ECCO XXXII Conference 2019

Conference of the

European Chapter on Combinatorial Optimization

St. Julian's
Malta

30 May – 1 June 2019

Welcome Address

Merħba! We welcome you to **ECCO XXXII**, this year's Conference of the European Chapter on Combinatorial Optimization which is being held here in Malta for the very first time. The general aim of this series of conferences has remained the same throughout the years, namely to bring together researchers in the field of combinatorial optimization to present their work, share experiences, and discuss recent advances in theory and applications. We are confident that the interactions that will be fostered throughout these three days will continue to strengthen and build upon the sense of community that characterises this group of researchers.

This year's ECCO conference is bringing together approximately 90 researchers from over 25 countries. We have received almost 70 abstracts for talks which cover a whole spectrum of research areas on the theory of combinatorial optimization, algorithms, integer programming, graph theory, and applications of combinatorial optimization in areas including bio-informatics, logistics, energy production, manufacturing and tomography, amongst others. A special issue of the *Journal of Combinatorial Optimization* will be dedicated to ECCO 2019. The issue will be based on contributions presented at ECCO XXXII, but the invitation to submit will be extended to all ECCO members.

We would like to thank the ECCO Board, in particular the ECCO Coordinator Silvano Martello, for entrusting us with the organisation of the 32$^{\text{nd}}$ edition of the ECCO Conference. This Conference was also made possible through the support received from our sponsors, whom we thank wholeheartedly. We would also like to thank all those who have helped in some way or another to make this Conference possible.

Our final words of thanks go to all of you who are gathered here with us on our tiny Island, and we wish you an enjoyable and successful conference here in St. Julian's.

Peter Borg

John Baptist Gauci

Josef Lauri

Irene Sciriha

10 May 2019

Welcome from the ECCO Coordinator

It is a great pleasure to welcome you all to the 32nd Conference of the European Chapter on Combinatorial Optimization. This 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 plenary lectures delivered by outstanding invited speakers.

I want to take this opportunity to sincerely thank all those who supported the preparation of the event, and in particular to John Baptist Gauci, who chaired the Program and the Organizing Committees. I would also like to thank his colleagues of the Organizing Committee who have contributed to have an effective meeting. Malta is a beautiful island and a great location for our conference.

I hope you have a productive conference and you enjoy your visit to this Mediterranean gem.

Silvano Martello

Coordinator of ECCO

3 April 2019

Contents

Conference Information

ECCO XXXII Conference - 2019
30 May – 1 June 2019

Conference Venue:
Cavalieri Art Hotel, St. Julian's, Malta

Website:
`https://ecco2019.euro-online.org/`

e-mail address:
`ecco2019malta@outlook.com`

Invited speakers:

- ◇ Fred Glover – University of Colorado Boulder, United States,
  with Gary A. Kochenberger – University of Colorado Denver, United States
- ◇ Martin Charles Golumbic – University of Haifa, Israel
- ◇ Alexander S. Kulikov – St. Petersburg Department of Steklov Institute of Mathematics, Russia
- ◇ M. Grazia Speranza – Università degli Studi di Brescia, Italy

Social Programme

Registration

The Registration Desk will be open on **Wednesday 29 May** between **17:00 and 19:30** and on **Thursday 30 May** from **07:30 onwards** in the ***Olympia Syndicate*** on the 8th floor of the conference venue, the ***Cavalieri Art Hotel***.

Conference Photo and Welcome Reception

The Conference Photo will be taken on **Thursday 30 May** at **19:45**. We will meet in the ***Private Lido*** of the Cavalieri Art Hotel by the main pool.

The ECCO XXXII Welcome Reception will be held immediately after, between **20:00 and 23:00** in the **Babylon Terrace** (or in the **Babylon Suite** in case of inclement weather) on the 8th floor of the ***Cavalieri Art Hotel***. A variety of finger food, alcoholic and nonalcoholic beverages will be available for everyone's enjoyment.

Conference Excursion

The Conference Excursion will be on **Friday 31 May** in the afternoon, leaving at **12:30** from outside the Cavalieri Art Hotel.

