Banff International Research Station

for Mathematical Innovation and Discovery

Approximation Algorithms and Hardness of Approximation
August 3–8, 2014

MEALS

*Breakfast (Buffet): 7:00–9:30 am, Sally Borden Building, Monday–Friday
*Lunch (Buffet): 11:30 am–1:30 pm, Sally Borden Building, Monday–Friday
*Dinner (Buffet): 5:30–7:30 pm, Sally Borden Building, Sunday–Thursday
Coffee Breaks: As per daily schedule, in the foyer of the TransCanada Pipeline Pavilion (TCPL)
***Please remember to scan your meal card at the host/hostess station in the dining room for each meal.**

MEETING ROOMS

All lectures will be held in the lecture theater in the TransCanada Pipelines Pavilion (TCPL). An LCD projector, a laptop, a document camera, and blackboards are available for presentations.

SCHEDULE

Sunday

16:00	Check-in begins (Front Desk - Professional Development Centre - open 24 hours)
17:30–19:30	Buffet Dinner, Sally Borden Building
20:00	Informal gathering in 2nd floor lounge, Corbett Hall
	Beverages and a small assortment of snacks are available on a cash honor system.

Monday

7:00–8:45	Breakfast
8:45–9:00	Introduction and Welcome by BIRS Station Manager, TCPL
9:00–10:30	Lectures, TSP Session 1
	Shayan Oveis Gharan: *Effective Resistance Flows and Asymmetric TSP*
	Jens Vygen: *Ears and tours*
	Mohit Singh: *Computability of maximum entropy distributions and counting problems*
10:30–11:00	Coffee Break, TCPL
11:00–12:00	Hyung-Chan An: *LP-Based algorithms for capacitated facility location*
12:00–13:30	Lunch
15:30–16:00	Coffee Break, TCPL
16:00–17:30	Lectures, Network Design
	Anupam Gupta: *Greedy algorithms for Steiner forest*
	R. Ravi: *Deliver or hold: Approximation algorithms for the periodic inventory routing problem*
	Alina Ene: *Degree-bounded network design with node connectivity requirements*
17:30–19:30	Dinner

Tuesday

7:00–9:00	Breakfast
9:00–10:30	Lectures, Cuts and spectral algorithms
	Yury Makarychev: *Nonuniform graph partitioning with unrelated weights*
	Konstantin Makarychev: *Constant factor approximation for balanced cut in the PIE model*
	Tasos Sidiropoulos: *Spectral concentration, robust k-center, and simple clustering*
10:30–11:00	Coffee Break, TCPL
11:00–12:00	Prasad Raghavendra: *On the power of symmetric LP/SDP relaxations*
12:00–13:00	Lunch
13:00–14:00	Guided Tour of The Banff Centre; meet in the 2nd floor lounge, Corbett Hall
14:00	Group Photo; meet in foyer of TCPL.
15:30–16:00	Coffee Break, TCPL
16:00–17:30	Lectures, Miscellaneous
	Nisheeth Vishnoi: *TSP on regular graphs and beyond*
	Chaitanya Swamy: *Region-growing and combinatorial algorithms for k-route cut problems*
	Ola Svensson: *Combinatorial algorithm for restricted max-min fair allocation*
17:30–19:30	Dinner

Wednesday

7:00–9:00	Breakfast
9:00–10:30	Lectures, Constraint satisfaction problems
	Jan Vondrak: *Approximability of multiway partitioning problems and lower bounds from Sperner's colorings*
	Madhur Tulsiani: *A characterization of strong approximation resistance*
	Per Austrin: *$(2+\epsilon)$-SAT is NP-hard*
10:30–11:00	Coffee Break, TCPL
11:00–12:00	Irit Dinur, *Open questions in parallel repetition of games and PCPs*
12:00–13:30	Lunch
	Free Afternoon
17:30–19:30	Dinner

