sets of unit vectors which, in the context of association schemes, are equivalent to the scheme having a nontrivial sparse representation diagram (specifically a tree with possible loops, an augmented tree or tree). In this talk we will discuss recent work from the thesis of Gavin King on such sets of vectors, including new examples and partial classification results. We will conclude with conjectures concerning the relationship between sets of vectors with these conditions and the Q-polynomial property.

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MS21

Recent Progress Toward Goldberg's Conjecture

Gupta (1967), Goldberg (1973), Andersen (1977), and Seymour (1979) independently made the following conjecture: For every multigraph G, if $\chi'(G) > \Delta(G) + 1$ then $\chi'(G) = w(G)$, where $\chi'(G)$ is the chromatic index of G and $w(G) = \max_{H \subseteq G} \left\lceil \frac{|E(H)|}{\lfloor \frac{1}{2}|V(H)| \rfloor} \right\rceil$ is the density of G. The conjecture is commonly referred as Goldberg's Conjecture. We will present recent progress toward this conjecture.

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MS21

Delay Edge-colouring Bipartite Graphs

Consider a bipartite graph $G = ((X, Y), E)$ equipped with a delay function d from its edges to the integers. We say G is t-delay-colourable if for any choice of delay function, there exists an assignment $\rho : t \to E$ satisfying the following condition. For any pair of edges e, f meeting in X, $\rho(e) \neq \rho(f)$ mod t, and for any pair of edges e, f meeting in Y, $\rho(e)+d(e) \neq \rho(f)+d(f)$ mod t. Delay colouring was introduced by Haxell, Wilfong and Winkler who were motivated by applications in optical network scheduling. They conjectured that every bipartite graph is $\Delta(G) + 1$-delay-colourable, where $\Delta(G)$ denotes the maximum degree. We discuss recent progress on the conjecture, including a proof for graphs with maximum degree at most 4.

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MS21

t-Cores for $(\Delta + t)$-edge-colouring

We extend the edge-coloring notion of *core* (subgraph induced by the vertices of maximum degree) to *t-core* (subgraph induced by the vertices v with $d(v) + \mu(v) > \Delta + t$), and find a sufficient condition for $(\Delta+t)$-edge-colouring. In particular, we show that for any $t \geq 0$, if the t-core of G has multiplicity at most $t+1$, with its edges of multiplicity $t+1$ inducing a multiforest, then $\chi'(G) \leq \Delta + t$. This extends previous work of Ore, Fournier, and Berge and Fournier. More generally, we prove bounds on the *fan number* of a graph G, a parameter introduced by Scheide and Stiebitz as an upper bound on the edge chromatic number. We give an exact characterization of the multigraphs H such that $\mathrm{Fan}(G) \leq \Delta(G) + t$ for all graphs G having H as their t-core. We show how this characterization implies a theorem of Hoffman and Rodger about cores of Δ-edge-colourable simple graphs.

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MS21

Star Edge-colorings of Subcubic Multigraphs

The star chromatic index of a multigraph G, denoted $\chi'_s(G)$, is the minimum number of colors needed to properly color the edges of G such that no path or cycle of length four is bi-colored. A multigraph G is star k-edge-colorable if $\chi'_s(G) \leq k$. Dvořák, Mohar and Šámal in 2013 proved that every subcubic multigraph is star 7-edge-colorable. They conjectured in the same paper that every subcubic multigraph should be star 6-edge-colorable. In this talk, I will present our recent work on this conjecture. We prove that it is NP-complete to determine whether $\chi'_s(G) \leq 3$ for an arbitrary graph G. This answers a question of Mohar. Applying the discharging method, we prove that every subcubic multigraph G is star 6-edge-colorable if $mad(G) < 5/2$, and star 5-edge-colorable if $mad(G) < 12/5$, respectively, where $mad(G)$ is the maximum average degree of a multigraph G. This is joint work

with Hui Lei, Yongtang Shi and Tao Wang.

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MS22

The 4/3 Additive Spanner Exponent Is Tight

A spanner is a sparse subgraph that approximately preserves the pairwise distances of the original graph. It is well known that there is a smooth tradeoff between the sparsity of a spanner and the quality of its approximation, so long as distance error is measured *multiplicatively.* A central open question in the field is to prove or disprove whether such a tradeoff exists also in the regime of *additive* error. That is, is it true that for all $\epsilon > 0$, there is a constant k_ϵ such that every graph has a spanner on $O(n^{1+\epsilon})$ edges that preserves its pairwise distances up to $+k_\epsilon$? Our main result is a surprising negative resolution of the open question, even in a highly generalized setting. We show a new information theoretic *incompressibility* bound: there is no function that compresses graphs into $O(n^{4/3-\epsilon})$ bits so that distance information can be recovered within $+n^{o(1)}$ error. As a special case of our theorem, we get a *tight* lower bound on the sparsity of additive spanners: the +6 spanner on $O(n^{4/3})$ edges cannot be improved in the exponent, even if any *subpolynomial* amount of additive error is allowed. Our theorem implies new lower bounds for related objects as well; for example, the twenty-year-old +4 emulator on $O(n^{4/3})$ edges also cannot be improved in the exponent unless the error allowance is polynomial.

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MS22

Duality, Flows, and Shortest Paths in Planar Graphs

Even as far back as Ford and Fulkerson's paper on the max flow-min cut theorem, researchers have sought efficient algorithms for computing flows and cuts in plane graphs. The search for these algorithms has led to many surprising observations connecting planar graph duality, flows, and shortest paths. In this talk, I will discuss a handful of these observations and their consequences, including a new result on how dual spanning trees can be used to isolate minimum cost flows and shortest paths.

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MS22

Explicit Constructions of Ramsey Graphs via Randomness Extractors

An (N, K) Ramsey graph is a graph on N vertices with no clique or independent set of size K. In his 1947's seminal paper that inaugurated the probabilistic method, Erdős showed the existence of Ramsey graphs on N vertices with $K = O(\log N)$. It has since been a major open problem in combinatorics to construct explicit graphs that match this bound. Until 2006, the best known construction was by Frankl and Wilson, who gave an explicit Ramsey graph on N vertices with $K = 2^{\tilde{O}(\log N)}$. However, recently this problem has seen significant progress by exploiting the connections to a fundamental object in theoretical computer science known as randomness extractor. Today we have explicit constructions of Ramsey graphs on N vertices with $K = (\log N)^{O(\frac{\log\log\log N}{\log\log\log\log N})}$. In this talk I will briefly describe the connections and the techniques used in achieving this result.

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MS22

Fine-grained Complexity, Meta-algorithm and their Connections with Extremal Graph Theory

In this talk, we will focus on three extremal graph theory problems. The first one is about a conjecture of minimum rectilinear Steiner tree: in 1955, Few asked the question what is the minimum Steiner tree of n points in a unit square. 25 years later, Chung and Graham gave a tighter bounded and conjectured that the minimum rectilinear Steiner tree of $n (n \geq 2)$ points in a unit square is bound by $\sqrt{n} + 1$, which is still open. The second problem is related to one question of Erdös, he asked the question how to make a triangle-free graph to be bipartite? It was conjectured that if G is a simple triangle-free graph, then there is a set of at most $\frac{n^2}{25}$ edges whose deletion destroys every odd cycle. The Third problem is Lovász path removal conjecture (1975): there is an integer valued function $f(k)$ such that if G is any $f(k)$-connected graph has s and t are any two vertices of G, then there exists an induced path P with ends s and t such that $G - V(P)$ is k-connected. We will show how the fine-grained complexity and meta-algorithm results provide a better understanding of properties of those problems and show some corresponding structural results.

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MS22

A Fast New Algorithm for Weak Graph Regularity

Szemerédi's regularity lemma and its variants are some of the most powerful tools in combinatorics. This talks concerns some algorithmic aspects of the regularity lemma. We give a fast new deterministic algorithm that finds a weak regular partition of a graph. As an application, we give a new deterministic algorithm for approximating the number of copies of a fixed graph in a large graph, running in time quadratic in the number of vertices of the large graph.

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MS23

Hamilton Connectedness of Sdr Graphs

We discuss a class of graphs called *SDR graphs*, whose vertices correspond to Systems of Distinct Representatives (SDRs) of a specified collection of sets S, with two vertices adjacent if and only if their corresponding SDRs assign a different representative to exactly one set of S. The SDR graph G_S corresponding to the set collection S is shown to be connected if and only if a condition, similar to Hall's condition for the existence of an SDR, is satisfied. Finally, G_S is shown to be Hamilton connected whenever the number of distinct elements appearing in the sets of S is greater than twice the number of sets in S, and this bound is shown to be best possible.

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MS23

Invitation to Combinatorial Reconfiguration

Reconfiguration problems ask the reachability/connectivity of the solution space formed by feasible solutions of a combinatorial (search) problem. This framework has been applied to many central combinatorial problems in recent years, such as Satisfiability, Independent Set, and Coloring. Because the number of feasible solutions is usually exponential in the input size, it is a challenge to solve reconfiguration problems efficiently. Indeed, most reconfiguration problems are PSPACE-complete in general, although several efficiently solvable cases have been obtained recently. In this talk, I will give a broad introduction of combinatorial reconfiguration, and invite you to this exciting topic.

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MS23

Reconfiguration of Common Independent Sets of Matroids

We consider solution graphs of combinatorial problems that arise from their characterization in terms of common independent sets of matroids. In particular, we investigate the complexity of the following variant of the reachability problem: Given ℓ matroids, two sets S and T that are simultaneously independent in each matroid, and a number k, is it possible to transform S into T by adding or removing a single item in each step, such that after each step we have a common independent of cardinality at least $k-1$? We show that for $\ell = 2$ the problem can be solved in polynomial time for a large class of matroids. To this end we generalize an alternating paths-based algorithm for the reconfiguration of matchings. For $\ell \geq 3$ the problem is PSPACE-complete even for a severely restricted class of matroids. As a by-product of the hardness result, we show PSPACE-hardness of restricted variants of Positive Not-All-Equal 3-SAT Reconfiguration and Stable Set Reconfiguration.

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MS23

Reconfiguring Graph Colourings and Homomorphisms

The *reconfiguration problem* for graph colourings asks, given two proper k-colourings f and g of a graph G, is it possible to transform f into g by performing a sequence of single-vertex recolourings such that every intermediate mapping is a proper k-colouring? We consider a generalisation of this problem to graph homomorphisms. A *homomorphism* from a graph G to a graph H, also known as an H-colouring, is a mapping from $V(G)$ to $V(H)$ which preserves adjacency. Proper graph colourings can be seen as H-colourings where H is a clique. In this talk, we will discuss some recent results on the computational complexity of the reconfiguration problem for H-colourings and other related problems and mention a number of conjectures and open questions.

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MS23

The Independent Domination Graph

The *i-graph* of a graph G, denoted $\mathcal{I}(G)$, is the graph with vertices representing the minimum independent dominating sets of G (that is, the *i-sets* of G). Adjacency in $\mathcal{I}(G)$ follows a token sliding model where $u, v \in V(\mathcal{I}(G))$, corresponding to the i-sets S_u and S_v, respectively, are adjacent in $\mathcal{I}(G)$ if and only if there exists $xy \in E(G)$ such that $S_u = (S_v - x) \cup \{y\}$. A graph H is said to be an i-graph, or *i-graph realizable*, if there exists some graph G such that $\mathcal{I}(G) \cong H$. We present new results concerning the i-graph realizability of several classes of graphs, including block graphs, line graphs, and theta graphs.

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MS24

Forcing Oriented Cycles

Motivated by the well-known Caccetta-Häggkvist Conjecture, Kelly, Kühn and Osthus made a conjecture on minimal semidegree forcing directed cycle of a given length and proved it for cycles of length not divisible by 3. In the talk we will present an overview of a proof of all the remaining cases of their conjecture.