We will visit the megalithic temple complex of **Ħaġar Qim**, located on the southern coast of Malta and standing on a hilltop overlooking the sea and the islet of Filfla. It dates back to the Ġgantija phase, approximately 3600-3200 BC, making it one of the most ancient religious sites in the world.

We will then make our way to the complex of **St. Paul's Catacombs** in Rabat, representing the earliest archaeological evidence of Christianity in Malta. These catacombs are part of a large cemetery, probably originating in the Phoenician-Punic period. We will finish at **Mdina**, the old capital city of Malta. Also known as 'Città Notabile' or the 'Silent City', it remained as the capital of Malta until the arrival of the Knights of the Order of St. John in 1530.

The group will have the service of a tourist guide for the whole duration of the excursion. The entrance tickets to the two main attractions are also included in the Conference Registration Fee.

Conference Dinner

On **Friday 31 May** starting at **20:00** there will be the Conference Barbecue. It will take place in the ***Private Lido*** of the Cavalieri Art Hotel by the main pool and surrounded by the Mediterranean Sea. In case of inclement weather this will be shifted to the **Ottocento Restaurant**.

Optional Excursions

Optional Excursion 1

Depending on the number of people still present and their interests, an optional excursion may be organised on **Saturday 1 June** to visit ***Valletta***, Malta's Capital City, a UNESCO world heritage site and the European Capital City of Culture in 2018. One can stroll around the streets of this Baroque city, enjoy the majestic view of the Grand Harbour from the Upper Barrakka Gardens, or visit the sites that attract thousands of tourists every year (including the Palace Armoury, the Palace State Rooms, the National Museum of Archaeology, and MUŻA, Malta's new museum of art and the flagship project for Valletta's European Capital City of Culture Title in 2018). We will leave from in front of the Cavalieri Art Hotel at **14:00** and be back at the Hotel at around **18:00**.

Optional Excursion 2

If there are enough people interested, another optional excursion may be organised to ***Tarxien*** to experience a traditional Maltese Festa. Every village in Malta celebrates at least one patron saint throughout the Maltese summer. **Saturday 1 June** is the eve of the Feast celebrated in Tarxien and dedicated to the Annunciation of Our Lady. It is an opportunity to visit the church which will be beautifully adorned with riches for this occasion, walk around the streets with the marching band playing joyous traditional Maltese marches, watch the bright fireworks illuminate the skies, and much more! We will leave from in front of the Cavalieri Art Hotel at **20:00** and return at the Hotel at around **01:00** (early Sunday morning).

The Programme

Overview

Registration: Wednesday 17:00–19:30 and Thursday 07:30 onwards

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Daily

Thursday 30 May 2019

08:30–09:00	Welcome *Venue:* Babylon Suite		
09:00–10:00	*Plenary Talk:* **Fred Glover** with **Gary A. Kochenberger** *Chair:* Silvano Martello *Venue:* Babylon Suite		
10:00–10:30	Coffee Break		
Venue: *Chair:*	*Babylon Suite* *M. Szachniuk*	*Olympia Suite* *B. Yang*	*Olympia Syndicate* *V.-D. Cung*
10:30–10:50	A. Rybarczyk	B. Chen	İ. Kara
10:50–11:10	M. Radom	D. Skorin-Kapov	U. Pferschy
11:10–11:30	P. Łukasiak	C. C. Ribeiro	A. Nikolaev
11:30–11:50	M. Borowski	I. Sciriha	I. Averbakh
11:50–12:10	A. Świercz	Y. Qu	B. Tüű-Szabó
12:10–14:00	Lunch Break		
14:00–15:00	*Plenary Talk:* **M. Grazia Speranza** *Chair:* John Baptist Gauci *Venue:* Babylon Suite		
Venue: *Chair:*	*Babylon Suite* *A. Rybarczyk*	*Olympia Suite* *J. Lauri*	*Olympia Syndicate* *B. Chen*
15:00–15:20	M. Miłostan	E. Çela	P. Gritzmann
15:20–15:40	M. Sterna	P. Borg	S. Phusingha
15:40–16:00	M. Machowiak	C. Picouleau	M. Dahlbeck
16:00–16:30	Coffee Break		
Venue: *Chair:*	*Babylon Suite* *C. Potts*	*Olympia Suite* *B. Ries*	*Olympia Syndicate* *P. Gritzmann*
16:30–16:50	V. A. Strusevich	B. Yang	M. Antczak
16:50–17:10	D. Paraskevopoulos	B. Zavalnij	P. Kilby
17:10–17:30	J. E. Beasley	P. Panagopoulou	F. Klemm
17:30–17:50	C. Oğuz	D. Schindl	T. Byrne
17:50–18:10	K. Sylejmani	M. Delorme	
18:10–19:45			
19.45–20.00	Conference Photo *Venue:* Private Lido		
20.00–	Welcome Reception *Venue:* Babylon Terrace		

