Optimization and Discrete Geometry: Theory and Practice

April 24-27 2018

Tel Aviv University

Organizers: Antoine Deza, Frédéric Meunier, Tal Raviv

ABSTRACT BOOKLET

Contents

Tuesday, April 24

Session A1: 10h00-12h00

A11. **Discrete Geometry Meets Machine Learning**
Amitabh Basu (Johns Hopkins University)

There has been a surge of research activity in machine learning in the past decade. Consequently, there has been a growing interest in mathematically rigorous analysis to strengthen the foundations of this area. A surprisingly large number of applications seem to report empirically observed phenomena that suggest that there are some universal mathematical theorems underpinning the recent successes reported. However, for many (most?) of the interesting phenomena, such theoretical foundations have been elusive. Moreover, wherever such results have been obtained, it has been through the lens of continuous (convex and non-convex) optimization. We will try to make the case that techniques from discrete geometry and optimization are ideally placed to tackle some of the unsolved puzzles in this area, and perhaps provide competing methods even in some applications that have traditionally relied on continuous optimization techniques. The emphasis of the talk will be on open problems in machine learning that can be framed in the language of discrete geometry and optimization.

The talk will be based on recent work with Raman Arora, Poorya Mianjy and Anirbit Mukherjee.

A12. **Integer Programming in Strongly Polynomial Oracle Time**
Shmuel Onn (Technion)

We show that every integer program endowed with a suitable oracle can be solved in strongly polynomial time. We then realize such an oracle for four broad classes of integer programs, providing the first strongly polynomial fixed parameter tractable solution of programs with multistage stochastic or tree fold block structure parameterized by the block sizes, and of programs with bounded primal or dual treedepth parameterized by the treedepth. These results subsume all current results in the literature in this area and have numerous applications in parameterized complexity and more.

This is very recent joint work with Martin Koutecký and Asaf Levin.

A13. **Emulating the Expert: Inverse Optimization through Online Learning**
Sebastian Pokutta (Georgia Tech)

We show how to learn the objective function of a decision maker while only observing the problem input data and the decision maker's corresponding decisions over multiple rounds. Our approach is based on online learning techniques and works for linear objectives over arbitrary sets for which we have a linear optimization oracle and as such generalizes previous work based on KKT-system decomposition and dualization approaches. The applicability of our framework for learning linear constraints is also discussed briefly. Our algorithm converges at a rate of $O\left(1/\sqrt{T}\right)$, and we demonstrate its effectiveness and applications in preliminary computational results.

A14. **Easier derivation of bounded pitch inequalities for set covering problems**
Daniel Bienstock (Columbia University)

Given a 0-1 set-covering problem and a positive integer k, a valid inequality $a^T x \geq b$ is said to have pitch $\leq k$ if the k smallest nonzero a_i add up to at least b. Inequalities of pitch 1 are dominated by inequalities in the original system, but one can already obtain set covering problems with an exponential number of facets of pitch 2. In previous work it has been shown that for any fixed k, there is a polynomial size extended formulation that implies all valid inequalities of pitch $\leq k$. This construction involves a complex formulation. Recent work has highlighted interest in this family of inequalities. In this talk we present a much simpler formulation that implies the same result.

Joint work with Mark Zuckerberg.

Session A2: 13h30-15h00

A21. **Online Algorithms for Non-Linear Optimization**
Nguyen Kim Thang (Université d'Évry)

Convex objectives have been extensively studied in which analyses rely crucially on the convexity. However, problems with non-convex objectives resist against current approaches and non-convexity represents a strong barrier in optimization in general and in the design of online algorithms in particular.

In the talk, we present competitive online primal-dual algorithms for covering and packing problems with non-convex objectives based on configuration linear programs. We introduce a new notion called smoothness in order to characterize the competitiveness of our algorithm. As applications, our algorithms yield tight competitive ratios for non-negative polynomial objectives and for online submodular minimization/maximization problems.

A22. **Toward Breaking the Curse of Dimensionality: An FPTAS for Stochastic Dynamic Programs with Multidimensional Action and Scalar State**
Nir Halman (Hebrew University)

We propose an FPTAS for stochastic dynamic programs with multidimensional action, scalar state, convex piecewise linear costs and linear state transition function. The action spaces are polyhedral and described by parametric linear programs. The FPTAS relies on the solution of polynomial-sized linear programs to recursively compute an approximation of the value function at each stage. Our paper enlarges the class of dynamic programs that admit an FPTAS by showing how to deal with multidimensional action spaces and with vectors of continuous random variables under suitable conditions, therefore getting one step closer to overcoming the curses of dimensionality of dynamic programming.