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MS24

Extremal Graph Theory and Finite Forcibility

We study the uniqueness of optimal solutions to extremal graph theory problems. Our main result is a counterexample to a conjecture of Lovsz. The conjecture is often referred to as saying that "every extremal graph theory problem has a finitely forcible optimum". More precisely, the conjecture (which we show to be false) says that every finite feasible set of subgraph density constraints can be extended further by a finite set of subgraph density constraints such that the resulting set of constraints is satisfied by a unique graphon (up to equivalence).

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MS24

Step Sidorenko Property and Non-Norming Edge-Transitive Graphs

A graph H has the step Sidorenko property if a quasirandom multipartite graph minimizes the density of H among all graphs with the same edge densities between its parts. We show that many bipartite graphs fail to have the step Sidorenko property and use our results to show the existence of a family of bipartite edge-transitive graphs that are not weakly norming, answering a question of Hatami [Israel J. Math. 175 (2010), 125150].

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MS24

Inducibility in Graphs

In 1975, Golumbic and Pippenger observed that an iterated balanced blow up of a graph contains many induced copies of this graph. We further analyze the question for which graphs this bound is optimal.

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MS24

Large Multipartite Subgraphs of H-Free Graphs

A long-standing conjecture of Erdős states that any n-vertex triangle-free graph can be made bipartite by deleting at most $n^2/25$ edges. In this talk, we study how many edges need to be removed from an H-free graph for a general graph H. Generalizing a result of Sudakov for 4-colorable graphs H, we show that if H is 6-colorable then G can be made bipartite by deleting at most $4n^2/25$ edges. Moreover, this amount is needed only in the case G is a complete 5-partite graph with balanced parts. As one of the steps in the proof, we use a strengthening of a result of Füredi on stability of Turán's theorem.

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MS25

Pebbling on Graph Products and More!

Pebbling on graphs is a two-player game which involves repeatedly moving a pebble from one vertex to another by removing another pebble from the first vertex. The pebbling number $\pi(G)$ is the least number of pebbles required so that, regardless of the initial configuration of pebbles, a pebble can reach any vertex. Graham conjectured that the pebbling number for the cartesian product, $G \times H$, is bounded above by $\pi(G)\pi(H)$. We show that $\pi(G \times H) \leq 2\pi(G)\pi(H)$ and, more sharply, that $\pi(G \times H) \leq (\pi(G) + |G|)\pi(H)$. Furthermore, we provide similar results for other graph products and graph operations.

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MS25

Graph Pebbling Algorithms, Doppelgangers, and Lemke Graphs

In this talk I will briefly discuss algorithms to determine solvability and reachability, the pebbling number, and whether or not a graph has the two-pebbling property. These algorithms were used to determine that there are 22 Lemke graphs on eight vertices, 306 on nine, and (probably) 5958 on ten, all diameter-three graphs. Although some of the Lemke graphs are closely related to the original Lemke graph, others are vastly different. In this talk we will look at some of these new Lemke graphs and a new family of Lemke graphs that can be constructed using what we call doppelganger vertices. We will also give a conjecture about another family of Lemke graphs. Finally, we will present a surprising counterexample to a widely held belief in graph pebbling (unfortunately, not Graham's conjecture).

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MS25

Pebbling on Split Graphs

The pebbling number of a graph G is the least k such that given any distribution of k pebbles on the vertices of G and any target vertex v of G, a pebble can be brought to v trough a sequence of movements, each move taking two pebbles out of any vertex of G and placing one pebble on any other vertex adjacent to it. Computing the pebbling number is difficult in general. The problem of deciding, given G and k, whether G has pebbling number at most k was shown to be Π_2^{P}-complete. On the other hand, it is known that the pebbling number of a diameter two graph G is $|V(G)|$ or $|V(G)| + 1$. Diameter two graphs with pebbling number $|V(G)|$ have been totally described and can be recognized efficiently. In this work we consider that problem restricted to an important family of diameter three graphs called split graphs: the vertex set can be partitioned into a clique and an independent set. Split graphs are also characterized as those chordal graphs whose complement is chordal. We exhibit split graphs whose pebbling number reaches $\lfloor \frac{3}{2}|V(G)|\rfloor + 2$, the known upper bound for the pebbling number of diameter three graphs. We describe the structure of split graphs with pebbling number equal to $|V(G)|$ and $|V(G)| + 1$, respectively. We provide a formula for calculating the pebbling number of any split graph which can be computed efficiently.

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MS25

Pebbling on Semi-2-Trees

As we know computing the pebbling number is difficult in general. In contrast, the pebbling number is known for many graphs classes. Continuing with the program to study for which graphs their pebbling number can be computed in polynomial time, the authors produced a formula for the family of split graphs. The authors also conjectured that the pebbling number of a chordal graph of bounded diameter can be computed in polynomial time. In opposition to the small diameter, large tree width case of split graphs, we turn here to chordal graphs with large diameter and small tree width. A *simplicial* vertex in a graph is a vertex whose neighbors form a complete graph. It is *k-simplicial* if it also has degree k. A *k-tree* is a graph G that is either a complete graph of size k or has a k-simplicial vertex v for which $G - v$ is a k-tree. A *k-path* is a k-tree with exactly two simplicial vertices. A *semi-2-tree* is a graph in which each of its blocks is a 2-path, with each of its cut-vertices being simplicial in all of its blocks. In this talk we study the pebbling number of 2-paths, as well as semi-2-trees. We develop news tools in order to prove an exact formula that can be computed in linear time in both cases.

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MS25

A Brief Introduction to Graph Pebbling

In this talk, we give an overview of graph pebbling and its many variations as well as its rich history. This includes a summary of key techniques, main results, and open problems.

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MS26

Projective Planarity of 3-Nets and Biased Graphs

A biased graph is a graph with a class of selected circles called "balanced', such that no theta subgraph contains exactly two balanced circles. This graph gives rise to two matroids; the frame matroid and lift Matroid. A classical open question in matroid theory is whether a matroid of rank three can be embedded in a projective plane. In this talk we discuss a criteria for the embeddability of the frame matroid and lift Matroid in an arbitrary projective plane that is not necessarily Desarguesian. (In 2003 Zaslavsky gave criteria for the embeddability of those matroids in Desarguesian projective spaces.) The criteria depend on the embeddability of a quasigroup associated to the biased graph into the additive or multiplicative loop (a quasigroup with unity) of a ternary coordinate ring for the projective plane. Much is not known about embedding a quasigroup into a ternary ring, so we do not say our criteria are definitive. For instance, it is not even known whether there is a finite quasigroup that cannot be embedded in any finite ternary ring. If there is, then there is a finite rank-3 matroid (of the corresponding biased graph) that cannot be embedded in any finite projective plane—presently an unsolved problem. Joint work with Tom Zaslavsky.

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MS26

Algebraic Structures Related to Matroid Theory

In this talk I will describe certain algebraic structures related to Matroid Theory. After defining a matroid over a ring, I will focus on matroids over a field k and matroids over the integers Z.

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MS26

Interlacement and Activities in Delta-Matroids

We generalize theories of graph, matroid, and ribbon-graph activities to delta-matroids. As a result, we obtain an activities based feasible-set expansion for a transition polynomial of delta-matroids defined by Brijder and Hoogeboom. This result yields feasible-set expansions for the two-variable Bollobás-Riordan and interlace polynomials of a delta-matroid. In the former case, the expansion obtained directly generalizes the activities expansions of the Tutte polynomial of graphs and matroids.

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MS26

Graph and Matroid Designs

Characterizations of graphs and matroids that have cycles or circuits of specified cardinality have been given by authors including Edmonds, Junior, Lemos, Murty, Reid, Young, and Wu. In particular, a matroid with circuits of a single cardinality is called a Matroid Design. This talk presents joint work with Costalonga, Hart, Lemos, and Wu that characterizes some such classes of graphs of matroids with circuits of a few different cardinalities.

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MS26

Delta-Matroids and Rigidity Matroids

Planar rigidity is well studied and characterized. Rigidity and planarity have little to do with each other, but for some practical applications, for example in mechanical engineering, it is desirable to have a planar underlying graph for a particular mechanism. Recently the study of rigidity for graphs embedded on other surfaces received some attention. We will show how delta matroids can be used to describe the rigidity of graphs whose vertices are constrained to move on a fixed cylinder or torus. This is joint work with Avohou Remi Cocou.

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MS27

Dynamic Parameterized Problems and Algorithms

Abstract Not Available At Time Of Publication.

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MS27

Solving Feedback Vertex Set via Half-Integral Relaxation

Feedback Vertex Set is a problem of finding a minimum vertex set whose removal makes the input graph a forest. In this talk, we present a $(4^k + |E|)k^{O(1)}$-time FPT algorithm for Feedback Vertex Set, where k is the solution size. A solver based on this algorithm won 1st place in the Parameterized Algorithms and Computational Experiments (PACE) challenge 2016. Our algorithm exploits half-integral relaxation, a powerful tool in the design of FPT algorithms. We first introduce a key property called persistency and then obtain an $O^*(4^k)$-time FPT algorithm and an $O(k^2)$-size kernel. Finally, we present a linear-time augmenting path algorithm for solving the half-integral relaxation.

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MS27

Delta Decomposition

Abstract Not Available At Time Of Publication.

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MS27

Modifications to Chodal Graphs

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MS28

Polychromatic Colorings of the Integers and Integers Mod N

Given a finite subset S of the integers, we say a coloring of the integers with r colors is S-polychromatic if every translate of S gets all r colors. The polychromatic number of S is the largest r for which there is an S-polychromatic coloring with r colors. We show that the polychromatic number of any set of size 4 is at least 3. A corollary is that the codensity of any set of size 4 in the integers is at most 1/3, confirming a conjecture of Newman. We also consider polychromatic colorings of the integers mod n, where aspects of the problem have a different flavor.

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MS28

Edge-Colouring Planar Graphs with Precoloured Edges

Let G be a planar graph and let H be a subgraph of G which has been properly edge-coloured with no more than $\Delta(G) + t$ colours. We show we can always extend this edge-colouring of H to a $\Delta(G) + t$-edge-colouring of G if $\Delta(G)$ is large enough. For us large enough can take on different bounds depending upon the relationship between t and $\Delta(H) \leq k$. For example if $t = k$, then $\Delta(G)$ must be at least $16 + k$.

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MS28

Polychromatic Colorings of Complete Graphs with Respect to 1-,2-factors and Hamiltonian Cycles

If G is a graph and $\mathcal{H}$ is a set of subgraphs of G, then an edge-coloring of G is called $\mathcal{H}$-polychromatic if every graph from $\mathcal{H}$ gets all colors present in G. The $\mathcal{H}$-polychromatic number of G, denoted $\mathrm{poly}_{\mathcal{H}}(G)$, is the largest number of colors such that G has an $\mathcal{H}$-polychromatic coloring. In this talk, we explore $\mathrm{poly}_{\mathcal{H}}(G)$ when G is a complete graph and $\mathcal{H}$ is the family of all 1-factors. In addition we determine $\mathrm{poly}_{\mathcal{H}}(G)$ up to an additive constant term when G is a complete graph and $\mathcal{H}$ is the family of all 2-factors, or the family of all Hamiltonian cycles.

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MS28

Total List Coloring of Planar Graphs

Total coloring is a variant of edge coloring where both vertices and edges are to be colored. A graph is totally k-choosable if for any list assignment of k colors to each vertex and each edge, we can extract a proper total coloring. In this setting, a graph of maximum degree D needs at least $D + 1$ colors. For a planar graph, Borodin proved in 1989 that $D + 2$ colors suffice when D is at least 9. In this talk, we explain how to improve this lower bound to 8.

