ECCO XXXI - CO 2018

Joint conference of the

European Chapter on Combinatorial optimization (ECCO)

and the

International Symposium on Combinatorial optimization (CO)

University of Fribourg
Fribourg, Switzerland
June 14 - 16, 2018

We would like to thank our sponsors for their support

GUROBI OPTIMIZATION

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Welcome to Fribourg,
Welcome to ECCO XXXI - CO 2018

Dear participant,

First of all, we would like to thank you for participating at the ECCO XXXI - CO 2018 Joint Conference on Combinatorial Optimization taking place in the small, but beautiful city of Fribourg. After 2002 (Lugano), ECCO is finally back in Switzerland and we are very happy to host this joint edition with CO.

The conference offers a very attractive program with over 60 contributed talks and 4 plenary talks given by well-known researchers in the domain of combinatorial optimization: Christos Papadimitriou (Columbia University), Yves Crama (HEC Liège), John Gauci (University of Malta) and Daniel Kuhn (EPF Lausanne). We hope that you take the opportunity to exchange ideas with colleagues and/or start new collaborations.

Besides this excellent scientific program, you will also be able to enjoy our social program, which will allow you to get a bit familiar with the local as well as the Swiss culture.

We would also like to thank the ECCO board as well as the CO board for having entrusted the organisation of the conference to us, in particular the ECCO coordinator Silvano Martello.

Now dear participant, please enjoy your time in Fribourg, from a scientific and from a social point of view.

Bernard Ries, Marino Widmer
On behalf of the OC

From the ECCO coordinator

Dear Conference Participant,

It is with great pleasure that I welcome you to the charming Fribourg and to the ECCO XXXI - CO 2018 Joint conference on Combinatorial Optimization. Every fourth year, ECCO (the European Chapter on Combinatorial Optimization, a EURO Working Group founded in 1987) helds its annual conference jointly with CO (the International Symposium on Combinatorial Optimization, a series of conferences that started in the UK in 1977). I am sure that the meeting will provide a stimulating opportunity for a global interchange of ideas on all recent advances in our field. The program is enriched by a distinguished set of four plenary lectures delivered by outstanding invited speakers. In addition, as is the tradition with ECCO conferences, a number of social events are scheduled.

I want to take this opportunity for sincere thanks to all who supported the preparation of the event, and in particular to Bernard Ries, who chaired to Program and the Organizing Committee, and to his collaborators.

I wish you an exciting and enjoyable meeting.

Silvano Martello
Coordinator of ECCO

A very warm welcome to ECCO XXXI - CO 2018 Joint Conference!

Together with ECCO, the CO is pleased to be party to this quadrennial ECCO-CO Joint Conference, which brings together the combinatorial optimization community across Europe and beyond to exchange knowledge of recent developments in the theory and applications of combinatorial optimization.

CO is a series of biennial international symposia on combinatorial optimization that started in the UK in 1977. Since it established a working partnership with ECCO in the 1990s, the CO series has alternated its meeting venues between the UK and continental Europe, which makes the ECCO-CO Joint Conferences an especially enjoyable experience.

Taking this opportunity, we wish to thank the local Organizing Committee, led by Bernard Ries, for all their hard work in making this conference happen in Fribourg.

Bo Chen and Chris Potts
Coordinators of the CO conference series

ECCO is back in Switzerland !

After 16 years of peregrinations through Europe following the 2002 Lugano meeting, ECCO comes back to Switzerland and welcomes its participating members in Fribourg.

According to Wikipedia our working group has now more than 1400 members from 77 countries. When we created ECCO with Catherine Roucairol and Alexander Rinnooy Kan, it was initially called European Club of Combinatorial Optimization and the basic rule was to have a scientific meeting every year in a spectacular environment.

But marketing arguments compelled us to turn the too convivial and friendly Club into a more serious looking Chapter. Even with this change of title we were then far from believing that such an institution was going to thrive and develop over many years.

This remarkable success is mainly due to the everlasting enthusiasm of many local organizers who have offered so much energy and competence to set up a high quality conference every year since 1987! Thanks to their efforts our working group is now a scientifically well established and internationally recognized institution. By the way notice that even if you reverse ECCO it will still sound like OK ! Is this not a striking proof of robustness?

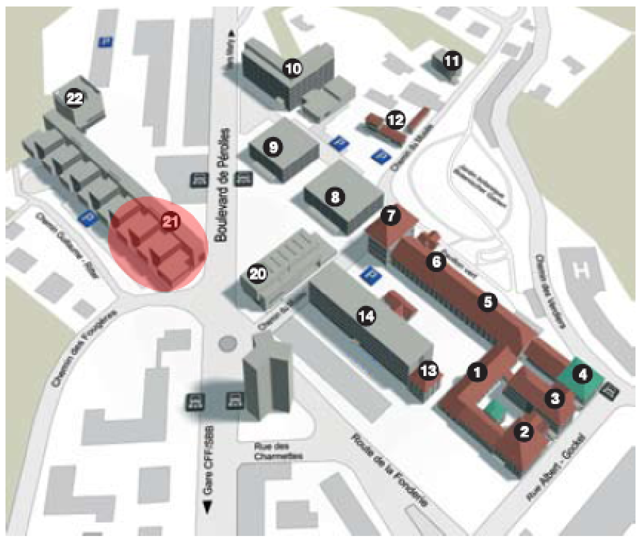
On behalf of the founders of ECCO I am extremely happy to thank the organizers of ECCO XXXI and to welcome the participants to this conference among whom are undoubtedly many organizers of future ECCO meetings.

Finally remember that in the same way as Operations Research was defined as the “science of better“, for us Combinatorial Optimization should be seen as the “science of best“!

Dominique de Werra
Co-founder of ECCO

CONFERENCE VENUE

The conference will take place at the University of Fribourg on *Boulevard de Pérolles 90, 1700 Fribourg*, in building 21 (see map below). The plenary talks will take place in Room A140 and the parallel sessions will take place in Rooms A140 / B130 / C130 / D130 (all rooms are on the 1st floor).



To get to the venue from the city center, you can walk along the *Boulevard de Pérolles* up to the roundabout at the *Route de la Fonderie*. The walk will take 20-25 minutes.

You can also take the bus. From the train station of Fribourg, there are 4 bus lines which go directly to the conference venue:

- Bus 1 (direction "Marly, Gérine"), stop at "Pérolles, Charmettes /Plateau-de-Pérolles"
- Bus 3 (direction "Pérolles, Charmettes"), stop at "Pérolles, Charmettes"
- Bus 7 (direction "Cliniques"), stop at "Pérolles, Charmettes"
- Bus 9 (direction "Pérolles, Charmettes"), stop at "Pérolles, Charmettes"

Timetables can be found on the website of the *Transports Publics Friboourgeois*. The cost of a single bus ticket is CHF 2.90 but most of the hotels distribute a passport that allows you to use the busses in Fribourg for free.

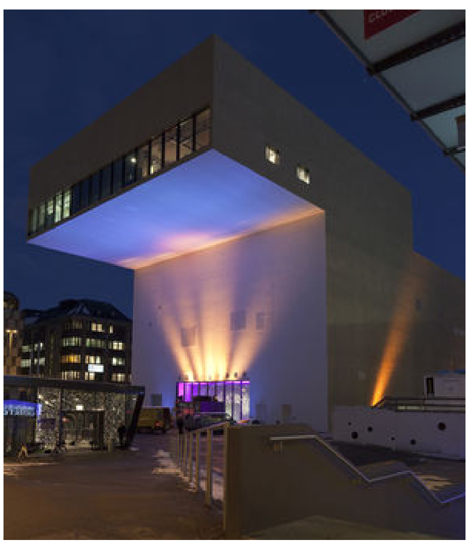
There are also taxis that can be used. The approximate cost of a taxi for a ride in Fribourg is around CHF 10.–.

SOCIAL PROGRAM

Below you will find some useful information concerning the social program of ECCO XXXI - CO 2018: welcome cocktail, social activity and gala dinner. Additional information will be given during the conference.

WELCOME COCKTAIL

The Welcome Cocktail of ECCO XXXI - CO 2018 takes place on **Wednesday evening, June 13, 2018**, at the **theatre *Equilibre*** in the city center (see map below) from **18h00 to 20h00**. Registration will be possible during the welcome cocktail.



SOCIAL ACTIVITY

On Friday afternoon, we will go by bus to **Broc** where you will have the opportunity to visit the **famous chocolate factory of *Cailler*** (organised tour). Afterwards, we continue to **Gruyères** where you can visit the **city and the 13th-century *Château de Gruyères*** (on your own). Not to miss: inside the small St. Germain Castle, the H.R. Giger Museum shows artwork relating to the film *Alien*.

We will meet at **13h20 on the parking** behind the building *Pérolles 21* (more details will be given during the conference).

GALA DINNER

At the **restaurant *Fleur de Lys*** (Rue du Bourg 14, 1663 Gruyères) in Gruyères, we will meet for an **aperitif at 18h30**. Finally, we go to the **restaurant *Auberge de la Halle*** (Rue du Bourg 24, 1663 Gruyères), where the Gala Dinner of ECCO XXXI - CO 2018 takes place **around 20h00**. After the dinner, we will go back to Fribourg by bus again.

SCIENTIFIC PROGRAM

Thursday June 14

8.00 - 12.00	**Registration (*inside Room A140*)**
8.30 - 9.00	**Opening session (*Room A140*)**
9.00 - 10.00	**Plenary talk (*Room A140*) (chair: Silvano Martello)**
Christos Papadimitriou	A computer scientist thinks about the brain
10.00 - 10.30	**Coffee break**
10.30 - 12.10	**Parallel sessions**

Room A140 (chair: Esther Mohr)

Harshal Lowalekar	Theory of Constraints Replenishment Solution for Perishable Items Supply Chains
Elif Özgörmüş	Market Basket Data Analysis for Grocery Store Layout Problem
Jedrzej Musial	The Impact of the Trust Factor on Online Shopping Decisions
Francisco J. Tapia-Ubeda	On Inventory Control Policies within the Joint Inventory Location Problem: Modelling and Solution Approach

Room B130 (chair: Marta Szachniuk)

Malgorzata Sterna	Late Work and Early Work Scheduling on Parallel Machines
Klaus Jansen	Scheduling Monotone Moldable Jobs in Linear Time
Asaf Levin	A unified framework for designing EPTAS's for load balancing on parallel machines
Yakov Zinder	A 5-parameter complexity classification of the two-stage flow shop scheduling problem with job dependent storage requirements

Room C130 (chair: Tony Hürlimann)

Mohammadreza Galavii	The inverse p-maxian problems
Jörg Kalcsics	Minmax Regret Maximal Covering Location Problems on Networks with Edge Demand
Thomas Byrne	Location Problems with Continuous Demand on a Polygon with Holes: Characterising Structural Properties of Geodesic Voronoi Diagrams
Ivan Contreras	Branch-and-cut for Multi-level Uncapacitated Facility Location Problems

Room D130 (chair: Pierre Hauweele)

Oylum Şeker	A De composition Approach to Solve the Selective Graph Coloring Problem in Perfect Graphs
Christophe Picouleau	Minimal graphs for hamiltonian extension
Gauvain Devillez	Minimizing the eccentric connectivity index with a fixed number of pending vertices
Eunjeong Yi	Broadcast domination in permutation graphs

14.00 - 15.00 **Plenary talk (*Room A140*) (chair: Bernard Ries)**

Daniel Kuhn	From Data to less Data to Decisions

15.10 - 16.00 **Parallel sessions**

Room B130 (chair: Malgorzata Sterna)

Jakub Wiedemann	N-way junction modeling and analysis
Kaja Chmielewska	A heuristic for finding some sets of transitions of Petri net-based models of complex biological systems

Room C130 (chair: Eric Gourdin)

Xuan Vinh Doan	Robust retrofitting planning under ambiguous endogenous uncertainty
Bernhard Primas	Transmission Line Route Planning: Algorithm Design and Structural Properties of Underlying Networks

Room D130 (chair: Michal Stern)

Mercedes Landete	Rankings subsets of a set from a single ranking of its elements
Sammani D. Abdullahi	Degeneracy in Vertex Enumeration: A Comparative Approach of Two Basis Oriented Pivoting Algorithms

16.00 - 16.30 **Coffee break**

16.30 - 18.10 **Parallel sessions**

Room B130 (chair: John Gauci)

Luka Borozan	Integer Linear Programming methods for Group Steiner Tree and related problems
Michal Stern	Clustered Spanning Tree - Conditions for Feasibility
Uwe Schwerdtfeger	Non-linear Generalizations Algebraic Connectivity

Room C130 (chair: Christophe Picouleau)

Alain Hertz	An IP-based algorithm for the metric dimension problem in hypercubes
Lu Han	A local search approximation algorithm for the uniform capacitated k-means problem
Ruiqi Yang	Robust Submodular Maximization over Sliding Window

Room D130 (chair: Monique Guignard)

Andrei Nikolaev	On the skeleton of the polytope of pyramidal tours with step-backs
Rostislav Staněk	An ILP-based improvement method for the travelling salesman problem
Gorka Kobeaga	Adapting efficient TSP exact algorithms for large orienteering problems

Friday June 15

9.00 - 10.00	**Plenary talk (*Room A140*) (chair: Alain Hertz)**
John Gauci	Super-connectivity and super-edge-connectivity of graphs

10.00 - 10.30	**Coffee break**

10.30 - 12.10	**Parallel sessions**

Room A140 (chair: Marino Widmer)

Yuval Cohen	Stopping Technique for Search-Based Combinatorial Optimization
Saranthorn Phusingha	Meta-Heuristics for Multi-Period Sales Districting Problem
José Brandão	An iterated local search algorithm for the multi-depot open vehicle routing problem
Esther Mohr	Distribution-free Customer Demand Prediction

Room B130 (chair: Chris Potts)

Cinna Seifi	Job scheduling with simultaneous assignment of machines and multi-skilled workers: a mathematical model
Jędrzej Marszałkowski	Multi-instalment divisible loads scheduling on heterogeneous hierarchical memory systems for time and energy criteria
Joanna Berlińska	Scheduling algorithms for data gathering in networks with background communications
Norbert Trautmann	An assignment-based continuous-time MILP model of the resource-constrained project scheduling problem

Room C130 (chair: Bo Chen)

Özkan Öztürk	Optimal Control of Unmanned Aerial Vehicles on Time Scale Theory
Grzegorz Pawlak	Single track railway scheduling problem
Nivedita Haldar	Application of Quantum Modelling based Combinatorial Bilevel Optimization in Urban Road Transport Problem
Szymon Wasik	Optil.io: Crowdsourcing Platform for Solving Optimization Problems

