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Contents

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Convex relaxation of hybrid discrete–continuous control problems

Christian Clason

Faculty of Mathematics, University of Duisburg-Essen, 45117 Essen.
Email: christian.clason@uni-due.de

We consider control problems for partial differential equations where the distributed control should take on values only from a given discrete and hence non-convex set. Such problems occur for example in parameter identification or topology optimization. Similar to their use in sparse optimization, L^1-type norms can be used to formulate a convex relaxation which can be solved by semi-smooth Newton methods. We illustrate this approach using linear model problems and discuss the extension to vector-valued and nonlinear control problems.

Joint work with: Florian Kruse, Karl Kunisch, Philip Trautmann (University of Graz)
Carla Tameling, Benedikt Wirth (University of Münster)

Optimization Areas:

- Convex Optimization
- Mixed-Integer Non-Linear Optimization
- Optimal Control

On dynamic discrete tomography: Constrained flow and multi assignment problems for plasma particle tracking

Peter Gritzmann

TU Munich, Department of Mathematics, Boltzmannstr. 3, D-85747 Garching.
Email: gritzmann@tum.de

The talk deals with a problem from dynamic discrete tomography which originates from the demand of particle tracking in plasma physics. The main objective is that of reconstructing the paths of a set of points over time, where, at each of a finite set of moments in time the current positions of the points in space are only accessible through a small number of their line X-rays.

As it turns out the problem can be viewed as constrained version of min-cost-flow and multi assignment problems. We will present various new theoretical and algorithmic results and also deal with the practical side of the task. Also, we will indicate some consequences for certain problems in combinatorial optimization, particularly for the min weight max cardinality bipartite matching problem.

Joint work with: Andreas Alpers, University of Liverpool

Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Linear Programming

Mathematical Programming and Machine Learning

Laura Palagi

Dip. di Ingegneria informatica automatica e gestionale A. Ruberti Sapienza – Università di Roma.
Email: palagi@diag.uniroma1.it

Optimization is the most essential ingredient in the recipe of machine learning algorithms. Indeed learning from available data requires the definition of a model whose parameters are chosen by means of the optimization of a loss function. The talk focuses on methods for Deep Networks (DN) in a regression setting which mainly involves nonlinear optimization. We first recall the learning optimization paradigm for DN and briefly discuss schemes for the joint choice of the network topologies and of the network parameters. The main part of the talk focuses on the core subproblem which is the continuous unconstrained (regularized) weights optimization problem with the aim of reviewing theoretical and practical aspects of widely used batch and online gradient methods.

PDE constrained Mixed-Integer Optimal Control

Sebastian Sager

Institute of Mathematical Optimization, Otto-von-Guericke Universität Magdeburg.
Email: sager@ovgu.de

The mathematical modeling of many practical optimization problems leads to a combination of nonlinear differential equations and integer control functions. These mixed-integer nonlinear optimization problems constrained by ODEs or PDEs can be reformulated such that all integer control variables are binaries. From a computation point of view it is attractive to decompose the problem into a part that captures the nonlinearities, and a part that captures the combinatorial structures. The two-step approach of computing a canonically relaxed solution and approximating the continuous controls with binary controls in a specific pseudo-metric is called Combinatorial Integral Approximation (CIA) decomposition. For the CIA decomposition a priori bounds on the integer gap are available. The flexible approach also allows the usage of structure-exploiting algorithms for the two subproblems. We survey the general idea and recent developments concerning this methodology.

EXPEDIS: Solving Constrained Binary Quadratic Problems via Max-Cut

Angelika Wiegele

Alpen-Adria-Universität Klagenfurt, Universitätsstraße 65–67, 9020 Klagenfurt, Austria.
Email: angelika.wiegele@aau.at

We address the problem of minimizing a quadratic function subject to linear constraints over binary variables. We introduce the exact solution method called EXPEDIS where the constrained problem is transformed into a max-cut instance, and then the whole machinery available for max-cut can be used to solve the transformed problem. We derive the theory in order to find a transformation in the spirit of an exact penalty method; however, we are only interested in exactness over the set of binary variables. In order to compute the maximum cut we use the solver BiqMac. Numerical results show that this algorithm can be successfully applied on various classes of problems.

Joint work with: Nicolò Gusmeroli

Optimization Areas:

- Conic Optimization
- Convex Optimization
- Discrete and Combinatorial Optimization

Mixed E-duality for E-differentiable vector optimization problems under (generalized) V-E-invexity

Najeeb Abdulaleem

Department of Mathematics, Hadhramout University
P.O. BOX : (50511-50512), Al-Mahrah, Yemen.
Faculty of Mathematics and Computer Science, University of Łódź
Banacha 22, 90–238 Łódź, Poland.
Email: nabbas985@gmail.com

In this paper, a class of E-differentiable vector optimization problems with both inequality and equality constraints is considered. The so-called vector mixed E-dual problem is defined for the considered E-differentiable vector optimization problem with both inequality and equality constraints. Then, several mixed E-duality theorems are established under (generalized) V-E-invexity hypotheses.

Key Words: E-differentiable function; V-E-invex function; Generalized convexity; Mixed E-duality.

AMS Classification: 90C26, 90C30, 90C46.

Optimization Areas:

- Multiobjective Programming
- Nonlinear Programming

The Flexible Γ-Approach for Robust Nonlinear Discrete and Combinatorial Optimization

Dennis Adelhütte

Friedrich-Alexander-Universität Erlangen-Nuremberg, Department Mathematik
Cauerstraße 11
91058 Erlangen.
Email: dennis.adelhuette@fau.de

In this talk, we study the flexible Γ-approach that was first introduced by Bertsimas and Sim in [1] for robust mixed-integer linear optimization problems under uncertainty. This approach is flexible with respect to the level of conservatism. It is often used for combinatorial optimization problems with uncorrelated interval uncertainty. Let an objective function $c^T x$ with $c = (c_i)_{i=1,\dots,m}$ and uncertain coefficients residing in intervals be given. One chooses an integral parameter $\Gamma \in \{0, 1, \dots, m\}$ that regulates the level of conservatism. Algorithmically tractable equivalent reformulations are derived that determine optimum solutions which are robust against at most Γ many coefficients that attain their worst-case uncertainty realization. We generalize this approach to non-linear (discrete and combinatorial) optimization problems under uncorrelated uncertainty and derive algorithmically tractable reformulations. If the objective function is a sum of m functions under uncorrelated uncertainty, one aims to find solutions which are robust against $\Gamma \in \{0, 1, \dots, m\}$ functions deviating from their nominal value. Thereby, we consider two cases, namely concavity (and especially linearity) and non-concavity of the functions in the uncertainty. In order to derive equivalent optimization problems with a finite number of constraints, we apply re-formulation techniques that were introduced in [2] and explicitly formulate robust counterparts for some nonlinear combinatorial problems.

As an example, we derive an algorithmically tractable counterpart for simple piecewise linear functions which are convex (but not concave) in the uncertainty.
Finally, we demonstrate that the computational complexity of the given robust counterparts depends on the geometry of the uncertainty, the structure of the feasible set and that of the nominal objective function.

Joint work with: Jana Dienstbier, Frauke Liers

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Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Mixed-Integer Non-Linear Optimization
- Robust Optimization

Efficient and Design-Rule Aware Detailed Routing in VLSI-Design

Markus Ahrens

Research Institute for Discrete Mathematics, University of Bonn
Lennéstr. 2
53113 Bonn
Germany.
Email: ahrens@dm.uni-bonn.de

In VLSI-routing, we need to pack millions of vertex-disjoint Steiner trees into a graph with billions of vertices, while respecting a set of complicated design rules. Routing is solved in two or more stages: Global routing computes an approximate layout for each Steiner tree, solving the global packing problem while ignoring local constraints. We consider detailed routing which computes the actual layout based on the global routing solution. Since detailed routing requires very fast algorithms, the Steiner trees are usually built out of paths.

We present our design-rule aware path search framework that is based on an efficient implementation of Dijkstra's algorithm and demonstrate its effectiveness on real-world instances. Our implementation of this algorithm is part of BonnRoute, a routing solution developed at the University of Bonn in joint work with IBM that was used for the design of hundreds of chips, e.g. the CPU in Summit, the currently fastest supercomputer. An earlier version of the path search is described in [1].

Moreover, we propose to compute each Steiner tree with a single call of a modified version of the Dijkstra-Steiner algorithm [2] (a goal-oriented version of the Dreyfus-Wagner algorithm [3]). We modify the algorithm to find Steiner trees that are similar to the global routing solution in terms of topology and approximate location of Steiner points, thereby recovering electrical and packing properties optimized in global routing. Moreover, the restrictions speed up the algorithm in theory and in practice.