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MS28

Independence Number of Edge-chromatic Critical Graphs

Let G be a simple graph with maximum degree $\Delta(G)$ and chromatic index $\chi'(G)$. A classic result of Vizing indicates that either $\chi'(G) = \Delta(G)$ or $\chi'(G) = \Delta(G)+1$. The graph G is called Δ-critical if G is connected, $\chi'(G) = \Delta(G) + 1$ and for any $e \in E(G)$, $\chi'(G - e) = \Delta(G)$. Let G be an n-vertex Δ-critical graph. Vizing conjectured that $\alpha(G)$, the independence number of G, is at most $\frac{n}{2}$. The current best result on this conjecture, shown by Woodall, is that $\alpha(G) < \frac{3n}{5}$. We show that for any given $\varepsilon \in (0, 1)$, there exist positive constants $d_0(\varepsilon)$ and $D_0(\varepsilon)$ such that if G is an n-vertex Δ-critical graph with minimum degree at least d_0 and maximum degree at least D_0, then $\alpha(G) < (\frac{1}{2}+\varepsilon)n$. In particular, we show that if G is an n-vertex Δ-critical graph with minimum degree at least d and $\Delta(G) \geq (d + 2)^{6d+12}$, then $\alpha(G) < \frac{7n}{12}$ if $d = 3$, $\alpha(G) < \frac{4n}{7}$ if $d = 4$, and $\alpha(G) < \frac{d+2+\sqrt[3]{(d-1)d}}{2d+4+\sqrt[3]{(d-1)d}}n$ if $d \geq 19$, where $\frac{d+2+\sqrt[3]{(d-1)d}}{2d+4+\sqrt[3]{(d-1)d}} < \frac{4}{7}$ when $d \geq 19$.

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MS29

Geometric Networks and Graph Limits

Many real-life networks can be modeled by stochastic processes with a spatial embedding. The spatial reality can be used to represent attributes of the vertices which are inaccessible or unknown, but which are assumed to inform link formation. The graph formation is then modeled as a stochastic process, where the probability of a link occurring between two vertices decreases as their metric distance increases. A fundamental question is to determine whether a given network is compatible with a spatial model. That is, given a graph how can we judge whether the graph is likely generated by a spatial model, and if so what is the underlying metric space? Using the theory of graph limits, we show how to recognize graph sequences produced by random graph processes with a linear embedding (a natural embedding into real line). In particular, we introduce parameters to measure the "geometricity' of the network, and to recognize almost-geometric networks. This talk is based on a joint papers with Chuangpishit, Hurshman, Janssen, and Kalyaniwalia.

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MS29

On Geometric Embedding of Graphs and Random Graphs

The graph model of a real-world problem consists of nodes or vertices which represent the entities of a real-life network, and the links or the edges identifying the relation between the entities of the network. These types of real-world networks usually share a common property that "the more similar the two entities are the higher the probability of being linked'. An appropriate way to take this fact into account is to consider a metric space in which the nodes are embedded so that the connections between the nodes are influenced by their metric distance. That is, similar nodes have smaller metric distance, and they are more likely to attach to each other if they are "close'. Such graph models are called *spatial models*. Consider the metric space $(\mathbb{R}^k, d)$, where d is a metric obtained from one of the L_p-norms. A natural question arising in the study of spatial graph models is as follows. Given a graph model G, whether the graph model is compatible with a notion of spatial graph model? In this talk the goal is to address this question for special classes of graphs and random graphs. The metric space, we consider, is $(\mathbb{R}^k, \|.\|_\infty)$, where $\|.\|_\infty$ is the metric derived from L_∞-norm. For $x, y \in \mathbb{R}^k$, the distance between $x = (x_1, \ldots, x_k)$ and $y = (y_1, \ldots, y_k)$ in the L_∞-metric is $\|x - y\|_\infty = \max_i |x_i - y_i|$.

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MS29

Random Geometric Graphs in Normed Spaces

Often, random geometric graphs are generated by placing points randomly in a metric space and then joining points within a fixed distance. Recently, Bonato and Janssen introduced another model in which the vertices are a fixed countable dense set in a normed space and pairs at distance at most 1 are joined by an edge with a given probability, independently of all others. While the properties of the resulting graph may depend heavily on the geometry of the underlying space and on the choice of the set of vertices, it was shown that in some cases, the graphs generated in this way will almost surely be isomorphic to each other. In these cases, the set of vertices is said to be *Rado*. I shall discuss some new results on Rado sets in arbitrary finite-dimensional normed spaces. This is based on joint work with Balister, Bollobás, Leader, and Walters.

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MS29

Infinite Random Geometric Graphs

Abstract Not Available At Time Of Publication.

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MS29

Layout of Random Circulant Graphs

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MS30

On the Turán Number of Ordered Forests

An ordered graph H is a simple graph with a linear order on its vertex set. The corresponding Turán problem, first studied by Pach and Tardos, asks for the maximum number $ex_<(n, H)$ of edges in an ordered graph on n vertices that does not contain H as an ordered subgraph. It is known that $ex_<(n, H) > n^{1+\varepsilon}$ for some positive $\varepsilon = \varepsilon(H)$ unless H is a forest that has a proper 2-coloring with one color class totally preceding the other one. Making progress towards a conjecture of Pach and Tardos, we prove that $ex_<(n, H) = n^{1+o(1)}$ holds for all such forests that are "degenerate' in a certain sense. This class includes every forest for which an $n^{1+o(1)}$ upper bound was previously known, as well as new examples. Our proof is based on a density-increment argument.

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MS30

Induced Subgraphs of Ramsey Graphs

An n-vertex graph is called C-Ramsey if it has no clique or independent set of size $C \log n$. We discuss two new additions to the ongoing line of research showing that all Ramsey graphs must obey certain "richness' properties characteristic of random graphs. First, resolving a conjecture of Narayanan, Sahasrabudhe and Tomon, motivated by an old problem of Erdős and McKay, we prove that every C-Ramsey graph has $\Omega(n^2)$ induced subgraphs with different numbers of edges. Second, resolving a conjecture of Erdős, Faudree and Sós, we prove that every C-Ramsey graph has $\Omega(n^{5/2})$ induced subgraphs, no two of which have the same numbers of vertices and edges.

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MS30

Counting Tree-Like Graphs in Locally Dense Graphs

We prove that a class of graphs obtained by gluing complete multipartite graphs in a tree-like way satisfies a conjecture of Kohayakawa, Nagle, Rödl, and Schacht on random-like counts for small graphs in locally dense graphs. This implies an approximate version of the conjecture for graphs with bounded tree-width. We also prove an analogous result for odd cycles instead of complete multipartite graphs. The proof uses a general information theoretic method to prove graph homomorphism inequalities for tree-like structured graphs, which may be of independent interest.

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MS30

The Erdos-Gallai Theorem for Berge-Cycles in Hypergraphs

The Erdős–Gallai theorem gives an upper bound for the maximum number of edges in a graph with bounded circumference. We prove an analogue of this theorem for hypergraphs: for any $k \geq 4$ and $n > r \geq k+1$, every n-vertex r-uniform hypergraph with no Berge cycle of length at least k has at most $\frac{(k-1)(n-1)}{r}$ edges. Furthermore, this bound is sharp and we describe the extremal hypergraphs. The result also implies as a corollary the theorem of Győri, Katona and Lemons that for $n > r \geq k \geq 3$, every n-vertex r-uniform hypergraph with no Berge path of length k has at most $\frac{(k-1)n}{r+1}$ edges.

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MS30

Polynomial Time Smoothed Analysis for Local Max-Cut

In 1988, Johnson, Papadimitriou and Yannakakis wrote that "Practically all the empirical evidence would lead us to conclude that finding locally optimal solutions is much easier than solving NP-hard problems". Since then the empirical evidence has continued to amass but formal proofs of this phenomenon have remained elusive. A canonical (and indeed complete) example is the local max-cut problem for which no polynomial time method is known. In a breakthrough paper, Etscheid and Röglin proved that the smoothed complexity of local max-cut is quasi-polynomial. In this paper we prove smoothed polynomial complexity for local max-cut, thus confirming that finding locally optimal solutions for max-cut is much easier than solving it. In this short talk, I will give a gentle introduction to this problem and some proof sketch. This is a joint work with Omer Angel, Sebastien Bubeck, and Yuval Peres.

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MS31
Thresholds for Random Pebbling

In this talk, we will present several well known but poorly understood models of randomized pebbling – the configuration model and the uniform model. In these models, the initial configurations are randomized. The questions here are natural – what conditions on the randomization guarantee solvability? We'll explore some of the history and recent progress in determining thresholds for pebbling in both models, as well as some generalizations. In particular, we'll discuss recent work determining bounds (and even, on occasion, precise thresholds) for the configuration model on grids and paths. We will emphasize open problems and future directions – this is in some ways unavoidable, as the landscape of randomized pebbling remains shrouded in fog.

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MS31
Optimal Pebbling Number of Graphs with Given Minimum Degree

The optimal pebbling number of a graph is the smallest number of pebbles which we can distribute on the vertices of the graph in such a way that each vertex is reachable. In this talk we will discuss results and problems which relate the optimal pebbling number of a graph to its minimum degree. In particular, we will show that if G is a connected graph with diameter at least three, then it's optimal pebbling number is at most $15n/(4(\delta(G)+1))$. This is a joint work with Hurlbert, Katona and Papp.

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MS31
The Weight Function Lemma and Its Applications

Graph pebbling is a network model for studying whether or not a given supply of discrete pebbles can satisfy a given demand via pebbling moves. A pebbling move across an edge of a graph takes two pebbles from one endpoint and places one pebble at the other endpoint. It has been shown that deciding whether a supply can meet a demand on a graph is NP-complete. The pebbling number of a graph is the smallest t such that every supply of t pebbles can satisfy every demand of one pebble by a vertex. Deciding whether the pebbling number is at most k is Π_2^{P}-complete. In this talk we present the Weight Function Lemma, a tool for computing upper bounds and sometimes exact values for pebbling numbers with the assistance of linear optimization. With this tool we are able to calculate the pebbling numbers for many families of graphs, with simple and short certificates (typically of size at most $n\Delta$). Here we apply the Weight Function Lemma to several specific graphs, including the Petersen, Lemke, 4^{th} weak Bruhat, and Lemke squared, as well as to a number of infinite families of graphs, such as trees, cycles, graph powers of cycles, cubes, and some generalized Petersen and Coxeter graphs. In doing so we partly answer a question of Pachter, et al., by computing the pebbling exponent of cycles to within an asymptotically small range. It is conceivable that this method yields an approximation algorithm for graph pebbling.

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MS31
Distance Pebbling on Directed Cycle Graphs

We define the distance d pebbling number of a graph G to be the smallest number n such that if n pebbles are placed on G, then at least one of them can be moved to a vertex which is a distance of at least d from its starting point through a sequence of pebbling moves. In this talk, we determine the distance d pebbling numbers for directed cycle graphs. If time permits, we will discuss a connection between this problem and a problem in number theory about finding 2-adic zeros of diagonal forms.

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MS31
A Graph Pebbling Algorithm on Weighted Graphs

A pebbling move on a weighted graph removes some pebbles at a vertex and adds one pebble at an adjacent vertex. The number of pebbles removed is the weight of the edge connecting the vertices. A vertex is reachable from a pebble distribution if it is possible to move a pebble to that vertex using pebbling moves. The pebbling number of a weighted graph is the smallest number m needed to guarantee that any vertex is reachable from any pebble distribution of m pebbles. Regular pebbling problems on unweighted graphs are special cases when the weight on every edge is 2. A regular pebbling problem often simplifies to a pebbling problem on a simpler weighted graph. We present an algorithm to find the pebbling number of weighted graphs. We use this algorithm together with graph simplifications to find the regular pebbling number of all connected graphs with at most nine vertices.