Room D130 (chair: Jacek Blazewicz)

Marta Szachniuk	RNA structure reparation with combinatorial algorithms
Tomasz Zok	RNA Pseudoknot Analysis: A Graph-Coloring Approach
Joanna Miskiewicz	Computational Modeling and Analysis of G-quadruplex Structures
Piotr Lukasiak	Combinatorial model of proteins and RNA

Afternoon	**Social activity**
Evening	**Gala Dinner**

Saturday June 16

9.00 - 10.00	**Plenary talk (*Room A140*) (chair: Dominique de Werra)**
Yves Crama	Reformulations of nonlinear binary optimization problems
10.00 - 10.30	**Coffee break**
10.30 - 12.10	**Parallel sessions**

Room A140 (chair: Grzegorz Pawlak)

Elisabeth Rodriguez-Heck	Linear and quadratic reformulation techniques for nonlinear 0-1 optimization problems
Monique Guignard	Primal Heuristics and Dual Bounds for 0-1 Quadratic Optimization Problems with Linear Constraints
Michele Monaci	The Non-Linear Generalized Assignment Problem
Özgü Turgut	An Exact Parallel Objective Space Decomposition Algorithm for Solving Multi-objective Integer Programming Problems

Room B130 (chair: Yves Crama)

Gur Mosheiov	Minmax Scheduling and Due-Window Assignment with Position-Dependent Processing Times and Job Rejection
Bo Chen	Price of Fairness in Two-Agent Single-Machine Scheduling Problems
Mohammed Khatiri	A new analysis of Work Stealing with latency
Alan Soper	Scheduling to Minimize Total Completion Time under Position dependent and cumulative Rate-modifying Effects on a Single Machine

Room C130 (chair: Xuan Vinh Doan)

Leah Epstein	Batched bin packing
Krzysztof Szkatula	Probabilistic analysis of the Two-Constraint Binary Knapsack Problem
Roberto Zanotti	A New Exact Algorithm for the Multidimensional Multiple-Choice Knapsack Problem
Eric Gourdin	Some bin-packing problems in telecommunication networks

Room D130 (chair: Christophe Picouleau)

Tony Hürlimann	Sport League Scheduling
Chris Potts	Planning and Scheduling in Open-Pit Mining
Elmar Swarat	Two Column Generation based Heuristics for Optimal Toll Enforcement
Clea Martinez	Polynomial subcases of the home health care routing and scheduling problem with fixed services

12.10 - 12.30	**Closing session (*Room A140*)**

LIST OF ABSTRACTS

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Contributed talks

Reformulations of nonlinear binary optimization problems

Yves Crama
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HEC Liège

A pseudo-Boolean function is a real-valued function $f(x) = f(x_1, x_2, ..., x_n)$ of n binary variables. It is well-known that every pseudo-Boolean function can be uniquely represented as a multilinear polynomial in its variables. Nonlinear binary optimization problems, or pseudo-Boolean optimization (PBO) problems, of the form $\min\{f(x) : x \in \{0,1\}^n\}$ where $f(x)$ is a pseudo-Boolean polynomial, have attracted the attention of numerous researchers for more than 50 years. These problems are notoriously difficult, as they naturally encompass a broad variety of models such as maximum satisfiability, max cut, graph coloring, or image restoration. In this talk, I present recent results (obtained in collaboration with Martin Anthony, Endre Boros, Christoph Buchheim, Aritanan Gruber, and Elisabeth Rodriguez-Heck) regarding reformulations of nonlinear PBO problems either as linear integer programming problems or as quadratic PBO problems.

Super-connectivity and super-edge-connectivity of graphs

John B. Gauci
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Network design focuses on determining how to best connect nodes such that the resulting network is, among other considerations, efficient, resistant to threats, cost-effective and fault tolerant. A topological optimisation question that addresses the requirement of fault-tolerance asks for the connectivity of the graph (or digraph) underlying the network. The property of a graph being connected depends only on whether the graph contains a path for every pair of vertices. However, besides the classical connectivity measures that study the minimum number of vertices or edges that need to be deleted to disconnect the graph, other types of connectivity have recently received much attention. These include connectivity parameters that impose some restrictions on the components of the remaining graph; a notion proposed by Harary (1983) and known as conditional connectivity. Given a graph G and some graph theoretical property P, the size of the smallest set S of vertices (or edges), if such a set exists, such that the graph $G - S$ is disconnected and every remaining component has property P is the conditional connectivity (or conditional edge-connectivity) of G. Although, theoretically, any property P can be chosen, the most popular choices of P are those having practical applications.

In this talk we restrict our attention to the super-connectivity and the super-edge-connectivity of a graph. These notions respectively study the least number of vertices and edges that need to be deleted from a graph to disconnect the graph such that each remaining component is not trivial. In other words, the property that each component must possess is that of not being an isolated vertex, or equivalently, that of containing at least one edge. We will present well-known bounds for these parameters and discuss sufficient conditions for the bounds to be attained in terms of vertex-degrees, diameter and girth. Finally we review the super-connectivity and the super-edge-connectivity of some families of graphs, including circulant graphs, hypercubes, generalized Petersen graphs, Kneser graphs and Johnson graphs.

From Data to Less Data to Decisions

Daniel Kuhn
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The proliferation of “big data" created by mobile devices, social media, sensor networks, satellites etc. offers the potential to make more informed decisions, but it also poses a significant challenge to the scalability of the current optimization methods and decision support tools. This raises a number of fundamental questions: How should uncertain parameters in the big data regime be represented so that they lend themselves to integration into optimization problems? Which observations and features of a high-dimensional parameter set are most relevant for a particular optimization problem? How can these relevant observations and features be identified efficiently? How can one maintain the computational tractability of the emerging optimization problems? In the first part of the talk I will introduce tractable approaches for reducing large datasets to smaller ones at minimal loss of information. In the second part I will describe tractable methods for recognizing balanced clusters of similar datapoints in large unstructured datasets. Both methods come with rigorous performance guarantees. Implications for practical decision-making will be highlighted.

A computer scientist thinks about the brain

Christos H. Papadimitriou
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University of California at Berkeley

How does the Brain beget the Mind? How do neurons and synapses, molecules and genes, give rise to behavior and cognition, love and sadness, language and intelligence? Despite lightning progress in recording and molecular technology and a deluge of experimental data, we do not seem to get closer to an answer. This is a talk about admiring and appreciating the problem, and proposing a new approach based on a recognized but little studied intermediate level of Brain computation carried out by the synchronous firing of large and highly interconnected sets of neurons called assemblies. We show that assemblies give rise to a novel algebra and calculus, and we speculate that they instrument our higher cognitive functions, such as language and math.

Degeneracy in Vertex Enumeration: A Comparative Approach of Two Basis Oriented Pivoting Algorithms

Sammani Danwawu Abdullahi
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Qatar University

Degeneracy in Vertex Enumeration (VE) algorithms has been challenging issues in 60s, 70s, 80s and 90s. VE algorithms explored methods and procedures of determining solutions that lie at corners of convex polyhedron that are formed by system of linear equations or inequalities. A vertex (extreme point) is said to be degenerate if more number of hyperplanes are binding than the corresponding dimension. A Comparison of two Basis Oriented Pivoting (BOP) algorithms that handle low-level of vertex-degeneracy using some examples are presented and a new VE algorithm is suggested for handling polyhedra that have high-level of vertex-degeneracy.

Scheduling algorithms for data gathering in networks with background communications

Joanna Berlińska
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Adam Mickiewicz University in Poznań

We study scheduling in a star data gathering network with variable communication speed. Each of the network's worker nodes holds a dataset that has to be transferred to the base station. At most one node can communicate with the base station at a time. Background communications taking place in the network degrade the communication speed perceived by the analyzed data gathering application. In more detail, we are given a set of time intervals in which the speed of individual communication links is decreased by a constant factor. Our goal is to organize the dataset transfers so that all data will be gathered in the shortest possible time. We study both the preemptive and the nonpreemptive version of this problem.
We show that in the preemptive case, the problem can be solved in polynomial time, using linear programming. On the contrary, the nonpreemptive version is strongly NP-hard, which we prove by pseudopolynomial transformation from the 3-Partition problem. For this case, we propose an exponential-time dynamic programming algorithm and three polynomial-time greedy heuristics. The quality of the solutions delivered by the heuristics is tested in a series of computational experiments.

Integer Linear Programming methods for Group Steiner Tree and related problems

Luka Borozan
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J.J. Strossmayer University of Osijek, Department of Mathematics
joint work with Slobodan Jelić

Consider the graph $G = (V, E)$ with a non negative weight function $w : E \to \mathbb{R}_+$. Let $G_1, \ldots, G_k$ be arbitrary subsets of V called groups. Group Steiner Tree (GST) problem pertains to constructing a minimum cost tree $T = (V', E')$ where $V' \subseteq V$ and $E' \subseteq E$ such that it spans at least one vertex from each of the groups. It is one of the cornerstone combinatorial optimization problems known to be NP-hard since it generalises both Steiner tree and set cover problem.

Our aim is to provide integer linear programming (ILP) methods for solving the GST problem to optimality using state-of-the-art MILP solver Gurobi. We compare implementations of three ILP formulations: cut, flow and subtour elimination along with additional strengthening constraints. An insight on the sizes of the problems we are able to solve will be given.

Along with the numerical preprocessing which Gurobi steadily applies, we will employ several GST instance preprocessing techniques which tackle the complexity increasing factors for the GST problem.

Experiments with both synthesised and real-world instances are given. The latter come from keyword search problem in relational databases and team formations in social networks.

An iterated local search algorithm for the multi-depot open vehicle routing problem

José Brandão
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University of Minho

The multi-depot open vehicle routing problem consists of defining a set of open routes for delivering goods to a given number of customers with known demand and location such that the total travelling cost is minimised. Each route is constituted by a depot and a set of customers that are visited in a given sequence. Each route is assigned to a vehicle that starts at the depot and ends at the last customer of the route, not returning to the depot, being this reason why the problem, as well as the route, is called open. The demand of each customer must be satisfied by exactly one vehicle. There are many published papers that study the multi-depot vehicle routing problem, but there are only very few that study the same problem with open routes. All these articles assume that the objective is to minimise the total travelling distance. In our research we study two versions: one that has the objective of minimising the total travelling distance and another that has two hierarchical objectives - the first is to minimise the number of vehicles used and the second is to minimise the total distance travelled. We created an iterated local search algorithm for solving this problem. The performance of this algorithm is compared with other published algorithms, using a set of benchmark problems from the literature.

Location Problems with Continuous Demand on a Polygon with Holes: Characterising Structural Properties of Geodesic Voronoi Diagrams

Thomas Byrne
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The University of Edinburgh
joint work with Jörg Kalcsics

The problem of finding optimal locations for a set of service facilities is of strategic importance and has generated a large body of research literature. In most models customer demand is assumed to be discrete and aggregated to a relatively small number of points. However, in many urban applications the number of potential customers can be in the millions and representing every customer residence as a separate demand point is usually infeasible. Therefore it may be more accurate to represent customer demand as continuously distributed. Recently, in Averbakh et al. [1], a new exact algorithm has been proposed for several conditional planar facility location problems with constant demand distribution.

Moreover, the region of demand and the region over which a facility can be feasibly located are often assumed to be convex polygons. However, this supposition is not a realistic one for real world applications. While a non-convex demand region can be modelled as its convex hull with zero demand where appropriate, a non-convex feasibility region requires more work. Yet more problems occur when we introduce areas that cannot be traversed (for example, holes) since then we can no longer use rectilinear distance and must instead use geodesic rectilinear distances.

We assume that the facilities can be located anywhere on the plane that is traversable and customers obtain service from the closest open facility. While the discussion below applies to a variety of location problems that can be defined in this setting, for concreteness we consider the market share problem where the locations of $p-1$ facilities are fixed, and we seek to find the optimal location for an additional facility with the objective of maximising the total demand attracted by that facility. Once the locations of all p facilities are specified, the demand space is partitioned into regions called "Voronoi cells"; the resulting partition is known as the "Voronoi diagram". However, due to the presence of holes we no longer have the classic Voronoi diagram, but instead the geodesic equivalent diagram. As well as defining the boundaries within this altered diagram, an additional difficulty is that it is generally impossible to represent the objective function in closed form. In fact, the representation of the objective function depends on the *structure* of the Voronoi diagram, i.e., the position and the geometry of the cell boundaries. Unfortunately, this structure can change drastically with the location of the "free" facility, making the underlying optimisation problems quite difficult. The optimisation problem is greatly simplified if the location of the new facility is restricted to a sub-region where the resulting geodesic Voronoi diagram is "structurally identical" for every point in the region. Given such regions, we can derive a parametric representation of the objective function which is valid for any location in the region. This in turn allows us to optimise the location of the new facility over this region using classical non-linear programming techniques.

In this talk we extend the structural properties of classic Voronoi diagrams to geodesic rectilinear distances and show how to use them to identify the desired sub-regions. In addition, we discuss how to determine efficiently the parametric representation of the objective function over each region and how to solve the resulting non-linear optimisation problem.

References

[1] I. Averbakh, O. Berman, J. Kalcsics, and D. Krass, Structural Properties of Voronoi Diagrams in Facility Location Problems with Continuous Demand, Operations Research,62(2), 394–411, 2015

Price of Fairness in Two-Agent Single-Machine Scheduling Problems

Bo Chen
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joint work with Gaia Nicosia and Andrea Pacifici

We investigate the concept of price of fairness in resource allocation and apply it to two-agent single-machine scheduling problems, in which two agents, each having a set of jobs, compete for use of a single machine to execute their jobs. We consider the situation where one agent aims at minimizing the total of the completion times of his jobs, while the other seeks to minimize the maximum tardiness with respect to a common due date for her jobs. We first explore and propose a definition of utility, then we study both max-min and proportionally fair solutions, providing a tight bound on the price of fairness for each notion of fairness. We extend our study further to the problem in which both agents wish to minimize the total of the completion times of their own jobs.