Joint work with: Stefan Rabenstein

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Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization

Using Frank-Wolfe as a Relaxation-Guided Solver for a Class of Robust Combinatorial Problems with an Ellipsoidal Uncertainty Set

Chifaa Al Dahik

FEMTO-ST institute, Univ. Bourgogne Franche-Comté, CNRS, ENSMM, Besançon, France.
Email: chifaa.dahik@femto-st.fr

This work addresses a specific class of combinatorial problems with correlated cost coefficients belonging to an ellipsoidal uncertainty set. An absolute robust problem in these settings is a well-known NP-Hard problem [1]. To tackle this problem, we propose a heuristic approach based on the Frank-Wolfe (FW) algorithm [2]. In our approach, we take a radically different perspective on FW by looking at the exploration power of the integer inner iterates of the method. Experimental tests have been realized for the robust shortest path problem as a first test case to discover the behavior of our approach. Comparisons with the optimal solution given by the mixed integer second order cone programming [3] solver of CPLEX have also been provided. Our main discovery is that, for small dimensional instances, our algorithm is able to provide the same optimal integer solution as CPLEX, after no more than a few hundred iterations. Moreover, as opposed to CPLEX, our FW-guided integer exploration approach applies to large scale problems as well, such as graphs with thousands of edges (i.e. big grid graphs, Barcelona graph and Berlin-Mitte-Center graph). Our findings are illustrated by comprehensive numerical experiments.

Joint work with: Zeina Al Masry, Stéphane Chrétien, Jean-Marc Nicod, and Landy Rabehasaina

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Optimization Areas:

- Application of Optimization in Real-World Problems
- Mixed-Integer Non-Linear Optimization
- Robust Optimization

On the Circumcentered-Reflection Method for the Convex Feasibility Problem

Roger Behling

Affiliation and address. School of Applied Mathematics, Fundação Getúlio Vargas
Rio de Janeiro, RJ – 22250-900, Brazil.
Email: rogerbehling@gmail.com

The ancient concept of circumcenter has recently given birth to the Circumcentered-Reflection method (CRM). CRM was firstly employed to solve best approximation problems involving affine subspaces. In this setting, it was shown to outperform the most prestigious projection based schemes, namely, the Douglas-Rachford method (DRM) and the method of alternating projections (MAP). We now prove convergence of CRM for finding a point in the intersection of a finite number of closed convex sets. This striking result is derived under a suitable product space reformulation in which a point in the intersection of a closed convex set with an affine subspace is sought. It turns out that CRM skillfully tackles the reformulated problem. We also show that for a point in the affine set the CRM iteration is always closer to the solution set than both the MAP and DRM iterations. Our theoretical results and numerical experiments, showing outstanding performance, establish CRM as a powerful tool for solving general convex feasibility problems.

Joint work with: Yunier Bello-Cruz. Department of Mathematical Sciences, Northern Illinois University. DeKalb, IL – 60115-2828, USA. Email: yunierbello@niu.edu

Luiz-Rafael Santos. Department of Mathematics, Federal University of Santa Catarina. Blumenau, SC – 88040-900, Brazil. Email: l.r.santos@ufsc.br

Optimization Areas:

- Convex Optimization
- Nonlinear Programming

Matrix generation algorithms for binary quadratically constrained quadratic problems

Enrico Bettiol

Technische Universität Dortmund, Vogelpothsweg 87, 44227, Dortmund, Germany.
Email: enrico.bettiol@math.tu-dortmund.de

We consider binary quadratically constrained quadratic problems and propose a new approach to generate stronger bounds than the ones obtained using the semidefinite programming relaxation. After rewriting the problem in matrix form, we describe a relaxation based on the Boolean Quadric Polytope (BQP) and, by using barycentric coordinates to re-parameterize the problem, we solve it via a Dantzig-Wolfe decomposition algorithm in the matrix space. We then extend the approach to block decomposable problems. We introduce a relaxation that takes into account some given block structures and analyze its properties.

We notice that the problem of studying the equivalence between this relaxation and the one based on the Boolean Quadric Polytope can be seen as the BQP-matrix completion problem. We characterize classes of block structures for which the two formulations are equivalent and conjecture a general result. We then adapt the tailored decomposition algorithm in the matrix space to efficiently calculate a bound for those sparse structured problems. We report some preliminary numerical results showing that the proposed approach gets very good bounds in reasonable time.

Joint work with: Immanuel Bomze (University of Vienna), Lucas Létocart (Université Paris 13), Francesco Rinaldi (University of Padova), Emiliano Traversi (Université Paris 13).

Optimization Areas:

- Conic Optimization
- Mixed-Integer Non-Linear Optimization
- Nonlinear Programming

A New Modeling Framework Aligning Different Concepts of Optimization under Uncertainty Applied to Lot Sizing

Viktor Bindewald

Discrete Optimization and Logistics Group
Institute for Operations Research
Karlsruhe Institute of Technology.
Email: viktor.bindewald@kit.edu

In this talk we present a new framework which allows to model different time-dynamic optimization problems under uncertainty that vary in representation of the uncertain parameters. We will demonstrate the framework and its capabilities by applying it to the Lot Sizing Problem with uncertain demands.

Many real-life applications are characterized by the need for dynamic decision making. However, decision makers often do not have complete knowledge about the future but have to react to random or scheduled events while new information is revealed gradually. Our framework is designed to model this broad class of applications flexibly by decoupling the uncertainty representations from the algorithms. Furthermore, our framework allows to study the influence of different algorithms, amount of available information and applied methodology on the solution quality.

In alignment with the framework, we consider a generic, uncertainty-inflicted model of lot sizing. The setting is the following: we have an open time horizon, the costs are fixed over time and information about the demands is available only for a small number of upcoming stages. Consequently, unlike in the classical, deterministic Lot Sizing Problem, here we have to decide on lot sizes without knowing the complete future. Hence, the multi-stage problem dissolves into a series of highly coupled snapshot problems that contain uncertain parameters. The goal is to balance production, storage, setup and penalty costs while not knowing all forthcoming demands exactly. Information about the future demands may be present in different ways: For a small portion of the future, the next demands can be known with certainty. This approach is amenable to techniques from online optimization with lookahead. The demand information may be also based on forecasts derived from historical data which results in probability distributions or scenarios that can be realized in the future. This kind of information is amenable to stochastic programming and robust optimization, respectively. We conclude the talk by discussing first computational results which compare different approaches to dealing with demand uncertainty in lot sizing described above.

Joint work with: Fabian Dunke and Stefan Nickel

Optimization Areas:

- Application of Optimization in Real-World Problems
- Robust Optimization
- Stochastic Programming

Scalable generalized median graph estimation and applications in computational biology

David B. Blumenthal

Chair of Experimental Bioinformatics, Technical University of Munich, Maximus-von-Imhof-Forum 3, 85354 Freising.

Email: david.blumenthal@wzw.tum.de

In some biomedical application scenarios, we are faced with the task to compute prototypes for a given collection of attributed graphs. This task can be formalized as the problem of computing a generalized median graph (GMG), i. e., a graph that minimizes the overall edit distance to all graphs in the collection. We have studied the problem of computing GMGs both from a theoretical and from a practical perspective. On the theoretical side, we have shown that GMGs exist under mild assumptions, that they are in general non-unique, and that their computation is NP-hard. On the practical side, we have designed a local search algorithm based on block coordinate update for heuristically estimating GMGs. Unlike all existing heuristics, our algorithm be configured to run in linear time w. r. t. the size of the graph collection. Thanks to its low runtime complexity, it can efficiently be used as a building block of higher-level algorithms such as K-medians graph clustering, which is especially important for the aforementioned biomedical application scenarios.

Joint work with: Nicolas Boria, Sébastien Bougleux, Luc Brun, Johann Gamper, Benoit Gaüzère

Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization

Optimization over the Efficient Set bi-objective knapsack problem

CHAABANE Djamal

Professor CHAABANE Djamal, MCD& RO Laboratory, USTHB, Bp 32 el Alia, BEZ, 16111, Algiers, Algeria.

Email: dchaabane@usthb.dz

This paper deals with the problem of optimizing a linear function over the efficient set of a 0/1 bicriteria knapsack problem. Such a function represents the main criterion of the problem posed. The resolution process is based essentially on dynamic programming. The proposed method provides a subset of efficient solutions including one which optimizes the main criterion without having to enumerate all the efficient solutions of the problem. A numerical experiment is reported, different instances with large sizes of the associated efficient sets are considered to show the efficiency of our algorithm compared with some previous algorithms. Keywords: Multiple objective programming, Bicriteria knapsack problem, Dynamic programming, Efficient set, Optimal solution.

Joint work with: Dr. LACHEMI Nadia

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Optimization Areas:

- Application of Optimization in Real-World Problems
- Conic Optimization
- Convex Optimization
- Discrete and Combinatorial Optimization
- Integer Linear Programming
- Combinatorial Optimization
- Mixed-Integer Non-Linear Optimization
- Multiobjective Programming

Discrete optimization of the sum of ratios

Yacine Chaiblaine

PhD student at USTHB, Algiers, Algeria.
Email: yacinechaiblaine@gmail.com

The optimization of the sum of several fractions has important applications in several areas. A fraction might represent a quality measurement, a probability, a ratio between two objectives, etc. However, this problem is proven to be NP-Hard. Therefore, its resolution approaches have both theoretical and practical relevance that attracts researchers attention. This work consists of solving the discrete variant of the problem, using an effective combination of branch and bound and cutting plane techniques. We conducted an experimental study. The obtained results are conclusive in which it demonstrates the effectiveness of our method.

Joint work with: Moulaï Mustapha.

Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Multiobjective Programming
- Nonlinear Programming

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A Branch-and-Price Algorithm for the Maximum Weight Perfect Matching Problem with Conflict Constraints †

Alim Buğra Çınar[1], Temel Öncan[2], İ. Kuban Altınel[3]

Boğaziçi Üniversitesi, Endüstri Mühendisliği Bölümü, İstanbul, Türkiye[1,3],
Galatasaray Üniversitesi, Endüstri Mühendisliği Bölümü, İstanbul, Türkiye[2].
Email: bugra.cinar@boun.edu.tr[1], ytoncan@gsu.edu.tr[2], altinel@boun.edu.tr[3]

In this work we tackle with the Maximum Weight Perfect Matching Problem with Conflict Constraints (MWPMC) which is known to be NP-hard. Although, the Maximum Weight Perfect Matching Problem (MWPM) is a well-known and easy-to-solve problem adding conflict constraints makes it difficult. A conflict-pair is defined as a pair of edges which are not allowed to be in a matching at the same time. Hence, the conflict constraints in the MWPMC allow at most one of the edges of the conflicting-pairs to be in a matching.

We propose a new Branch-and-Price (B&P) algorithm for the solution of the MWPMC. A subproblem which is easy to solve is crucial for the efficiency of the B&P algorithms. To this end, a formulation which includes the MWPM as a subproblem is devised. In our B&P scheme, the master problem produces a conflict-free column with the largest possible weight. The subproblem feeds the master problem by producing maximum weight perfect matchings with respect to the dual values obtained with the solution of the master problem. The B&P algorithm is implemented and preliminary computational tests are realized on randomly generated test instances. Computational experiments have shown that the B&P algorithm is promising and deserve further research effort.

Optimization Areas:

- Discrete and Combinatorial Optimization
- Linear Programming

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Cutting-plane algorithm for robust bi-objective optimization

Fabian Chlumsky-Harttmann

TU Kaiserslautern, FB Mathematik, Paul-Ehrlich-Straße, Gebäude 14, 67663 Kaiserslautern.
Email: chlumsky@mathematik.uni-kl.de

We consider optimization problems with two objectives that are both uncertain. The algorithm we present is designed to approximate the Pareto front of minmax robust efficient solutions to such a problem. To this end, we start with a smaller uncertainty set and solve a weighted sum scalarization of that easier problem. We then increase the uncertainty set iteratively by adding scenarios and, hence, effectively add cutting planes. In each iteration we decide which new scenarios to include and what weighted-sum scalarization to choose is beneficial to ensure fast convergence.

Joint work with: Anita Schöbel, Marie Schmidt

Optimization Areas:

- Multiobjective Programming
- Robust Optimization

Robust optimization for clustering of big data sets

Carina Moreira Costa

Trier University
Email: costa@uni-trier.de

The k-means clustering method is widely applied in the context of big data analysis. However, it does not compensate for possible errors in the data such as measurement errors or bias problems. In this work, we seek to find a robust solution for the k-means clustering problem under uncertainties. First, we derive strict and Γ-robust counterparts of the k-means clustering problem. All these problems are mixed-integer nonlinear optimization problems, which are in general NP-hard to solve to global optimality. Thus, we propose a tailored alternating direction method to compute partial optimal solutions. Preliminary numerical results are discussed.

Joint work with: Jan Pablo Burgard, Martin Schmidt.

Optimization Areas:

- Mixed-Integer Non-Linear Optimization
- Robust Optimization

Deep Infeasibility Exploration Method for Vehicle Routing Problems

Piotr Cybula

Faculty of Mathematics and Computer Science, University of Lodz, Poland.
Emapa S.A., Warsaw, Poland.
Email: piotr.cybula@wmii.uni.lodz.pl

We propose a new method for the vehicle routing problems with constraints. Instead of trying to improve the typical metaheuristics used to efficiently solve vehicle routing problems, like large neighborhood search, iterated local search, or evolutionary algorithms, we allow them to explore the deeply infeasible regions of the search space in a controlled way. The key idea is to find solutions better in terms of the objective function even at the cost of violation of constraints, and then try to restore feasibility of the obtained solutions at a minimum cost. Furthermore, in order to preserve the best feasible solutions, we maintain two diversified pools of solutions, the main pool and the temporary working pool. The main pool stores the best diversified (almost) feasible solutions, while the working pool is used to generate new solutions and is periodically refilled with disturbed solutions from the main pool. We demonstrate our method on the vehicle routing problems, with variants including time windows, heterogeneous fleets, pickup and deliveries, and multiple depots, respecting time, vehicle capacity and fleet limitation constraints. Our method provided a large number of new best-known solutions on well-known benchmark datasets (see [1]). Although our method is designed for the family of vehicle routing problems, its concept is fairly general and it could potentially be applied to other NP-hard problems with constraints.

Joint work with: Piotr Beling, Andrzej Jaszkiewicz, Marek Rogalski, Piotr Sielski

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Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Multiobjective Programming
- Robust Optimization

Global Interconnect Optimization

Siad Daboul

University of Bonn, Regina-Pacis-Weg 3, 53113 Bonn
Email: daboul@dm.uni-bonn.de

Packing Steiner trees is a fundamental step in chip design. In addition to the packing aspect, the solution has to obey global signal delay constraints. The involved delay functions are approximately quadratic. It is essential to insert repeaters to linearize delays.

Traditional approaches use multiple stages, which optimize either timing or routing constraints. We show how to integrate routing capacity constraints, placement congestion, global timing constraints, power consumption, etc. into a single resource sharing formulation. This generalized fractional packing problem can be solved by a multiplicative weight update scheme.

The core of our algorithm is a new buffered cost-distance Steiner tree subroutine. Given a net and Lagrangean resource prices for routing, timing, placement, and power, it computes a buffered Steiner tree. The resource sharing algorthm invokes this oracle function a near-linear amount of times. If we solve this subroutine with a guarantee, this carries over to the solution of the fractional packing problem, which is finally rounded.

Our algorithm is fast enough for practical instances. We demonstrate experimentally on 7nm IBM microprocessor units that it significantly improves timing while simultaneously reducing netlength and power consumption compared to the previous state-of-the-art flow. Our new algorithm was quickly adopted to the design process of upcoming microprocessors used in future supercomputers.

Joint work with: Stephan Held, Bento Natura and Daniel Rotter [1].

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Optimization Areas:

- Discrete and Combinatorial Optimization
- Convex Optimization
- Application of Optimization in Real-World Problems

A Mixed-Integer Programming Approach for the T-Row and Multi-Bay Facility Layout Problem with three bays

Mirko Dahlbeck

TU Dortmund University, Faculty of Business and Economics.
Email: mirko.dahlbeck@tu-dortmund.de

We introduce a new shape of a facility layout problem, which we call T-Row Facility Layout Problem (TRFLP). The TRFLP consists of a set of one-dimensional departments with pairwise transport weights between them and two rows which are orthogonal to each other such that they form a T and such that two departments which lie in different rows cannot overlap. The aim is to find a non-overlapping assignment of the departments to the rows such that the sum of the weighted center-to-center distances measured in horizontal and vertical directions is minimized. The TRFLP is a generalisation of the well-known NP-hard Multi-Bay Facility Layout Problem (MBFLP) with $m = 3$, where the departments are assigned to m parallel rows with a fixed left border such that inner-row distances are measured in horizontal directions and inter-row distances are equal to the sum of the distances of the departments to the left border. The TRFLP and the MBFLP have wide applications, e.g., heavy manufacturing, semiconductor fabrication and arranging rooms in hospitals.

We show that there always exists an optimal T-row layout where one department in the horizontal row lies directly opposite the vertical row, so we fix department s_M on this position and denote the obtained problem by sm-TRF. We enumerate over each department fixed on this position. We present a mixed-integer programming model for the sm-TRF and in order to couple inter-row distances we use betweenness variables which might be in contrast to the literature equal to one if the three departments lie in two different rows. We present cutting planes for the sm-TRF which significantly improve the performance of our branch-and-cut algorithm. Futhermore we adapt our mixed-integer programming approach to the MBFLP with $m = 3$ and we clearly outperform the best known solution approach.

Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization

The Unit Re-balancing Problem

Robin Dee

Brandenburg University of Technology, Institute of Mathematics, Platz der Deutschen Einheit 1, 03046 Cottbus, Germany.

Email: deerobin@b-tu.de

We describe the problem of optimally re-balancing several military units distributed over a large geographic area of locally independent domains (such as islands). Each unit consists of three components: the number of people, their armor, and their equipment. A real number between 0 and 1 (representing 0% to 100%) describes the current status of each component. For each of the three components, a nonlinear function is introduced that converts the numerical status into an assessment, which is a real number, say, from 0 to 10, where zero is the weakest and ten is the strongest. It allows comparing the components between different units as well as with other components of the same unit. Based on this, we define the strength and the cost of each unit in the following way: The lowest assessment determines the strength, and the highest assessment determines the cost of a unit.