A23. **Computing nucleolus for cooperative matching games**
Kanstantsin Pashkovich (University of California, Berkeley)

The“nucleolus” is one of the ways to distribute the common profit among all participating players in some common business fairly. The first mention of this notion of fair distribution goes as far back as the Talmud. In this talk, we will present the first polynomial-time algorithm for computing the nucleolus for weighted cooperative matching games. Thus we settle one of the major open questions in the cooperative game theory. Our algorithm strongly relies on polyhedral theory and on the structure of optimal solutions for the optimization problems that arise in our approach.

Joint work with Jochen Koenemann and Justin Tóth.

Session A3: 15h30-17h00

A31. **Block partitions of sequences**
Imre Bárány (Alfréd Rényi Mathematical Institute)

Given a sequence $A = (a_1, \ldots, a_n)$ of real numbers, a block B of the A is either a set $B = \{a_i, a_{i+1}, \ldots, a_j\}$ where $i \leq j$ or the empty set. The size b of a block B is the sum of its elements. We show that when each $a_i \in [0, 1]$ and k is a positive integer, there is a partition of A into k blocks $B_1, \ldots, B_k$ with $|b_i - b_j| \leq 1$ for every i, j. We extend this result in several directions, including higher dimensional versions.

Joint work with V. Grinberg, E. Csóka, Gy. Károlyi, and G. Tóth.

A32. **An invariant and effective description of compact non-convex polyhedra**
Dmitrii Pasechnik (University of Oxford)

It is often assumed that the only way to represent a (compact) non-convex polyhedron $X \subset \mathbb{R}^d$ is by partitioning into convex polytopal pieces. Such partitions are very far from being unique or succinct; in particular in dimensions $d > 2$ one might need to introduce *Steiner points*—points in the interior of X which must arise as vertices of polytopal pieces.

We propose a description that is essentially unique: a rational function associated with the uniform measure $\mu(X)$ supported on X. It is given by an integral transform of $\mu(X)$ known as *Fantappiè transformation*

$$\mathcal{F}(\mu(X))(u) := d! \int_{\mathbb{R}^d} \frac{d\mu(X)(x)}{(1 - \langle u, x \rangle)^{d+1}} = \frac{P(u)}{\prod_{v \in V}(1 - \langle u, v \rangle)},$$

where $\langle x, y\rangle$ denotes the standard scalar product $\sum_i x_i y_i$. Expanding $\mathcal{F}$ into Taylor series gives a scaled moment generating function (m.g.f.) for $\mu(X)$, known in the univariate case as factorial m.g.f., and this allows for efficient computation of integrals over X, etc.

$\mathcal{F}$ admits decompositions into "elementary" summands with real weights, corresponding to certain simplices with vertices from V, which are analogous to triangulations of convex polytopes. In particular they allow an efficient way to check containment of a point in X. It is an interesting open question whether these weights can be chosen to be ± 1.

It is natural to homogenise $\mathcal{F}$, an operation that corresponds to switching to the Laplace-Fourier transform of a measure supported on the conic closure of X embedded into the hyperplane $\{x_0 = 1\} \subset \mathbb{R}^{d+1}$. It allows to apply powerful machinery of Jeffrey-Kirwan residues by Brion and Vergne, used in the theory of hyperplane arrangements.

A33. **On finite totally separable translative packings**

Károly Bezdek (University of Calgary)

This is a survey talk on volumetric inequalities and contact graphs of totally separable translative packings of convex bodies in Euclidean d-space.

Wednesday, April 25

Session B1: 10h00-12h00

B11. **Optimization with verification oracles**
Sergei Chubanov (University of Siegen)

One of the fundamental questions when solving an optimization problem is how to verify whether a given solution is optimal. An algorithm proving or disproving optimality of a given solution for a given objective function is called a verification oracle. In this talk we will discuss two algorithms, one for integer linear problems and one for separable convex optimization with linear constraints, which use verification oracles and run in a reasonable oracle time. In the case of integer problems we obtain an oracle time which is polynomial in the binary size of the problem and in the bounds on the variables. In the case of separable convex problems the running time is polynomial in the usual sense, provided that the verification oracle is a polynomial algorithm.