A heuristic for finding some sets of transitions of Petri net-based models of complex biological systems

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joint work with Piotr Formanowicz

A systems approach based on Petri nets is increasingly used to modeling and performing analysis of complex biological phenomena. The analysis of models expressed in the language of Petri nets theory can be based on t-invariants. These invariants correspond to subprocesses occurring in the modeled system which do not change its state. Searching for similarities among t-invariants can lead to identification of groups of subprocesses which influence on each other. This, in turn, may lead to better understanding of the modeled phenomenon, since such interactions may be the source of important properties of the analyzed biological system. For the purpose of conducting a more detailed analysis, some subsets of a set of transitions should be found. More precisely, subsets of a certain minimal cardinality, which are included in sufficiently large number of t-invariant supports, should looked for. Elements of these subsets correspond to elementary processes that appear in many subprocesses. Hence, their biological counterparts can play important roles in the modeled system. Since the combinatorial problem of finding such subsets of transitions is NP-hard, we propose a heuristic algorithm solving it.
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Stopping Technique for Search-Based Combinatorial Optimization

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This research draws on theories in discrete event simulation, order statistics and record-breaking statistics to develop a methodology for deciding when to stop a combinatorial optimization search. During the first optimization period, the objective function improves rapidly with the iterations, and the improvement slows gradually until it almost stalls. We adopt a popular method to detect the period of rapid improvements of the "warm-up period", and then we propose a special control chart technique to identify with a given certainty reaching a steady state. Then, we suggest using the theory of record-breaking to decide on a stopping criterion. In addition, the paper develops estimates for the optimum bounds and estimates for value and timing of the next expected improvement. The advantages and limitations of this approach are discussed.

Branch-and-cut for Multi-level Uncapacitated Facility Location Problems

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Multi-level facility location problems (MLFLPs) lie at the heart of network design planning in transportation and telecommunications systems. Given a set of customers that have a service requirement and a set of potential facilities partitioned into k levels, MLFLPs consist of selecting a set facilities to open at each level so that every customer is assigned to a sequence of opened facilities, exactly one from each level, while optimizing an objective function. We refer to [1] for a recent survey on MLFLPs.
In this talk we introduce a general class of MLFLPs denoted as *multi-level uncapacitated p-location problems with edge set-up costs* (MUpLP-E) in which cardinality constraints on the number of facilities to open at each level are considered at each level, and the selection of edges between levels of facilities is part of the decision process. Let $I = \{1, \cdots, m\}$ be the set of customers, and $V_1, \cdots, V_k$ be the sets of sites among which facilities of levels 1 to k can be selected (or opened), with $V = \cup_{r=1}^{k} V_r$. Also, consider $c_{ij_1 \cdots j_k}$ to be the profit associated with the allocation of customer i to the sequence of facilities $j_1, \cdots, j_k$, where $j_r \in V_r$. Now, let $p = (p_1, \cdots, p_k)$ be a vector of positive integers, f_{j_r} be the non-negative fixed cost associated with opening facility j_r at level r, and d^r_{ab} be the cost of opening the edge between facilities $a \in V_r$ and $b \in V_{r+1}$. The MUpLP-E consists of selecting sets of facilities and edges to open, such that no more than p_r facilities are opened at level r and of assigning each customer to a set of open facilities, exactly one at each level, while maximizing the total profit, minus the total setup cost. An edge can be opened if both of the corresponding facilities are open. When a customer is assigned to a set of opened facilities all the edges in the corresponding sequence must be activated.
We present a branch-and-cut algorithm based on a Benders reformulation to solve large-scale instances of the MUpLP-E. This reformulation is obtained by projecting out a large set of binary variables from an extension of the arc-based formulation introduced in [2] for the two-level case. Exact separation procedures are developed to efficiently generate feasibility and optimality cuts at fractional and integer points. We show that the well-known cut-set inequalities are sufficient to guarantee feasibility of the primal subproblem and thus, these can replace the standard feasibility cuts. In addition, we exploit the network flow structure of the reformulation to efficiently generate Pareto-optimal cuts using different strategies. In order to assess the performance of our algorithm, we have performed extensive computational experiments on several sets of benchmark instances for the general MUpLP-E and some special cases previously studied in the literature.

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Minimizing the eccentric connectivity index with a fixed number of pending vertices

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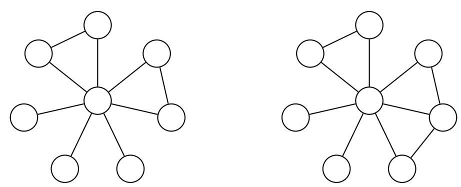
joint work with P. Hauweele, A. Hertz and H. Mélot

Extremal graph theory aims to determine bounds for graph invariants as well as the graphs that attain those bounds. For example, one can study the eccentric connectivity index (called ECI) and, given a number of nodes and pending vertices, search to minimize it.
Given a connected graph $G = (V, E)$, we define the eccentricity of a vertex v ($e_G(v)$) as the maximal distance between v and any other vertex of G. The degree of a vertex ($d_G(v)$) is the number of adjacent vertices and vertices with degree 1 are called pending. We define ECI as the sum for every vertex of the product between its degree and its eccentricity. This invariant was introduced by Sharma *et al.* [1].

$$ECI(G) = \sum_{v \in V} d_G(v) \cdot e_G(v).$$

We define the graph $G_{n,p}$ as the graph with n vertices and p pending vertices obtained by taking a star with n vertices and adding a maximum matching between $n - p - 1$ pending vertices. If $n - p - 1$ is odd, the one too many pending vertex is made adjacent to one of the vertices covered by the matching.



$G_{8,3}$ $G_{8,2}$

In this talk we determine which graphs have a minimum value of ECI for a given number n of vertices and a given number p of pending vertices. We show that among these graphs, $G_{n,p}$ is the graph minimizing ECI with the exception of some particular cases.

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Robust retrofitting planning under ambiguous endogenous uncertainty

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Retrofitting planning concerns about how to strengthen strategic links in an infrastructure network which subjects to failures due to disasters. The main aim is to maintain the connectivity of the network if disasters happen. Another important aim is to keep post-disaster travel costs as low as possible. Peeta et al. [1] develop a two-stage integer stochastic optimization problem to solve the retrofitting problem given a limited budget. The resulting problem has a highly non-linear objective due to the assumption that random link failures are independent in addition to the fact that these random failures are decision-dependent or endogenous. Peeta et al. [1] propose to solve the problem by approximating the objective with a monotonic multi-linear function. Prestwich et al. [2] propose a scenario aggregation approach (scenario bundling) and analyze the set of decision-dependent probability distributions (distribution shaping) to reformulate the problem as a mixed-integer linear optimization problem. In this paper, we relax the independence assumption of random link failures and propose a robust optimization formulation given the distributional ambiguity. We analyze several properties of optimal solutions, which allows us to reformulate the problem as an mixed-integer linear optimization problem. We propose a constraint generation method to solve the problem given the large number of potential scenarios. We analyze the tractability of sub-problems, which depend on whether the information of (allowed) paths are given or not. Finally, we demonstrate the approach with several numerical experiments and analyze the performance of the robust optimization formulation given the distributional ambiguity.

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Batched bin packing

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Standard or classic bin packing is the problem of partitioning a set of items of rational sizes in (0,1] into subsets or bins of total sizes at most 1. In the offline scenario, items are all presented at once, as a set. In the online scenario, items are presented and packed one by one, without any knowledge on any properties of future items. Batched bin packing is an intermediate version which has features of both the online problem and the offline scenarios. In this problem, items are presented in k batches, for a fixed integer $k \geq 1$, such that the items of a batch are presented as a set, and must be packed before the items of the next batch are presented. The case $k = 1$ is the offline variant. There are two models for any fixed $k \geq 2$. In the disjunctive model [1], the algorithm must use separate bins for the different batches. In the augmenting model [2], the algorithm may use existing bins, where items were already packed in previous batches, as well as new bins. Obviously, any algorithm for the disjunctive model can be seen as an algorithm for the augmenting model, with the same performance.

In this work, we analyze the asymptotic approximation ratio and the absolute asymptotic approximation ratio for the disjunctive model completely, and show tight bounds for them as a function of k. The asymptotic approximation ratio tends to approximately 1.69103, while the tight absolute approximation ratio is exactly k. Moreover, our results provide an improved upper bound on the asymptotic approximation ratio for the augmenting model with two batches. This last algorithm has an asymptotic approximation ratio of 1.5, improving over the algorithm of Dósa [1]. For the analysis, we will define subsets of items called *combined items*, and use them for the analysis of an optimal solution rather than dealing with the actual items. Moreover, we analyze a particular offline algorithm for the combined items, rather than analyzing an optimal solution. We also show that the absolute approximation ratios for the augmenting model with two and at least three batches are $\frac{3}{2}$ and $\frac{5}{3}$, respectively.

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The inverse p-maxian problems

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Let $G = (V, E)$ be a graph with vertex set V and edge set E. A location problem in which all vertices are associated with negative weights is called the obnoxious facility location problem. Two different types of objective functions for the obnoxious p-median problems can be investigated: the sum of the minimum weighted distances from X in G with $X = p$ to all vertices and the sum of the weighted minimum distances [1] which are known as (P_1)-version and (P_2)-version, respectively. In [2], first, two new concepts on the graph G have been defined: the dominating pair (the dominating path) and the graph diameter, with respect to every vertex. Then, the conditions for the graph G which have the dominating pair have been derived. Regarding the mentioned new concepts, it has been demonstrated that the dominating pair of the graph G is an optimal solution of the p-maxian problem (p great or equal 2) on the graph G regarding the (P_1)-version. This leads to an optimal criterion which can be utilized in the inverse p-maxian problem considering the (P_1)-version. The inverse optimization problem consists of changing parameters of the problem at minimum cost such that a prespecified solution becomes optimal. In this study the efficient algorithms for the inverse p-maxian problems will be developed with respect to the (P_1)-version.

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Some bin-packing problems in telecommunication networks

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The bin-packing problem is a well known strongly NP-hard combinatorial optimization problem. Many exact resolution approaches [1] and approximation scheme [2] have been proposed for this extensivelly studied problem. The problem consists in finding a way to pack n objects, each object i of size $a_i > 0$, into a minimum number of bins, each bin of capacity $C > 0$. This problem has many applications, in its standard form, or in one of its many variants [3].

As expected, the bin-packing problem is very generic and it appears in many applications. In telecommunications, the design of networks often implies to install equipments in some location, or functionalities in servers, and since capacities are often limited, there is always a packing question somewhere. There is a recent paradigm shift in telecommunications stating that most of the operations that were originally running on specific vendor equipments are going to be virtualized so that they could be running on any standardized server. As a result, many traditional network functions will have to be deployed in a virtual fashion. But since Virtual Machines (VMs) have ultimatelly to run on concrete HardWares (HW), optimal choices will heavilly depend on the solution of packing problems.

In some cases, fractions of item can be packed in the various bins. This problem is often refered to as *bin-packing with item fragmentation* [4]. The problem is NP-hard when costs are associated to the fragmentation of objects. We propose another variant where load balancing constraints are introduced. More precisely, the capacity of each bin must be equally shared among the items to which it is assigned. We propose MIP formulations for some of these telecom specific bin-packing problems and report preliminary computational results.

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Primal Heuristics and Dual Bounds for 0-1 Quadratic Optimization Problems with Linear Constraints

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joint work with Aykut Ahlatcioglu and Jongwoo Park

This talk will present generic approaches specially designed for 0-1 quadratic optimization problems with linear constraints. We will first describe the Convex Hull Heuristic, or CHH, which can be used to generate quickly good feasible solutions. We compare the results for the crossdock door assignment problem (CDAP) with two versions of a specific local search heuristic. Early results were presented in [1]. We present newer results for much larger instances and show that the solutions obtained by both types of heuristics are roughly of the same quality. The largest instances have up to 6,000 0-1 variables, and for these larger instances, CHH is definitely faster. We also present results for the quadratic 0-1 knapsack problem.
The second part of the talk concentrates on obtaining quickly strong bounds on the optimum. We show how to construct a level 1 RLT-type model [2] that lends itself to a strong, decomposable Lagrangean relaxation. The linear subproblems in that relaxation are no larger than the original model and can be solved in integers [3]. We present results with the same extended dataset from [1], of the same quality as RLT2 bounds with much reduced computation times.

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Application of Quantum Modelling based Combinatorial Bilevel Optimization in Urban Road Transport Problem

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Bilevel Programming is being used widely in Stackelberg game modelling when there is a hierarchical interactive decision making between two independent decision makers. Depending on who is taking the decision prior and later, the players are termed as the leader and the follower respectively. Solving general bilevel programming requires brunch and bound algorithm to solve the single level mixed integer programming that is formed after converting the follower problem to its equivalent constraints sets for the leader problem. In addition, if the decision variables are discrete or binary in nature, the combinatorial optimization technique has to be used. Further, if the decision variables take some discrete or binary values with some probabilities, the solution method calls for the stochastic modelling techniques. Quantum mechanics based stochastic modelling are popular and there is the wide scope of combining quantum modelling with combinatorial optimization. In this paper, we have developed and explained the methodology for solving a bilevel programming model of combinatorial nature using a quantum mechanics inspired genetic algorithm. The algorithm is used to solve a typical logistics problem in India, where the government takes entry fee to enter urban areas from commercial vehicles and charges heavy penalty if the drivers enter urban areas during prohibited time windows (when there is a heavy traffic flow). The goods carrying vehicles do not generally enter urban areas during prohibited time windows, but are sometimes compelled to enter under demand fulfillment terms and conditions. When there is high demand at the distributor's or retailer's end and the demand has to be fulfilled within a fixed deadline, the manufacturer has two options: either (i) to increase the number of vehicles or (ii) to increase the frequencies of delivery. Due to cost constraints, the first option is not always a viable option, but, the manufacturer often opts for the second option to maintain intended service level and in the process delivers during prohibited time windows. The problem of the manufacturer is to decide whether to go for penalization and deliver or drop service levels. If it chooses to deliver, then how many times in a delivery cycle it must give penalties so that it can maintain its service level and do not face lost sales (and lose a customer in a long run). The problem of the government is to charge penalty adequate enough that commercial vehicles do not enter urban areas during prohibited time windows because of higher delivery cost, high enough for preferring lost sales against flouting regulatory provisions by the manufacturer.

A local search approximation algorithm for the uniform capacitated k-means problem

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joint work with Dachuan Xu, Donglei Du and Dongmei Zhang

In this paper, we consider the uniform capacitated k-means problem (UC-k-means), an extension of the classical k-means problem in machine learning. In the UC-k-means, we are given a set of n points $\mathcal{D}$ in a d-dimensional space and an integer k. Each point in the d-dimensional space has an uniform capacity which is an upper bound of the number of points in $\mathcal{D}$ that can be served by this point. Our goal is to find at most k points in the space as centers to serve all the points in $\mathcal{D}$ without violating the capacity constraint, such that the sum of the squared distance of each point in $\mathcal{D}$ to its nearest center is minimized. Our main contribution is to propose a local search bi-criteria approximation algorithm for the UC-k-means, which violates the cardinality constraint.