Thursday

7:00–9:00	Breakfast
9:00–10:30	Lectures, Satisfiability
	Moses Charikar: *Smoothed analysis of tensor decompositions*
	Anke van Zuylen: *On some recent MAX SAT approximation algorithms*
	Matthias Poloczek: *Limitations of greedy algorithms for MAX SAT*
10:30–11:00	Coffee Break, TCPL
11:00–12:00	David Steurer: *Sum-of-squares method, tensor decomposition, and dictionary learning*
12:00–13:30	Lunch
15:30–16:00	Coffee Break, TCPL
16:00–17:30	Lectures, Geometry
	Thomas Rothvoss: *Constructive discrepancy minimization for convex sets*
	James Lee: *Talagrand's convolution conjecture and anti-concentration of smoothed functions*
	Andreas Wiese: *Approximation schemes for maximum weight independent set of rectangles*
17:30–19:30	Dinner

Friday

7:00–9:00	Breakfast
9:00–10:00	Lectures, Parting shots
	Mohammad Salvatipour: *Approximation Algorithms for Minimum-Load k-Facility Location*
	Chandra Chekuri: *Routing and Treewidth*
10:-10:30	Coffee Break, TCPL
11:30–13:30	Lunch

Checkout by 12 noon.

** 5-day workshop participants are welcome to use BIRS facilities (BIRS Coffee Lounge, TCPL and Reading Room) until 3 pm on Friday, although participants are still required to checkout of the guest rooms by 12 noon. **

Approximation Algorithms and Hardness of Approximation
August 3–8, 2014

ABSTRACTS
(in alphabetic order by speaker surname)

Speaker: **Hyung-Chan An** (EPFL, Lausanne)
Title: *LP-Based Algorithms for Capacitated Facility Location*
Abstract: Linear programming has played a key role in the study of algorithms for combinatorial optimization problems. In the field of approximation algorithms, this is well illustrated by the uncapacitated facility location problem. A variety of algorithmic methodologies, such as LP-rounding and primal-dual method, have been applied to and evolved from algorithms for this problem. Unfortunately, this collection of powerful algorithmic techniques had not yet been applicable to the more general capacitated facility location problem. In fact, all of the known algorithms with good performance guarantees were based on a single technique, local search, and no linear programming relaxation was known to efficiently approximate the problem. In this paper, we present a linear programming relaxation with constant integrality gap for capacitated facility location. We demonstrate that fundamental concepts from the matching theory, including alternating paths and residual networks, provide key insights that lead to the strong relaxation. Our algorithmic proof of integrality gap is obtained by finally accessing the rich toolbox of LP-based methodologies: we present a constant factor approximation algorithm based on LP-rounding. Our results resolve one of the ten open problems selected by the textbook on approximation algorithms of Williamson and Shmoys. This is joint work with Mohit Singh and Ola Svensson.

Speaker: **Per Austrin** (KTH Stockholm)
Title: $(2+\epsilon)$*-SAT is NP-hard*
Abstract: We prove the following hardness result for a natural promise variant of the classical CNF-satisfiability problem: given a CNF-formula where each clause has width w and the guarantee that there exists an assignment satisfying at least $g = w/2 - 1$ literals in each clause, it is NP-hard to find a satisfying assignment to the formula (that sets at least one literal to true in each clause). On the other hand, when $g = w/2$, it is easy to find a satisfying assignment via simple generalizations of the algorithms for 2-SAT.

We also prove that given a $(2k+1)$-uniform hypergraph that can be 2-colored such that each edge has perfect balance (at most $k+1$ vertices of either color), it is NP-hard to find a 2-coloring that avoids a monochromatic edge. In other words, a set system with discrepancy 1 is hard to distinguish from a set system with worst possible discrepancy.

Joint work with Venkatesan Guruswami and Johan Håstad.

Speaker: **Moses Charikar** (Princeton)
Title: *Smoothed Analysis of Tensor Decompositions*
Abstract: Low rank tensor decompositions are a powerful tool for learning generative models, and uniqueness results give them a significant advantage over matrix decomposition methods. However, tensors pose significant algorithmic challenges and tensors analogs of much of the matrix algebra toolkit are unlikely to exist because of hardness results. Efficient decomposition in the overcomplete case (where rank exceeds dimension) is particularly challenging. We introduce a smoothed analysis model for studying these questions and develop an efficient algorithm for tensor decomposition in the highly overcomplete case (rank polynomial in the dimension). In this setting, we show that our algorithm is robust to inverse polynomial error – a crucial property for applications in learning since we are only allowed a polynomial number of samples. While algorithms are known for exact tensor decomposition in some overcomplete settings, these are not known to be stable to noise.