Friday 31 May 2019

09:00–10:00	*Plenary Talk:* **Martin Charles Golumbic** *Chair:* Jacek Błażewicz *Venue:* Babylon Suite		
10:00–10:30	Coffee Break		
Venue: *Chair:*	*Babylon Suite* *V. A. Strusevich*	*Olympia Suite* *P. Borg*	*Olympia Syndicate* *C. Picouleau*
10:30–10:50	G. Mosheiov	B. Ries	A. Hertz
10:50–11:10	B. Mor	T. Ekim	M. Szachniuk
11:10–11:30	Y. Zinder	J. M. Y. Leung	H. İ. Karakaş
11:30–11:50	T. Martinez-Sykora	A. Behmaram	C. Domínguez
11:50–12:30	Lunch Break		
12:30–19:45	Conference Excursion		
19:45–20:00			
20:00–	Conference Dinner *Venue:* Private Lido		

Saturday 1 June 2019

09:00–10:00	*Plenary Talk:* **Alexander S. Kulikov** *Chair:* Paolo Toth *Venue:* Babylon Suite		
10:00–10:30	Coffee Break		
Venue: *Chair:*	*Babylon Suite* *I. Sciriha*	*Olympia Suite* *A. Hertz*	*Olympia Syndicate* *Y. Zinder*
10:30–10:50	A. Knippel	C. Archetti	O. Ősz
10:50–11:10	A. Kononov	A. Sipahioglu	A. Alpers
11:10–11:30	D. Müller	C. Lopes	P. Healy
11:30–11:50	T. Kis	A. M. Rodrigues	D. Arkhipov
11:50–12:10		S. Mancini	F. Rodrigues
12:10–12:30	Closing Session *Venue:* Babylon Suite		
12:30–14:00	Lunch Break		
14:00–18:10	Optional Excursion 1		
18:10–20:00			
20:00–	Optional Excursion 2		

Abstracts of Plenary Talks

Integrating Classical and Quantum Computing for Combinatorial Optimization Using the QUBO Model

Thursday
09:00-10:00

Fred Glover

University of Colorado

Fred.Glover@colorado.edu, U.S.A.

(*joint work with* Gary A. Kochenberger and Manuel Laguna)

We have witnessed the remarkable discovery in recent years that the Quadratic Unconstrained Binary Optimization (QUBO) model unifies a wide variety of combinatorial optimization problems, and moreover is the foundation of adiabatic quantum computing – the realm that underlies the quantum computers developed by D-Wave Systems and actively being explored for its research and practical applications by Google and Lockheed Martin in the commercial realm and by Los Alamos National Laboratory and Oak Ridge National Laboratory in the public sector. Computational experience is being amassed by both the classical and the quantum computing communities that highlights not only the potential of the QUBO model but also its effectiveness as an alternative to traditional modeling and solution methodologies. We survey, in a tutorial manner, a variety of applications of the QUBO model and highlight state of the art solution methods. These developments disclose a rich potential for integrating classical and quantum computing, by using appropriately designed classical systems to provide pre-processing and post-processing functions for quantum systems. We describe a recent software innovation in the classical area to support such an integration and relate the combined classical/quantum research to machine learning.

Friday
09:00-10:00

The wonderful world of chordal graphs

Martin Charles Golumbic

University of Haifa, Israel

golumbic@cs.haifa.ac.il

Chordal graphs are perhaps the second most interesting and important family of graphs – after trees and before planar graphs. Their fame is due to their beautiful and classical characterizations, their diverse mathematical properties, and their numerous applications in combinatorial optimization, linear algebra, statistics, constraint programming, relational databases, signal processing, machine learning, and techniques for exploiting sparsity in large positive semidefinite matrices. Originally known as rigid circuit graphs and later triangulated graphs, they are defined by the property that for every cycle of length greater than or equal to four there is an edge (called a chord) connecting two vertices that are not consecutive on the cycle.