An IP-based algorithm for the metric dimension problem in hypercubes

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We have all experimented recommender systems on the web, whether it is for choosing a movie, a book, a restaurant, or a holiday destination. Roughly speaking, a recommender system is a platform that seeks to predict the rating or preference that a user would give to an item.

More formally, consider a set I of items and a set A of Boolean attributes. A Boolean vector $\boldsymbol{x}_i$ with $|A|$ components can be associated with every item $i \in I$ so that the j-th component of $\boldsymbol{x}_i$ equals 1 if and only if the j-th attribute in A is true for item i. For example, if I is a set of restaurants and the first attribute is "vegetarian", then the first component of vector $\boldsymbol{x}_i$ associated with restaurant $i \in I$ equals 1 if and only if i is a restaurant offering vegetarian food.

Consider now a set U of users. A Boolean vector $\boldsymbol{y}_u$ with $|A|$ components can be associated with every user $u \in U$ so that the j-th component of $\boldsymbol{y}_u$ equals 1 if and only if user u has interest for the j-th attribute. In our example, the first component of vector $\boldsymbol{y}_u$ associated with user $u \in U$ equals 1 if and only if u has interest for vegetarian restaurants. While these vectors $\boldsymbol{y}_u$ are not known, we show how resolving sets can predict them, which makes it to possible to recommend to user u all items i with a vector $\boldsymbol{x}_i$ closest to $\boldsymbol{y}_u$.

We say that a vector $\boldsymbol{a}$ resolves two vectors $\boldsymbol{b}$ and $\boldsymbol{c}$ if the Hamming distance between $\boldsymbol{a}$ and $\boldsymbol{b}$ is different from that between $\boldsymbol{a}$ and $\boldsymbol{c}$. A subset I' of items is a *resolving set* if every two distinct vectors $\boldsymbol{y}_u$ and $\boldsymbol{y}_{u'}$ are resolved by at least one vector $\boldsymbol{x}_i$ with $i \in I'$.

Given a resolving set $I' = \{i_1, \ldots, i_r\}$ with r items, we can associate a vector $\boldsymbol{z}_u$ with r integer components to every user u so that the k-th component of $\boldsymbol{z}_u$ is the Hamming distance between $\boldsymbol{x}_{i_k}$ and $\boldsymbol{y}_u$. As a consequence, given two users u and u', $\boldsymbol{z}_u \neq \boldsymbol{z}_{u'}$ if and only if $\boldsymbol{y}_u \neq \boldsymbol{y}_{u'}$. In other words, it is possible to differentiate between two users with distinct preferences on the basis of their distances to the vectors $\boldsymbol{x}_i$ with $i \in I'$.

We show in this talk that it is easy to determine resolving sets of small size. For example, for 20 attributes (which allows the classification of the items in more than one million categories), resolving sets with 12 items can be determined. In other words, it is sufficient to determine the 12 components of $\boldsymbol{z}_u$ for every user u to predict the preference vector $\boldsymbol{y}_u$ of user u for more than one million item types.

Sport League Scheduling

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Most sport events where several opponents play against each other are organized in a schedule which defines when and which opponent plays against another. A *(sport) match schedule* is the allocation of matches between teams, groups or persons during the match days (rounds) of a tournament. In a round-robin tournament, each team plays a number k of games against every other team. The match days (or the match slot) correspond to the so-called rounds, in which every team plays (or – in the event that an odd number of teams is participating – one team sits out). A tournament with n teams (or opponents), in which every team plays exactly once against every other team ($k = 1$), thus consists of $n - 1$ rounds, so that every team plays against a different opponent in every round. In each match, one team plays at its respective home stadium. For that team, this is called a home game, while for the opposing team it is an away game. This sort of tournament – especially when it involves every team playing exactly twice against every other team – is quite common in sports such as soccer, ice hockey, basketball, handball, and others.
Besides of generating a feasible schedule, many additional requirements for a good and acceptable schedule must often be fulfilled:

- Security (not too many matches in a region at the same time),
- Fairness (each team should have the chance of a well-balanced home-away schedule),
- Fan attractiveness (important matches at home),
- TV station commitments,
- Club requests (stadium occupation, home game wishes), and others.

Finding a feasible and good schedules with such additional requirements becomes a challenging combinatorial problem. In this talk, an OR approach using integer programming is proposed. This approach of a mathematical model is especially appealing because various requirements can be switched on or off just by activating/unactivating various constraints. Conflicting requirements can easily be modeled by a carefully elaborated goal programming. An end-user high-level GUI has been built on top of the model such that sport league user can use the software without consulting OR experts.
The application and the same basic model has been applied to and is in use at several European National sport leagues with varying requirements.

Scheduling Monotone Moldable Jobs in Linear Time

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joint work with Felix Land

We study the following scheduling problem: We are given a set $\mathcal{J}$ consisting of n jobs and a number m of processors. The processing time $t_j(1)$ on one processor is given for eaxh job, as well as the speedup $s_j(k)$ that is achieved when executing it on $k > 1$ processors. The processing time on k processors then is given as $t_j(k) = \frac{t_j(1)}{s_j(k)}$. The goal is to produce a schedule that assigns for each job a starting time and a number of allotted processors such that the makespan, i.e. the completion time of the last job, is minimized. Without restriction, we assume that the speedup is non-decreasing, or equivalently, the processing time is non-increasing in the number of processors. A job is called monotone if its work function $w_j(k) = k \times t_j(k)$ is non-decreasing.

We improve the understanding of scheduling monotone moldable jobs in several ways. First we resolve the complexity of the considered problem. We prove that the decision problem whether a set of monotone jobs can be scheduled with a given makespan is strongly NP-hard. We proceed to describe an extremely efficient FPTAS for the case that the number m of machines is large enough. We present an FPTAS for the case that $m \geq 8n/\epsilon$ with a running time $O(n \log^2 m(\log m + \log 1/\epsilon))$. In combination with the PTAS by Jansen and Thöle, this yields a PTAS with compact encoding of processing times. Finally, we describe the $(3/2 + \epsilon)$-approximate algorithm due to Mounie, Rapine, and Trystram and improve its running time to $T(n, m, \epsilon)$, where $T(n, m, \epsilon)$ is linear in n and polynomial in $1/\epsilon$ and $\log m$.

Minmax Regret Maximal Covering Location Problems on Networks with Edge Demand

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joint work with Antonio Rodríguez-Chía

We discuss the minmax regret maximal covering location problem on a network where demand is continuously distributed along the edges. In the classical version of the maximal covering location problem, the goal is to locate a given number of facilities on the network so that the total amount of covered demand in the nodes is maximal. In the variant we discuss, demand is not concentrated in the nodes but distributed continuously along the edges of the network. Moreover, we assume that the exact demand is not known in advance. With respect to the latter, we consider two scenarios. In the first, demand is assumed to be constant along an edge, lying between a known upper ub and lower bound lb (that can be different for each edge), i.e., $lb \leq f_e(t) = const \leq ub$, $t \in [0, 1]$, where $f_e(\cdot)$ denotes the demand function on edge $e \in E$. In the second, demand is assumed to be linear along the edge, lying between two known linear functions $ub(t)$ and $lb(t)$, $t \in [0, 1]$, that define the upper and lower bound, respectively, of the demand on the edge, i.e., $lb(t) \leq f_e(t) \leq ub(t)$, $t \in [0, 1]$.

We focus on the single facility problem. For the deterministic MCLP with edge demands, Berman et al. [1] showed how to partition the network into subsets and find the exact optimum over each subset, to obtain the global optimum. Starting with the constant demand case, we first study the characteristics of the possible demand functions on an edge. Afterwards, we show how to extend the partition for the deterministic case to the minmax regret problem, allowing us to optimize the problem again over each subset separately. Following a similar approach, we then explain how to solve the problem with linear demand.

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A new analysis of Work Stealing with latency

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We study how to extend the analysis of the Work Stealing (WS) algorithm in a distributed-memory context, where communications matter. WS is a classical on-line scheduling algorithm proposed for shared-memory multi-cores [1].

Distributed-memory clusters consist in independent interconnected processing elements with private local memories. In such architectures, communication issues are crucial, they highly influence the performances [2]. There are only few works dealing with optimized allocations and the relationships between allocation and scheduling are most often ignored. In practice, the impact of scheduling may be huge since the whole execution can be highly affected by the latency of interconnection networks. The most commonly studied objective in scheduling is to minimize the makespan (max completion time $C_{\max}$) assuming centralized algorithms. This assumption is not always realistic, especially for distributed memory allocations and an on-line setting. WS is an efficient decentralized scheduling mechanism targeting medium range parallelism of multi-cores for fine-grain tasks. Its principle is that each processor manages its own (local) list of tasks. When a processor becomes idle, it randomly chooses another one and steals some work (if possible). The cost of stealing is negligible in shared memory but not in distributed memory. Its analysis is probabilistic since the algorithm itself is randomized. Today, the research on WS is driven by the question on how to extend the analysis for new computing platforms (distributed memory, large scale and heterogeneous).

WS has been studied originally by Blumofe and Leiserson [3]. They showed that the expected Makespan of a series-parallel precedence graph with $\mathcal{W}$ unit tasks on p processors is bounded by $E(C_{\max}) \leq \frac{\mathcal{W}}{p} + \mathcal{O}(D)$ where D is the length of the critical path of the graph (its depth). This analysis has been improved in Arora *et al.* [1] using potential functions. More recently, in [4], the authors provided the best bound: $\frac{\mathcal{W}}{p} + c.(\log_2 \mathcal{W}) + \Theta(1)$ where $c \approx 3.24$.

We study here how communication latency impacts work stealing. Based on a new realistic model for distributed-memory clusters of p identical processors including latency denoted by λ. We provide an upper bound of the expected makespan, which is composed of the usual lower bound on the best possible load-balancing $\frac{\mathcal{W}}{p}$ plus an additional term proportional to $\lambda \log_2(\frac{\mathcal{W}}{\lambda})$. We also provide simulation results to assess this bound, which show that the theoretical bound is roughly 4 times greater than the one observed in the experiments but that the additional term is $c\lambda \log_2(\frac{\mathcal{W}}{\lambda})$. The theoretical analysis shows that $c < 16.12$ while the simulation results suggest $c \approx 4$. The worst case analysis is based on an adequate potential function. The main reason that distinguishes this analysis in regard to the existing ones is that it determines the right function. Its property is that it should diminish after any steal related operation.

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Adapting efficient TSP exact algorithms for large orienteering problems

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The Orienteering Problem (OP) is a route optimization problem. Given a graph with profits on the nodes and weights on the edges, the goal of the problem is to find a simple cycle that maximizes the total collected profit subject to a total weight limitation. Our aim is to develop an exact algorithm, based on the Branch-and-Cut (B&C) methodology, for solving large-scaled OP.

Due to the successful application of B&C algorithms to Travelling Salesperson Problem (TSP) and its similarity to the OP, we will concentrate our efforts in developing an efficient adaptation for OP able to deal with large problems. Current B&C approaches for the OP [3], [4] are not competitive (in terms of computation time and/or solution quality) with heuristics algorithms for the instances with more than 400 nodes [5], [6], [7].

We base on the fact that the research carried out in the TSP has highlighted the importance of choosing a proper representation for the cuts in order to solve large problems [1]. The subtour elimination constraints and the additional cuts can be represented in at least two core representations: the outside form and the inside form. We refer to the outside form when all the edges taking part in the inequality are represented by incidence edges of subsets of vertices. We refer to the inside representation when all the edges are represented explicitly. We plan to present the formulation of the OP and the additional cuts in the outside form, in terms of hypergraph inequalities.

So far, in the exact approaches published for the OP [2], [3], [4] the outside representation has been used for the subtour inequalities whereas the inside representation has been used for all the cuts other than subtours. By reformulating the OP in terms of hypergraph inequalities, we expect to improve the pricing phase, reduce the storage requirement and speed up the LP solving phase in order to obtain a more competitive exact algorithm for the OP.

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Rankings subsets of a set from a single ranking of its elements

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Given a ranking of the elements of a set and given a disjoint partition of the same set, the ranking do not generally implies a total order of the partition. In this paper we introduce the Kendall-τ partition ranking, a linear order of the subsets of the partition which follows from the given ranking and which is related with the Linear Ordering Problem. We prove that the Kendall-τ partition ranking is robust in the sense that it remains the same when removing subsets of the partition. Then, we give several results concerning the adequacy of the ranking for ordering the partition and we prove that the linearity GAP of the 0-1 problem associated to the Kendall-τ partition ranking tends to $5/6$. Finally, an application with data in the Programme for International Student Assessment (PISA) is presented: countries are ordered from the ranking of its schools.

A unified framework for designing EPTAS's for load balancing on parallel machines

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We consider a general load balancing problem on parallel machines. Our machine environment in particular generalizes the standard models of identical machines, and the model of uniformly related machines, as well as machines with a constant number of types, and machines with activation costs. The objective functions that we consider contain in particular the makespan objective and the minimization of the ℓ_p-norm of the vector of loads of the machines both with possibly job rejection.
We consider this general model and design an efficient polynomial time approximation scheme (EPTAS) that applies for all its previously studied special cases. This EPTAS improves the current best approximation scheme for some of these cases where only a polynomial time approximation scheme (PTAS) was known into an EPTAS.

Theory of Constraints Replenishment Solution for Perishable Items Supply Chains

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This paper analyzes the performance of Theory of Constraints (TOC) frequent replenishment model for supply chains of deteriorating items. We consider a setting where a producer manufactures a variety of items and supplies them to retailers. These items are deteriorating in nature and have different lifetimes ranging from very low perishability to very high perishability. Two models are considered for the purpose of this paper:

Model 1 (Traditional Model): The retailer places orders with the producer and decides the ordering frequency as well as the target inventory levels for each of the items. The cost of transportation as well as the cost of disposal is borne by the retailer. Model 2 (TOC's Replenishment Model): The retailer does not decide the order quantities but instead the producer decides the ordering frequency as well as the target inventory levels of each of the items to be maintained at the retailers' end. The producer replenishes the stock of various items to bring their inventories back to the desired level. The cost of transportation as well as the cost of disposal is borne by the producer. The retailer is only charged by the producer for the items that are eventually sold.

We first develop an analytical model for a generic deteriorating item for a periodic review system where the time between two consecutive reviews is a random variable. The time required to produce and ship the item from the producer to the distributor is assumed to be negligible. Using the analytical model we obtain the expressions for expected shortage, wastage, holding, ordering and purchasing costs per unit time using a Markovian approach. The two models are then compared for different scenarios of ordering cost, wholesale price and retailer's cash constraint.