B12. **Disjunctive conic cuts: the good, the bad, and implementation**
Julio Góez (Norwegian School of Economics)

In recent years, the generalization of Balas disjunctive cuts for mixed integer linear optimization problems to mixed integer non-linear optimization problems has received significant attention. Among these studies, mixed integer second order cone optimization (MISOCO) is a special case. For MISOCO one has the disjunctive conic cuts approach. That generalization introduced the concept of disjunctive conic cuts (DCCs) and disjunctive cylindrical cuts (DCyCs). Specifically, it showed that under some mild assumptions the intersection of those DCCs and DCyCs with a closed convex set, given as the intersection of a second order cone and an affine set, is the convex hull of the intersection of the same set with a parallel linear disjunction. The key element in that analysis was the use of pencils of quadrics to find close forms for deriving the DCCs and DCyCs. The first part of this talk will summarize the main results about DCCs and DCyCs including some results about valid conic inequalities for hyperboloids and non-convex quadratic cones when the disjunction is defined by parallel hyperplanes. In the second part, we will discussed some of the limitation of this approach to derive useful valid inequalities in the context of MISOCO. In the last part, we will briefly describe the software libraries that together constitute DisCO, a full-featured solver for MISOCP which we are currently used to explore the potential of DCCs and DCyCs.

B13. **Barvinok's naive algorithm for dimensionality reduction**
Leo Liberti (CNRS & École Polytechnique)

In 1997, A. Barvinok gave a probabilistic algorithm to derive a feasible solution of a quadratically (equation) constrained problem from its semidefinite relaxation. We generalize this algorithm to handle matrix (instead of vector) variables and to two-sided inequalities, and derive a heuristic for the distance geometry problem. We showcase its computational performance on a set of instances related to protein conformation. We then discuss its potential as a dimensionality reduction algorithm, and evaluate its performance on a number of other applications.

Joint work with Ky Vu.

B14. **Elections, bribery, and integer programming**

Martin Koutecký (Technion)

The usefulness of integer programming to solving some tasks related to elections has been known since the influential work of Barholdi, Tovey and Trick in 1989. However, while many new models were invented in the subsequent 28 years and ILP has continued to be relevant, all the ILP formulations in use remained essentially the same. In recent developments, we have solved several open problems in the field of computational social choice by taking a more distinctively geometric perspective at elections and briberies and applying powerful but previously unused tools from the integer programming arsenal.

Session B2: 13h30-15h00

B21. **Optimization Problems with Sparsity-Inducing Terms**

Amir Beck (Tel Aviv University)

We consider several optimization problems that contain the l_0-norm expression. These problems are considered to be extremely difficult to solve and analyze due to the nonconvexity and discontinuity of the l_0 expression. We establish under some symmetry assumptions a hierarchy between stationarity-based optimality conditions and conditions based on coordinate-wise optimality. These results also imply a hierarchy between several corresponding algorithms. A key mathematical tool used in analysis is the proximal mapping of symmetric functions including l_0-norm expressions.

The lecture is based on a joint work with Nadav Hallak.

B22. **More Virtuous Smoothing**

Jon Lee (University of Michigan)

In the context of global optimization of mixed-integer nonlinear optimization formulations, we consider smoothing univariate concave increasing functions that have poorly behaved derivative at 0 (for example, root functions). Extending earlier work of Lee and Skipper, we give general conditions under which our smoothing is concave and increasing, is an underestimator, and dominates a simple "shift smoothing".

This is joint work with Luze Xu and Daphne Skipper.

B23. **First Order Methods for Solving Convex Bi-Level Optimization Problems**
Shoham Sabach (Technion)

We study convex bi-level optimization problems for which the inner level consists of minimization of the sum of smooth and nonsmooth functions. The outer level aims at minimizing a smooth and strongly convex function over the optimal solutions set of the inner problem. We analyze first order methods and global sublinear rate of convergence of the method is established in terms of the inner objective function values.

The talk is based on joint work with Shimrit Shtern (Technion).