Our main technical contribution is to show that tensor products of perturbed vectors are linearly independent in a robust sense (i.e. the associated matrix has singular values that are at least an inverse polynomial). This key result paves the way for applying tensor methods to learning problems in the smoothed setting. In particular, we use it to obtain results for learning multi-view models and mixtures of axis-aligned Gaussians where there are many more "components" than dimensions. The assumption here is that the model is not adversarially chosen, formalized by a perturbation of model parameters. We believe this an appealing way to analyze realistic instances of learning problems, since this framework allows us to overcome many of the usual limitations of using tensor methods.

Joint work with Aditya Bhaskara, Ankur Moitra and Aravindan Vijayaraghavan.

Speaker: **Chandra Chekuri** (University of Illinois)
Title: *Routing and Treewidth*
Abstract: The study of approximation algorithms for the maximum edge and node disjoint paths problems raised an interesting question on the structure of graphs with large well-linked sets (which are closely related to graph treewidth). The breakthrough work of Chuzhoy in 2011 obtained a poly-logarithmic approximation for the maximum edge disjoint paths problem with constant congestion. Several new results have been obtained by building on her insights and other ideas. We will describe some of these and point out some open problems.

Speaker: **Irit Dinur** (Weizmann Institute)
Title: *Open questions in parallel repetition of games and PCPs*
Abstract: I will talk about a collection of questions that have to do with parallel repetition and PCPs.

1. Parallel repetition of k Player games ($k = 3$ or more): while we know a lot about the value of a repeated two player game, there is much less for k-players.

2. Direct sum of games: if parallel repetition is the direct product of games, then the direct sum operation is easy to define for XOR games. Some interesting things are known here, but no XOR lemma, as of yet.

3. Derandomized parallel repetition: what can we expect to get? Is there a PCP theorem with polynomially small error?

Speaker: **Alina Ene** (Princeton and U. Warwick)
Title: *Degree-bounded network design with node connectivity requirements*
Abstract: We consider degree bounded network design problems with element and vertex connectivity requirements. In the degree bounded Survivable Network Design (SNDP) problem, the input is an undirected graph $G = (V, E)$ with weights $w(e)$ on the edges and degree bounds $b(v)$ on the vertices, and connectivity requirements $r(uv)$ for each pair uv of vertices. The goal is to select a minimum-weight subgraph H of G that meets the connectivity requirements and it satisfies the degree bounds on the vertices: for each pair uv of vertices, H has $r(uv)$ disjoint paths between u and v; additionally, each vertex v is incident to at most $b(v)$ edges in H. We give an $(O(1), O(1)b(v))$ bicriteria approximation algorithms for the degree-bounded SNDP problem with element connectivity requirements and for several degree-bounded SNDP problems with vertex connectivity requirements. Our algorithms construct a subgraph H whose weight is at most $O(1)$ times the optimal such that each vertex v is incident to at most $O(1)b(v)$ edges in H. Our approach extends to network design problems in directed graphs with both in-degree and out-degree constraints.

This talk is based on joint work with Ali Vakilian (MIT).

Speaker: **Anupam Gupta** (CMU)
Title: *Greedy algorithms for Steiner forest*
Abstract: We consider the following simple algorithm for the Steiner forest problem: find the closest pair of terminals have not been connected to their respective mates yet, and connect them by a shortest path.

Contract the edges in this path and repeat this process until we get a feasible solution. We show that this algorithm is a constant factor approximation for Steiner forest, and use it to get cost-sharing schemes for the Steiner forest problem.

This is joint work with Amit Kumar.