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MS32
Triangle Roundedness in Matroids

A matroid N is said triangle-rounded in a class of matroids $\mathcal{M}$ if each 3-connected matroid $M \in \mathcal{M}$ with a triangle T and an N-minor has an N-minor with T as triangle. Reid gave a result useful to identify such families as stated next: suppose that $M > N$ are binary 3-connected matroids, T is a triangle of M and $e \in T \cap E(N)$; then, there is a 3-connected matroid M' with T as triangle such that

$M \geq M' \geq N$ and $|E(M')| \leq |E(N)| + 2$. We strengthen this result dropping the condition of the existence of such element e and proving that there are 3-connected minors M' of M and N' of M' with $N' \cong N$ and $E(M') - E(N') \subseteq T$. We also extend this result to the non-binary case and we prove that $\{M(K_5)\}$ is triangle-rounded in the class of regular matroids.

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MS32

Deletion Sets in Binary Matroids

An element in a 3-connected matroid is called a deletable element if its removal preserves 3-connectivity. A 3-connected matroid is minimally 3-connected if it has no deletable elements. Suppose M is a rank r minimally 3-connected binary matroid. In this paper we give an upper bound for the number of elements in M in terms of r.

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MS32

Beta Invariants of 3-Connected Matroids

Using the beta invariant and the characteristic polynomial of a matroid M, we prove that if G is a 3-connected graph such that the chromatic polynomial of G is equal to the chromatic polynomial of a wheel graph, then G is isomorphic to the wheel graph. And we show a splitting formula of the beta invariant of a general parallel connection across a 3-point line and 3-sum of two matroids and how this result is related to the connectivity condition of the chromatic polynomial result.

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MS32

Efficient Enumeration of Binary Matroids Using a New Canonical Form

We describe generating a catalog of small binary matroids up to isomorphism. This catalog is useful for numerical experiments and verification of conjectures. In the preceding work, the catalog of binary matroids of cardinality ≤ 15 was generated [H. Fripertinger and M. Wild, A catalogue of small regular matroids and their Tutte polynomials, arXiv:1107.1403v1, 2011]. We newly generated the catalog of cardinality ≤ 17. Each binary matroid in a catalog is represented by a binary matrix. The difficulty lies in the fact that multiple different matrices can represent an identical matroid. Therefore, we must carefully choose exactly one matrix among multiple representations of each matroid. This specified matrix is called a canonical form. The preceding work defined each canonical form as the lexicographically smallest matrix. However, it is time-consuming to check whether a given matrix is the lexicographically smallest among multiple representations. In this work, we re-defined canonical forms as follows. For a matrix, let f_k be the number of linearly independent subsets of the leftmost k columns. Then, each canonical form is defined as the lexicographically smallest matrix among those which lexicographically maximize f. The matrices maximizing f are very few practically, and can be enumerated efficiently. Thus, we can speed up checking canonicity and generating a catalog.

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MS33

An Improvement on the Intersecting Shadow Theorem

Introduce the notation $[n] = \{1, 2, \ldots, n\}$, then the family of all k-element subsets of $[n]$ can be denoted as $\binom{[n]}{k}$. Suppose that $\mathcal{F} \subset \binom{[n]}{k}$. Then its shadow $\sigma(\mathcal{F})$ is the family of all $k-1$-element sets obtained by deleting single elements from the members of $\mathcal{F}$, that is $\sigma(\mathcal{F}) = \{A : |A| = k-1$, there is an $F \in \mathcal{F}$ such that $A \subset F\}$. The shadow theorem determines $\min |\sigma(\mathcal{F})|$ for fixed n, k and $|\mathcal{F}|$. The situation is very different if the members of $\mathcal{F}$ are pairwise intersecting. In general, we say that $\mathcal{F}$ is t-intersecting if $F, G \in \mathcal{F}$ implies $|F \cap G| \geq t$. It seems to be difficult to find the exact minimum of the shadow for t-intersecting families. However, an old theorem (proved by the author in 1964) determines the minimum of the ratio $|\sigma(\mathcal{F})|/|\mathcal{F}|$ for fixed n, k and t-intersecting families. The main goal of the present talk is to exhibit a new improvement of this result for the case when $|\mathcal{F}|$ is large.

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MS33

Problems and Results Related to Maximal Antichains

We consider maximal antichains $\mathcal{A}$ on $[n] = \{1, 2, \ldots, n\}$ such that $|A| \in K$ for all $A \in \mathcal{A}$ and some given $K \subseteq [n]$. We study the problem of minimizing $|\mathcal{A}|$ and related problems. For $K = \{2, 3\}$ our problem is equivalent to maximizing $e - t$ over all simple graphs G of order n such that every edge is contained in some triangle, where e, t are the numbers of edges and triangles, resp. The maximum of $e-t$ turns out to be $\lfloor (n+1)^2/8 \rfloor$. Results on a weighted version are given as well. (Grüttmüller, Kalinowski, Hartmann, L., Roberts 2009) For $K = \{2, 3\}$ we consider maximal antichains $\mathcal{A}$ which are r-regular, We prove lower bounds on r and describe constructions for regular maximal antichains with small regularity. (Kalinowski, L., Reiher, Roberts 2016) For the case $1 \notin K$, $2 \in K$ a general construction of such antichains is given. If $3 \in K$, then our construction is asymptotically best, up to an $o(n^2)$ error term. We conjecture this to be the case also for $3 \notin K$, and we prove a weaker bound for $K = \{2, 4\}$. (Kalinowski, L., Roberts 2013) A more general weighted version of the problem is completely solved if $K = \{k-1, k\}$ for some $k \in [n]$ and under the additional constraint that $\mathcal{A}$ is squashed, i.e. the k-sets in $\mathcal{A}$ form an initial segment w.r.t. antilexicographic order. (Griggs, Hartmann, Kalinowski, L., Roberts 2017)

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MS33

Ramsey-Type of Problems on Posets in the Boolean Lattices

A family $\mathcal{F}$ of subsets of $[n] := \{1, \ldots, n\}$ is said to be a copy of a poset P, if there is a bijection f from P to $\mathcal{F}$ such that $x \leq_P y$ if and only if $f(x) \subseteq f(y)$. A k-coloring on the Boolean lattice B_n is a function c from B_n to $[k]$. In this talk, we study the colorings on the Boolean lattices, and present some results on the existence a monochromatic copy of the given posets, or a rainbow copy of them.

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MS33

On Difference Graphs and the Local Dimension of Posets

The dimension of a partially-ordered set (poset) is the minimum number of linear extensions sufficient to ensure that for every incomparable x and y, there is one of the extensions that yields $x < y$. Introduced by Dushnik and Miller, the dimension is a well-studied parameter. However, in any given realization of the dimension of a poset, a given element might not be in many linear extensions. Ueckerdt introduced the invariant called local dimension which, instead, uses partial linear extensions and which is bounded above by the Dushnik-Miller dimension. For instance, the dimension of the standard example of order n is $\lfloor n/2 \rfloor$, but the local dimension is only 3. In this talk, we study the local dimension of show that the maximum local dimension of a poset of order n is $\Theta(n/\log n)$, the local dimension of the n-dimensional Boolean lattice is at least $\Theta(n/\log n)$ and make progress toward resolving a version of the removable pair conjecture for local dimension. We also connect the computation of local dimension of a poset to the decomposition of the edges of a graph into what are called difference graphs.

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MS33

Forbidden Induced Subposets

Let P be a partially ordered set. The function $\mathrm{La}^{\#}(n, P)$ denotes the size of the largest family $\mathcal{F} \subset 2^{[n]}$ that does not contain an *induced* copy of P. By discovering a connection between $\mathrm{La}^{\#}(n, P)$ and a certain matrix pattern problem, Methuku and Pálvölgyi proved that there exists a constant C_P (depending only on P) such that $\mathrm{La}^{\#}(n, P) < C_P\binom{n}{\lfloor n/2 \rfloor}$. We explore this connection in more depth in the hope of finding good bounds on this constant C_P. We show that for every positive integer h there exists a constant c_h such that if P has height at most h, then

$$\mathrm{La}^{\#}(n, P) \leq |P|^{c_h} \binom{n}{\lfloor n/2 \rfloor}.$$

Our methods also allow us to generalize our results to the setting of grids $[k]^{[n]}$. That is, we show that if $\mathcal{F} \subset [k]^n$ such that $\mathcal{F}$ does not contain an induced copy of P and $n \geq 2|P|$, then

$$|\mathcal{F}| \leq |P|^{c_h} w,$$

where w is the width of $[k]^n$. Also, we prove that if $\mathcal{F}$ does not contain a *weak* copy of P and $n \geq 2 \log |P|$, then

$$|\mathcal{F}| = O(wh \log^{3/2} |P|).$$

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MS34

An $O(k^4)$ Kernel for Unit Interval Vertex Deletion

Abstract Not Available At Time Of Publication.

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MS34

A Polynomial Kernel of Distance-Hereditary Vertex Deletion

A graph is distance-hereditary if for any pair of vertices, their distance in every connected induced subgraph containing both vertices is the same as their distance in the original graph. The Distance-Hereditary Vertex Deletion problem asks, given a graph G on n vertices and an integer k, whether there is a set S of at most k vertices in G such that $G - S$ is distance-hereditary. This problem is important due to its connection to the graph parameter rank-width; distance-hereditary graphs are exactly the graphs of rank-width at most 1. Eiben, Ganian, and Kwon (MFCS' 16) proved that Distance-Hereditary Vertex Deletion can be solved in time $2^{\mathcal{O}(k)}n^{\mathcal{O}(1)}$, and asked whether it admits a polynomial kernelization. We show that this problem admits a polynomial kernel, answering this question positively. For this, we use a similar idea for obtaining an approximate solution for Chordal Vertex Deletion due to Jansen and Pilipczuk (SODA' 17) to obtain an approximate solution with $\mathcal{O}(k^3 \log n)$ vertices when the problem is a Yes-instance, and we exploit the structure of split decompositions of distance-hereditary graphs to reduce the total size.

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MS34

Maximum Induced Matching Algorithms via Vertex Ordering Characterizations

We study the maximum induced matching problem on a graph G. Induced matchings correspond to independent sets in $L^2(G)$, the square of the line graph of G. The problem is NP-complete on bipartite graphs. We show that for a number of graph families characterized by vertex orderings, almost all forbidden patterns on three vertices are preserved when taking the square of the line graph. We give linear time algorithms (in the size of the input graph) to compute these orderings. These results generalize and unify previous ones on showing closure under $L^2(\cdot)$ for various graph families. Furthermore, these orderings on $L^2(G)$ can be exploited algorithmically to compute a maximum induced matching on G faster. We illustrate this latter fact in the second half of the talk where we focus on cocomparability graphs, a large graph class that includes interval, permutation, trapezoid graphs, and co-graphs, and we present the first $\mathcal{O}(mn)$ time algorithm to compute a maximum *weighted* induced matching on cocomparability graphs; an improvement from the best known $\mathcal{O}(n^4)$ time algorithm for the *unweighted* case. This is joint work with Michel Habib.

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MS34

Complexity Dichotomies for H-free Edge Modification Problems

For a graph H, the H-free Edge Deletion problem asks whether there exist at most k edges whose deletion from the input graph G results in a graph without any induced copy of H. H-free Edge Completion and H-free Edge Editing are defined similarly where only completion (addition) of edges are allowed in the former and both completion and deletion are allowed in the latter. We completely settle the classical complexities of these problems by proving that H-free Edge Deletion is NP-complete if and only if H is a graph with at least two edges, H-free Edge Completion is NP-complete if and only if H is a graph with at least two nonedges, and H-free Edge Editing is NP-complete if and only if H is a graph with at least three vertices. Our result on H-free Edge Editing resolves a conjecture by Alon and Stav [Theoret. Comput. Sci., 2009, pp. 49204927]. Additionally, we prove that these NP-complete problems cannot be solved in parameterized subexponential time, i.e., in time $2^{o(k)}|G|^{O(1)}$, unless the exponential time hypothesis fails. Furthermore, we obtain implications on the incompressibility and the inapproximability of theseproblems.