Over time, it turned out that some units became slightly unbalanced so that they are too costly and too inefficient at the same time. Now that military leaders identified this issue, they desire to move components between different units by transferring people and shipping material. The desired goal is to have units that are equally well equipped at the lowest possible cost. On a secondary level, the cost for the re-balancing should also be as low as possible. We describe a mixed-integer nonlinear programming formulation for this problem. This model formulation describes the potential movement of components between units as a multi-commodity flow at minimum cost. It is also possible to shut down a unit completely and re-distribute all its components to the others. Additional constraints identify the lowest and the highest assessment, where the nonlinear functions enter the model formulation. These functions are typically table-based piecewise-linear functions, and thus can be re-formulated by introducing additional binary variables and constraints to fit into the framework of mixed-integer linear programming. After such a transformation to a mixed-integer linear program, numerical standard solvers (such as Cplex and Gurobi) can find proven optimal solutions. This approach works well for up to 100 units. We present numerical solutions for a set of test instances and a bi-criteria objective function, demonstrating the trade-off between cost and efficiency.

Joint work with: Armin Fügenschuh, George Kaimakamis

Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Mixed-Integer Non-Linear Optimization
- Multiobjective Programming

Improving ADMMs for Solving Doubly Nonnegative Programs through Dual Factorization

Marianna De Santis

DIAG - Sapienza University of Rome, Via Ariosto 25 00185 Roma.
Email: marianna.desantis@uniroma1.it

Augmented Lagrangian methods are among the most popular first-order approaches to handle large scale semidefinite programs. In particular, alternating direction methods of multipliers (ADMMs), which are a variant of augmented Lagrangian methods, gained attention during the past decade. In this talk, we focus on solving doubly nonnegative programs (DNN), which are semidefinite programs where the elements of the matrix variable are constrained to be nonnegative. Starting from two algorithms already proposed in the literature on conic programming, we introduce two new ADMMs by employing a factorization of the dual variable.

It is well known that first order methods are not suitable to compute high precision optimal solutions, however an optimal solution of moderate precision often suffices to get high quality lower bounds on the primal optimal objective function value. We present methods to obtain such bounds by either perturbing the dual objective function value or by constructing a dual feasible solution from a dual approximate optimal solution. Both procedures can be used as a post-processing phase in our ADMMs.

Numerical results for DNNs that are relaxations of the stable set problem are presented. They show the impact of using the factorization of the dual variable in order to improve the progress towards the optimal solution within an iteration of the ADMM. This decreases the number of iterations as well as the CPU time to solve the DNN to a given precision. The experiments also demonstrate that within a computationally cheap post-processing, we can compute bounds that are close to the optimal value even if the DNN was solved to moderate precision only. This makes the ADMMs applicable also within a branch-and-bound algorithm.

Joint work with: Martina Cerulli, Elisabeth Gaar, Angelika Wiegele

Optimization Areas:

- Conic Optimization
- Discrete and Combinatorial Optimization

Multiobjective Mixed Integer Convex Optimization by a Decision Space Branch-and-Bound

Gabriele Eichfelder

Teschnische Universität Ilmenau, PF 10 05 65, 98684 Ilmenau, Germany.
Email: gabriele.eichfelder@tu-ilmenau.de

We present a numerical method for solving multiobjective mixed integer convex optimization problems as introduced in [1]. The method uses a branch-and-bound strategy based on a partitioning of the feasible set in the pre-image space, i. e. in the decision space. For discarding, lower and upper bounds are used. Lower bounds are obtained by an adaptive outer approximation of the nondominated set of relaxations of the original problems. If necessary, these outer approximations are tightened by taking the convex hull of the image set of the original problem, restricted to the sub-boxes, into account.

In contrast to criterion space methods, which are often limited to bi-objective problems, our approach can be generalized to an arbitrary number of objective functions. We are able to guarantee correctness in terms of detecting both the efficient and the nondominated set of multiobjective mixed integer convex problems according to a prescribed precision. As far as we know, the procedure is the first deterministic algorithm devised to handle this class of problems which avoids to scalarize the problems.

Joint work with: Marianna De Santis, Julia Niebling, Stefan Rocktäschel

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Optimization Areas:

- Mixed-Integer Non-Linear Optimization
- Multiobjective Programming

Semidefinite Programming Approach to Optimal Power Flow with FACTS Devices

Bartosz Filipecki

TU Chemnitz, Reichenhainer Straße 39, 09126 Chemnitz.
Email: bartosz.filipecki@mathematik.tu-chemnitz.de

Producing accurate and secure solutions to the Optimal Power Flow problem becomes increasingly important due to rising demand and share of renewable energy sources. To address this, we consider an Optimal Power Flow model with additional decision variables associated with line switching and FACTS devices, such as phase-shifting transformers (PSTs) or thyristor-controlled series capacitors (TCSCs). We show, how a Lasserre hierarchy can be applied to this model to obtain a semidefinite programming relaxation. Finally, we provide results of numerical experiments on this relaxation.

Joint work with: Christoph Helmberg

Optimization Areas:

- Application of Optimization in Real-World Problems
- Conic Optimization
- Discrete and Combinatorial Optimization
- Mixed-Integer Non-Linear Optimization

Critical multipliers and how they can be avoided numerically

Andreas Fischer

Technische Universität Dresden, Faculty of Mathematics, 01062 Dresden, Germany.
Email: Andreas.Fischer@tu-dresden.de

Primal-dual Newton-type methods are well-established solution techniques for constrained nonlinear optimization problems. Usually, these methods show a local fast (superlinear) convergence. However, if the set of Lagrange multipliers associated to the primal solution is not a singleton, then the sequence of multipliers generated by such a Newton-type method is frequently attracted by a critical multiplier. Unfortunately, the latter causes slow convergence of the method. The existence of critical multipliers is quite common, if the set of Lagrange multipliers is not a singleton. For equality-constrained optimization problems, we present a universal local technique to obtain an approximation of a Lagrange multiplier of good quality that stays away from the critical multiplier in question. When combined with stabilized or regularized Newton-type methods, this allows to significantly reduce the domain of attraction of this critical multiplier. The accelerating effect on the convergence speed of this technique is demonstrated by numerical experiments.

Joint work with: Alexey F. Izmailov and Wladimir Scheck

Optimization Areas:

- Nonlinear Programming

Mission and Path Planning for Unmanned Aerial Vehicles

Armin Fügenschuh

Brandenburg University of Technology, Institute of Mathematics, Platz der Deutschen Einheit 1, 03046 Cottbus, Germany.

Email: fuegenschuh@b-tu.de

The mission and path planning problem for an inhomogeneous fleet of unmanned aerial vehicles (UAVs) asks for optimal trajectories that together visit a largest possible subsets from a list of desired targets. When selected, each target must be traversed within a certain maximal distance and within a certain time interval. The UAVs differ with respect to their sensor properties, speeds, and operating ranges. If the targets are surrounded by radar surveillance, then the UAVs' trajectories should be chosen to avoid these forbidden areas. In contrast to classical vehicle routing problems with time windows, this problems allows for free-flight routes which are not bound to street-like networks. Additionally, the fuel consumption rates during cruise (at various speed and altitude levels), climb and descend are crucial and thus need to be considered within the model. We formulate the mission and path planning problem for UAVs as mixed-integer nonlinear control problem, and apply discretization and linearization strategies to obtain a mixed-integer linear programming problem which can be solved numerically using available software tools. We discuss the applicability of this approach with respect to the number of potential targets, the fleet size, and the number of restricted areas.

Joint work with: Daniel Müllenstedt, Johannes Schmidt

Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Mixed-Integer Non-Linear Optimization
- Optimal Control

A continuation method for multiobjective optimization problems with inexact objective gradients

Bennet Gebken

Paderborn University, Paderborn, Germany.
Email: bgebken@math.upb.de

One of the fundamental results in the field of multiobjective optimization are the first-order optimality conditions, the so-called *KKT* conditions, that define an approximation of the Pareto set, the so-called *Pareto critical set*, via the gradients of the objective functions. In many applications, these gradients have to be approximated, since the exact evaluation is too computationally expensive. Naturally, when considering the KKT conditions with these inexact gradients, the resulting Pareto critical set is only an approximation of the actual Pareto critical set.

In this talk, we show that a tight super set of the actual Pareto critical set can be derived using only the inexact gradients and an upper bound for the supremum of the approximation error for each individual objective gradient. This super set has the same dimension as the variable space, which means that it is more efficient to compute its boundary instead of the whole set. To this end, we show that typically, this boundary can locally be written as a level set of a continuously differentiable function, suggesting that it possesses a tangent space (almost everywhere). We then propose a continuation method that uses this tangent space to compute the boundary of the super set.

We apply our method to a multiobjective optimization problem with PDE constraints, where reduced order modelling is used to obtain an approximation of the objective gradients. In our numerical experiments, when compared to the exact solution of the problem (using FEM for the PDE constraints), the method we propose is about 60 times faster than the exact solution.