Speaker: **James Lee** (Univ. of Washington)
Title: *Talagrand's convolution conjecture and anti-concentration of smoothed functions*
Abstract: A fundamental tool in Fourier analysis, hardness of approximation, and complexity of Boolean functions is the hypercontractive inequality for the noise operator: If one applies some noise to a nice function on the hypercube, the noised function is more well-behaved than the original. Technically speaking, if the L^p norm of f is bounded for some $p > 1$, then so is the L^q norm of the noisy version, for some $q > p$. But what about functions where we don't have an a-priori smoothness bound? (e.g. indicators of small sets)

Talagrand conjectured that for any non-negative function f, the noised version of f cannot be too concentrated in a precise (dimension-independent) sense. I will present a proof of the conjecture for functions on Gaussian space. Previous work in this setting verified the conjecture in fixed dimension (Ball, Barthe, Bednorz, Oleszkiewicz, and Wolff, 2010). The proof proceeds by analyzing a stochastic evolution of the Gaussian measure to our target measure. We will actually see something more general: Every function on Gaussian space that is not too log-concave (noised functions are a special case) cannot be too concentrated. I will discuss some relationships with Fourier analysis and information theory.

Joint work with Ronen Eldan.

Speaker: **Konstantin Makarychev** (Microsoft Research, Redmond)
Title: *Constant Factor Approximation for Balanced Cut in the PIE Model*
Abstract: We propose and study a new semi-random semi-adversarial model for Balanced Cut, a planted model with permutation-invariant random edges (PIE). Our model is much more general than planted models considered previously. Consider a set of vertices V partitioned into two clusters L and R of equal size. Let G be an arbitrary graph on V with no edges between L and R. Let E_{random} be a set of edges sampled from an arbitrary permutation-invariant distribution (a distribution that is invariant under permutation of vertices in L and in R). Then we say that $G + E_{\text{random}}$ is a graph with permutation-invariant random edges. We present an approximation algorithm for the Balanced Cut problem that finds a balanced cut of cost $O(|E_{\text{random}}|) + n\text{polylog}(n)$ in this model. In the most interesting regime, this is a constant factor approximation with respect to the cost of the planted cut.

Joint work with Yury Makarychev and Aravindan Vijayaraghavan.

Speaker: **Yury Makarychev** (TTI Chicago)
Title: *Nonuniform Graph Partitioning with Unrelated Weights*
Abstract: We give a bi-criteria approximation algorithm for the Minimum Nonuniform Partitioning problem, recently introduced by Krauthgamer, Naor, Schwartz and Talwar (2014). In this problem, we are given a graph $G = (V, E)$ on n vertices and k numbers $\rho_1, ..., \rho_k$. The goal is to partition the graph into k disjoint sets $P_1, ..., P_k$ satisfying $|P_i| \leq \rho_i n$ so as to minimize the number of edges cut by the partition. Our algorithm has an approximation ratio of $O(\sqrt{\log n \log k})$ for general graphs, and an $O(1)$ approximation for graphs with excluded minors. This is an improvement upon the $O(\log n)$ algorithm of Krauthgamer, Naor, Schwartz and Talwar (2014). Our approximation ratio matches the best known ratio for the Minimum (Uniform) k-Partitioning problem.

We extend our results to the case of "unrelated weights" and to the case of "unrelated d-dimensional weights". In the former case, different vertices may have different weights and the weight of a vertex may depend on the set P_i the vertex is assigned to. In the latter case, each vertex u has a d-dimensional weight $r(u, i) = (r_1(u, i), ..., r_d(u, i))$ if u is assigned to P_i. Each set P_i has a d-dimensional capacity $c(i) = (c_1(i), , c_d(i))$. The goal is to find a partition such that $\sum_{uP_i} r(u, i)c(i)$ coordinate-wise.
Joint work with K. Makarychev

Speaker: **Shayan Oveis-Gharan** (Univ. of Washington)
Title: *Effective Resistance Flows and Asymmetric TSP*
Abstract: I will talk about connections between the recent proof of the Kadison-Singer conjecture and the thin tree conjecture and approximability of Asymmetric TSP.