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MS34

Modification of Matroids and Matrices

For a target rank r, the rigidity of a matrix A over a field $\mathbb{F}$ is the minimum Hamming distance between A and a matrix of rank at most r. Rigidity is a classical concept in computational complexity theory. In this talk, I will discuss several aspects of the computation of the rigidity of matrices in the framework of parameterized complexity. Specifically, I will address the Matrix Rigidity problem, where given parameters r and k, our task is to decide whether the rigidity of A for the target rank r is at most k.

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MS35

Mitigating Overexposure in Viral Marketing

In traditional models for word-of-mouth recommendations and viral marketing, the objective function has generally been based on reaching as many people as possible. However, a number of studies have shown that the indiscriminate spread of a product by word-of-mouth can result in overexposure, reaching people who evaluate it negatively. This can lead to an effect in which the over-promotion of a product can produce negative reputational effects, by reaching a part of the audience that is not receptive to it. How should one make use of social influence when there is a risk of overexposure? In this paper, we develop and analyze a theoretical model for this process; we show how it captures a number of the qualitative phenomena associated with overexposure, and for the main formulation of our model, we provide a polynomial-time algorithm to find the optimal marketing strategy. We also present simulations of the model on real network topologies, quantifying the extent to which our optimal strategies outperform natural baselines.

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MS35

New Perspectives on Measuring Network Clustering

A fundamental property of many complex networks is the tendency for nodes to cluster. The extent of the clustering at a node is typically quantified by the number of pairs of neighbors that induce a 3-clique, or a triangle. This talk presents two new angles on measuring clustering. The first introduces higher-order clustering coefficients that measure the closure probability of larger cliques and provide a more comprehensive view of how the edges of complex networks cluster. The second introduces closure coefficients that measure the frequency of length-2 path closure from the tail node of the path. These are a measurement for the old adage that "a friend of my friend is my friend". We derive theoretical properties for both coefficients and show how to use them to gain new insights into the structure of real-world networks from several domains.

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MS35

Modeling and Mining Dynamic Competition Networks

We consider social networks of competing agents that evolve dynamically over time. Such dynamic competitive networks are directed, where a directed edge from nodes u to v corresponds a negative social interaction. We present a novel hypothesis that serves as a predictive tool to uncover alliances and leaders within dynamic competition networks. We validate the hypothesis using voting record data of the social game shows Survivor and Big Brother.

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MS35

Hypergraph Kronecker Models for Networks

A Kronecker model for a network consists of a random draw from a matrix of edge probabilities arising from repeated Kronecker products between matrices. We explore a simple generalization of this model to generate a regular hypergraph by creating a tensor of edge probabilities via repeated tensor Kronecker products. A sample from this hypergraph distribution is then collapsed into a network model by treating each hyperedge as a motif, such as a triangle. We discuss efficient strategies to generate these networks and show there are surprising number of connections with topics across discrete mathematics, including Morton codes and ranking and unranking multiset permutations. We also discuss expected motif counts in the resulting collapsed network on the way towards fitting these models.

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MS36

Generalizations of Cobham's Theorem

Cobham's theorem states that a sequence cannot be simultaneously automatic with respect to two different bases, except for the trivial cases when the two bases are multiplicatively dependent or when the sequence is ultimately periodic. The theorem has sparked much research, and many generalizations of the result have been obtained in domains as varied as symbolic dynamics, logic, nonstandard numeration systems, fractals, number theory, and Galois theory. Many of those generalizations have also led to new ways to understand the original result and its proof. In the talk, I will give an overview of some of these generalisations, with special emphasis on those aspects that remain open.

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MS36

Introduction to Combinatorics on Words

This brief survey talk will introduce results and open questions in combinatorics on words. Starting with the classic topic of repetitions in words, I will introduce research problems, new and old, in the areas of pattern avoidance, repetition threshold, patterns with reversal, additive powers, and abelian repetitions and patterns. Starting with Thue's construction of an infinite binary sequence avoiding cubes, many historical constructions in this area have involved the iteration of morphisms. This leads us to decision problems involving semigroup morphisms and their fixed points, including conditions ensuring that the fixed point of a morphism avoids some pattern. When the construction of a pattern-avoiding infinite sequence over a finite alphabet involves a k-uniform morphism, followed by a letter-to-letter coding, the proof is typically smoother than with more general compositions of morphisms. Sequences arising in such a way are closely linked to automata, and are known as k-automatic. The automatic sequences form an area of independent interest, linking combinatorics on words to decision methods for automata, and to numeration systems. While morphisms are a powerful tool in combinatorics on words, other tools have emerged, including the probabilistic method, entropy compression, and the method of fixing block inequalities. We will share some results and research questions involving non-constructive methods in combinatorics on words.

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MS36

Decidability and the Ostrowski Numeration System

The Ostrowski numeration system have appeared naturally in the study of combinatorics on words and in logic. In this talk I will review what is known (and what is not) about the decidability of certain questions about Ostrowski numeration systems. While I look at the problems as a logician, I will assume no knowledge of first-order logic.

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MS36

The Additive K'th Power Problem and Generalizations

A word is a sequence over a finite set that we call the alphabet. A factor of a word is a contiguous subsequence of this word. Let $(G, +)$ be a semigroup and Σ be a finite subset of G. A word $w \in \Sigma^*$ is an additive k-th power if there are words $u_1, u_2, \ldots, u_k \in \Sigma^*$ such that $w = u_1 u_2 \ldots u_k$ and all the u_j have the same length and sum. For instance, with $(G, +) = (\mathbb{N}, +)$ and $\Sigma = \{0, 1, 2, 3, 4\}$, 321042 is an additive 2nd power. A word is said to avoid additive k-th powers if none of its factors is an additive k-th power. Additive k-th powers are avoidable over an alphabet Σ (resp. a group $(G, +)$) if there exists an infinite word over Σ (resp., over a finite subset of G) avoiding additive k-th powers. Pirillo and Varricchio showed that, for any k, if additive k-th powers are avoidable over a finite subset of $\mathbb{Z}$, they are also avoidable over any finitely-generated infinite group. This led them to ask what is the smallest value of k such that additive k-th powers are avoidable over $\mathbb{Z}$. Cassaigne *et Al.* recently showed that additive 3rd powers are avoidable over $\mathbb{Z}$. In this talk we will give recent results and open questions on this topic, with a particular emphasis on the case where the semi-group is $(\mathbb{N}^n, +)$.

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MS36

Automatic Sequences and p-adic Asymptotics

Many integer sequences that arise in combinatorics have the property that reducing each term modulo p produces a p-automatic sequence. For sequences whose generating functions are algebraic, this phenomenon is explained by Christol's characterization of p-automatic sequences as the coefficients of algebraic power series over a finite field of characteristic p. More generally, if $s(n)_{n \geq 0}$ is the diagonal of a rational power series, then $(s(n) \bmod p^\alpha)_{n \geq 0}$ is p-automatic. Given a sequence $s(n)_{n \geq 0}$ and a fixed prime p, the sequences obtained by varying α naturally project to one another. Therefore one would ideally like to study all these sequences simultaneously. The correct setting for this is the field of p-adic numbers. I'll discuss some early results toward a theory of p-adic analytic combinatorics — a p-adic analogue of the study of asymptotics of integer sequences by analyzing singularities of their generating functions in the complex plane.

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MS37

Variations on the Pebbling Game: Critical, Weighted, and Transport Pebbling

In this talk I'll present three variations of graph pebbling I developed with three different teams of students. In critical pebbling, a configuration of pebbles is considered solvable only if it fails when any pebble is removed. In weighted pebbling, we're allowed to adjust the cost of a pebbling move on each edge, keeping the average cost the same. In transport pebbling, we identify a special cargo pebble, and must get this pebble to the root vertex to win the pebbling game. I'll present results and open questions for each pebbling variation.

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MS37

Optimal Pebbling Number of Grids

Graph pebbling is a game on graphs invented by Chung in 1989. Some pebbles are placed at the vertices of the graph. A *pebbling move* removes two pebbles from a vertex and places one pebble at a neighbor. A vertex is called *reachable* if a pebble can be moved to that vertex using pebbling moves. $\pi^*(G)$ is the *optimal pebbling number* of graph G, which is the minimum number of pebbles that one can distribute on the vertices such that every vertex of G is reachable. Optimal pebbling number of the square grid graph $G_{n,m}$ is investigated by several people and the exact values are determined when $m < 4$ [D.P. Bunde, E. W. Chambers, D. Cranston, K. Milans, D. B. West, Pebbling and optimal pebbling in graphs, J. Graph Theory 2008, C. Xue, C. Yerger, Optimal Pebbling on grids, Graphs and Combinatorics 2015]. Lower and upper bounds for $\pi^*(G_{n,m})$ are given by Xue and Yerger. They proved that $\pi^*(G_{n,m}) \leq \frac{4}{13}nm + O(n+m)$. They also conjectured that equality holds. We show a construction which proves that $\pi^*(G_{n,m}) \leq \frac{2}{7}nm + O(n+m)$. We conjecture that our construction is optimal and we show some facts supporting this conjecture. We created a new method which can be used to prove lower bounds on the optimal pebbling number. Using this method, we show that $\pi^*(G_{n,m}) \geq \frac{2}{13}nm$.

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MS37

On Some Questions Regarding Class 0 Graphs

The pebbling number of a graph G, $\pi(G)$, is the lest integer m such that, however m pebbles are placed on the vertices of G, we can move a pebble to any vertex by a sequence of moves, each move taking two pebbles from one vertex and placing one of these on an adjacent vertex (while discarding the other). The pebbling number $\pi(G)$ is always at least the number of vertices $|V(G)| := n$ in the graph. We investigate graphs with $\pi(G)$ close to or equal to n for which the size of G, $|E(G)|$, is small. Problems, conjectures and some results are given.

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MS37

Pebbling Bounds for Class 0 Graphs

Pebbling is a game played on graphs. Given a configuration of pebbles on the vertices of a connected graph G, a *pebbling move* removes two pebbles from some vertex and places one pebble 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. A *Class 0* graph is a graph for which the pebbling number equals its number of vertices. With the discharging technique, we are able to show that every n-vertex Class 0 graph has at least $5n/3 + 11/3$ edges, disproving a conjecture of Blasiak et al. For diameter 2 graphs, we strengthen this lower bound to $2n - 5$, which is best possible.

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MS37

Pebbling on Low Diameter Interval Graphs

One interesting question in graph pebbling is determining whether the pebbling number of a particular class of graphs can be computed in polynomial time or not. In general, computing the pebbling number of a graph is an NP-complete problem. In this talk, we will investigate the structure of interval graphs of diameter three and discuss progress towards computing the pebbling number of all these interval graphs with a structural characterization. This is joint work with Davidson College undergraduate Xuchen (Louise) Zhou.

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MS38

Spanning Subgraphs of Randomly Perturbed Graphs

Randomly perturbed graphs are obtained by adding, to a given deterministic graph satisfying a certain minimum degree condition, a certain number of random edges. In this talk I present a new absorbing type method for proving results concerning spanning subgraphs of randomly perturbed graphs, and illustrate how this method can be used to obtain new results.

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MS38

The Junta Method in Extremal Hypergraph Theory and Chvátals Conjecture

Numerous problems in extremal hypergraph theory ask to determine the maximal size of a k-uniform hypergraph on n vertices that does not contain an "enlarged" copy $\mathcal{H}^+$ of a fixed hypergraph $\mathcal{H}$, obtained from $\mathcal{H}$ by enlarging each of its edges by distinct new vertices. We present a general approach to such problems, using a "junta approximation method" that originates in the analysis of Boolean functions. We show that any $\mathcal{H}^+$-free hypergraph is essentially contained in a "junta" – a hypergraph determined by a small number of vertices – that is also $\mathcal{H}^+$-free, which effectively reduces the extremal problem to an easier problem on juntas. Using this approach we obtain (for all $C < k < n/C$) a characterization of all hypergraphs $\mathcal{H}$ for which the maximal size of an $\mathcal{H}^+$-free family is $\binom{n-t}{k-t}$, in terms of intrinsic properties of $\mathcal{H}$. We apply our method to Chvátal's conjecture (1974), which asserts that for any $d < k < \frac{d-1}{d}n$, the maximal size of a k-uniform family that does not contain a d-simplex (i.e., $d+1$ sets with empty intersection such that any d of them intersect) is $\binom{n-d-1}{k-d-1}$. We prove the conjecture for all d and k, provided that $n > n_0(d)$.