Joint work with: Stefan Banholzer, Michael Dellnitz, Sebastian Peitz, Stefan Volkwein

Optimization Areas:

- Multiobjective Programming
- Nonlinear Programming

Extending the Robust (Relative) Regret Approach to a Multicriteria Setting

Patrick Groetzner

University of Augsburg, Department of Mathematics, Universitätsstraße 14, 86159 Augsburg.
Email: patrick.groetzner@math.uni-augsburg.de

Consider a multiobjective decision problem with uncertainty given as a set of scenarios. In the single criteria case, robust optimization methodology helps to identify solutions which remain feasible and of good quality for all possible scenarios. An alternative method is to compare the possible decisions under uncertainty against the optimal decision with the benefit of hindsight, i.e. to minimize the (possibly scaled) regret of not having chosen the optimal decision. In this talk, we extend the concept of regret to the multiobjective setting and introduce a proper definition of multivariate (relative) regret. All early attempts in such a setting mix scalarization and optimization, whereas we first model regret and then solve the resulting problem separately. Moreover, in contrast to the existing approaches, we are not limited to a finite uncertainty sets or interval uncertainty and further, computations remain tractable in most common special cases.

Joint work with: Ralf Werner

Optimization Areas:

- Multiobjective Programming
- Robust Optimization

Computing minimal elements of finite families of sets w.r.t. preorder relations in set optimization

Christian Günther

Martin Luther University Halle-Wittenberg, Faculty of Natural Sciences II & III, Institute of Mathematics & Institute of Informatics, 06099 Halle (Saale), Germany.

Email: christian.guenther@mathematik.uni-halle.de

Different concepts of optimality are currently known in set optimization and various types of binary relations can be used in order to define them. In particular, by considering a real linear space E, a nonempty **finite** family of sets $\mathcal{A} \subseteq \mathcal{P}(E)$, and a preorder (i.e., reflexive and transitive) relation $\preccurlyeq$ on $\mathcal{A}$, an element $A \in \mathcal{A}$ is said to be a:

- minimal element of $\mathcal{A}$ w.r.t. $\preccurlyeq$, if

$$\forall A' \in \mathcal{A}: \; A' \preccurlyeq A \implies A \preccurlyeq A';$$

- strictly minimal element of $\mathcal{A}$ w.r.t. $\preccurlyeq$, if

$$\forall A' \in \mathcal{A}: \; A' \preccurlyeq A \implies A = A'.$$

By reflexivity of $\preccurlyeq$ it is easily seen that each strictly minimal element of $\mathcal{A}$ w.r.t. $\preccurlyeq$ is a minimal element as well. Of course, these two concepts coincide when $\preccurlyeq$ is antisymmetric, but this is not always the case.

The principal aim of this talk is to present new algorithms ([2], [3]) for computing the sets $\mathrm{MIN}_{\preccurlyeq}(\mathcal{A})$ and $\mathrm{SMIN}_{\preccurlyeq}(\mathcal{A})$ of all minimal and strictly minimal elements of $\mathcal{A}$ w.r.t. $\preccurlyeq$. These algorithms are mainly based on certain set-valued counterparts of some methods originally conceived for vector optimization problems, such as the well-known Graef-Younes reduction procedure and Jahn-Graef-Younes method (see Eichfelder [1], Günther and Popovici [4], Jahn [5]). More precisely, first we present two algorithms for computing the set $\mathrm{MIN}_{\preccurlyeq}(\mathcal{A})$. One of our algorithms consists of two subsequent (forward-backward) reduction procedures, similarly to the classical Jahn-Graef-Younes method. Another algorithm involves a pre-sorting procedure with respect to a strongly increasing real-valued function, followed by a single (forward) reduction procedure. Furthermore, we present two algorithms for computing the set $\mathrm{SMIN}_{\preccurlyeq}(\mathcal{A})$. The first algorithm is similar to a method proposed by Eichfelder [1] (see also Köbis and Le [6]), while the second algorithm consists in computing $\mathrm{MIN}_{\preccurlyeq}(\mathcal{A})$ and thereafter $\mathrm{SMIN}_{\preccurlyeq}(\mathrm{MIN}_{\preccurlyeq}(\mathcal{A}))$.

Numerical experiments in MATLAB allow us to compare our algorithms for special test families of rectangles with respect to ℓ-type and u-type preorder relations, currently used in set optimization.

Joint work with:
Elisabeth Köbis (Martin Luther University Halle-Wittenberg, Halle, Germany)
Nicolae Popovici (Babeş-Bolyai University, Cluj-Napoca, Romania)

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Optimization Areas:

- Multiobjective Programming

Optimization over Integer Efficient Set by Decomposition of Criteria Cone

Hamadou Sarah

PhD Student Hamadou Sarah, MCD& RO Laboratory, USTHB, Bp 32 el Alia, BEZ, 16111, Algiers, Algeria.

Email: sarah.hamadou@icloud.com

The notion of a single optimal solution in single objective optimization disappears for multiple objective optimization problems in favor of the notion of a set of optimal Pareto solutions. Although understanding the trade-offs between objectives can be valuable some researchers argue that presenting too many efficient solutions can confuse a decision maker and so may make selecting a preferred solution almost impossible. An approach that alleviates this issue is finding a preferred solution among the set of efficient solutions directly (without enumerating explicitly all efficient solutions) and is known as optimizing over the efficient set, which is a global optimization problem (Benson 1984). In this approach, the goal is to directly optimizes a linear function over the set of efficient solutions.

In the literature there are two main categories of algorithms for optimization over the efficient set: Algorithms based on decision space solutions and algorithms based on objective space solutions. In this communication, we propose a new exact method to optimize a linear function over the integer efficient set. The work is inspired from the most recent developed idea **Craig A. Piercy, Ralph E. Steuer 2019**. The method is articulated on three main parts executed in parallel: decomposition (subdividing the criteria cone and sub-cone), evaluation (the main objective) and separation (after reducing the admissible region). The cpu time is substantially reduced compared to method that exists in the literature.

Joint work with: Pr. Chaabane Djamal

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Optimization Areas:

- Application of Optimization in Real-World Problems
- Conic Optimization

- Convex Optimization
- Discrete and Combinatorial Optimization
- Linear Programming
- Mixed-Integer Non-Linear Optimization
- Multiobjective Programming
- Optimal Control

New neighbourhood generation strategy for BOSCP

HAMIDI Imane

USTHB University, MCDM & RO Laboratory, Faculty of Mathematics, Department of Operations Research, Bab-Ezzouar, Algiers, Algeria. Email: imane.hamidi.ro@gmail.com

The combinatorial optimization occupies a very important place in operational research and in discrete mathematics. Its importance is justified, on the one hand, by the great difficulty of the associated problems and, on the other hand, by the large number of real applications which can be modelled in the form of a combinatorial optimization problem, namely, the assignment problem, the travelling salesman problem, the set covering problem, ..., etc. Indeed, most of these problems belong to the class of NP-hard problems.

In this abstract, we are particularly interested to solve the bi-objective set covering problem by Multi-Objective Simulated Annealing (MOSA) metaheuristic where many real and practical problems can be modelled, namely: manufacturing and service planning, scheduling, location problems. For MOSA, it is preferable to start with a good solution. The latter will speed up the search for efficient solutions to the multi-objective problem.

In the first contribution, we have developed a heuristic allowing us to have a good initial solution. The heuristic principle consists in adding to a solution some columns in order to cover the rows not covered. Priority will be given to the columns in ascending order of the efficiency coefficient of each column.

For the second contribution, the choice of the neighbourhood structure of the current solution is very important. Indeed, this neighbourhood makes it possible to have a reasonable computation time, and generally, it depends on the nature of the considered optimization problem.

For the set covering problem, we consider the peculiarity of the fact that if we remove a lot of columns from the current solution, we risk having an unfeasible solution. However, the solutions which constitute the neighbourhood of the current solutions must contain columns which cover the rows not covered.

Joint work with:

CHAABANE Djamel, USTHB University, MCDM & RO Laboratory, Faculty of Mathematics, Department of Operations Research, Bab-Ezzouar, Algiers, Algeria
Email: dchaabane@usthb.dz

Optimization Areas:

- Linear Programming
- Multiobjective Programming

Preconditioned Conjugate Gradients in Interior Point Methods for the Bundle Subproblem

Christoph Helmberg

Department of Mathematics, TU Chemnitz, 09107 Chemnitz.
Email: helmberg@math.tu-chemnitz.de

The software package ConicBundle extends traditional bundle methods for nonsmooth convex optimization by nonpolyhedral models for support functions over semidefinite and second order cones. In such methods the next candidate is an approximate minimizer of a cutting surface model augmented by a proximal term that keeps the point close to a current center of stability and allows to include some curvature information. Due to the semidefinite and second order parts, interior point methods are the current method of choice for solving this bundle subproblem. Typically the computational cost of the interior point solver exceeds that of function evaluations by far. We explore possibilities to speed up the solution of the internal primal-dual KKT system by preconditioned conjugate gradient methods that use Johnson-Lindenstrauss for reducing the dimension of relevant subspaces and present first (mixed) computational results.

Optimization Areas:

- Conic Optimization
- Convex Optimization

The bilevel continuous knapsack problem with uncertain follower's objective

Dorothee Henke

Technische Universität Dortmund, Fakultät für Mathematik, Lehrstuhl V, 44221 Dortmund.
Email: dorothee.henke@math.tu-dortmund.de

We consider a bilevel continuous knapsack problem where the leader controls the capacity of the knapsack and the follower's profits are uncertain. Adopting the robust optimization approach and assuming that the follower's profits belong to a given uncertainty set, our aim is to compute a worst case optimal solution for the leader. We show that this problem can be solved in polynomial time for both discrete and interval uncertainty. Moreover, we show that the same problem becomes NP-hard when each coefficient can independently assume only a finite number of values. In particular, this shows that replacing uncertainty sets by their convex hulls may change the problem significantly, different from the classical single-level robust optimization setting.