Speaker: **Matthias Poloczek** (Cornell)
Title: *Limitations of greedy algorithms for MAX SAT*
Abstract: The maximum satisfiability problem (MAX SAT) is a fundamental problem in discrete optimization. Given a collection of clauses with nonnegative weights, our goal is to find an assignment to the variables that satisfies clauses of maximum total weight. Recently, Poloczek and Schnitger proposed a randomized greedy algorithm was proposed that achieves a 3/4 approximation for MAX SAT (see the talk of Anke van Zuylen for an overview of subsequent work). In particular, its performance is comparable to Yannakakis' algorithm based on flows and LP (1994) or the LP-rounding algorithm of Goemans and Williamson (1994). The simple algorithm processes the variables in a worst case order and draws its strength from carefully chosen assignment probabilities.

In this talk we explore the limitations of the greedy paradigm using the model of priority algorithms of Borodin, Nielsen, and Rackoff (2003). On the one hand, we wonder if a better approximation ratio can be obtained by further fine-tuning the assignment probabilities of the randomized greedy algorithm? On the other hand, we study the question whether the greedy algorithm can be derandomized, and therefore investigate the strength of deterministic greedy algorithms. We conclude with a structural result on balanced MAX 2SAT and show that the deterministic greedy algorithm of Johnson (1974) achieves a 3/4 approximation for such instances.

Based on joint work with Alice Paul and David P. Williamson.

Speaker: **Prasad Raghavendra** (UC Berkeley)
Title: *On the power of Symmetric LP/SDP relaxations*
Abstract: In this talk we will present two results:

1. We show that for $k < n/4$ the k-rounds sum-of-squares or Lasserre SDP relaxation achieve best possible approximation guarantee for Max-CSPs among all symmetric SDP relaxations of size at most $\binom{n}{k}$.
2. We will show how to construct linear programs for TSP that are instance-optimal among all symmetric linear programs.

Speaker: **R. Ravi** (CMU)
Title: *Deliver or hold: Approximation algorithms for the periodic inventory routing problem*
Abstract: The inventory routing problem involves trading off inventory holding costs at client locations with vehicle routing costs to deliver frequently from a single central depot to meet deterministic client demands over a finite planning horizon. In this paper, we consider periodic solutions that visit clients in one of several specified frequencies, and focus on the case when the frequencies of visiting nodes are nested. We give the first constant-factor approximation algorithms for designing optimum nested periodic schedules for the problem with no limit on vehicle capacities by simple reductions to prize-collecting network design problems. For instance, we present a 2.55-approximation algorithm for the minimum-cost nested periodic schedule where the vehicle routes are modeled as minimum Steiner trees. We also show a general reduction from the capacitated problem where all vehicles have the same capacity to the uncapacitated version with a slight loss in performance. This reduction gives a 4.55-approximation for the capacitated problem. In addition, we prove several structural results relating the values of optimal policies of various types.

Joint work with Takuro Fukunaga and Afshin Nikzad.

Speaker: **Mohammad Salavatipour** (University of Alberta)
Title: *Approximation Algorithms for Minimum-Load k-Facility Location*

Abstract: We consider a facility-location problem that abstracts settings where the cost of serving the clients assigned to a facility is incurred by the facility. Formally, we consider the minimum-load k-facility location (MLKFL) problem, which is defined as follows. We have a set $\mathcal{F}$ of facilities, a set $\mathcal{C}$ of clients, and an integer $k \geq 0$. Assigning client j to a facility f incurs a connection cost $d(f, j)$. The goal is to open a set $F \subset \mathcal{F}$ of k facilities, and assign each client j to a facility $f(j) \in F$ so as to minimize $\max_{f \in F} \sum_{j \in \mathcal{C}: f(j)=f} d(f, j)$; we call $\sum_{j \in \mathcal{C}: f(j)=f} d(f, j)$ the *load* of facility f. This problem was studied under the name of min-max star cover but only has bicriteria approximation algorithms for when $\mathcal{F} = \mathcal{C}$. MLKFL is rather poorly understood, and only an $O(k)$-approximation is currently known even for line metrics. We present some approximation schemes for MLKFL on line and tree metrics. We also show that (a) even a configuration-style LP-relaxation has a bad integrality gap; and (b) a multi-swap k-median style local-search heuristic has a bad locality gap.