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MS38

Isoperimetric Stability for the Cube

The n-cube is the graph on vertex set $\{0,1\}^n$ in which two vertices are adjacent if they differ in a single coordinate. Given a subset $A \subset \{0,1\}^n$, one may ask how much A 'expands'. Two natural measurements of expansion are given by the edge boundary (how many edges leave A) and the vertex boundary (how many vertices are adjacent to some element in A). Optimal bounds for these quantities based on the size of A are given by the edge and vertex isoperimetric inequalites for the cube. In this talk I will discuss some recent work which gives stability for these inequalities.

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MS38

On Subgraphs of 2k-cycle-free Graphs and Some Generalised Turán Problems

Kühn and Osthus showed that every bipartite C_{2k}-free graph G contains a C_4-free subgraph with at least $1/(k-1)$ fraction of the edges of G. We present a new simple proof of this result. Győri et. al. showed that if c denotes the largest constant such that every C_6-free graph G contains a bipartite C_4-free subgraph having c fraction of edges of G, then $3/8 \leq c \leq 2/5$. We show that $c = 3/8$. Our proof is probabilistic. This is joint work with Grósz and Tompkins. We will also present results on Generalised Turán problems for even cycles, extending the work of Alon and Shikhelman. Given graphs H and F, let $ex(n, H, F)$ denotes the maximum possible number of copies of H in an F-free graph on n vertices. We determine the order of magnitude of $ex(n, C_{2l}, C_{2k})$ for any $l, k \geq 2$. Moreover, we determine $ex(n, C_4, C_{2k})$ asymptotically for all k. Solymosi and Wong proved that if Erdős's Girth Conjecture holds then for any $l \geq 3$, the maximum number of C_{2l}'s in a graph of girth $2l$ is $\Theta(n^{2l/(l-1)})$. We prove that their result is sharp in the sense that if an even cycle of any other length is also forbidden then the order of magnitude is smaller. More precisely, for any $k > l$, the maximum number of C_{2l}'s in a C_{2k}-free graph of girth $2l$ is $\Theta(n^2)$. This is joint work with Gerbner, Győri and Vizer.

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MS38

Proof of Komlos's Conjecture on Hamiltonian Subsets

Komlós conjectured in 1981 that among all graphs with minimum degree at least d, the complete graph K_{d+1} minimises the number of Hamiltonian subsets, where a subset of vertices is Hamiltonian if it contains a spanning cycle. We prove this conjecture when d is sufficiently large. In fact we prove a stronger result: for large d, any graph G with average degree at least d contains almost twice as many Hamiltonian subsets as K_{d+1}, unless G is isomorphic to K_{d+1} or a certain other graph which we specify.

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MS39

An Algorithm Approach to Bounding Families of Subsets Avoiding a Subposet in Boolean Lattices

Burcsi and Nagy (2013) proposed a double-chain method to get an upper bound for the largest size of families of subposets avoiding an finite poset P of given height in Boolean lattices. In this talk, I will introduce a dynamic programming approach to elaborate their double-chain method to obtain a new upper bound. This result enables us to find more posets verifying an important conjecture by Griggs and Lu.

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MS39

Sizes of Maximal Antichains in B_n

For a positive integer n, $[n]$ denotes the set $\{1, \ldots, n\}$, and B_n the power set of $[n]$, ordered by inclusion. By Sperner's theorem, any antichain $\mathcal{A}$ in the poset B_n has size at most $\binom{n}{\lfloor n/2 \rfloor}$, and this maximum is obtained if and only if $\mathcal{A}$ is the collection of all subsets of size $\lfloor n/2 \rfloor$ or the collection of all subsets of size $\lceil n/2 \rceil$. An antichain $\mathcal{A}$ is called *flat* if there exists an integer k such that $\mathcal{A}$ contains only k-sets and $(k-1)$-sets. We will discuss the following two questions.

1. Which integers m occur as the size of a maximal antichain in B_n? In other words, we want to determine the set
$$S(n) = \{|\mathcal{A}| \,:\, \mathcal{A} \in \mathcal{M}(n)\},$$
where $\mathcal{M}(n)$ is the set of maximal antichains in B_n.
2. For $2 \leq k \leq n$, which integers m occur as the sizes of maximal flat antichains containing only k-sets and $(k-1)$-sets? In other words, we want to determine the set
$$S(n,k) = \{|\mathcal{A}| \,:\, \mathcal{A} \in \mathcal{M}(n,k)\},$$
where $\mathcal{M}(n,k)$ is the set of maximal antichains in B_n containing only k-sets and $(k-1)$-sets.

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MS39

An Upper Bound on the Size of Diamond-Free Families of Sets

Let $La(n, P)$ be the maximum size of a family of subsets of $[n] = \{1, 2, \ldots, n\}$ not containing P as a (weak) subposet. The diamond poset, denoted Q_2, is defined on four elements x, y, z, w with the relations $x < y, z$ and $y, z < w$. $La(n, P)$ has been studied for many posets; one of the major open problems is determining $La(n, Q_2)$. It is conjectured that $La(n, Q_2) = (2 + o(1))\binom{n}{\lfloor n/2 \rfloor}$, and infinitely many significantly different, asymptotically tight constructions are known. Studying the average number of sets from a family of subsets of $[n]$ on a maximal chain in the Boolean lattice $2^{[n]}$ has been a fruitful method. We use a partitioning of the maximal chains and introduce an induction method to show that $La(n, Q_2) \leq (2.20711 + o(1))\binom{n}{\lfloor n/2 \rfloor}$, improving on the earlier bound of $(2.25 + o(1))\binom{n}{\lfloor n/2 \rfloor}$ by Kramer, Martin and Young.

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MS40

Tuning the Activity of Neural Networks at Criticality

Abstract Not Available At Time Of Publication.

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MS40

Evaluating Overfit and Underfit in Models of Network Community Structure

A common data mining task on networks is community detection. Although many methods now exist, the recently proved No Free Lunch theorem for community detection implies that each makes some kind of tradeoff, and no algorithm can be optimal on all inputs. Thus, different algorithms will over- or under-fit on different inputs, finding more, fewer, or just different communities than is optimal, and evaluation methods that use a metadata partition as a ground truth will produce misleading conclusions about general accuracy. As a result, little is known about how over- and under-fitting varies by algorithm and input. Here, we present a broad evaluation of over- and underfitting in community detection, comparing the behavior of 16 state-of-the-art community detection algorithms on a novel and structurally diverse corpus of 406 real-world networks. We find that (i) algorithms vary widely both in the number of communities they find and in their corresponding composition, given the same input, (ii) algorithms can be clustered into distinct high-level groups based on similarities of their outputs on real-world networks, and (iii) these differences induce wide variation in accuracy on link prediction and link description tasks. We then introduce a new diagnostic for evaluating overfitting and underfitting in practice, and use it to roughly divide community detection methods into general and specialized learning algorithms.

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MS40

Graph Matching Via Low Rank Factors

Graph alignment is the problem of finding a one-to-one matching between nodes of two graphs in a way that maximizes the total overlap between the two graphs. The problem has direct applications in networks coming from Biology, social networks, transportation networks, and many more. A challenging step in the alignment process, is running a matching algorithm on a dense similarity matrix whose (i, j) entry corresponds to the similarity score between node i in the first graph and node j in the second graph. This problem quickly becomes computationally expensive and demands an $\mathcal{O}(mn)$ space where m and n are the number of nodes in each graph respectively. In this talk, I will show how to perform network alignment while avoiding the creation of this full dense matrix. And, yet, achieving high quality results from a matching algorithm that runs on the low rank factors of the dense similarity matrix instead of the full matrix itself.

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MS40

Detectability of Hierarchical Community Structure in Preprocessed Multilayer Networks

It is commonplace to preprocesses multilayer and temporal networks by aggregating together layers that are similar. This includes, for example, binning temporal network data into time windows. In previous research [D Taylor, RS Caceres and PJ Mucha (2017) Physical Review X 7, 031056, D Taylor, S Shai, N Stanley and PJ Mucha (2016) Physical Review Letters 116, 228301], we analyzed how layer aggregation can enhance community detection by lowering the fundamental limits on detectability. We extend this work by allowing layers to be drawn from hierarchical stochastic block models (SBMs). We develop random matrix theory to analyze the eigenvalues and eigenvectors of modularity matrices for networks obtained from the aggregation of L layers. Each dominant eigenvalue that is well-separated (i.e., isolated) from the bulk eigenvalues has an associated eigenvector that correlates with the hierarchical community structure. By analyzing the dependence of eigenvalues and eigenvectors on L, we identify a novel phenomenon: as one increases L, there is a cascade of detectability phase transitions in which first the coarse-scale community structure becomes detectable, and then in subsequent transitions each of these breaks up into finer communities.

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MS41

Graphons: From Graph Limits to Non-Parametric Graph Models and Estimation

Graphons were invented to model the limit of large, dense graphs. While this led to interesting applications in combinatorics, most applications require limits of sparse graphs. In this talk, I will review recent progress on graph limits for sparse graphs, and then discuss applications to nonparametric modeling and estimation of sparse graphs. This is joint work with Jennifer Chayes, Henry Cohn, and many others.

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MS41

Bayesian Optimization with Exotic Structure

Bayesian optimization methods are designed to optimize objective functions that take a long time or are expensive to evaluate. Such objective functions arise in hyperparameter tuning of deep neural networks, A/B-testing-based design of mobile apps and online marketplaces, aerospace engineering, and materials science. These methods use Gaussian process regression from machine learning to build a surrogate for the objective, and value of information analysis from Bayesian decision theory to select points at which to evaluate. The now well-established expected improvement method performs well under the standard problem structure assumed in Bayesian optimization: that we evaluate a noise-free objective one point at a time, subject to a constraint on the number of evaluations. This method, however, does not generalize easily to more exotic problems. We show how a generalization of the knowledge-gradient acquisition function for standard Bayesian optimization can be used to simultaneously solve a large class of problems with exotic problem structure, including optimization of integrals and sums of expensive-to-evaluate integrands; optimization with multiple fidelities and information sources; and optimization with derivatives.

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MS41

Stochastic Combinatorial Optimization with Queries

In some real-world applications, we have to solve combinatorial optimization problems with uncertain parameters. There are many frameworks to handle those problems such as expectation optimization, robust optimization, and multi-stage stochastic optimization. Recently, a new framework, called "optimization with queries" attracts attention. In this framework, we can actively resolve the uncertainty by conducting queries by paying some cost. In this talk, we present an overview of this framework and introduce our recently proposed model that seeks a solution having almost the same quality as the full-information solution.

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MS41

Learning Determinantal Point Processes

Abstract Not Available At Time Of Publication.

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MS41

Mathematical and Computational Grand Challenges in Estimating the Tree of Life

Estimating the Tree of Life is one of the grand computational challenges in science and has applications to many areas of science and biomedical research. Despite intensive research over the past several decades, many problems remain inadequately solved. In this talk, I will discuss species tree estimation from genome-scale datasets. In addition, I will describe these problems and what is understood about these them from a mathematical perspective. Furthermore, I will identify some of the open problems in this area where mathematical research, drawing from graph theory, combinatorial optimization, and probability and statistics, is needed. This talk will be accessible to mathematicians, computer scientists, probabilists and statisticians, and does not require any knowledge of biology.