In algorithmic graph theory, chordal graphs were one of the earliest families for which structural properties fundamentally help in solving hard problems efficiently, including the coloring, clique, independent set, and clique cover problems. They lead to researchers looking carefully at the tree structure of graphs and hypergraphs, and developing the notion of treewidth and partial k-trees, which have many algorithmic consequences. Lexicographic breadth first search (LexBFS) and maximum cardinality search (MCS) have their origins in recognizing chordal graphs. A large hierarchy of graph classes has been built around chordal graphs, each with its own characterizing properties and applications. In this lecture, we will present some of the significant developments involving chordal graphs and related families of graphs.

Boolean Circuit Size: Overview of known results and open problems

Saturday
09:00-10:00

Alexander S. Kulikov

St. Petersburg Department of Steklov Institute of Mathematics, Russia

alexander.s.kulikov@gmail.com

Boolean circuits is arguably the most natural model for computing Boolean functions. Despite intensive research, for many functions (even for simple ones), the gap between known lower and upper bounds on their circuit size is large. In the first part of the talk, we will discuss upper bounds. In particular, we will show how to use SAT-solvers for finding efficient circuits and will discuss the limitations of this approach. We will then review known approaches for proving lower bounds. We will conclude the talk with a few approaches that could potentially lead to improved (lower and upper) bounds.

Thursday
14:00-15:00

Integrated and collaborative routing problems

M. Grazia Speranza

University of Brescia, Italy

grazia.speranza@unibs.it

The technological and scientific advances have favored a trend that is leading to the optimization of increasingly integrated parts of the logistic systems and to the optimization of logistic problems arising from collaboration agreements among companies. The reason for studying these problems comes from the economic advantages that can be achieved. At the same time, integration and collaboration may imply additional costs and organizational challenges. For this reason, it is vital to quantify the benefits coming from an integration or a collaboration project. In this talk, different examples of integrated vehicle routing problems and of collaborative routing problems will be presented and discussed.

Abstracts of Contributed Talks

On Tomographic Super-Resolution Imaging

Saturday
10:50-11:10

Andreas Alpers

Technical University of Munich, Germany

alpers@ma.tum.de

(*joint work with* Peter Gritzmann)

Super-resolution imaging aims at improving the resolution of images by enhancing them with other images or data that might have been acquired using different imaging techniques or modalities. Motivated by applications in materials science and plasma physics, we consider the task of enhancing the resolution of tomographic grayscale images of binary objects by fusion with higher-resolution tomographic data.

Based on formulations as discrete optimization problems, we show that the resolution of binary objects can be doubled if the data are reliable. On the other hand, we show that noisy data in the low-resolution image do not simply reduce the quality of the reconstruction but add additional algorithmic complexity.

Polynomial-time algorithms for structural alignment of short- and long-range contact-based 3D substructures

Thursday
16:30-16:50

Maciej Antczak

Institute of Computing Science, Poznań University of Technology, Poland

maciej.antczak@cs.put.poznan.pl

(*joint work with* Marta Kasprzak, Piotr Łukasiak, Jacek Błażewicz)

A spatial neighborhood of a residue, known as a structural descriptor, is represented by a set of discontinuous fragments of a molecule chain closely located in three dimensions, however not necessarily close along the sequence. The concept of local descriptors was proposed in order to reliably analyze sequence-structure relationships in non-homological proteins. Descriptor conformations, which incorporate short- as well as long-range interactions, are treated as basic, geometrical units of protein folds. In the literature, there are several applications of the descriptor concept that prove its usefulness for insight into protein structures, e.g., residue-residue contact prediction, structural alignment of protein structures. However, there was no reliable and efficient algorithm for structural alignment of descriptors, which is crucial for the applications. To fill this gap, we proposed a novel combinatorial model based on the maximum-size assignment problem and new polynomial-time algorithms that ensure high quality results in terms of accuracy and processing efficiency [1]. All proposed algorithms are integrated in a highly configurable open source tool that can be simply applied, e.g., to reveal recurring local substructures within RNA-protein complexes, RNA-ligand binding sites, RNA pseudoknots, and to analyze sequence-structure relationships in helices of transmembrane proteins. PDB and mmCIF formats are supported.