The results from the analytical model show that the TOC's replenishment solution will increase the profits of both the producer and the retailers in the supply chain. The producer of deteriorating items can increase its profits by more than 60

Combinatorial model of proteins and RNA

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Understanding details of machinery of human organism has been a great challenge for humanity. Alignment of structural models of proteins and RNA is one of the most important problems in bioinformatics. The tertiary structure of a biomolecule correlates with its function, but computationally derived 3D models often are characterized by serious deviations from the native structure. The comparison of particular model against other structures is the easiest way to confirm or reject obtained artificial prediction of 3D model. The structural alignment of a pair of biomolecules can be defined using the idea of descriptors. The descriptor is a local substructure of protein molecule. It allows us to minimize the original problem and propose a more efficient algorithmic solution. Known applications using descriptors concept prove its usefulness, but proposed approaches can be treated as trials to solve that problem from biological perspective. Here, new combinatorial model and new polynomial-time algorithms for the structural alignment of descriptors are presented. The model is based on the maximum-size assignment problem. Besides a simplification of the considered problem coming from the combinatorial modeling, high quality of obtained results has been obtained in terms of 3D alignment accuracy and processing efficiency. Proposed combinatorial model has proved to be relevant for the considered problem. Its processing time and the way of explorations the entire solution space give advantage for solving real problems. Presented approaches might be used for descriptor sizes belonging to different ranges and can be successfully applied in the process of protein and RNA 3D model quality assessment. Together with the proposed method, new libraries of protein descriptors are determined and applied during protein 3D structure modeling experiments.

Multi-instalment divisible loads scheduling on heterogeneous hierarchical memory systems for time and energy criteria

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In this presentation scheduling divisible loads on heterogeneous distributed systems with hierarchical memory is considered. Divisible loads are a scheduling and performance evaluation model of data-parallel computations. In the model it is assumed that a big volume of data, conventionally referred to as load, is distributed from a central server for processing on a set of remote computers. The load can be partitioned flexibly because grains of parallelism, i.e. units of data, are small compared to the total volume of work. Moreover, there are no data dependencies, so the parts of load can be processed in parallel independently of each other. Contemporary computer systems have hierarchical memory structures: At the top of the hierarchy CPU registers are the fastest but also the scarcest. Virtual, or external, memory at the bottom of the hierarchy is the slowest but has the greatest size. Here the hierarchy is divided into two parts: core memory (CPU registers, caches and RAM) and out-of-core memory (SSD, HDD, other forms of external memory). The limited size of core memory has great impact on the performance of computations both with respect to time and consumed energy. One of the consequences is that it is advantageous to process the load in many pieces of small size. This is called multi-installment load processing. The scheduling problem consists in choosing the set of machines participating in the computation, determining the sequence of communications with the machines and sizing the load chunks such that schedule length and consumed energy are minimum. A machine may receive more than one message with load to process. The machines are defined by communication rate, machine startup time and energy, energy consumed in the idle mode, piece-wise linear dependencies of computing time and energy on the size of the assigned load. This is a bicriteria optimization problem. A mixed integer linear program and a set of fast greedy heuristics are proposed to solve this problem. Their performance is compared in a set of computational experiments with respect to energy vs makespan, and solution quality vs algorithm runtime trade-offs.

Polynomial subcases of the home health care routing and scheduling problem with fixed services

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In home services agencies, planners are in charge of scheduling and routing caregivers to clients' homes to provide services. This problem is called the Home Health Care Routing and Scheduling Problem [1] and it is usually treated as a variant of a VRP with specific constraints such as time windows, legal regulations or skill requirements. Obviously, this problem is NP-hard so most papers address it with matheuristics [2] or other optimization methods such as branch-price-and-cut algorithms [3].
We will focus on two polynomial subcases of the HHCRSP, and use tools from graph theory to solve them. We study a specific case inspired by a real case [4] where the starting times and ending times of the services are fixed. We simplify the problem by considering that all caregivers start from the same depot, without any working time regulation or skill requirement. Our goal is to minimize the number of caregivers needed to provide all the services.
In our first subcase, we consider that traveling times are included in the duration of the task, as it is often the case for home services in France, especially in urban areas. Let's consider the interval graph $G(V, E)$ of the problem, where the vertices represent the services, and the edges join overlapping services. Any independant set is an admissible tour for a careworker so we are looking for a minimum independent set partition. Since interval graphs are chordal, we can find a perfect elimination ordering of V in polynomial time. By applying a greedy coloring algorithm to this ordering we obtain a perfect coloring of the graph, that is to say a solution with the optimal number of careworkers.
For the second problem, traveling times are not included in the tasks anymore, and we make the assumption that they follow the triangle inequality. We consider the complementary of the interval graph which is a comparability graph, and we delete the edges between incompatible services in regards with traveling times. We can find a transitive orientation of this new graph in linear time. Then, Dilworth's chain decomposition theorem gives us the width of the set of vertices, i.e the minimum number of caregivers needed to perform all the services. We transform the graph into a circulation network by adding a source and a sink, lower bounds on vertices, weights and upper bounds on some arcs. Then, we can solve a minimum-cost circulation problem with the strongly polynomial Tardos' algorithm and we get the solution which requires the minimum number of careworkers, and which minimizes traveling times in a second part.
This method can lead to unbalanced tours between caregivers, so it would be interesting to take into account constraints related to work regulation in future work.

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Computational Modeling and Analysis of G-quadruplex Structures

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G-quadruplexes are non-canonical structural formations that exist in guanosine-rich DNA, RNA and even in nucleic acids analogs [1]. The G-quadruplex form may be built by one, two or four strands and their orientation determine the polarity of the G-quadruplex structure – parallel, antiparallel, and hybrid-type antiparallel [2]. Due to a specific structure, G-quadruplex is involved in various biological processes, such as mRNA processing, regulation, and transcription, which may be influenced by recruiting protein factors. Moreover, G-quadruplexes are promising targets in many strategies of drug development, including anticancer and neurological disease therapies[2]. In our research, we have analyzed G-quadruplex structures in human microRNAs (small non-coding molecules) and we proposed a new computational way to visualize their secondary structure. We searched through miRBase database[3] for human miRNA sequences rich in guanosines (more than 8G per sequence), and among the chosen ones, we defined possible G-quadruplex motifs. For the first time, we have used RNAComposer[4] with new functionality to model the 3D structures of example G-quadruplexes in silico. From PDB database[5] we obtained structures recognized as the ones containing G-quadruplexes. We analysed these structures and defined their strands orientation in G-quadruplexes by using RNApdbee[6]. Based on the chosen PDB structures as templates, we were able to create miRNA models which consist of G-quadruplex formations.

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Distribution-free Customer Demand Prediction

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We aim to predict customer demand in a distribution-free setting. Potential predictors of demand are derived from a set of expert recommendations on the optimal order quantity. We exploit the formal theory of *prediction and learning with expert advice*. The outcome are two data-driven learning algorithms that adaptively converge towards the optimal a-posteriori solution in reasonable time. Under the assumption that the greatest possible initial information are historical upper and lower demand bounds, our approach applies for observable as well as unobservable lost sales. We experimentally explore the decision making of our algorithms across different unknown distribution types. Results are encouraging: the deviation from the a-posteriori optimum profit is at most 10%. We believe that the implemented expert learning techniques contribute to a better decision making in supply chain management under uncertainty.

The Non-Linear Generalized Assignment Problem

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joint work with Claudia D'Ambrosio and Silvano Martello

Given a set of n items, each with positive profit and weight, and a container (knapsack) with a given capacity, the Knapsack Problem (KP) requires to select a subset of items so that the total weight of the selected items does not exceed the capacity and the total profit of the selected items is a maximum. One of the most studied generalizations of the KP is the Generalized Assignment Problem (GAP). In this problem, there are m heterogeneous knapsacks available for packing the items, and the profit and weight associated with the packing of a certain item j into a certain knapsack i depend on both i and j. While the KP is weakly NP-hard and can be solved efficiently in practice, the GAP is strongly NP-hard and turns out to be extremely challenging from a computational viewpoint.

We consider a version of the GAP in which the items can be fractionated among knapsacks, and profits and weights are described by general non-linear functions. The resulting Non-Linear Generalized Assignment Problem (NLGAP) is a continuous optimization problem in which nonlinearities appear both in the objective function and in (some of) the constraints.

We present a mathematical formulation of the problem and use it to derive possible relaxations, thus producing upper bounds on the optimal solution value. We also introduce approximate algorithms and local search procedures that are used to compute high-quality heuristic solutions.

We report on preliminary computational experiments on a large set of randomly generated instances to compare the proposed algorithms with state-of-the-art solvers for nonlinear programming.

Minmax Scheduling and Due-Window Assignment with Position-Dependent Processing Times and Job Rejection

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We study a single machine scheduling and due-window assignment problem. The objective function is of a minmax type, i.e., the goal is to minimize the largest cost among all scheduled jobs. We assume position-dependent job processing times in the most general way. A polynomial time solution procedure is introduced. We further allow job rejection, where the scheduler may decide not to process certain jobs, which are penalized accordingly. For this setting, a polynomial time solution is presented, provided that the processing times deteriorate, i.e., the (generally position-dependent) processing times are non-decreasing functions of the job position.

The Impact of the Trust Factor on Online Shopping Decisions

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The Internet started and has already continued to grow rapidly for few decades. Great amount of online information, knowledge, commerce, entertainment and social networking stimulate the expansion. One of the most important and popular activity ones is electronic commerce (e-commerce), which has become a part of modern society.
When it comes to the online trading - as for the sellers they can offer products to wider audience. However, this possibility gives some advantages for sellers, nonetheless, it can be unfavorable for customers. Customers can become overwhelmed with a huge number of the new shopping possibilities that makes it very difficult to make the best choice. The optimization problem of multi-item online shopping was modeled as the Internet Shopping Optimization Problem [1],[2],[3]. It answers the question what shops should we pick to pay the lowest possible bill for all our shopping (many products at a time) including shipping costs, discounts and other important factors.
What is interesting, clients usually prefer to sacrifice better deals (lower prices) to buy more expensive product, offered by a known and trusted store with a higher rate of repurchase and better prestige among other consumers. Taking this into account it will be interesting to present a new, enhanced model of the Internet Shopping Optimization Problem to include a metric for each store that represents its trust value. The new model should present to the customer a set of solutions based on the reputability of stores.
Price is still one of the most important factors, however, we are sure that trust, reputation and the voice of customers are the most crucial and influence on clients' decisions. Consumers accept to pay more (10-30%) for products from well-rated sellers with good overall reputation factor (it can be complex and build from many different components).
During the research, a survey was conducted. Results showed that in most cases users prefer stores that are based on solid security features on payment methods, the consistency of products quality (based on clients ratings), wide delivery options. Naturally the final price is the key factor, however previously mentioned ones have a lot of influence on the final decision of shop selection.
For the full problem description, mathematical models, definitions, algorithms and survey details please follow the publication by Musial and Lopez-Loces [4].

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On the skeleton of the polytope of pyramidal tours with step-backs

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The traveling salesperson problem is the problem of finding the optimal tour $\tau = (i_1, i_2, \ldots, i_n)$ which traverses every vertex exactly once, a Hamiltonian cycle, in the complete graph K_n. For a tour τ we denote by $\tau(i)$ the successor of a vertex i and by $\tau^{-1}(i)$ the predecessor of i. A vertex i, satisfying $\tau^{-1}(i) < i$ and $\tau(i) < i$, is called a peak. A tour τ is called a pyramidal tour if it has only one peak n. A step-back peak is the vertex i such that

$$\tau^{-1} < i,\ \tau(i) = i - 1 \text{ and } \tau^2(i) > i, \text{ or } \tau^{-2} > i,\ \tau^{-1}(i) = i - 1 \text{ and } \tau(i) < i.$$

A proper peak is a peak i which is not a step-back peak. A pyramidal tour with step-backs is a Hamiltonian cycle τ which has exactly one proper peak n. Pyramidal tours and pyramidal tours with step-backs have two nice properties: a minimum cost tour can be determined in $O(n^2)$ time by dynamic programming, and there exist certain combinatorial structures of distance matrices that guarantee the existence of a shortest tour that is pyramidal [2] or pyramidal with step-backs [3].
The skeleton of the polytope P, also known as 1-skeleton, is the graph whose vertex set is the vertex set of P and edge set is the set of 1-faces of P. We define the traveling salesperson polytope TSP(n), the pyramidal tours polytope PYR(n), and the polytope of pyramidal tours with step-backs PSB(n) as the convex hulls of characteristic vectors of all corresponding tours in the complete graph K_n.
We consider the adjacency relation and the diameter of the skeleton. It is known that the question whether two vertices of TSP(n) are nonadjacent is NP-complete [4], and the diameter of TSP(n) skeleton is bounded above by 4 [5]. At the same time, for the polytope PYR(n) the vertex adjacency can be verified in linear time $O(n)$, and the diameter equals 2 [1]. We describe the necessary and sufficient condition for the adjacency of vertices in PSB(n) skeleton. Based on that, we establish the following properties:

Theorem The vertex adjacency in PSB(n) skeleton can be verified in linear time $O(n)$. The diameter of PSB(n) skeleton is bounded above by 4.

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Market Basket Data Analysis for Grocery Store Layout Problem

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Store layout can play a key role in grocery stores since it influences the customers purchasing behavior and satisfaction. Market basket analysis is an important component of analytical system in retail organizations to determine the placement of goods, designing sales promotions for different segments of customers. Supermarkets use frequent itemset mining to understand the customers more clearly and make arrangements on the store layout. The most common algorithm is Apriori algorithm to generate the association rules however it has some important limitations when it comes to analyzing customer transactions. It does not take into account the purchase quantities and all items are viewed as having the same importance, utility of weight. For this reason another methodology high utility mining algorithm is proposed. This paper proposes a new layout for grocery stores by analyzing the customer transactions. Both methodologies are applied to the data to understand the association rules. Real data from Turkish grocery chain is provided to illustrate the methodology. Based on the findings of these rules, an alternative layout is proposed.