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MS42

The Zero Forcing Polynomial of a Graph

Zero forcing is an iterative graph coloring process, where given a set of initially colored vertices, a colored vertex with a single uncolored neighbor causes that neighbor to become colored. A zero forcing set is a set of initially colored vertices which causes the entire graph to eventually become colored. This talk discusses the counting problem associated with zero forcing. It introduces the zero forcing polynomial of a graph G of order n as the polynomial $\mathcal{Z}(G;x) = \sum_{i=1}^{n} z(G;i)x^i$, where $z(G;i)$ is the number of zero forcing sets of G of size i. The extremal coefficients of $\mathcal{Z}(G;x)$ are characterized, closed form expressions for the zero forcing polynomials of several families of graphs are presented, and various structural properties of $\mathcal{Z}(G;x)$ are explored, including multiplicativity, unimodality, and uniqueness.

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MS42

A Forest Building Process for Simple Graphs

Consider the following process on a simple graph without isolated vertices: order the edges randomly and keep an edge if and only if it contains a vertex which is not contained in some preceding edge. The resulting set of edges forms a spanning forest of the graph. We determine the probability of building a k component forest for complete bipartite graphs, as well as a formula for the expected number of components in any graph. We also discuss a generic recurrence for the generating function associated with the probability of building k components for any graph.

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MS42

Graph Saturation Problems with Colored Edges

Let $\mathcal{C}$ be a family of edge-colored graphs. A t-edge colored graph G is $(\mathcal{C},t)$-saturated if G does not contain any graph in $\mathcal{C}$ but the addition of any edge in any color in $[t]$ creates a copy of some graph in $\mathcal{C}$. Similarly to classical saturation functions, define $\mathrm{sat}_t(n,\mathcal{C})$ to be the minimum number of edges in a $(\mathcal{C},t)$ saturated graph. Let $\mathcal{C}_r(H)$ be the family consisting of every edge-colored copy of H which uses exactly r colors. We consider a variety of colored saturation problems. We determine the order of magnitude for $\mathrm{sat}_t(n,\mathcal{C}_r(K_k))$ for all r, showing a sharp change in behavior when r is large enough relative to k. A particular case of this theorem proves a conjecture of Barrus, Ferrara, Vandenbussche, and Wenger. We determine $\mathrm{sat}_t(n,\mathcal{C}_2(K_3))$ exactly and determine the extremal graphs. This is joint work with Mike Ferrara, Dan Johnston, Sarah Loeb, Flo Pfender, Alex Schulte, Heather Smith, Eric Sullivan, and Casey Tompkins.

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MS42

Degree Conditions for Small Contagious Sets in Bootstrap Percolation

Bootstrap percolation is a cellular automaton that models the spread of information or infection in a network. In *r-neighbor bootstrap percolation* on a graph G, all vertices are either ‘infected’ or ‘uninfected.’ The initially infected set $A \subseteq V(G)$ grows by iteratively infecting all uninfected vertices with at least r infected neighbors. If all vertices eventually become infected, the initial set A is called r-*contagious*. Let $r \geq 2$ and let $m(G, r)$ denote the minimum size of an r-contagious set in G. It is easy to see that $m(G, r) \geq \min\{|V(G)|, r\}$. What conditions on G imply that $m(G, r) = r$? Let $\sigma_2(G) = \min\{d(x) + d(y) : xy \notin E(G)\}$. Freund, Poloczek, and Reichman showed that if $\sigma_2(G) \geq n$, then $m(G, 2) = 2$, and that this bound is best possible. We show that if $\sigma_2(G) \geq n-2$, then $m(G, 2) = 2$ or G is in one of five exceptional classes of graphs. We also prove a Chvátal-type degree sequence condition: if G is a graph with degree sequence $d_1 \leq \cdots \leq d_n$ such that for all $1 \leq i < n/2$, either $d_i \geq i + 1$ or $d_{n-i} \geq n - i - 1$, then either $m(G, 2) = 2$, $G \cong C_5$, or G is in one of two infinite classes of graphs.

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MS42

I,F Partitions of Sparse Graphs

An I, F-partition of a graph G is a partition of the vertex set $V = I \cup F$ such that $G[F]$ is a forest and for all $x, y \in I$ we have that $xy \notin E(G)$ and $N(x) \cap N(y) = \emptyset$. A graph is star k-colorable if it can be properly k-colored such that the union of any two color classes forms a forest. The motivation for studying I, F-partitions is that such a partition implies the graph is star 4-colorable. We prove that if each subgraph H of G satisfies $|E(H)| < 5|V(H)|/4$, then G has an I, F-partition. This is sharp: there exists an infinite family of graphs that have no I, F-partition and each subgraph H of G satisfies $|E(H)| \leq 5|V(H)|/4$. This result also implies that a planar graph with girth at least 10 is star 4-colorable, which improves upon results by Timmons (2008) and Bu, Cranston, Montassier, Raspaud,and Wang (2009). The proof is constructive and gives an I, F-partition (or a star 4-coloring) in polynomial time.

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MS43

Kissing Numbers in High Dimensions

The kissing number, $K(d)$, is the maximum number of non-overlapping unit spheres that can touch a single unit sphere in dimension d. We improve the classical lower bound on $K(d)$ due to Chabauty, Shannon, and Wyner by a linear factor in d. We obtain a similar linear factor improvement to the best known lower bound on the maximal size of a spherical code of acute angle θ in high dimensions. We will also discuss a connection between this problem and extremal problems in locally sparse graphs. This is joint work with Felix Joos and Will Perkins.

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MS43

Turan Exponents of Bipartite Graphs

Given a family F of graphs, the Turan number $ex(n, F)$ is the maximum number of edges in an n-vertex graph that does not contain any member of F as a subgraph. Verifying a long-standing conjecture of Erdos and Simonovits (and reiterated by Frankl and Furedi and Simonovits), Bukh and Conlon showed that for each rational number r with $1 < r < 2$ there exists a family F of bipartite graphs such that $ex(n, F) = \Theta(n^r)$. A more difficult question of Erdos and Simonovits asks if for each rational number r with $1 < r < 2$ there exists a single bipartite graph H such that $ex(n, H) = \Theta(n^r)$. This conjecture is still wide open. Until recently the conjecture was only verified for $r = 1 + 1/k$ and $r = 2 - 1/k$ where k is an integer at least 2, achieved by so-called theta graphs and complete bipartite graphs, respectively. In this talk, we show that the answer to the Erdos-Simonovits question is affirmative for all rational numbers r of the form $4k/(2k + 1)$, where k is a positive integer and for$r = 7/5$. This provides infinitely many new bipartite graphs H for which the order of magnitude of $ex(n, H)$ is determined. This is joint work with Jie Ma and Liana Yepremyan.

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MS43

Extremal Problems for Multigraphs

We study the problem of determining the maximum product of the edge multiplicities in multigraphs where every s vertices span at most q edges. We obtain asymptotically sharp results in many cases and also prove results on the number of such multigraphs with vertex set [n]. Our work can be viewed as a generalization to multigraphs of the Erdos-Kleitman-Rothschild theorem that almost every triangle-free graph with vertex set [n] is bipartite. This is joint work with Caroline Terry.

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MS43

Embedding Trees with Minimum and Maximum Degree Conditions

We will discuss degree conditions which imply that a graph contains all trees of a certain size as subgraphs. We conjecture that if a graph G has minimum degree at least k/2 and a maximum degree at least 2k then every tree with k edges is a subgraph of G. We prove an approximate version of this for large dense graphs and bounded degree trees. Our method of proof also yields approximate versions of the recent 2/3-conjecture of Havet-Reed-Stein-Wood, and of the Erdos-Sos conjecture, for large dense graphs and bounded degree trees. This is joint work with G. Besomi and M. Pavez-Sign.

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MS43

Independent Sets in Sparse Hypergraphs

We study random constructions in incidence structures using a general theorem on independent sets in sparse hypergraphs, generalizing earlier results of Ajtai, Komlós and Szemerédi. Our main results apply to a wide variety of well-studied problems in finite geometry to give almost tight bounds on the sizes of various substructures, including the well-studied cases of partial ovoids, complete arcs and blocking sets. As an example, our theorem produces a maximal partial ovoid of size $O(q \log q)$ in the elliptic quadrics $Q^{-}(5, q)$, which is best possible up to a factor $O(\log q)$.

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MS44

Hereditary Families and the Dominance Order

The dominance order is the partial order on integer partitions determined by majorization. Among the partitions of an even integer, those that are degree sequences of simple graphs form a downward-closed subset of poset elements. In contrast, a few classes of graphs, such as the threshold graphs and the split graphs, have degree sequences that form upward-closed sets when the dominance order is restricted to graphic partitions. We demonstrate a connection between a degree sequence's position within the dominance order and how tight the degree sequence's Erdos–Gallai inequalities are. Relating this tightness to the presence of certain induced subgraphs, We show that the classes of threshold and split graphs are just two of infinitely many hereditary families having upward-closed sets of degree sequences. We show that these classes of graphs, besides having characterizations in terms of degree sequences and induced subgraphs, also have iterative construction algorithms and discuss how these aid in enumerating both the graphs and their degree sequences.

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MS44

Structured Graphs and Posets Overview

In this talk, I will discuss the connections between the different structured families of graphs in the minisymposium, with an emphasis on the difference between hereditary and non-hereditary properties.

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MS44

Hamiltonian Path Variants in Structured Graph Families

Variants on the Hamiltonian path problem have polynomial algorithms on certain structured graph families. Usually in these cases there also is a polynomial certificate of optimality and a corresponding characterization theorem. We will examine several versions for covering the vertices of a graph with paths or walks: Path partitions (minimum number of vertex disjoint paths to cover the vertices), Path covers (minimum number of edge disjoint paths needed to cover the vertices), Fixed endpoint path partition (certain vertices specified to be ends of paths), Open k-walk number (minimum k such that there is a walk covering the vertices with each vertex appearing at most k times), Hamiltonian walk number (minimum length of a walk covering all vertices). We will see the sorts of characterization theorems we can get in highly structured families such as 2-trees, block graphs, unit interval graphs and threshold graphs and some limits to extending to larger classes.

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MS44

Non-monochromatic Triangles in 2-edge-coloured Graphs

Given an edge-coloured graph G, when can we guarantee that there exists a non-monochromatic triangle? We provide a best possible answer for 2-edge-colourings. Joint work with Matt DeVos and Amanda Montejano.

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MS44

Using Three-Sided Brambles to Bound Treewidth in Planar Graphs

We describe an algorithm for obtaining upper and lower bounds on the treewidth of a planar graph. Building on techniques of Bodlaender, Grigoriev and Koster, our algorithm simultaneously searches a planar graph for an obstruction to treewidth and creates a tree decomposition of the graph in $O(|G|^3)$-time. Unlike previous techniques that rely on finding a large square grid minor, our algorithm searches for a more general structure, which we call a *net* in the graph. The upper and lower bounds on treewidth returned by the algorithm are both at most a constant factor away from optimum. Moreover, these bounds improve upper and lower bounds given by Bodlaender et al.

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MS45

Using Curvature to Bound Stretches in Eigenfunctions of Graphs

We examine several notions of the curvature for graphs, which can then be used to prove a strong version of the Harnack inequality for graphs. One implication of the strong Harnack inequality is the fact that the 'stretches' of edges determined the the eigenfunctions are particularly 'small' (in terms of the associated eigenvalue and curvature) near the maximum point.

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MS45

Curvature and the Geometry of Graphs

In this introductory talk for the minisymposium, I will give some introduction to various recent notions of curvature developed from graphs, along with their aims and some successes. In particular, this talk will describe some recent successes to understanding the evolution to heat solutions on graphs satisfying a curvature lower bound and describe how these can be used to understand geometric properties of graphs.

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MS45

Large Scale Ricci Curvature on Graphs

We define a hybrid between Ollvier and Bakry Emery curvature on graphs with dependence on a variable neighborhood. The hexagonal lattice is non-negatively curved under this new curvature notion. Bonnet-Myers diameter bounds and Lichnerowicz eigenvalue estimates follow from the standard argu- ments. We prove gradient estimates similar to the ones obtained from Bakry Emery curvature allowing us to prove Harnack and Buser inequalities.