References:

[1] M. Antczak, M. Kasprzak, P. Łukasiak, J. Błażewicz, Structural alignment of protein descriptors - a combinatorial model, *BMC Bioinformatics* **17** (2016) 383.

Kernel Search Heuristic for the Multi-Vehicle Inventory Routing Problem

Saturday
10:30-10:50

Claudia Archetti

University of Brescia, Italy

claudia.archetti@unibs.it

(*joint work with* Gianfranco Guastaroba, Diana L. Huerta-Muñoz, M. Grazia Speranza)

We study an inventory routing problem in which an optimal distribution plan to replenish a set of customers has to be determined, by routing a limited fleet of capacitated vehicles over a discrete planning horizon. Each customer consumes a per period quantity of products and has a maximum inventory capacity. Products can be distributed by a supplier to the customers in advance compared to their consumption, provided that their inventory capacity is not violated. The goal is to minimize the total distribution cost, that comprises the routing and the inventory costs. We develop a novel matheuristic approach to solve this problem. The algorithm is based on Kernel Search (KS), a heuristic framework that has been shown to find high-quality solutions for a number of combinatorial optimization problems. The basic idea of KS is to identify subsets of the decision variables and then solving, using a general-purpose solver, a sequence of Mixed-Integer linear Programs (MIPs), each one restricted to a subset of variables. Extensive computational experiments are conducted on a very large set of benchmark instances. The results show that KS outperforms state-of-the-art heuristic algorithms. It finds 103 new best-known solutions out of 240 large-scale instances.

References:

[1] C. Archetti, N. Boland, and M. G. Speranza, A matheuristic for the multivehicle inventory routing problem, *INFORMS Journal on Computing* **29** (2017) 377–387.

[2] M. Chitsaz, J.-F. Cordeau and R. Jans, A unified decomposition matheuristic for assembly, production and inventory routing. *INFORMS Journal on Computing* (to appear).

[3] G. Guastaroba,M. Savelsbergh and M.G. Speranza, Adaptive kernel search: A heuristic for solving mixed integer linear programs, *European Journal of Operational Research* **263** (2017) 789–804.

Saturday
11:30-11:50

Resource capacity and time lag propagation techniques for RCPSP MAX problem

Dmitry Arkhipov

ISAE-SUPAERO, Université de Toulouse, France
V.A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences, Moscow, Russia

miptrafter@gmail.com

(*joint work with* Olga Battaïa, Ilia Tarasov)

Constraint programming is one of the most popular approaches for solving the well-known Resource-Constrained Project Scheduling Problem (RCPSP) and its generalizations (i.e. RCPSP MAX, MRCPSP). However, since even a classical statement of RCPSP is NP-complete, constraint programming is not able to find suitable solutions in reasonable time for large-scale instances. In this paper, we propose some new propagation techniques based on resource capacity and time lags propagation to make constraint programming more efficient for solving RCPSP and its generalized statement RCSPSP MAX which consider precedence relations with time lags. We show that these new algorithms are able to make tasks domains tighter and to improve the performance of existing propagators.

Acknowledgements: This research is supported by the Russian Foundation for Basic Research (grant 18-37-00295 mol_a).

References:

[1] M. Garey and D. Johnson, Complexity results for multiprocessor scheduling under resource constraints, *SIAM Journal on Computing* **4** (1975) 397–411.

[2] P. Baptiste, C. Le Pape and W. Nuijten, *Constraint-Based Scheduling*, Kluwer Academic Publishers, Netherlands (2001).

[3] P. Laborie, Algorithms for propagation of resource constraints in AI planning and scheduling: Existing approaches and new results, *Artificial Intelligence* **143** (2003) 151–188.

[4] P. Vilim, *Global Constraints in Scheduling*, Ph.D. Thesis, Charles University in Prague (2007).