Joint work with: S. Ahmadian, B. Behsaz, Z. Friggstad, A. Jorati, C. Swamy.

Speaker: **Thomas Rothvoss** (Univ. of Washington)
Title: *Constructive discrepancy minimization for convex sets*
Abstract: A classical theorem of Spencer shows that any set system with n sets and n elements admits a coloring of discrepancy $O(\sqrt{n})$. Recent exciting work of Bansal, Lovett and Meka shows that such colorings can be found in polynomial time. In fact, the Lovett-Meka algorithm finds a half integral point in any "large enough" polytope. However, their algorithm crucially relies on the facet structure and does not apply to general convex sets. We show that for any symmetric convex set K with measure at least $\exp(-n/500)$, the following algorithm finds a point $y \in K \cap [-1, 1]^n$ with $\Omega(n)$ coordinates in $\{-1, +1\}$: (1) take a random Gaussian vector x; (2) compute the point $y \in K \cap [-1, 1]^n$ that is closest to x. (3) return y. This provides another truly constructive proof of Spencer's theorem and the first constructive proof of a Theorem of Giannopoulos.

Speaker: **Anastasios (Tasos) Sidiropoulos** (Ohio State University)
Title: *Spectral concentration, robust k-center, and simple clustering*
Abstract: A popular graph clustering method is to consider the embedding of an input graph into R^k induced by the first k eigenvectors of its Laplacian, and to partition the graph via geometric manipulations on the resulting metric space. Despite the practical success of this methodology, there is limited understanding of several heuristics that follow this framework. We provide theoretical justification for a natural such heuristic that has been previously proposed [Balakrishnan et al., 2011, Ng, Jordan, and Weiss, 2001].

Our result can be summarized as follows. We say that a partition of a graph is strong if each cluster has small external conductance, but large internal conductance. We consider a spectral clustering algorithm which computes a partition into k clusters by approximating the robust k-center problem on the metric induced by the embedding into k-dimensional eigenspace. We show that for bounded-degree graphs with a sufficiently large gap between the k-th and $(k+1)$-th eigenvalue of its Laplacian, this algorithm computes a partition that is arbitrarily close to a strong one.

Our proof uses a recent result due to [Gharan and Trevisan, 2014] on the existence of strong partitions in graphs with sufficiently large spectral gap. Combining our result with a greedy 3-approximation for robust k-center due to [Charikar et al., 2001] gives us the desired spectral partitioning algorithm. We also show how a simple greedy algorithm for k-center can be implemented in time $O(nk^2 \log n)$. Finally, we evaluate our algorithm on some real-world, and synthetic inputs.

Speaker: **Mohit Singh** (Microsoft Research, Redmond)
Title: *Computability of Maximum Entropy Distributions and Counting Problems*
Abstract: Given a polytope P and a point $x \in P$, there can be many ways to write x as a convex combination of vertices of P. Interpreting any convex combination as a probability distribution over vertices of P, the distribution that maximizes entropy has received considerable interest. Interest in such distributions arises due to their applicability in areas such as statistical physics, economics, biology, information theory, machine learning, combinatorics and, more recently, approximation algorithms. In this

talk, I will discuss the computability of maximum entropy distributions. A key difficulty in computing max-entropy distributions has been to show that they have polynomially-sized descriptions. We show that such descriptions exist under general conditions. Subsequently, we show how algorithms for (approximately) counting the vertices of P can be translated into efficient algorithms to (approximately) compute max-entropy distributions. In the reverse direction, we show how access to algorithms that compute max-entropy distributions can be used to count, which establishes an equivalence between counting and computing max-entropy distributions.

This is joint work with Nisheeth Vishnoi.

Speaker: **David Steurer** (Cornell)
Title: *Sum-of-Squares Method, Tensor Decomposition, and Dictionary Learning*
Abstract: The sum-of-squares method is a widely-studied, conceptually simple meta-algorithm that, for a broad range of problems, captures the best known algorithms and potentially achieves better and plausibly optimal guarantees for these problems. We introduce a general approach for proving guarantees of efficient approximation algorithms based on the sum-of-squares method by exploiting connections to proof complexity. Following this approach, we give efficient algorithms with significantly improved guarantees for several problems arising in machine learning and optimization, in particular, robust tensor decomposition and dictionary learning. Based on joint works with Boaz Barak and Jonathan Kelner.