Session B3: 15h30-17h30

B31. **On Moser's shadow problem**
Arnau Padrol (Sorbonne Université)

In a famous list of problems in combinatorial geometry from 1966, Leo Moser asked for the largest $s(n)$ such that every 3-dimensional convex polyhedron with n vertices has a 2-dimensional shadow with at least $s(n)$ vertices. I will describe the main steps towards the answer, which is that $s(n)$ is of order $\log(n)/\log\log(n)$, found recently in collaboration with Jeffrey Lagarias and Yusheng Luo, and which follows from 1989 work of Chazelle, Edelsbrunner and Guibas. I will also report on current work with Alfredo Hubard concerning higher-dimensional generalizations of this problem.

B32. **Circuit Walks in Integral Polyhedra**
Steffen Borgwardt (University of Colorado Denver)

Circuits play a fundamental role in the theory of linear programming due to their intimate connection to algorithms of combinatorial optimization and the Simplex method. We are interested in better understanding the properties of circuit walks in integral polyhedra.

We introduce a hierarchy for integral polyhedra based on different types of behavior exhibited by their circuit walks. Many problems in combinatorial optimization fall into the most interesting categories of this hierarchy – steps of circuit walks in the associated polyhedra only stop at integer points, at vertices, or follow actual edges. We categorize classical families of polyhedra within the hierarchy, including 0/1-polytopes, polyhedra defined by totally unimodular matrices, and more specifically matroid polytopes, transportation polytopes, and partition polytopes. Further, we prove several equivalent characterizations of the non-degenerate polytopes that appear in the bottom level of the hierarchy, where all circuit walks are edge walks.

B33. **The Simplex Method for LP and the Length of a Path**

Shinji Mizuno (Tokyo Institute of Technology)

The simplex method for a linear programming problem finds an optimal solution by generating a sequence of vertices of a polyhedron (or a sequence of basic solutions of the feasible region) such that the object function value is minimized. Then the sequence of vertices could be seen as a monotone path on the network consisted of the vertices and the edges of the polyhedron. If the problem is non-degenerate, the number of iterations of the simplex method is equal to the length of the path. Otherwise, the number could be much bigger than the length. We will discuss lower and upper bounds for the number of iterations and the length of the path in the two cases. We also show simple linear programming instances for which the simplex method requires an exponential number of iterations, but the length of the path is very small.

B34. **Discrete geometry of functional equations in cutgeneratingfunctionology**

Matthias Köppe (University of California, Davis)

I present recent results and open questions regarding Cauchy's and Pexider's functional equation on restricted (polyhedral) domains, which arise from the study of cut-generating functions in integer optimization.

Thursday, April 26

Session C1: 10h00-12h00

C11. **A New Look at First Order Methods: Lifting the Lipschitz Gradient Continuity Restriction**
Marc Teboulle (Tel Aviv University)

The gradient method, invented by Cauchy about 170 years ago, is today an icon in modern optimization algorithms and applications, through many of its relatives/variants classes of First Order Methods (FOM). These algorithms are attractive due to their computational simplicity allowing to tackle very large scale optimization problems arising in a huge spectrum of applications.

A crucial and standard assumption common to almost all (FOM) requires the gradient of the smooth part in a given objective function to be globally Lipschitz continuous, precluding the use of FOM in many important applied scenarios.

In this talk, we introduce a simple and elegant framework for FOM, which allows to circumvent this longstanding smoothness restriction, by capturing all at once, the geometry of the objective and the feasible set. The new framework translates into first order methods with proven guaranteed complexity estimates, and pointwise global convergence for the fundamental composite convex optimization model. It paves a new path for tackling broad classes of problems, which

Joint work with H. Bauschke (UBC) and J. Bolte (TSE).

C12. **Total Dual Integrality for Convex, Semidefinite, and Extended Formulations**
Levent Tunçel (University of Waterloo)

We propose a notion of total dual integrality for SDPs that generalizes the notion for LPs, by relying on an “integrality constraint” for SDPs that is primal-dual symmetric. A key ingredient for the theory is a generalization to compact convex sets of a result of Hoffman for polytopes, fundamental for generalizing the polyhedral notion of total dual integrality introduced by Edmonds and Giles. We study the corresponding theory applied to SDP formulations for stable sets in graphs using the Lovász theta function and show that total dual integrality in this case corresponds to the underlying graph being perfect. We also relate dual integrality of an SDP formulation for the maximum cut problem to bipartite graphs. Total dual integrality for extended formulations naturally comes into play in this context.

Based on joint work with M. de Carli Silva.