[5] A. Shutt, T. Feydy, P.J. Stuckey and M.G. Wallace, Solving RCPSP/max by lazy clause generation, *Journal of Scheduling* **16(3)** (2013) 273–289.

The Traveling Salesmen Location Problem with Path-Tours

Thursday
11:30-11:50

Igor Averbakh

University of Toronto Scarborough, Canada

averbakh@utsc.utoronto.ca

(*joint work with* Wei Yu)

We consider the following probabilistic location-routing problem. Customers residing at nodes of a transportation network may generate calls for service independently with known probabilities. The calls are allocated to several mobile servers which are located at the same node (*depot*); then, each server visits its allocated customers on a shortest path-tour (that is, the server is not required to return to the depot). The calls are allocated to the servers by a dispatcher optimally so as to minimize the total length of the servers' path-tours. It is required to find a location for the depot that minimizes the expected total length of the path-tours of the servers.

In the talk, we discuss motivation and applications of the problem, and focus on the following issues: a) Fast heuristics for general networks and their worst-case approximation performance, and b) The possibility of polynomial-time exact solution on tree networks.

Order allocation, rack allocation and rack sequencing for pickers in a mobile rack environment

Thursday
17:10-17:30

John E. Beasley

Brunel University, United Kingdom

john.beasley@brunel.ac.uk

(*joint work with* Cristiano A. Valle)

In this paper we investigate the problem of simultaneously allocating orders and mobile storage racks to pickers. Here storage racks are allocated to pickers to enable them to pick all the products for the orders that have been allocated to them. In situations of this type the pickers remain at fixed locations and racks are brought to them by robots, e.g. as in Amazon fulfilment centres that use Kiva robots. We also consider the problem as to how to sequence the racks for presentation to each picker to assist in order picking. Problems of the type considered here arise in facilities operating as robotic mobile fulfilment systems.

Computational results are presented for randomly generated test problems, that are made publicly available, involving up to 500 products, 100 orders, 100 racks and 10 pickers.

Friday
11:30-11:50

Some New Results on Dominating Induced Matching

Afshin Behmaram

Faculty of Mathematical Sciences, University of Tabriz, Iran

behmaram@tabrizu.ac.ir

(*joint work with* Saeed Akbari)

The concept of domination in graphs appears as a natural model for facility location problems, and has many applications in design and analysis of communication networks, network routing and coding theory, among others.

An edge of G dominates itself and every edge adjacent to it. A *dominating induced matching* (DIM) (or *efficient edge dominating set* (EEDS) in some papers) of G is an induced matching that dominates every edge of G. We denote $dim(G)$ to be the size of the smallest DIM in G. Clearly, not every graph has DIM. For every edge e, let D_e be the set of edges that are dominated by e. Note that for a DIM, all edges are being dominated by exactly one of the edges in DIM. The cycle C_n has a DIM if and only if $n = 3k$. Dominating induced matchings have been extensively studied by several authors, for instance see [1], [2], [3].

Theorem 1. If G is a graph of order n with a DIM, then $dim(G) \geqslant \frac{n-\alpha(G)}{2}$.

To see this, let $M = \{v_1w_1, \ldots, v_kw_k\}$ be DIM set for the graph G, where $k = dim(G)$. Therefore $V(G) \setminus M$ is independent set and we have $|V(G) \setminus M| \leqslant \alpha(G)$, and therefore

$$dim(G) \geqslant \frac{n - \alpha(G)}{2}.$$

Theorem 2. If a graph G has a DIM, then $\chi(G) \leqslant 3$.

Theorem 3. Let G be a graph. If D_1 and D_2 are two DIM of G, Then $|D_1| = |D_2|$.

Theorem 4. Let G be a graph of order n with at least one DIM. Then the following inequalities hold:

$$\frac{\delta(G)}{\Delta(G) - 1} \leq \frac{2dim(G)}{n - 2dim(G)} \leq \frac{\Delta(G)}{\delta(G) - 1}.$$

In particular, if G is a k-regular graph, then

$$dim(G) = \frac{nk}{4k - 2}.$$

Corollary. Let G be a k-regular graph of order n with at least one DIM. Then, $4k - 2|nk$.

Now, according to the previous corollary we present a conjecture about cubic graphs
.