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MS45

Volume Growth and Buser's Inequality in Graphs

We study the volume growth of metric balls as a function of the radius in discrete spaces, and focus on the relationship between volume growth and discrete curvature. We improve volume growth bounds under a lower bound on the so-called Ollivier curvature, and discuss similar results under other types of discrete Ricci curvature. Following recent work in the continuous setting of Riemannian manifolds (by the first author), we then bound the eigenvalues of the Laplacian of a graph under bounds on the volume growth. In particular, the spectral gap of the graph can be bounded using a weighted discrete Hardy inequality and the higher eigenvalues of the graph can be bounded by the eigenvalues of a tridiagonal matrix times a multiplicative factor, both of which only depend on the volume growth of the graph. As a direct application, we relate the eigenvalues to the Cheeger isoperimetric constant. Using these methods, we describe classes of graphs for which the Cheeger inequality is tight on the second eigenvalue. We also describe a method for proving Buser's Inequality in graphs, particularly under a lower bound assumption on curvature.

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MS46

On Small k-chromatic Graphs of Girth g

We consider the problem of finding smallest graphs with specified girth and chromatic number, when the girth is at least 6. The general problem has an interesting history. It may have begun when Tutte (1954), in answer to a problem posed by Peter Ungar in the Monthly, showed that there exist graphs with girth 6 and chromatic number k, for arbitrarily large values of k. A year later, Mycielski showed that one can obtain triangle free $k+1$-chromatic graphs from triangle free k-chromatic graphs. Then, in what has become a standard demonstration of the power of the probabilistic method in Graph Theory, Erdős (1959) proved that for any positive integers k and g, there exist graphs with chromatic number at least k and girth at least g. For girth $g > 5$, the previously known examples seem to be rather large. Some techniques for generating relatively small examples are outlined. Some example graphs are described which, it will be argued, may be close to optimal.

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MS46

Generating New Patterns for Antique Lace

Bobbin lace is a 500-year-old art form in which threads are braided together in an alternating manner to produce a lace fabric. Elaborate designs are created from smaller patterns, called grounds, which are repeated periodically to fill a region of any size. I will present a mathematical model for bobbin lace grounds representing the structure as the pair $(\Delta(G), \zeta(v))$ where $\Delta(G)$ is a topological embedding of a 2-regular digraph, G, on a torus and $\zeta(v)$ is a mapping from the vertices of G to a set of braid words. As the number of allowed crossings increases, the number of patterns grows exponentially producing an infinite number of prime workable patterns. I will present two ways to generate patterns that conform to the model: 1) A key property of the model is that it must be possible to partition $\Delta(G)$ into a set of osculating circuits such that each circuit has a wrapping index of $(1, 0)$; that is, the circuit wraps once around the meridian of a torus and does not wrap around the longitude. This property suggests an approach of gluing together lattice paths in an osculating manner. 2) Patterns with a high degree of symmetry generally hold more aesthetic interest. I will present a linear time algorithm for identifying successful combinatorial embeddings. Then, using harmonic one-forms to create maximally symmetric graph diagrams, I will demonstrate how we can play with the edge weights to draw out interesting arrangements.

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MS46

Computational Bounds on Classical Ramsey Numbers

Abstract Not Available At Time Of Publication

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MS46

Chromatic Folkman Numbers and Some Related Computational Challenges

For graph G and integers $a_1 \geq \cdots \geq a_r \geq 2$, we write $G \to (a_1, \cdots, a_r)^v$ if and only if for every r-coloring of the vertex set $V(G)$ there exists a monochromatic K_{a_i} in G for some color $i \in \{1, \cdots, r\}$. The vertex Folkman number $F_v(a_1, \cdots, a_r; s)$ is defined as the smallest integer n for which there exists a K_s-free graph G of order n such that $G \to (a_1, \cdots, a_r)^v$. It is well known that if $G \to (a_1, \cdots, a_r)^v$ then $\chi(G) \geq m$, where $m = 1 + \sum_{i=1}^{r}(a_i - 1)$. We study such Folkman graphs G with chromatic number $\chi(G)$ equal to m, which leads to a new concept of chromatic Folkman numbers. We prove constructively some existential results and discuss related computational challenges. A special case of chromatic Folkman numbers for $s = 3$, when $a_i = 2$ for all i, is the famous problem of finding the smallest order of triangle-free graphs with given chromatic number. We conjecture that, in some cases, our construction is the best possible, in particular that for every s there exists a K_{s+1}-free graph G on $F_v(s, s; s + 1)$ vertices with $\chi(G) = 2s - 1$ such that $G \to (s, s)^v$. Finally, we summarize what was accomplished computationally, and what not, for similar but more general Folkman problems.

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MS46

Rotation Systems for Hamilton Cycles

A rotation system is a graph together with a circular order on the edges incident to each vertex. Rotation systems are typically used to describe graph embeddings on orientable surfaces, and in this context they allow for a combinatorial description of each face in the embedding. For example, when a graph is embedded in the plane, we can obtain a face by traveling along some edge, and then repeatedly exiting the previously entered vertex along the 'next' edge in clockwise order. In this talk we demonstrate how rotation systems can be used to construct and understand Hamilton cycles. In particular, we discuss the recent paper *A Hamilton Path for the Sigma-Tau Problem* by Sawada and Williams (SODA 2018) which solved a 40 year-old open problem with a simple algorithm. Time permitting we will also revisit Compton and Williamson's doubly-adjacent Gray code for permutations which can be used to braid n strands.

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MS47

Statistical Estimation Under Group Actions: The Sample Complexity of Multi-Reference Alignment

Many problems in signal/image processing, and computer vision amount to estimating a signal, image, or tri-dimensional structure/scene from corrupted measurements. A particularly challenging form of measurement corruption are latent transformations of the underlying signal to be recovered. Many such transformations can be described as a group acting on the object to be recovered. Examples include the Simulatenous Localization and Mapping (SLaM) problem in Robotics and Computer Vision, where pictures of a scene are obtained from different positions and orientations; Cryo-Electron Microscopy (Cryo-EM) imaging where projections of a molecule density are taken from unknown rotations, and several others. One fundamental example of this type of problems is Multi-Reference Alignment: Given a group acting in a space, the goal is to estimate an orbit of the group action from noisy samples. For example, in one of its simplest forms, one is tasked with estimating a signal from noisy cyclically shifted copies. We will show that the number of observations needed by any method has a surprising dependency on the signal-to-noise ratio (SNR), and algebraic properties of the underlying group action. Remarkably, in some important cases, this sample complexity is achieved with computationally efficient methods based on computing invariants under the group of transformations.

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MS47

Differential Privacy for Growing Databases

We study the design of differentially private algorithms for adaptive analysis of dynamically growing databases, where a database accumulates new data entries while the analysis is ongoing. We provide a collection of tools for machine learning and other types of data analysis that guarantee differential privacy and accuracy as the underlying databases grow arbitrarily large. We give both a general technique and a specific algorithm for adaptive analysis of dynamically growing databases. Our general technique is illustrated by two algorithms that schedule black box access to some algorithm that operates on a fixed database to generically transform private and accurate algorithms for static databases into private and accurate algorithms for dynamically growing databases. These results show that almost any private and accurate algorithm can be rerun at appropriate points of data growth with minimal loss of accuracy, even when data growth is unbounded. Our specific algorithm directly adapts the private multiplicative weights algorithm to the dynamic setting, maintaining the accuracy guarantee of the static setting through unbounded data growth. Along the way, we develop extensions of several other differentially private algorithms to the dynamic setting, which may be of independent interest for future work on the design of differentially private algorithms for growing databases.

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MS47

Catalyst, Generic Acceleration Scheme for Gradient-based Optimization

We introduce a generic scheme called Catalyst for accelerating first-order optimization methods in the sense of Nesterov, which builds upon a new analysis of the accelerated proximal point algorithm. The proposed approach consists of minimizing a convex objective by approximately solving a sequence of well-chosen auxiliary problems, leading to faster convergence. This strategy applies to a large class of algorithms, including gradient descent, block coordinate descent, SAG, SAGA, SDCA, SVRG, Finito/MISO, and their proximal variants. For all of these methods, we provide acceleration and explicit support for non-strongly convex objectives. Furthermore, the approach can be extended to venture into possibly nonconvex optimization problems without sacrificing the rate of convergence to stationary points. We present experimental results showing that the Catalyst acceleration scheme is effective in practice, especially for ill-conditioned problems where we measure significant improvements.

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MS47

Robustness and Submodularity

When important decisions and predictions rely on observed data, robustness is an important aspect in learning and optimization. Robust formulations, however, can lead to more challenging, e.g., nonconvex, optimization problems. This talk will summarize some recent ideas at the intersection of robust optimization, generalization in learning, and submodular optimization. In particular, submodular optimization can help robust optimization, and vice versa.

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MS47

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Abstract Not Available At Time Of Publication

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MS48

The Theory of Network Reliability

Given a finite undirected graph G, the (all-terminal) reliability $\mathrm{Rel}(G, p)$ is the probability that all vertices can communicate, given that the vertices are always operational, but the edges independently fail with probability $q = 1 - p \in [0, 1]$. While much work has been directed to finding efficient algorithms for bounding reliability, in this talk we shall present a variety of theoretical results about these functions and their roots, using a variety of techniques from combinatorics, analysis and algebra.

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MS48

On the Stability of Independence Polynomials

The independence polynomial of a graph is the generating polynomial for the number of independent sets of each size and its roots are called independence roots. In this talk, we investigate the stability of such polynomials, that is, conditions under which the independence roots lie in the left half-plane. We use results from complex analysis to determine graph operations that result in a stable or nonstable independence polynomial. In particular, we prove that every graph is an induced subgraph of a graph with stable independence polynomial. We also show that the independence polynomials of graphs with independence number at most three are necessarily stable, but for larger independence number, we show that the independence polynomials can have roots arbitrarily far to the right. (This is a joint work with Jason Brown)

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MS48

Chromatic Symmetric Functions and e-Positivity

Richard Stanley introduced the chromatic symmetric function X_G of a simple graph G, which is the sum of all possible proper colorings with colors $\{1, 2, 3, \dots\}$ coded as monomials in commuting variables. These formal power series are symmetric functions and generalize the chromatic polynomial. In this talk we discuss which graphs G have a X_G that can be written as a non-negative sum of elementary symmetric functions, and additionally we will also resolve Stanley's e-Positivity of Claw-Contractible-Free Graphs. This is joint work with Angele Foley and Stephanie van Willigenburg.

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MS48

Counting Increasing Spanning Forests in Graphs

Let T be a tree with vertices labeled by distinct integers. We say T is an *increasing tree* if the labels along any path starting at the smallest vertex are increasing. Now suppose that G is a graph with vertices labeled by $\{1, 2, \dots, n\}$. We say a spanning subgraph H of G is an *increasing spanning forest* if each connected component of H is an increasing tree. In this talk we will discuss the generating function for the increasing spanning forests of a graph. Time permitting, we will also discuss forests which avoid certain permutation patterns.

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MS48

On the Roots of Wiener Polynomials of Graphs

The *Wiener polynomial* of a connected graph G is defined as $W(G; x) = \sum x^{d(u,v)}$, where $d(u, v)$ denotes the distance between u and v, and the sum is taken over all unordered pairs of distinct vertices of G. We examine the nature and location of the roots of Wiener polynomials of graphs, and in particular trees. We show that while the maximum modulus among all roots of Wiener polynomials of graphs of order n is $\binom{n}{2} - 1$, the maximum modulus among all roots of Wiener polynomials of trees of order n grows linearly in n. We prove that the closure of the collection of real roots of Wiener polynomials of all graphs is precisely $(-\infty, 0]$, while in the case of trees, it contains $(-\infty, -1]$. Finally, we demonstrate that the imaginary parts and (positive) real parts of roots of Wiener polynomials can be arbitrarily large.

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