C13. **Cardinality-constrained least squares problem for sparse matrices**
Santanu Dey (Georgia Tech)

Cardinality-constrained least squares problem is a fundamental problem is statistics. In this paper, we prove that the least squares problem where the data matrix has structured sparsity is polynomially solvable. Our approach is completely combinatorial and uses classical results from discrete geometry.

This is joint work with Alberto Del Pia and Robert Weismantel.

C14. **Mixed Integer Second Order Cone Optimization (MISOCO): Conic Cuts, Warm Start, and Rounding**
Tamás Terlaky (Lehigh University)

MISOCO has numerous applications in engineering sciences, finance, and healthcare, thus MISOCO has gained considerable interest in recent years. Efficient Interior Point Methods and software are available to solve continuous SOCO problems. The theory of Disjunctive Conic Cuts (DCCs) for MISOCO is well developed, and several recent papers prove the power of DCCs in solving in solving MISOCO problems. Recent developments, as the main focus of this presentation, include the identification of pathological disjunctions, the identification of the optimal partition, new efficient warm start strategies, and a novel rounding heuristic.

Session C2: 13h30-15h00

C21. **Treewidth-based Extension Complexity Lower Bounds**
Gonzalo Muñoz (Polytechnique Montréal)

In this work, we study the extension complexity of 0-1 sets parametrized by treewidth: a graph-theoretical parameter that measures structured sparsity. If a 0-1 set can be formulated as the set of binary vectors that satisfy a certain system of constraints, and those constraints present a sparsity pattern whose treewidth is k, then it is known that the extension complexity of the convex hull of the set is $O(n2^k)$. The goal of this work is to prove the existence of 0-1 sets that (nearly) meet this bound, for any arbitrary treewidth level k. To the best of our knowledge, this is the first work to provide parametric lower bounds on extension complexity based on the treewidth.

C22. **Ordered sets and their polytopes in mixed-integer optimization**
Akshay Gupte (Clemson University)

We discover and exploit the structure imposed by total ordered sets in discrete optimization. The ordered sets arise by considering maximal and minimal points under different permutations and with respect to some monomial order on $\mathbb{Z}^n$. For a pure integer program, we obtain a hierarchy of primal and dual bounds on the optimal value. Although the bounds can be as bad as n-approx, we show that for 0/1 problems, each hierarchy converges to the optimum. This yields a structural characterization for 0/1 programs with connections to matroid optimization, heuristics for general integer programs, and a new approach for strong valid inequalities to the integer hull. For mixed-integer problems, these ordered sets yield a new two-term disjunction that generalizes the split disjunction and can be used to strengthen split cuts such as the Gomory cut.

Our approach naturally motivates the study of polytopes corresponding to monomial orders. We extend the literature on this and study the combinatorial properties of some of these polytopes, such as vertices, facets, graph, diameter, f-vector. As a result, for any dimension $d \geq 3$, we characterize two new families of Dantzig figures and polytopes with small diameter.

C23. **Balas formulation for the union of polytopes is optimal**

Yuri Faenza (Columbia University)

A celebrated theorem of Balas gives an extended formulation for the convex hull P of the union of two polytopes P_1 and P_2. Balas' theorem is used to model disjunctive constraints and in cutting-plane algorithms (not only) for Integer Programming. The number of inequalities in Balas' formulation is linear in the number of facets f_1 of P_1 and f_2 of P_2, and the number of additional variables is linear in the dimension of the space where P_1 and P_2 leave. In this talk, we consider the following question: can we always express P with polynomially many (in $f_1 + f_2$) inequalities, but with a sublinear number of additional variables? We show that this is not possible. Our counterexample is based on the Cayley embedding of suitable perturbations of the polar of the cyclic polytope. We also show that this result essentially carries over if one wants to approximate P and in the more restrictive setting of lift-and-project.

Joint work with Michele Conforti and Marco Di Summa.

Session C3: 15h30-17h30

C31. **A Polynomial-Time Approximation Scheme for Sequential Batch-Testing of Series Systems**

Danny Segev (University of Haifa)

We study a recently-introduced generalization of the classic sequential testing problem for series systems, consisting of multiple stochastic components. The conventional assumption in such settings is that the overall system state can be expressed as a boolean function, defined with respect to the states of individual components. However, unlike the classic setting, rather than testing components separately, one after the other, we allow aggregating multiple tests to be conducted simultaneously, while incurring an additional set-up cost. This feature is present in many practical applications, where decision-makers are incentivized to exploit economy of scale by testing subsets of components in batches.