Optimal Control of Unmanned Aerial Vehicles on Time Scale Theory

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During recent decays, quadrotor helicopters have quickly become one of the most popular unmanned aerial vehicle (UAV) platform. Its popularity comes mainly from its simple construction when compared to the conventional helicopters. Also, its suitability for applications like surveillance and search and rescue can be mentioned as benefits of UAVs. Mechanically, a quadrotor UAV employs fixed pitch rotors so that its rotor speed can be adjusted to achieve control as opposed to mechanical control linkages used in conventional helicopters. We develop an optimal controller for quadrotor unmanned aerial vehicles (UAVs) on time scales. The UAVs are assumed to have desired positions and orientations and the proposed controller is used to bring the UAVs to the desired positions and orientations by minimizing a cost function on time scales. The proposed controller will be able to work for general time scales such as the discrete time intervals with time-varying sampling interval and the bounded graininess. This will provide several benefits such as computational cost reduction in real-time applications. The effectiveness of our optimal controller of quadrotor UAVs is demonstrated in a simulation, which validates our theoretical claims. We consider the following system:

$$\begin{cases} x^{\Delta\Delta}(t) = -\frac{u(t)\sin\theta(t)}{m} \\ y^{\Delta\Delta}(t) = \frac{u(t)\cos\theta(t)\sin\phi(t)}{m} \\ z^{\Delta\Delta}(t) = \frac{u(t)\cos\theta(t)\cos\phi(t)}{m} - g \\ \phi^{\Delta\Delta}(t) = u_\phi(t) \\ \theta^{\Delta\Delta}(t) = u_\theta(t) \\ \psi^{\Delta\Delta}(t) = u_\psi(t), \end{cases} \tag{1}$$

where (x, y, z) are position coordinates, m is the total mass of the quadrotor, g is the gravity, (ϕ, θ, ψ) are orientations of UAV referred as roll, pitch and yaw, respectively, and u, u_ϕ, u_θ and u_ψ are described as controllers.

Single track railway scheduling problem

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Problem description

Australian Hunter Valley single track railway, used for transporting coal and iron ore from mains to the gulf, is the practical motivation for considering the train scheduling problem. The intermediate stations have the limited capacity which is defined as the maximum trains number which can wait at the station at a time. Only end stations has unlimited capacity. The travel time of the trains differs between the empty and fully loaded trains. The heavy load trains should dwell at the station longer than the empy ones. The maximum possible paths of the trains is scheduled during the time windows which is 24 hours. The continues scheduling is considered it means the schedule takes into account the trains from previous day.

Constraints

The main constraints in the model are as follows.

- trains cannot cross within a section
- Station capacity - the maximum number of trains at a station at any particular time
- Headway time (safety time) - it is the time (in minutes) which must elapse between subsequent trains leaving the same station in the same direction.
- Number of up paths need to be same as down paths.
- Dwell time - the time train needs to dwell (after stop), must do so for a minimum period (for example 5 min). This models the time, taken to stop and start as well as recharge the pneumatic brakes. The total maximum dwell time for the train path is defined. No dwell time for the terminal stations.

Objective

The objective is two fold find the maximum number of paths, and for that number of paths the minimum sum of delay across all trains. The number of paths is simply the number of Up (or Down) paths in the network. Given the number of paths, we need to generate a timetable (covering 24 hours) listing the arrival and departure times for all trains across the network. Solutions to railway scheduling problems can often be quite hard to achieve. Due to this, and the limitations of computational power in the past, many different problem formulations and solutions methods have been applied [1].

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Meta-Heuristics for Multi-Period Sales Districting Problem

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In the sales districting problem, we are given a set of customers and a set of sales representatives in some area. The customers are given as points distributed across the area and the sales representatives have to provide a service at the customers' locations to satisfy their requirements. The task is to allocate each customer to one sales representative. This partitions the set of customers into subsets, called districts. Each district is expected to have approximately equal workload and travelling time for each sales representative to promote fairness among them and the overall travelling distance should be minimal for economic reasons. However, the real travelling distance is often hard to calculate due to many complicating factors, e.g. time windows or unexpected situations like traffic jams, resulting in a loss of service. Therefore, one of the alternative ways is to approximate the travelling distance by considering geographical compactness instead.

We now extend this problem to be more realistic by considering that each customer requires recurring services with different visiting frequencies like every week or two weeks during the planning horizon. This problem is called *Multi-Period Sales Districting Problem*. In addition to determining the sales districts, we also want to get the weekly visiting schedule for the sales representative such that the weekly travelling distances are minimal and the workload and travelling time are balanced each week. Although the problem is very practical, it has been studied just recently.

In this talk, we focus on the scheduling problem for one sales representative in a specific district, which is already an NP-hard problem. We start by presenting a mixed integer linear programming formulation for the problem. As only small data sets can be solved optimally, we are currently developing a meta-heuristics to solve larger instances. We will present numerical experiments comparing both approaches.

Minimal graphs for hamiltonian extension

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Let $G = (V, E)$ be a simple loopless finite undirected graph. We say that G is hamiltonian extensible if for any non-edge uv then adding uv to E there exists a hamiltonian cycle F that contains uv. The problem we are interested is the following: Given a positive integer $n \geq 3$, the cardinality of the vertex set V, what is the minimum cardinality of E such that it exists $G = (V, E)$ which is hamiltonian extensible? We give extremal graphs.

Planning and Scheduling in Open-Pit Mining

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The profitability of an open-pit mining project is highly dependent on a plan that specifies what material is to be extracted and when this will occur. It is common practice to create a discrete version of the problem by partitioning the area to be mined into a set of blocks, where each block has an estimated monetary value if it is mined. The problem is to decide which blocks are to be mined in each time period of the planning horizon so that the net present value is maximized. There is a complex system of precedence constraints that restrict the order in which blocks are mined. Intuitively, a block cannot be mined until the blocks immediately above have already been extracted. More generally, safety considerations prevent the slope created by the remaining blocks in the mine from becoming too steep. As a further constraint, the amount of mining within any time period is limited by the speed at which blocks can be extracted and by the capacity of the plant that processes the blocks that are mined.

This talk reviews the literature on models and algorithms for scheduling the extraction of blocks in open-pit mining. Moreover, we describe our solution methods that have been developed for the Phase-X Mine Design Challenge that was run by Unearthed in collaboration with BHB Billiton in 2016: for the competition's outcome, see
https://unearthed.solutions/phase-x-delivers-novel-mine-design-algorithms-for-bhp-billiton/

Transmission Line Route Planning: Algorithm Design and Structural Properties of Underlying Networks

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Transmission line routing plays a crucial role in satisfying energy demands. Given two locations in a geographic region and terrain characteristics, the problem consists in finding a path connecting both locations such that the cost of constructing a transmission line along that path is minimized. In its most general setting, the problem does not have a well-defined underlying graph due to the infinite possibilities for selecting tower locations. Another difficulty is related to the multiple components of the cost function such as (a) wires' costs, (b) towers' costs dependent on the terrain, the spans between consecutive towers and the angles between consecutive segments, and (c) environmental aspects.

A widely accepted approach is based on covering the region with a square or hexagonal grid and collecting cost-related data using Geographical Information System (GIS) methods. Each element of the grid (a square or a hexagon) is assigned a cumulative cost that reflects factors (a)-(c) and estimates the cost of the fragment of the transmission line passing the corresponding area. The grid gives rise to several network models for selecting the most promising corridor for the transmission line.

In this presentation we analyze different types of underlying networks, discuss their specific features and properties, and develop fast algorithms for finding minimum-cost paths for large-size networks. Algorithms are evaluated theoretically by an approximation analysis and empirically on two case studies formulated for North England and Scotland.

This research is carried out in collaboration with NM Group, a British network company that optimizes the performance of electricity networks.

Linear and quadratic reformulation techniques for nonlinear 0-1 optimization problems

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Nonlinear unconstrained optimization in binary variables is a very general class of problems that has many applications in classical operations research problems such as production planning or supply chain management, but also in engineering and computer science topics such as computer vision or machine learning [1], [2]. Nonlinear optimization problems are currently of great interest to the mathematical programming community; recent papers from different authors have focused on this type of problems and there exists a strong trend towards a better understanding of the nonlinear case. We consider methodological aspects of the resolution of nonlinear optimization problems in binary variables. More precisely we examine resolution techniques based on linear and quadratic reformulations of nonlinear problems by introducing artificial variables. This approach attempts to draw benefit from the extensive literature on integer linear and quadratic programming.

In the framework of linear reformulations, we defined a class of inequalities that improve a well-known linearization technique. The use of these inequalities leads to very good computational results for several classes of problems, especially for a class of instances inspired from the image restoration problem in computer vision, for which we obtain up to ten times faster computing times with respect to a commercial solver when using our inequalities [3].

Concerning quadratic reformulations, we focus on the question of using the smallest possible number of artificial variables. We present a quadratic reformulation that reduces the required number of artificial variables from linear to logarithmic for monomials with a positive coefficient, which is a very simple but fundamental class of functions [4]. Indeed, the definition of a quadratic reformulation for monomials with a positive coefficient together with a reformulation for negative monomials allows us to reformulate any multilinear optimization problem in binary variables. Moreover, we extend this result to more general classes of functions and we show that a logarithmic number of variables is the best we can hope for. Finally we present a computational study comparing several linear and quadratic reformulations.

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Non-linear Generalizations Algebraic Connectivity

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For a simple graph $G = (V, E)$ the algebraic connectivity $a(G)$ is defined as the second smallest eigenvalue of the Laplacian matrix L of G. The latter can be written as $L = R^\top R$ where $R \in \mathbb{R}^{E \times V}$ is a gradient matrix of G, that is an edge-vertex incidence matrix with exactly one -1 and one 1 in each row. The smallest eigenvalue of L is therefore 0 afforded by the all ones vector and $a(G) = 0$ if and only if G is disconnected. By the Rayleigh-Ritz theorem we have

$$a(G) = \min_{\substack{x \neq 0 \\ \mathbb{1}^\top x = 0}} \frac{x^\top L x}{x^\top x} = \min_{\substack{x \neq 0 \\ \mathbb{1}^\top x = 0}} \left(\frac{\|Rx\|_2}{\|x\|_2} \right)^2$$

and we generalize the notion of algebraic connectivity by replacing the 2-norms by arbitrary norms on $\|\cdot\|_E$ on $\mathbb{R}^E$ and $\|\cdot\|_V$ on $\mathbb{R}^V$ and adjusting the constraints. We define the Rayleigh quotient $\mathcal{R}_{\|\cdot\|_E, \|\cdot\|_V}(x)$ by

$$\mathcal{R}_{\|\cdot\|_E, \|\cdot\|_V}(x) := \frac{\|Rx\|_E}{\|x\|_V}.$$

and consider the generalized eigenvalue problem for $\mathcal{R}$ which asks for $\lambda \in \mathbb{R}$, $x \in \mathbb{R}^V \setminus \{0\}$ with

$$\partial \|R \cdot\|_E (x) \cap \lambda \partial \|\cdot\|_V (x) \neq \emptyset.$$

Here $\partial f(x)$ denotes the subdifferential of a convex function f at x. By the chain rule we have that $\partial \|R \cdot\|_E (x) = R^\top \partial \|\cdot\|_E (Rx)$. It follows that every subgradient s of $\|R \cdot\|$ satisfies $\mathbb{1}^\top s = 0$ and we are lead to define the generalized algebraic connectivity as

$$a_{\|\cdot\|_E, \|\cdot\|_V}(G) = \min_{\substack{x \neq 0 \\ 0 \in \mathbb{1}^\top \partial \|x\|_V}} \mathcal{R}_{\|\cdot\|_E, \|\cdot\|_V}(x).$$

It is non-zero if and only if G is connected. The case where both norms are a p-norm $p \geq 1$ has been studied in **??**, for $p = 1$ the generalized algebraic connectivity is the isoperimetric number of the graph. We discuss several cases where $\|\cdot\|_E = \|\cdot\|_p$ and $\|\cdot\|_V = \|\cdot\|_q$, with a focus on non-smooth cases. In particular the case $p = \infty$ and $q = 1$ could be interesting for finding small vertex separators in sparse graphs which separate parts of approximately equal size, as, for example, desired in divide and conquer schemes. Lastly, we address computational aspects.

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Job scheduling with simultaneous assignment of machines and multi-skilled workers: a mathematical model

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We consider a mathematical program for a job scheduling problem with simultaneous assignment of machines and personnel based on a real problem in a German potash mine. The primary task of mining companies is the extraction of mineral raw materials. For Potash mines, which are typically underground mines, the room-and-pillar mining method using the drilling and blasting technique is generally applied. This method of excavation is characterized by nine process steps: (1) scaling of the mine roof and side walls, (2) removing the scaled material, (3) bolting of the roof with anchors, (4) drilling large diameter boreholes, (5) removing the drilling dust, (6) drilling blast holes, (7) filling blast holes with explosive substances, (8) blasting, (9) transporting broken material to the tipple. Each process step (except process step (8)) has to be executed by a specific machine and an appropriate worker. A typical potash mine is divided into different mining districts, where each one contains several tipple areas. Each tipple area involves several underground locations, which are regarded as a sequence of blocks. In order to excavate one block all process steps must be executed at a working place. After processing all steps (1)-(9) for a block, a new working place is available, which can be operated afterwards. In this regard, a job has two characteristics, a location and a type. The location of a job indicates which working place should be processed and the type of a job is the process step that has to be executed for that working place. Moreover, an expected amount of crude material is attributed to each job so that, at the end of the work shift, we can figure out the amount of raw mineral that is excavated for each process step based on the type of the processed jobs. The processing time of jobs depends on the assigned devices and workforces, in particular, on the skill levels of the workforces for the devices. Apart from that, for the simultaneous assignment problem, driving times between two working places and the transfer time, if a worker changes his machine, have to be taken into account. Derived from a superordinate planning level as well as a constant comparison of planned and actual data of the excavated raw material, the quantity of material that must be achieved for each process step within one work shift is predetermined. The aim is to minimize the lower deviation from the prescribed amount of crude mineral, which is accumulated over all process steps. This means, if the prescribed target value is exceeded, we do not consider the difference in the objective function. In our problem, we deal with several kinds of restrictions. On the one hand, jobs have precedence relations regarding to their types. For example, at a working place, process step (3) is not allowed to be started before process step (2) is completed. On the other hand, no more than one job is allowed to be processed in an underground location at the same time. An important point is that a job does not need to be completely processed within one work shift. In this case, we will determine what percentage of the job is executed and calculate the excavated material accordingly by the end of the work shift. Furthermore, we have to consider that workforces make a 30-minute break within a two-hour interval. We formulated a mixed-integer linear program to solve our problem using a MIP solver. Preliminary results show that our formulation is suitable for practical problem instances.

A Decomposition Approach to Solve the Selective Graph Coloring Problem in Perfect Graphs

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Graph coloring is the problem of assigning minimum number of colors to vertices of a graph such that no two adjacent vertices receive the same color. Selective Graph Coloring Problem (SEL-COL) is a generalization of the standard graph coloring problem; given a graph with a partition of its vertex set into clusters, the objective is to choose exactly one vertex per cluster so that, among all possible selections, the number of colors necessary to color the vertices in the selection is minimum. SEL-COL is known to be NP-hard, and remains so in many special classes of graphs. In this study, we focus on a decomposition based exact solution framework for SEL-COL in perfect graphs, and also generalize it to solve the problem on graphs with no particular structure.