Joint work with: Christoph Buchheim

Optimization Areas:

- Bi-Level Optimization
- Discrete and Combinatorial Optimization
- Robust Optimization

Faster Linear-Size Adder Circuits

Anna Hermann

Research Institute for Discrete Mathematics, University of Bonn, Germany.
Email: hermann@dm.uni-bonn.de

We consider the fundamental problem of constructing fast adder circuits, i.e., circuits for the summation of two n-bit binary numbers. We propose a new algorithm with running time $\mathcal{O}(n \log_2 n)$ for the construction of linear-size adder circuits with a depth of at most $\log_2 n + \log_2 \log_2 n + \log_2 \log_2 \log_2 n + \text{const}$, improving the previously best depth of $\log_2 n + 8\sqrt{\log_2 n} + 6 \log_2 \sqrt{\log_2 n} + \text{const}$ by Held and Spirkl [3]. Even for computing the final carry bit in an adder circuit, there is a general lower bound on the depth of $\log_2 n + \log_2 \log_2 \log_2 n + \Theta(1)$ by Commentz-Walter and Sattler [2], and when inverters are forbidden, there is a lower bound of $\log_2 n + \log_2 \log_2 n + \Theta(1)$ by Commentz-Walter [1]. As our circuits do not use inverters, we significantly reduce the gap to both lower bounds.

Joint work with: Ulrich Brenner

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Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization

ARRIVAL: A Zero-Player Reachability Switching Game

Hung Hoang

ETH Zürich, Department of Computer Science, 8092 Zürich, Switzerland.
Email: hung.hoang@inf.ethz.ch

Suppose we run a train on a directed (multi-)graph, where every vertex has out-degree 2 and is equipped with a switch. At the beginning, the switch at each vertex points to one of the two outgoing edges. When the train reaches a vertex, it will traverse along the edge pointed by the switch, and then the switch at that vertex shifts to the other outgoing edge. Given such a graph with an origin vertex o and a destination vertex d, the problem is to decide if the train starting from o can reach d. The problem above was first investigated and named as ARRIVAL by Dohrau et al. [1]. They showed that the problem is in NP and co-NP. The open question is whether it is in P. An approach to find a polynomial-time algorithm is to model the problem as an integer programme and examine the primal and dual of the linear relaxation. In this talk, I will present the current interim result with this approach, which is a polynomial-time algorithm for a subclass of the problem.

Joint work with: Bernd Gärtner

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Optimization Areas:

- Linear Programming

Stochastic demands in single allocation hub location

Nicolas Kämmerling

TU Dortmund University, Institute of Transport Logistics, Leonhard-Euler-Straße 2, 44227 Dortmund.
Email: kaemmerling@itl.tu-dortmund.de

The design of hub-and-spoke transport networks is a strategic planning problem as the choice of hub locations has to remain unchanged for long time periods. In this talk we develop a two-stage stochastic optimization formulation for single allocation hub location problems where the allocations to the hubs are viewed as variable over time. This allows to modify the routing in the hub-and-spoke transport network according to the current scenario, but also blows up the number of variables in the model and, thus, makes the problem much harder to solve. In order to solve large-scale instances to proven optimality, the problem is decomposed into scenario-specific subproblems which are interlinked by generalized Benders cuts for a common choice of hub locations. The decomposition also allows us to dissolve the inherent quadratic structure of the classical formulation of single allocation hub location problems. Embedded into a modern mixed-integer solver our decomposition approach is able to solve large instances under demand uncertainty.

Joint work with: Borzou Rostami, Christoph Buchheim, Joe Naoum-Sawaya, Uwe Clausen

Optimization Areas:

- Application of Optimization in Real-World Problems
- Stochastic Programming

On optimizing a quadratic function over the efficient set

KENTACHE Sarah

Operationnal Research and Management in University if Science and Technology Houari Boumedien.
Email: sarouchette07@gmail.com

Multiobjective integer linear programming (MOILP) are often adequate models for many real-world situations. However enumerating all the efficient set is not practical since it can be huge. Therefore many researchers proposed methods to optimize a preference function that translates the decision maker needs, over the efficient set. In general, the problem is hard to solve due to the non-convexity of the feasible region. Our work consists of proposing a method that solves the problem of optimizing a quadratic function, which reflects better the preference of the decision-maker than an affine function, over the efficient integer set. The algorithm finds the optimal solution to the problem without listing all the efficient set by using efficient cuts, that eliminate the undesirable (not interested) points and reduce progressively the admissible region.

Joint work with: CHAABANE Djamal

Optimization Areas:

- Discrete and Combinatorial Optimization
- Multiobjective Programming
- Nonlinear Programming

Min-max-min Robust Combinatorial Optimization under Budgeted Uncertainty

Jannis Kurtz

RWTH Aachen University
Pontdriesch 10, 52062 Aachen.
Email: kurtz@mathc.rwth-aachen.de

In this talk we study combinatorial optimization problems with uncertain parameters appearing in the objective function. As in the classical robust optimization framework we assume that all relevant outcomes of the uncertain parameters are contained in a given uncertainty set. The min-max-min robust optimization approach aims to calculate a set of feasible solutions which is worst-case optimal if we consider the best of the calculated solutions in each scenario.

In this talk we present recent results for min-max-min robust combinatorial problems with convex and discrete budgeted uncertainty sets. We show complexity results for a selection of combinatorial problems and present exact and heuristic solution methods.

Joint work with: André Chassein, Marc Goerigk and Michael Poss

Optimization Areas:

- Discrete and Combinatorial Optimization
- Robust Optimization

Engineering Fused Lasso Solvers on Trees

Elias Kuthe

Computer Science XI, TU Dortmund University.
Email: elias.kuthe@tu-dortmund.de

The graph fused lasso optimization problem seeks, for a given input signal $y = (y_i)$ on nodes $i \in V$ of a graph $G = (V, E)$, a reconstructed signal $x = (x_i)$ that is both element-wise close to y in quadratic error and also has bounded total variation (sum of absolute differences across edges), thereby favoring regionally constant solutions. An important application is denoising of spatially correlated data, especially for medical images.

Currently, fused lasso solvers for general graph input reduce the problem to an iteration over a series of "one-dimensional" problems (on paths or line graphs), which can be solved in linear time. Recently, a direct fused lasso algorithm for tree graphs has been presented, but no implementation of it appears to be available.

We here present a simplified exact algorithm and additionally a fast approximation scheme for trees, together with engineered implementations for both. We empirically evaluate their performance on different kinds of trees with distinct degree distributions (simulated trees; spanning trees of road networks, grid graphs of images, social networks). The exact algorithm is very efficient on trees with low node degrees, which covers many naturally arising graphs, while the approximation scheme can perform better on trees with several higher-degree nodes when limiting the desired accuracy to values that are useful in practice.

Joint work with: Sven Rahmann

Optimization Areas:

- Application of Optimization in Real-World Problems
- Convex Optimization

On nondegenerate M-stationary points for mathematical programs with sparsity constraint

Sebastian Lämmel

Department of Mathematics, Chemnitz University of Technology, Reichenhainer Str. 41, 09126 Chemnitz, Germany.

Email: sebastian.laemmel@mathematik.tu-chemnitz.de

We study mathematical programs with sparsity constraint (MPSC) from a topological point of view. Special focus will be on M-stationary points from Burdakov et al. (2016). We introduce nondegenerate M-stationary points, define their M-index, and show that all M-stationary points are generically nondegenerate. In particular, the sparsity constraint is active at all local minimizers of a generic MPSC. Some relations to other stationarity concepts, such as S-stationarity, basic feasibility, and CW-minimality, are discussed. By doing so, the issues of instability and degeneracy of points due to different stationarity concepts are highlighted. The concept of M-stationarity allows to adequately describe the global structure of MPSC along the lines of Morse theory.

Joint work with: Vladimir Shikhman

Optimization Areas:

- Nonlinear Programming

Computing Convex Hulls of Trajectories

Andreas Löhne

Friedrich Schiller University Jena, Department of Mathematics and Computer Science, 07737 Jena.
Email: andreas.loehne@uni-jena.de

We study the convex hulls of trajectories of polynomial dynamical systems. Such trajectories include real algebraic curves. The boundary of the resulting convex bodies are stratified into families of faces. We develop numerical algorithms for identifying these patches. An implementation based on the vector optimization solver Bensolve is presented. This furnishes a key step in computing attainable regions of chemical reaction networks.

Joint work with: Daniel Ciripoi, Nidhi Kaihnsa, Bernd Sturmfels

Optimization Areas:

- Application of Optimization in Real-World Problems
- Linear Programming
- Multiobjective Programming
- Optimal Control

Compact Linearization for Binary Quadratic Programs

Sven Mallach

Department of Mathematics & Computer Science, University of Cologne, Albertus-Magnus-Platz, 50923 Köln, Germany.