Speaker: **Ola Svensson** (EPFL, Lausanne)
Title: *Combinatorial Algorithm for Restricted Max-Min Fair Allocation*
Abstract: We study the basic allocation problem of assigning resources to players so as to maximize fairness. This is one of the few natural problems that enjoys the intriguing status of having a better estimation algorithm than approximation algorithm. Indeed, a certain configuration-LP can be used to estimate the value of the optimal allocation to within a factor of $4 + \epsilon$. In contrast, however, the best known approximation algorithm for the problem has an unspecified large constant guarantee.

In this paper we narrow this gap by giving a 13-approximation algorithm for the problem. Our approach develops a local search technique introduced by Haxell for hypergraph matchings, and later used in this context by Asadpour, Feige, and Saberi. For our local search procedure to terminate in polynomial time, we introduce several new ideas such as lazy updates and greedy players. Besides the improved approximation guarantee, the highlight of our approach is that it is purely combinatorial and uses the configuration-LP only in the analysis.

This is joint work with Chidambaram Annamalai and Christos Kalaitzis.

Speaker: **Chaitanya Swamy** (Univ. of Waterloo)
Title: *Region-Growing and Combinatorial Algorithms for k-Route Cut Problems*
Abstract: We study the k-route generalizations of various cut problems, the most general of which is k-route multicut (k-MC), wherein we are given r source-sink pairs and the goal is to delete a minimum-cost set of edges to reduce the edge-connectivity of every source-sink pair to below k. The k-route extensions of multiway cut (k-MWC), and the minimum s-t cut problem (k-(s,t)-Cut), are similarly defined. These cut problems arise naturally in the study of k-route flows, which are dual objects to k-route cuts, and can also be motivated directly the viewpoint of network interdiction problems, which abstract settings where an attacker seeks to disrupt a network while incurring minimum cost.

For k-route multiway cut, we devise simple combinatorial algorithms that yield bicriteria approximation guarantees that markedly improve upon the previous-best guarantees. For k-route multicut, we design algorithms that improve upon the previous-best approximation factors by roughly an $O(\sqrt{\log r})$-factor, when $k = 2$, and for general k and unit costs and any fixed violation of the connectivity threshold k. Notably, our guarantees also translate to integrality-gap results for a natural linear-programming (LP) relaxation for k-MC. The main technical ingredient and innovation is the definition of a new, powerful region-growing lemma that allows us to perform region-growing in a recursive fashion even though the LP solution yields a *different metric* for each source-sink pair, and without incurring an $O(\log^2 r)$ blow-up in the cost that is inherent in some previous applications of region growing to k-route cuts. We complement these results by showing that (even) the k-route s-t cut problem is at least as hard to approximate as the *densest-k-subgraph* (DkS) problem on uniform hypergraphs. This rules out sub-poly(k)-factor unicriterion approximation unless one improves the state-of-the-art for DkS on graphs, and proves the existence of a family of one-way functions.

Joint work with Guru Guruganesh and Laura Sanita.

Speaker: **Madhur Tulsiani** (TTI Chicago)
Title: *A Characterization of Strong Approximation Resistance*
Abstract: For a predicate $f : \{-1,1\}^k \mapsto \{0,1\}$ with $\rho(f) = \frac{|f^{-1}(1)|}{2^k}$, we call the predicate *strongly approximation resistant* if given a near-satisfiable instance of CSP(f), it is computationally *hard* to find an assignment such that the fraction of constraints satisfied is outside the range $[\rho(f) - \Omega(1), \rho(f) + \Omega(1)]$.

We present a characterization of strongly approximation resistant predicates under the Unique Games Conjecture. We also present characterizations in the *mixed* linear and semi-definite programming hierarchy and the Sherali-Adams linear programming hierarchy. In the former case, the characterization coincides with the one based on UGC. Each of the two characterizations is in terms of existence of a probability measure on a natural convex polytope associated with the predicate.