The main contribution of this paper is to devise a polynomial-time approximation scheme (PTAS) for the sequential batch testing problem, thereby significantly improving on the constant-factor performance guarantee of $6.829 + \varepsilon$ due to Daldal et al. [Naval Research

Logistics, 63(4):275-286, 2016]. Our approach is based on developing and leveraging a number of innovative techniques in approximate dynamic programming, based on a synthesis of ideas related to efficient enumeration methods, state-space collapse, and charging schemes. These theoretical findings are complemented by extensive computational experiments, where we demonstrate the practical advantages of our methods.

C32. **Flexibility of Distributionally Robust Choice Models in Traffic Equilibrium**
Selin Ahipasaoglu (Singapore University of Technology and Design)

Traffic equilibrium models are fundamental to the analysis of transportation systems. The stochastic user equilibrium (SUE) model relaxes the perfect information assumption of the deterministic user equilibrium. SUE models predict traffic equilibrium flow assuming that users choose their perceived maximum utility paths (or perceived shortest paths) while accounting for the effects of congestion that arise due to users sharing links. Inspired by recent work on distributionally robust optimization, we develop two new user equilibrium models. The CMM-SUE model uses the mean and covariance information on path utilities but does not assume a particular form for the distribution. In the MDM-SUE model, the marginal distributions of the path utilities are specified, but the joint distribution is not. Robustness to distributional assumptions is obtained by minimizing the worst-case expected cost over all distributions with fixed two moments for the CMM model and over all distributions with given marginals for the MDM model. We show that under mild conditions, both equilibria exist and are unique. We provide convex formulations for both and develop customized algorithms to calculate the equilibrium flows. Preliminary computational results indicate that CMM-SUE provides a practical alternative to the well-known MNP-SUE (Multinomial Probit-Stochastic User Equilibrium) model that requires distributional (normality) assumptions to model correlation effects from overlapping paths. For specific choices of marginal distributions, the MDM-SUE model recreates the optimization formulation of logit SUE and weibit SUE. Moreover, the model is flexible since it can capture perception variance scaling at the route level and allows for modeling different user preferences by allowing for skewed distributions and heavy tailed distributions.

C33. **Handling difficult linking constraints in column generation**
Axel Parmentier (École Nationale des Ponts et Chaussées)

We consider a vehicle routing problem. The objective is to deliver goods to clients at minimum cost using a fleet of electric vehicles. Vehicles have limited capacity and regularly come back to a depot to load goods. Vehicles battery are charged only at certain client locations, but not at the depot. As it is a vehicle routing problem, it is well solved by column generation, where columns correspond to routes, that is, to sequences of deliveries starting and ending at the depot. As batteries are not charged at the depot, there are "linking' constraints on the routes that can be operated one after the other by the same vehicle to avoid running out of electricity.

Traditional methodology of column generation is not well-suited to handle this kind of "linking constraints, yet relevant in practice. We propose a method to address this kind of constraints with proven experimental efficiency. A key element in our approach is a lemma about the dual solution of a bipartite circulation problem and which might be of independent interest. Roughly speaking, we show that some combinatorial monotonicity property of the bipartite graph translates into a similar monotonicity property for the dual solution. The monotonicity of the dual solution then enables to design efficient algorithms to build new columns, which is a critical element in a column generation scheme.

C34. **The Maximum Expected Value All-or-Nothing Subset Problem and Extensions**

Noam Goldberg (Bar-Ilan University)

An unconstrained nonlinear binary optimization problem of selecting a maximum expected value subset of items is considered. Each item is associated with a profit and probability. Each of the items succeeds or fails independently with the given probabilities, and the profit is obtained in the event that all selected items succeed. The objective is to select a subset that maximizes the total value times the product of probabilities of the chosen items. The problem is proven NP-hard by a nontrivial reduction from subset sum. We consider extensions of the problem to maximizing the same objective in more general constrained settings of networks and set systems. We develop polynomial time approximation schemes for different variants of this problem. We also experiment with and compare (non-polynomial time) exact solution approaches using dynamic programming and integer nonlinear programming.

Based on collaborations with Michael Poss and Gabor Rudolf.

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