Our decomposition approach suggests to solve SEL-COL by dealing with the selection and coloring tasks separately, and in that regard, we concentrate on graph classes where the classical coloring problem can be solved efficiently. We test our method on graphs with various size and edge densities, present computational results for perfect graphs in general and some perfect graph families; in particular, permutation, generalized split and chordal graphs. For the three perfect graph families, we compare our results to those of a pure integer programming formulation and a state-of-the-art branch-and-price algorithm by Furini *et al.* [1]. Our computational experiments indicate that our decomposition approach significantly improves solution performance in low- and moderate-density instances compared to the branch-and-price algorithm, and in all cases compared to a pure integer programming formulation. The strength of our decomposition approach in the case of these three perfect graph classes comes from the fact that the coloring problem, or equivalently maximum clique problem as we are dealing with perfect graphs, is separately solved using polynomial-time combinatorial methods. However, since the number of cliques in a graph tend to increase in parallel to the increase in edge density, the performance of our decomposition approach shows some deterioration in dense graphs.

Classical coloring problem is known to be polynomially solvable in perfect graphs via semidefinite programming. For perfect graphs in its general form, we tested our algorithm by making use of semidefinite programming and another general maximum clique algorithm from literature [2] within our decomposition framework. Our computational experiments show that although semidefinite programming is a polynomial-time method in theory, it does not perform very well in practice. Together with the general maximum clique algorithm, however, the decomposition method outperforms the integer programming formulation in terms of the number of instances solved to optimality and average optimality gap.

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Scheduling to Minimize Total Completion Time under Position dependent and cumulative Rate-modifying Effects on a Single Machine

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Since the early 1990s, there has been a considerable interest in enhanced scheduling models in which the processing times of jobs are affected by their locations in a schedule. Mathematically, this is formalized in terms of various time-changing effects. Typically, we are given jobs of set $N = \{1, 2, \ldots, n\}$ to be processed on a single machine. Each job $j \in N$ is associated with its "*normal*" processing time p_j. It is convenient to think of normal processing times as the time required under normal processing conditions of the machine, which might change during the processing, thereby affecting the actual processing times. Time-changing effects are represented by explicit formulae for how the actual processing time of a job is affected. The two main types of so-called pure effects of interest here, can be informally classified as [6] : *positional* effects: the actual processing time of a job is a function of its normal processing time and the position it takes in a schedule; see a focused survey [5] and a discussion in [1]; *cumulative* effects: the actual processing time of a job depends on its normal processing time and a function of the normal processing times of previously scheduled jobs; see [2,3,4], where a similar effect is introduced.
In this paper we consider the single machine scheduling problem to minimize the sum of processing times of jobs. For the pure effects listed above, we provide conditions on the form of the time-changing effect which determines whether jobs are ordered according to a V-shaped criterion and shortest processing time criterion respectively.

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An ILP-based improvement method for the travelling salesman problem

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The *travelling salesman problem* (*TSP*) is one of the most prominent $\mathcal{NP}$-hard combinatorial optimization problems. Given a complete graph $G = (V, E)$ and non-negative distances d for every edge, the TSP asks for a shortest cycle through all vertices with respect to the distances d.
Exact algorithms are usually based on integer linear programming (ILP), often utilizing a branch-and-bound or branch-and-cut approach. Heuristically considered, besides classical construction heuristics as the nearest neighbour (NN) or farthest insertion (FI) and improvement methods like the famous k-opt or Lin-Kernighan (LK) procedures, also metaheuristics play a meaningful role. Recently, with the rise of commercial solvers, which is supported by the growing availability of more capable hardware, incomplete or partially exact linear optimization methods, so-called *matheuristics*, have been established. These models rely on ILPs and/or their relaxed versions, i.e. MILPs or (standard, real-valued) LPs. We propose such a matheuristic, an improvement procedure for the solving of the (symmetric) Euclidean TSP, where the vertices correspond to points in an Euclidean plane.
Similarly to *large neighbourhood search* methods, our *magnifying glass matheuristic* (MGM) partially destroys an initial solution by removing sub-paths in a specific area, given by the current position of a "magnifying glass" in the graph, and then repairs it optimally by means of an ILP. This is iteratively repeated until all sections of the graph are examined, while usually improving (but never worsening) the overall tour at various places. This approach was recently successfully introduced for the so-called *quadratic travelling salesman problem* (QTSP) in [1].
Using base solutions from NN and FI, variants of MGM were tested on randomly generated instances based on uniformly distributed points in the Euclidean plane and on a set of DIMACS instances with sizes ranging up to several hundred thousand vertices. All results, put into relation to those of 2- and 3-opt heuristics and to LK, illustrate that MGM significantly outperforms the k-opt approaches in both the objective function values and the running times and that it constitutes a competitive variant to the more sophisticated procedures like LK.

Keywords. Travelling salesman problem; integer linear programming; matheuristic; improvement heuristic

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Clustered Spanning Tree - Conditions for Feasibility

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Let $H =< G, \mathcal{S} >$ be a hypergraph, where $G = (V, E)$ is a complete undirected graph and $\mathcal{S}$ is a set of clusters $S_i \subseteq V$, which may intersect. The optimum Clustered Spanning Tree (CST) problem is to find whether there exists a spanning tree of G such that each cluster induces a subtree. The main result in this paper presents an algorithm which requires $O(|V|^2|\mathcal{S}|)$ time complexity. In the first stage of the algorithm a weighted graph is constructed, where the weight of each edge in the graph is equal to the number of clusters containing this edge. Next, we find a maximum spanning tree for this graph. A feasible solution for the CST problem exists if and only if the weight of this tree is $(\sum_{S_i \in \mathcal{S}} |S_i|) - |\mathcal{S}|$. When equality holds, the maximum spanning tree offers a feasible solution. The other techniques presented in this paper consider the structure of the intersection graph of H. First, we prove that when H has a solution tree T^H, then induced subtrees of T^H are solution trees for the corresponding induced sub problems. This also proves that when an induced hypergraph does not have a solution tree, neither does H. For the special case where every vertex in V is contained in at most 2 clusters from $\mathcal{S}$, the CST problem has a feasible solution if and only if the corresponding intersection graph is a tree. When the intersection graph contains a cut-edge, we prove that deciding whether a feasible solution exists can be based on the decision made for each part of the intersection graph independently. The feasible solution tree for the given hypergraph, if one exists, is constructed using the feasible solution subtrees created for the corresponding subproblems.
In [1] it is shown that a hypergraph has a feasible solution tree if and only if it satis es the Helly property and its intersection graph is chordal. In [2] a polynomial algorithm, which constructs a tree where each cluster spans a path, is presented. The most restricted problem where both the tree and subtrees are required to be paths, is in fact the Consecutive Ones Problem, which Booth and Leuker [3] solved in linear time using PQ-trees. In [1] Korach and Stern found an optimum solution in $O(|V|^4|\mathcal{S}|^2)$ time complexity for the optimization version of the CST problem.

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Late Work and Early Work Scheduling on Parallel Machines

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Scheduling problems with the late work criterion have been investigated for more than 30 years [1]. Late work is an objective function related to job completion times, penalizing parts of jobs executed after their due dates. It finds many practical applications, for example in control systems, manufacturing systems or agriculture. Research reported in the literature has been focused mainly on determining the complexity of particular scheduling models and designing exact as well as metaheuristic approaches [2].
Within the talk, results of recent studies on the parallel machine scheduling problem with a common due date are collected. The problem was proven to be binary NP-hard for two machines and unary NP-hard for at least three machines [3]. For the former case, the transformation from the partition problem and the pseudopolynomial time dynamic programming have been given. For the latter case, the transformation from the three-partition problem has been showed.
The further studies on the approximation algorithms resulted in disclosing interesting relationship between the late work criterion and the complementary early work criterion. The early work rewards parts of jobs executed before their due dates. For the early work maximization problem the approximation algorithm [3] and the approximation scheme [4] have been proposed, while the late work minimization problem is non-approximable.

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Two Column Generation based Heuristics for Optimal Toll Enforcement

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We present an interesting real-world application of a combinatorial optimization problem, namely an approach for an optimal toll enforcement. On German motorways and on several main roads all trucks weighting at least 7.5 tonnes must pay a distance based toll. The enforcement is partly conducted by mobile tours on the complete network. The tours are performed by approximately 250 *control teams* of one or two inspectors. Our challenge is to optimize the tours. In addition, feasible rosters of the inspectors need to be generated. We have called this integrated tour planning and duty rostering problem the *Toll Enforcement Problem (TEP)*.
The TEP is formulated by a standard multi-commodity flow model with some extensions in order to incorporate the control tours. It is based on a scheduling graph $G = (D, A)$. The set D corresponds to control tours that appear as duties for the inspectors. If two duties $u \in D$ and $v \in D$ can be performed successively by the same inspector we construct a duty sequence arc $(u, v) \in A$ in G. The flow model uses tour variables to indicate the choice of a tour and arc variables that define a flow of unit value for each inspector in G. The TEP was presented inter alia in [1] where an extensive description of the modeling power of the approach is given, including an analysis of the bi-criterion character of the TEP and computational results that analyze the complexity of real-world instances.
This talk presents two heuristics based on linear programming (LP) to solve the integrated problem. The first heuristic, called Price & Branch, is a column generation approach to solve the model's LP relaxation by pricing tour and roster arc variables. The reduced cost can easily be computed since all tours and duty sequence arcs are generated in advance. Then, we compute an integer feasible solution by restricting to all variables that were priced.
The second contribution is a coarse-to-fine approach. Its basic idea is to project variables to an aggregated variable space, which is much smaller and belongs to a coarse version of the original problem. We aim to spend as much algorithmic effort in the coarse model as possible and to only dive into more detail, i.e., in the fine model, if it turns out to be necessary. A similar approach was introduced to the Railway Rolling Stock Rotation Problem in [2]. In detail, the fine problem is solved by a column generation algorithm that operates mainly on the coarse level. It is an important property that the coarse reduced costs overestimate the (fine) reduced costs. In the first place, we only have to compute the reduced cost of the coarse variables. If these have a positive value then the reduced costs of the corresponding fine variables will be computed afterwards. This algorithm is again applied to the root node LP and afterwards the IP of the fine model is solved with the columns generated during the coarse-to-fine algorithm.
For both heuristic procedures we will show that feasible solutions with high quality can be computed even for very large industrial instances. A main focus will be on instances that can not be solved by an standard IP approach in acceptable time.

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RNA structure reparation with combinatorial algorithms

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joint work with Maciej Antczak and Tomasz Zok

With the growing interest in biological molecules, DNA, RNA and proteins, and their use in modern biomedicine, the number of computational methods to model and process molecular data is increasing rapidly. One of the trends developed over the past decades is the prediction of three-dimensional shapes of biomolecules and their detailed analysis. Computational algorithms that evolved within this course, complement or replace biochemical experiments whose purpose is to determine molecule structures and find their relationship to functions they play within the living organisms. Such in silico simulations are often computationally demanding. Therefore, heuristic algorithms are used or incomplete molecular models processed to provide the results of data processing in the reasonable time. The resulting 3D models of molecules are often fragmentary or defective and require post-prediction modeling to satisfy the users. Here, we present our solution to the problem of RNA 3D structure reparation. The method is based on our database of nucleotide conformations built using data extraction and clustering algorithms [1]. It applies graph-based model of conformation space that determines possible layouts of structure fragments. The final RNA 3D structures reveal significantly improved quality and no clashes caused by overlapping structure atoms.

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Probabilistic analysis of the Two-Constraint Binary Knapsack Problem

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In this presentation Two-Constraint Binary Knapsack Problem is considered:

$$
\begin{aligned}
&z_{OPT}(n) = \max \sum_{i=1}^{n} c_i \cdot x_i \\
&\text{subject to} \quad \sum_{i=1}^{n} a_{ji} \cdot x_i \leqslant b_j(n) \\
&\text{where } j = 1, 2, \;\; x_i = \; 0 \;\text{ or }\; 1, \; i = 1, \ldots, n.
\end{aligned}
$$

Two-Constraint Binary Knapsack Problem is well known to be $\mathcal{NP}$-hard in the strong sense combinatorial optimization problem and is the special case of the Multi-Constraint Knapsack Problem, where $j \geq 2$. Extensive literature is dedicated to the knapsack problems, cf. Martello and Toth. In the Szkatuła's papers, results of the asymptotical probabilistic analysis devoted to different cases of the binary multiconstraint knapsack problem were presented.

It is assumed that some of the problem coefficients (c_i and a_{ji}) are realizations of mutually independent uniformly distributed over $(0, 1]$ random variables. In the asymptotical case growth of a value of the optimal solution $z_{OPT}(n)$ may be influenced by the problem coefficients: n, c_i, $b_1(n), b_2(n)$, where $i = 1, \ldots, n$.

The aim of this presentation is to analyze the growth of the asymptotic, as $n \to \infty$, a value of $z_{OPT}(n)$ for the class of random Two-Constraint Binary Knapsack Problems and possibly full spectrum of the constraints right-hand-sides values $b_1(n)$ and $b_2(n)$. To achieve this aim distribution functions and expectations of the corresponding random variables and other probabilistic properties of the problem have been investigated. As the result, Lagrange multipliers, λ_1 and λ_2, have been established. Four cases have been identified:

1 The case of large values of the Lagrange multipliers, $1 \leq \lambda_2 \leq \lambda_1$,

2 case of mixed values of the Lagrange multipliers, $\lambda_2 \leq 1 \leq \lambda_1$,

3 case of moderate values of the Lagrange multipliers, $\lambda_2 \leq \lambda_1 \leq 1$, $\lambda_2 + \lambda_1 \geq 1$ and

4 case of small values of the Lagrange multipliers $\lambda_2 \leq \lambda_1 \leq 1$, $\lambda_2 + \lambda_1 \leq 1$.

Lagrange multipliers are enabling to analyze influence of the asymptotical, as $n \to \infty$, mutual relations of the problem right-hand-sides $b_1(n)$ and $b_2(n)$ on the growth of the optimal solution value $z_{OPT}(n)$. It is also possible to analyze other aspects of the random Two-Constraint Binary Knapsack Problems, e.g., activeness or passiveness of the constraints in the asymptotical case.