Email: mallach@informatik.uni-koeln.de

We present an extension of the so-called Compact Linearization technique to binary quadratic problems comprising some of a wide class of linear constraints. Quadratic constraints may exist as well. We analyze under which conditions Compact Linearizations are provably strong, and give some examples for prominent combinatorial optimization problems.

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Optimization Areas:

- Discrete and Combinatorial Optimization
- Linear Programming
- Mixed-Integer Non-Linear Optimization
- Nonlinear Programming

Computing Global Solutions of the Least-Squares Spline Approximation Problem with Free Knots

Robert Mohr

Institute for Operations Research, Karlsruhe Institute of Technology.
Email: robert.mohr@kit.edu

We consider a specific nonconvex data approximation problem which is known to possess a large number of local minimal points far from the globally optimal solution, namely the univariate least-squares spline approximation problem with free knots. Local optimization algorithms do not yield satisfactory solutions for this problem if the initial point is not chosen sufficiently close to a globally optimal solution. However, since in typical applications, neither the dimension of the decision variable nor the number of data points is particularly large, it is possible to make use of the specific problem structure in order to devise algorithmic approaches to approximate the globally optimal solution of problem instances of relevant sizes. We propose to approximate the continuous original problem with a combinatorial optimization problem, and investigate two algorithmic approaches for the computation of the optimal solution of the latter. Firstly, we propose an MIQCP formulation that can be solved via commercial optimization solvers. Secondly, we develop a branch-and-bound method for the solution of the combinatorial formulation. We compare the two approaches empirically on several real and synthetic data sets. Furthermore, we compare them to heuristic approaches that are commonly used in this problem setting.

Joint work with: Maximilian Koblenz und Peter Kirst

Optimization Areas:

- Convex Optimization
- Discrete and Combinatorial Optimization
- Mixed-Integer Non-Linear Optimization
- Nonlinear Programming

Multiobjective Optimal Control of a Non-Smooth Semi-Linear Elliptic PDE

Georg Müller

University of Konstanz, Universitätsstraße 10, 78457 Konstanz.
Email: georg.mueller@uni-konstanz.de

Scalar optimization problems with non-smooth PDEs have been researched considerably over the last years. When optimal compromises (i.e. Pareto optimal points) for optimization problems with multiple objectives and non-smooth PDE constraints are sought after, only few results are known. This talk addresses the multiobjective optimal control of a non-smooth semi-linear elliptic PDE with max-type nonlinearity. The presentation covers existence of Pareto optimal points, C- and strong stationarity conditions in the multiobjective setting as well as corresponding numerical results for examples with up to 3 cost functionals.

Joint work with: Constantin Christof (TU Munich)

Optimization Areas:

- Multiobjective Programming
- Optimal Control

Inner Parallel Cuts for Mixed-Integer Convex Optimization

Christoph Neumann

Insitute for Operations Research, Karlsruhe Institute of Technology.
Email: christoph.neumann@kit.edu

In this talk, we introduce an inner parallel cutting plane method (IPCP) to compute good feasible points along with valid cutting planes for mixed-integer convex optimization problems. The method iteratively generates polyhedral outer approximations of an enlarged inner parallel set (EIPS) of the continuously relaxed feasible set. This EIPS possesses the crucial property that any rounding of any of its elements is feasible for the original problem. The outer approximations are refined in each iteration by using modified Kelley cutting planes, which are defined via rounded optimal points of linear optimization problems (LPs).

We show that the method either computes a feasible point or certifies that the EIPS is empty. We further demonstrate how inner parallel cuts can be reversed so that they are valid for the original problem. We conclude with computational experiments which indicate that the IPCP is able to quickly find feasible points of remarkable quality for many practical applications and that the generated cutting planes can be quite useful.

Joint work with: Oliver Stein

Optimization Areas:

- Convex Optimization
- Discrete and Combinatorial Optimization
- Linear Programming
- Mixed-Integer Non-Linear Optimization

Optimizing operational kitting efforts by a scheduling MILP

Frederik Ostermeier

BMW Group, Petuelring 130, 80788 München.
Email: frederik.ostermeier@bmw.de

Kitting and line stocking constitute two part supply policies in industrial assembly that substantially differ in their operational efforts. Through line stocking part inventories are directly stocked at the border of line, from which the assembly operator picks the parts required for the next job. On the other hand, part inventories for kitting are stored in supermarkets, parts for a job are picked and put into a kitting container, and the kits are transported to the assembly line. There the assembly operator picks the part from the kit container. In this work we consider a travelling kit, i.e. that the kit consists of several parts for the same job but needed at different assembly stations, such that the kit travels from station to station. Despite its positive aspects of saving storage place at the line, reduced processing times and contribution to lower error rates, kitting is associated with a higher operational effort compared to line stocking due to the additional picking and transportation activities. However, the efforts depend on the production schedule, as grouping of identical jobs in the production sequence allows batch picking in the upstream supermarket. A mixed integer linear program (MILP) is set up to find a schedule that minimizes the operational efforts associated with kitting. Real data is used to validate the model.

Optimization Areas:

- Application of Optimization in Real-World Problems
- Linear Programming

Homotopy continuation for piecewise linear systems

Manuel Radons

Technische Universität Berlin, Chair of Discrete Mathematics/Geometry.
Email: radons@math.tu-berlin.de

Let A be a real $n \times n$ matrix and let $|\cdot|$ denote the componentwise absolute value of a real vector. The piecewise linear system $z - A|z| = b$ is called an absolute value equation (AVE). It is well known to be equivalent to the linear complementarity problem. The AVE is uniquely solvable if and only if a quantity called the sign-real spectral radius of A is smaller than one. Moreover, it is solvable if a quantity called the aligning spectral radius of A is smaller than one. We reworked the ideas which lead to the proofs of the aforementioned statements into a homotopy continuation type solver for the AVE. The solvers' output is not an approximation, but an exact solution of the AVE. For uniquely solvable systems it has finite termination for all b in $\mathbb{R}^n \setminus V$, where V is a semialgebraic set of dimension $n - 1$. We give a trivial upper bound for its runtime, but present experiments – both with random and real-world systems – that suggest a polynomial runtime. The trivial upper bound also holds for systems which are (not necessarily uniquely) solvable. But the algorithm becomes more involved.

Optimization Areas:

- Application of Optimization in Real-World Problems
- Nonlinear Programming

Solving set optimization problems using multiobjective subproblems

Stefan Rocktäschel

Technische Universität Ilmenau, Institut für Mathematik.
Email: stefan.rocktaeschel@tu-ilmenau.de

In this talk, we investigate set optimization problems (SOP). We will give a short motivation, explain different solution concepts and give a brief overview of the existing solution algorithms in this field. We recall basic concepts of multiobjective optimization. Afterwards, we present relations between solutions of (SOP) and a specific multiobjective optimization problem (MOP). Subsequently, we present a procedure which exploits these relations in order to obtain solutions of (SOP). Thereby, we outline the difficulties that could arise when solving the subproblems and discuss how these can be solved. The talk will end with some numerical results.

Temperature-Based Trajectory Optimization for Wire-Arc Additive Manufacturing

Johannnes Schmidt

Brandenburg University of Technology, Institute of Mathematics, Platz der Deutschen Einheit 1, 03046 Cottbus, Germany.

Email: johannes.schmidt@b-tu.de

In the additive manufacturing process of wire-arc additive manufacturing (WAAM), a moving heat source melts an electrode wire to deposit it through an electrical arc. The desired workpiece is built layer-wise on an underlying substrate plate. If it has a complex geometry, it is divided up into subparts with simpler shapes and built subpart-by-subpart. If necessary, the heat source can move without welding, called deadheading. The enormous heat of the welding head is transferred within the workpiece through conduction and radiation, leading to large temperature gradients. These temperature differences cause strain, deformation of the workpiece, or even thermal cracks. Thus a homogenous temperature distribution is desireable by minimizing these gradients. Considering a single layer of the workpiece as a graph, we describe the optimization problem of finding a eulerian path with a most homogenous temperature distribution. If the graph is non-eulerian, the necessary deadheading moves lead to additional edges. The heat equation describes the conduction, and there are additional constraints for the heating process and radiation to track the temperature distribution within the workpiece while minimizing the heat gradients between neighboring nodes of the graph. We formulate this problem as a mixed-integer linear programming model. To this end, we discretize the heat equation and linearize the radiation term. Then we demonstrate its solvability using standard mixed-integer solvers for several test instances. Furthermore, we carry out numerical experiments about the approximation of thermal radiation and compare the computed results to real processed workpieces.

Joint work with: Markus Bambach, Johannes Buhl, Armin Fügenschuh

Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Mixed-Integer Non-Linear Optimization

Haplotype Threading:
Accurate Polyploid Phasing from Long Reads

Sven Schrinner

Algorithmic Bioinformatics, HHU Düsseldorf, Email: sven.schrinner@hhu.de

The genome of many plant species, including important food crops, is polyploid, i.e. all cells contain $k > 2$ slightly different copies of each chromosome, called haploypes. Reconstructing these haplotypes is crucial for understanding the evolutionary history of polyploid species and for designing advanced breeding strategies. In read-based phasing methods this is done by taking a large set of DNA-snippets (reads), locating them in the genome and infering the haplotypes from differences between overlapping reads. The Minimum Error Correction (MEC) model is the most common and successful formalization for $k = 2$ (diploid phasing), where it finds the least contradictory bipartition of the reads. However, the formulation is not suited for the case of two or more haplotypes being locally identical, which is much more likely for polyploid genomes. In addition, dynamic programming techniques solving diploid MEC become infeasible in the polyploid case.