The predicate is called *approximation resistant* if given a near-satisfiable instance of CSP(f), it is computationally *hard* to find an assignment such that the fraction of constraints satisfied is at least $\rho(f) + \Omega(1)$. When the predicate is odd, i.e. $f(-z) = 1 - f(z), \forall z \in \{-1,1\}^k$, it is easily observed that the notion of approximation resistance coincides with that of strong approximation resistance. Hence for odd predicates, in all the above settings, our characterization of strong approximation resistance is also a characterization of approximation resistance.

Joint work with Subhash Khot and Pratik Worah.

Speaker: **Nisheeth Vishnoi** (EPFL, Lausanne)
Title: *TSP on Regular Graphs and Beyond*
Abstract: I will present a very simple algorithm for TSP on regular graphs which outputs better and better tours as the degree increases. Subsequently, inspired by these proof techniques, I will discuss approaches for the general TSP/ATSP problems.

Speaker: **Jan Vondrak** (IBM Almaden)
Title: *Approximability of Multiway Partitioning Problems and Lower Bounds from Sperner's Colorings*
Abstract: I will discuss several problems where the goal is partition a ground set into several pieces while minimizing a "cut-type" objective function - examples inlude Multiway Cut, Node-weighted Multiway Cut, Metric Labeling and Hypergraph Labeling. By now it is known that a natural LP gives an optimal approximation for these problems, assuming the Unique Games Conjecture (and the UGC assumption can be removed for certain submodular generalizations of these problems). However, we don't know how to round this LP in general and analyzing it for specific problems still leads to interesting questions. I will discuss some effective rounding strategies and constructions of integrality gaps that lead to questions about colorings of the simplex reminiscent of Sperner's Lemma.

Speaker: **Jens Vygen** (Univ. of Bonn)
Title: *Ears and tours*
Abstract: TBA

Speaker: **Andreas Wiese** (MPI)
Title: *Approximation Schemes for Maximum Weight Independent Set of Rectangles*
Abstract: In the Maximum Weight Independent Set of Rectangles (MWISR) problem we are given a set of n axis-parallel rectangles in the 2D-plane, and the goal is to select a maximum weight subset of pairwise non-overlapping rectangles. Due to many applications, e.g., in data mining, map labeling and admission control,

the problem has received a lot of attention by various research communities. We present the first $(1+\epsilon)$-approximation algorithm for the MWISR problem with quasi-polynomial running time $2^{\text{poly}(\log n/\epsilon)}$. In contrast, the best known polynomial time approximation algorithms for the problem achieve superconstant approximation ratios of $O(\log \log n)$ (unweighted case) and $O(\log n/\log \log n)$ (weighted case). Key to our results is a new geometric dynamic program which recursively subdivides the plane into polygons of bounded complexity. We provide the technical tools that are needed to analyze its performance. Finally, I will give an overview of recent follow-up work, in particular a generalization of the above result to arbitrary polygons.

Joint work with Anna Adamaszek.

Speaker: **Anke van Zuylen** (College of William and Mary)
Title: *On some recent MAX SAT approximation algorithms*
Abstract: Recently a number of randomized 3/4-approximation algorithms for MAX SAT have been proposed that all work in the same way: given a fixed ordering of the variables the algorithm makes a random assignment to each variable in sequence, in which the probability of assigning each variable true or false depends on the current set of satisfied (or unsatisfied) clauses.

To our knowledge, the first such algorithm was proposed by Poloczek and Schnitger (2011); Van Zuylen (2011) subsequently gave an algorithm that set the probabilities differently and had a simpler analysis. Buchbinder, Feldman, Naor, and Schwartz (2012), as a special case of their work on maximizing submodular functions, also give a randomized3/4-approximation algorithm for MAX SAT with the same structure as these previous algorithms. In this talk, we give an even simpler version of the algorithm and analysis that was proposed by Buchbinder et al and we show that in fact it is equivalent to the algorithm proposed by Van Zuylen. We also show how it extends to a deterministic LP rounding algorithm, which is the same algorithm that was also given by Van Zuylen (2011).

This is based on joint work with Matthias Poloczek and David Williamson.