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On Inventory Control Policies within the Joint Inventory Location Problem: Modelling and Solution Approach

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In the last two decades, a great number of the Inventory Location Models have been developed and studied for addressing logistic and Supply Chain Network design problems. These models usually jointly consider strategic decisions regarding facility location and tactical decisions related to inventory control. This paper presents three Inventory Location Models and a solution approach for each of them. Each mathematical model incorporates different Inventory Control Policies, which are the well-known (s, Q), (R, s, S) and (S-1, S). These models belong to a Mixed Non-Linear Non-Convex Integer Programming. A solution approach based on Generalized Benders Decomposition to solve each model is proposed. The results of computational tests are shown for the three models. Optimal results were obtained for each of the instances in competitive times. A future research discussion in terms of modeling and the related solution approach is presented, mainly focusing on addressing specific real-world industrial features to make this class of models more suitable for real-world applications.

An assignment-based continuous-time MILP model of the resource-constrained project scheduling problem

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The resource-constrained project scheduling problem (RCPSP) consists in determining a vector of start times for a set of completion-start precedence-related project activities that require time and scarce resources for execution such that all precedence relationships are respected, the total required quantity of each resource never exceeds its prescribed capacity, and the total project duration is minimized. The RCPSP poses a challenging combinatorial optimization problem; in addition to many problem-specific solution approaches, various types of mixed-integer linear programming (MILP) models have been proposed, which now receive increased attention due to the improved performance of MILP solvers and computer hardware. In discrete-time models (cf., e.g., [2]), the planning horizon is divided into a set of equal-length time intervals, and activities can start only at the beginning of each of these intervals; by contrast, in CT models (cf., e.g., [1]), activities can start at any point in time over the planning horizon.
In this talk, we present a variant of a novel CT model for the RCPSP that has been proposed in [3]. To model the resource constraints, two types of binary variables are used: assignment variables specify which individual resource units are used for the execution of each activity, and sequencing variables specify the order in which pairs of activities that are assigned to the same resource unit are processed. Our computational results indicate that the model performs particularly well when resources are very scarce or when the range of activity processing times is high.

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An Exact Parallel Objective Space Decomposition Algorithm for Solving Multi-objective Integer Programming Problems

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The globally Pareto-optimal sets of multi-objective integer programming (MOIP) problems are non-convex, and they are finite if the feasible regions are bounded. Finding these sets is NP-hard for most MOIP problems and current methods are unable to scale with the number of objectives. In this study, we propose a deterministic exact parallel algorithm for solving MOIP problems with any number of objectives. The proposed algorithm generates the full Pareto set based on an intelligent iterative decomposition of the objective space utilizing a particular scalarization scheme. The algorithm relies on a set of rules that exploits regional dominance relations among the decomposed partitions for pruning. These expediting rules are used in a pre-solve step as well as throughout parallel running threads. Using an extensive test-bed of MOIP instances with three and four objectives, the performance of the proposed algorithm is evaluated and compared with three leading algorithms. Results of the experimental study demonstrate the effectiveness of the proposed algorithm and the advantage of its parallelism.

Optil.io: Crowdsourcing Platform for Solving Optimization Problems

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The term crowdsourcing was introduced, for the first time, in 2006 by Jeff Howe [1] to describe outsourcing work to a vast, usually unnamed network of people in the form of an open call. However, successful applications of the crowdsourcing are much older, including many web-based projects such as Wikipedia, reCaptcha, OpenStreetMap, and Mechanical Turk [2]; it even solved scientific problems such as the determination of a ship's longitude, dating back to the 18th century. Nowadays, many scientific problems are solved using crowdsourcing in the form of specialized computer games, so-called crowdsourced serious games [3]. Moreover, recently, many platforms supporting crowdsourcing have been implemented such as InnoCentive or CrowdAnalytix.

Optil.io [4,5] is a platform that also make use of crowdsourcing. However, it is dedicated to solving optimization problems. Challenges organized using Optil.io platform employ the continues evaluation following Evaluation as a Service (EaaS) architecture [6]. Participants have possibility to submit source code of solutions in many programming languages or in binary form. Then the solutions are automatically compiled and evaluated in the cloud. An important feature of the EaaS methodology is the possibility to evaluate submissions continuously, at any moment of time, whenever they are submitted. This aspect differs EaaS from the simple collection of solutions through Internet using some web form, such as Kaggle. During the presentation, we would like to present the results demonstrating how Optil.io platform can be used to solve optimization problems based on the variant of Orienteering Problem [7]. We have analyzed over 2000 solutions submitted during the challenge based on this problem, and we would like to share our findings how the collaboration and the competition of the crowd of researchers can help to find good solutions to complex problems. We also want to give bits of advice to all scientists who consider solving optimization problems using crowdsourced challenges.

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N-way junction modeling and analysis

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In the last decade, high scientific activity could be observed in the field of a development of computational algorithms for modeling and analysis of RNA three-dimensional structures. With these new methods, a gap between the number of known sequences and structures of RNA molecules is tried to be reduced. However, the prediction of 3D structures of biomolecules still needs a lot of improvement since its results are far from perfect. Existing prediction methods are successful in handling quite many structure elements, but some motifs are not yet modelled in the reliable way. N-way junction (with N>2) is an example of structure motif that is found hard to predict accurately by most computational algorithms. In our work, we have collected all n-way junction structures found in experimentally determined RNAs and we analyzed their features. The motifs were identified using own search algorithm operating on dot-bracket representations of the input structures. The junctions were gathered to create the new n-way junction repository. For each candidate, a digraph model was proposed to represent selected features of its secondary structure and values of Euler angles describing the direction of outcoming stems. We believe, this data can be used in the process of modeling of unknown RNA 3D structures and in the refinement of the existing ones.
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Robust Submodular Maximization over Sliding Window

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Maximizing the submodular monotone functions subject to cardinality k is a classical problem in the fields of data mining and machine learning. In this paper, we first study this problem in a streaming fashion by combining two additional twists of sliding window and robust concept, which is named as the robust submodular maximization over sliding window (RSMOSW). For this problem, we are asked to find a solution only from the last W elements, from which some elements may be removed. In this context, we provide a $0.0745 - \epsilon$ approximation algorithm for any $\epsilon > 0$. In addition, the memory space and the update-time per element of our algorithm both are proved to be bounded by $O(poly(k, \tau, \log k\Phi))$, in which τ is the robust parameter, meaning that at most τ elements may be removed, and Φ is the ratio between the maximum and minimum values of singleton elements.

Broadcast domination in permutation graphs

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Broadcast domination models the idea of covering a network of cities by transmitters of varying powers while minimizing the total cost of the transmitters used to achieve full coverage. To be exact, let G be a connected graph of order at least two with vertex set $V(G)$ and edge set $E(G)$. Let $d(x,y)$, $e(v)$, and $diam(G)$, respectively, denote the length of a shortest $x-y$ path in G, the eccentricity of a vertex v in G, and the diameter of G. A function $f : V(G) \to \{0,1,\ldots,diam(G)\}$ is called a *broadcast* if $f(v) \leq e(v)$ for each $v \in V(G)$. A broadcast f is called a *dominating broadcast* of G if, for each vertex $u \in V(G)$, there exists a vertex $v \in V(G)$ such that $f(v) > 0$ and $d(u,v) \leq f(v)$. The *broadcast domination number*, $\gamma_b(G)$, of G is the minimum of $\sum_{v \in V(G)} f(v)$ over all dominating broadcasts f on G.

As an application of the well-known domination in communication networks, Liu [3] provided a broadcast model, where a dominating set represents cities with broadcast stations and its neighboring cities receive messages from the broadcast stations. Erwin [2] introduced *broadcast domination* that can be viewed as a generalization of Liu's model, where cities with broadcast stations have transmission power that enable them to broadcast messages to cities at distances greater than one (depending on the transmission power of broadcast stations).

For a given network, one naturally extends it to a larger network by considering two copies of the original network and a one-to-one correspondence between them; this may be represented as a permutation graph, which was introduced by Chartrand and Harary [1]. Let G_1 and G_2 be two disjoint copies of a graph G, and let $\sigma : V(G_1) \to V(G_2)$ be a bijection. Then a *permutation graph* $G_\sigma = (V,E)$ has the vertex set $V = V(G_1) \cup V(G_2)$ and the edge set $E = E(G_1) \cup E(G_2) \cup \{uv \mid v = \sigma(u)\}$.

For a connected graph G of order at least two, we prove the sharp bounds $2 \leq \gamma_b(G_\sigma) \leq 2\gamma_b(G)$; we give an example showing that there's no function h such that $\gamma_b(G) < h(\gamma_b(G_\sigma))$ for all pairs (G,σ). We characterize G_σ satisfying $\gamma_b(G_\sigma) = 2$, and examine $\gamma_b(G_\sigma)$ when G is a cycle, a path, or a complete multi-partite graph.

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A New Exact Algorithm for the Multidimensional Multiple-Choice Knapsack Problem

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The multidimensional multiple-choice knapsack problem (MMKP) is one of the most complex variants of the classical 0-1 knapsack problem. In this variant items with non-negative profits are partitioned into groups. Each item consumes a predefined non-negative amount of a set of resources with given availability. The problem looks for a subset of items, consisting of exactly one item for each group, that maximizes the overall profit without violating the resource constraints. We propose a new exact approach for the problem, called YACA (Yet Another Core Algorithm), inspired by an existing algorithm for the Multidimensional Knapsack (see [1]). YACA is characterized by two levels of search. In a *high level*, problem items are sorted following a predefined rule and *subproblems* are constructed by selecting subsets of items. The used sorting criterion aims at identifying the critical items and positioning them at the beginning. *Critical items* are the ones for which it is more difficult to decide if they belong or not to the optimal integer solution. Thanks to the sorting, these items are considered during the construction of the first subproblems. This guarantees that the optimal solutions of the first subproblems usually provide very good lower bounds that strongly help in solving the subsequent generated subproblems. At each iteration, a new subproblem of increased size is formulated and solved, possibly improving the current problem lower bound, until a stopping rule is satisfied, proving the optimality of the current incumbent integer solution. In a *low level*, each constructed subproblem is optimally solved through a recursive variable-fixing procedure that generates a search tree of *reduced subproblems* over each of which it is reapplied. Pruning conditions are introduced to prevent the procedure from exploring unnecessary branches of the search tree. When the size of a reduced subproblem decreases below a given threshold, it is exactly solved by using a MIP solver. The decision on how far to push the recursive fixing before calling the MIP solver is one of the most critical feature of the algorithm. The proposed exact approach is extremely versatile, since it can be easily converted to a heuristic method at no additional cost by simply fixing the number of subproblems to solve or by limiting the time devoted to tackle each subproblem. Moreover, the method has a general structure that makes it easily adaptable to exactly solve other binary or knapsack-like problems. Computational results over 37 complex benchmark instances from the literature show that our approach is able to close to optimality 8 out of the 35 open instances. YACA is extremely competitive with respect to the most recent state-of-the-art algorithms and with respect to Gurobi, that was able to close to optimality 5 instances different from the ones closed by YACA. In almost all the instances not solved to optimality, YACA has been able to improve the best known values, and what is more important its time to best is lower than the one of Gurobi in most cases.

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A 5-parameter complexity classification of the two-stage flow shop scheduling problem with job dependent storage requirements

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The talk presents NP-hardness results and polynomial-time algorithms for the two-stage flow shop scheduling problem with a buffer. In the majority of publications, the buffer only restricts the number of jobs that have completed the first operation and are waiting for the start of the next one. Much less is known about the more general model where different jobs have different buffer requirements. In particular, this model with the additional assumption that each job needs the buffer for the entire duration of its processing is important for multimedia systems, where data files share the same memory, [4] and for supply chains, where the change of the mode of transportation involves unloading and loading [1]. To the best of the authors' knowledge, only publications [2] and [3] studied the computational complexity of such scheduling problems.

The talk addresses this gap in the literature by presenting a classification that establishes the borderline between NP-hard and polynomially solvable cases of the makespan problem. According to this classification, all instances form families, each associated with a vector $\boldsymbol{\alpha} = (\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5)$. For $i \in \{1, 2\}$, $\alpha_i = 1$, if all processing times on machine i are the same. Otherwise, $\alpha_i = 0$. If $\alpha_3 = a$, the buffer requirement of each job is proportional to its processing time on the first machine. Otherwise, $\alpha_3 = 0$. The parameter $\alpha_4 \in \{=, \leq, \geq, \emptyset\}$ and specifies the relation between the processing times of each job on the first and second machine. Thus, $\leq$ indicates that, for each job, its processing on the first machine does not take more time than on the second. The parameter α_5 indicates whether or not any two jobs can occupy the buffer simultaneously.

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RNA Pseudoknot Analysis: A Graph-Coloring Approach

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RNAs are abundant molecules playing vital roles in cells of all living organisms. The way they function is highly related to the structure they fold *in vivo*. Fortunately, more and more experimentally solved RNA 3D structures are being steadily accumulated in public databases. The aggregated data is used in knowledge-based methods to construct libraries of common RNA shapes or structure prediction pipelines. This approach has been proven useful, however new difficulties arise with larger RNA structures. Especially when they contain less common but complex features such as pseudoknots. These are evolutionary conservative motifs found in several families of RNA molecules spanning multiple organisms. They have fundamental roles and therefore it is important to understand them better.

A structure of RNA in the most basic definition is a list of pairs (i, j), such that i-th and j-th nucleotide make a base pairing interaction. We say the pairs (i, j) and (i', j') are pseudoknotted if:

$$i < i' < j < j'$$

We also say that a sequence of pairs (i, j), $(i + 1, j - 1)$, ..., $(i + k, j - k)$ forms a region. This fact can be noted as a (i, j) region of size $k + 1$.

One can notice, that if pairs (i, j) and (i', j') are pseudoknotted, then regions containing these pairs are pseudoknotted as well. This relation can simultaneously be true for combination of regions (i, j), (i', j'), (i'', j''), and so on.

In [1] we proposed a feature called *pseudoknot order*. It is a value such that regions involved in a pseudoknot have it mutually different. At the same time, the sum of region sizes weighted by their pseudoknot order is to be minimized.

In [2] we designed, implemented and benchmarked several new algorithms assigning pseudoknot orders to regions. We have introduced them in RNApdbee 2.0 webserver [3] to analyze and visualize RNA 3D structures. However, there is still room for improvement as the scoring function is multi-objective and our exact algorithms worked on a single objective only.

The problem instance can be modeled as a graph. Let region (i, j) of size n be a vertex $v_{i,j}$ with weight $w(v_{i,j}) = n$. And let pseudoknot between regions (i, j) and (i', j') be an edge $e_{(i,j),(i',j')}$ between corresponding vertices. Any feasible vertex coloring of such graph is a solution to original problem provided that a mapping from colors to pseudoknot order values is given. However, this formulation is again single-objective only, because it ignores sizes of regions. We are currently working on an algorithm to color the graph taking into account weights of the vertices.

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