We propose a novel two-stage approach based on (i) clustering reads via cluster editing based on position-wise similarities between reads and (ii) infering the haplotypes by finding an optimal set of k paths through the clusters using dynamic programming [1]. We demonstrate that our method scales to whole chromosomes and results in more accurate haplotypes than those computed by the state-of-the-art tool H-PoP [2], which is based on a heuristic for the polyploid MEC model. Our algorithm is implemented as part of the widely used open source tool WhatsHap and is hence ready to be included in production settings.

Remaining challenges are the scaling to ploidies above six and handling highly divergent regions in plant genomes, which are not well described by reference genomes.

Joint work with: Rebecca Serra Mari, Jana Ebler, Tobias Marschall, Gunnar Klau

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Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Multiobjective Programming

A general branch-and-bound framework for global multiobjective optimization

Oliver Stein

Institute of Operations Research (IOR), Karlsruhe Institute of Technology (KIT).
Email: stein@kit.edu

We develop a general framework for branch-and-bound methods in multiobjective optimization. Our focus is on natural generalizations of notions and techniques from the single objective case. In particular, after the notions of upper and lower bounds on the globally optimal value from the single objective case have been transferred to upper and lower bounding sets on the set of nondominated points for multiobjective programs, we discuss several possibilities for discarding tests. They compare local upper bounds of the provisional nondominated sets with relaxations of partial upper image sets, where the latter can stem from ideal point estimates, from convex relaxations, or from relaxations by a reformulation-linearization technique.

The discussion of approximation properties of the provsional nondominated set leads to the suggestion for a natural selection rule along with a natural termination criterion. Finally we discuss some issues which do not occur in the single objective case and which impede some desirable convergence properties, thus also motivating a natural generalization of the convergence concept.

Joint work with: Gabriele Eichfelder, Peter Kirst, and Laura Meng

Optimization Areas:

- Multiobjective Programming
- Nonlinear Programming

Non-Smooth Optimization: Abs-Normal NLPs versus MPECs

Marc C. Steinbach

Leibniz University Hannover, Institute of Applied Mathematics,
Welfengarten 1, 30167 Hannover, Germany.
Email: mcs@ifam.uni-hannover.de

We consider NLPs with equality and inequality constraints in abs-normal form and generalize kink qualifications and optimality conditions of Griewank and Walther to this general non-smooth problem class. We also compare abs-normal NLPs to general MPECs and highlight intimate relationships of respective branch problems, constraints qualifications, and stationarity concepts.

Joint work with: Lisa Hegerhorst-Schultchen, Christian Kirches

Optimization Areas:

- Non-Smooth Optimization

A Meet and Regret heuristic for the dynamic vehicle synchronization problem with soft time windows

Belma Turan

WU Vienna, Research Institute for Supply Chain Management, Welthandelsplatz 1, 1020 Vienna.
Email: belma.turan@wu.ac.at

Cargo bikes as an environmentally friendly mode of transport gain increasing importance in urban freight delivery. This is not only due to a growing amount of greenhouse gas emissions and other harmful pollutants like particulate matters or nitrous oxides, but also due to increasing congestion in urban areas - both fields in which the use of cargo bikes can contribute to a mitigation. Nevertheless, route optimization models that take cargo bike specific issues into account are rare. Therefore, we deal with a dynamic vehicle routing problem which considers (1) a mixed fleet of vehicles consisting of cargo bikes and electric vans which start and end their tours at a micro-hub, (2) soft time windows at customers with a piecewise linear penalty function to penalize late arrivals, (3) pickup and delivery constraints, (4) the option to store goods for a limited amount of time in the micro-hub between pickup and delivery and (5) the potential synchronization to transship goods between vehicles. This synchronization aspect stems especially from discussions with cargo bike delivery companies, who include such synchronized meetings between drivers manually, whenever an order has to be transported from the area of one driver into the area of another driver. The problem is formulated as a mixed integer linear program and the objective function used covers economic cost as well as emission and social cost. The multi-objective aspect of the problem is dealt with by a weighted sum approach. Small problem instances are solved to optimality by using CPLEX. For problems of realistic instance sizes a metaheuristic based on a regret construction heuristic and an adaptive large neighbourhood search is developed. The test instances are generated based on realistic locations for customers, micro-hubs and meeting points for synchronized meetings in Vienna. Computational results point out the impact of parameter values and instance characteristics on the number of synchronizations in the solution and can, hence, contribute to the decision making process if such a distribution concept with synchronization can be beneficial.

Joint work with: Alexandra Anderluh (WU Vienna), Benjamin Biesinger (AIT Vienna) and Pamela Nolz (AIT Vienna)

Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Linear Programming
- Multiobjective Programming

A New Proximity Measure Based on KKT Conditions for Multiobjective Optimization Problems

Leo Warnow

Institute for Mathematics, Technische Universität Ilmenau, 98684 Ilmenau, Germany.
Email: leo.warnow@tu-ilmenau.de

In applications, often there is not only one but multiple objectives to be minimized at the same time. This leads to multiobjective optimization problems. To find optimal solutions for such optimization problems, computer algorithms are used, e.g. evolutionary algorithms. A central requirement is then to make sure that solutions found by these algorithms are actually optimal solutions or at least approximately locally optimal solutions. One way to do that is to consider necessary optimality conditions under certain regularity assumptions.

In this talk, we present a proximity measure which characterizes the fulfillment of the Karush-Kuhn-Tucker (KKT) optimality conditions. It can be used for candidate selection and also as a termination criterion for evolutionary algorithms. Moreover, we will show that the presented proximity measure is continuous in every efficient solution and can easily be computed by solving a linear optimization problem only assuming continuously differentiable objective and constraint functions as well as regularity.

Joint work with: Gabriele Eichfelder

Optimization Areas:

- Multiobjective Programming
- Nonlinear Programming

Efficient computation of the Wasserstein-∞ metric for distributions with finite support

Ralf Werner

Augsburg University, Institute of Mathematics, Universitätsstr. 14, 86159 Augsburg, Germany.
Email: ralf.werner@math.uni-augsburg.de

In this talk, we cover the efficient exact computation of the Wasserstein-infinity metric, defined as the limit of the widely studied Wasserstein-p metric for $p \to \infty$. We hereby focus on measures with finite support of size m and n. Despite their seemingly close relationship, (very efficient) algorithms for the Wasserstein-infinity metric are currently only available for special cases, e.g. in $\mathbf{R}^k$ for $m = n$ with equal probability $1/m$ and for the real line.

We add to the current literature by providing exact algorithms with low polynomial worst case complexities which are applicable for general metric spaces. Our general algorithm with complexity $\mathrm{O}(mn^2 log(m))$ is based on a bisection combined with a detailed analysis of the embedded max flow problem. Interestingly, it is possible to exploit geometric properties to obtain a more efficient approach in special cases. We do so by introducing the concept of a quasi-convex metric in a totally ordered space, which covers e.g. the real line with the usual order and the Euclidean distance. This allows for a $\mathrm{O}(mlog(m))$ algorithm for the Wasserstein-infinity metric as well as for an explicit characterization of the optimal coupling.

Joint work with: Christian Drescher, Augsburg University.

Optimization Areas:

- Application of Optimization in Real-World Problems
- Linear Programming

On an assignment problem for multi-way bucketed Cuckoo hash tables on genome-scale data

Jens Zentgraf

Bioinformatics, Computer Science XI, TU Dortmund University, Dortmund, Germany.
Email: jens.zentgraf@tu-dortmund.de

We discuss the the minimum cost assignment problem for multi-way bucketed Cuckoo hashing with $h \geq 2$ hash functions and buckets that store $b \geq 1$ elements each. The goal is to minimize the average lookup cost over all stored elements, assuming that an element in the bucket indicated by its j-th hash function incurs a lookup cost of j cache misses. We present a practical exact algorithm to solve this problem [1] Our method is based on a combination of the Bellman-Ford and Hopcroft-Karp algorithms for finding minimum cost paths in the Cuckoo assignment graph, using multiple sources in parallel. We find a cost-optimal assignment for the 2.38 billion canonical DNA 25-mers of the human genome in 4 to 48 hours of CPU time, using up to 48 GB of RAM, at hash table loads between 50% and 99.9% for bucket sizes 3 to 8. For bucket size 4 and 95% load, we obtain optimal costs of ≈ 1.2 cache misses per stored element and 1.4 per element that is not present, using 7 hours of CPU time.

As a secondary objective, we may want to maximize the number of buckets that have at least one empty slot available. For this extended problem, we are able to solve small instances on bacterial genomes (up to 5 million of DNA 25-mers) using integer linear programs.

Joint work with: Henning Timm and Sven Rahmann (Genome Informatics, University of Duisburg-Essen, University Medicine Essen, Germany)

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Optimization Areas:

- Application of Optimization in Real-World Problems
- Discrete and Combinatorial Optimization
- Multiobjective Programming