Conjecture. Let G be a cubic planar graph with $10k$ vertices and the girth of G be at least 5. Then G has a DIM.

References:

[1] D.M. Cardoso, J. Cerdeira, C. Delorme, P. Silva, Efficient edge domination in Regular graph, *Discerete Applied Mathematics* **156** (2008) 3060–3065.

[2] M. Zito, Maximum Induced Matching on Regular Graphs and Trees, *Lecture notes in computer Sciences* **1665** (1999) 89–100.

[3] K. Cameron, Induced matchings, *Discrete Appl. Math.* **24** (1989) 97–102.

Reducing the maximum degree of a graph

Thursday
15:20-15:40

Peter Borg

University of Malta, Malta

peter.borg@um.edu.mt

For a graph G, let $\lambda(G)$ denote the smallest number of vertices that can be removed from a graph G so that the resulting graph has a smaller maximum degree, and let $\lambda_{\mathrm{e}}(G)$ denote the smallest number of edges that can be removed for the same purpose. These parameters have recently been studied by Kurt Fenech and the speaker. Several sharp bounds have been established. Observations and results will be presented during the talk.

Thursday
11:30-11:50

Computing methods for analysis of lipidomics mass spectra

Marcin Borowski

Institute of Computing Science, Poznań University of Technology, Poland

Marcin.Borowski@cs.put.poznan.pl

(*joint work with* Bartlomiej Kokot)

In recent years, there has been an increase in interest in artificial intelligence methods. The ease of collecting data, so widely available through the Internet, and the increase in computing power of computers have shaped this field of science to the form we can now observe. An unquestionable advantage of computers over humans is the shorter time of calculations. This advantage increases with the amount of data to be transformed and calculated. The consequence of this is the use of computers, among others, in medicine and bioinformatics. Computers perform the tasks of DNA sequencing analysis, gene expression or proteins. Mass spectrometry, which is based on the measurement of the mass ratio to the electric charge of the ion, has gained a lot of popularity in the analysis of proteins. By combining methods of artificial intelligence with biological sciences, we are able to reach data conclusions faster. In this way, we accelerate the development of medicine and expand knowledge about the organisms and mechanisms responsible for them. By building descriptive models based on results obtained, for example, by a mass spectrometer, it is easier to understand the relationship between these data and a given feature. The paper presents an approach based on machine learning algorithms in a descriptive and predictive analysis of data obtained with mass spectrometry.

Thursday
17:30-17:50

The One-Round Voronoi Game Played on the Rectilinear Plane

Thomas Byrne

School of Mathematics, University of Edinburgh, United Kingdom

tbyrne@ed.ac.uk

(*joint work with* Sándor P. Fekete, Jörg Kalcsics)

Location is undoubtedly one of the most important issues when determining the success or failure of an operation. The distance between a proposed facility placement and its potential customer sites is perhaps the most natural way to discern the value of this position, and the need for effective facility locations becomes vital in competitive situations wherein customers will be gained or lost depending on whichever facility is closest. This importance of good location strategies is epitomised in the Voronoi game, a simple geometric model proposed in [1].

We consider this competitive facility location problem with two players. Players alternate placing points into the playing arena, until each of them has placed n points. The arena is then subdivided according to the nearest-neighbour rule, and the player whose points control the larger area wins.

This problem is the game theory interpretation of the market share problem where the optimal location of an additional facility within a region within which there already exist facilities (including competitor facilities) is to be decided. The objective there is to maximise the total market share (demand captured) by the player's facilities. The exact location in a convex market region was proven to be found in [2] with the l_1 norm.

While some literature on this game exists, there is a noticeable absence in the presentation of the game using the l_1 norm. A winning strategy for the second player, where the arena is a circle or a line segment, is presented in [1] for both variations where players can play more than one point at a time. There it is shown that the first player can ensure that the second player wins by an arbitrarily small margin. Optimal strategies for both players were found for a rectangular arena with Euclidean distance in [3] and it was ascertained that the particular values of n and the aspect ratio of the arena determine which player wins.

We start with a definition of our game. There are two players, White and Black, each having n points to play, where $n > 1$. As in chess, White starts the game, placing their n points on a rectangular playing area $\mathcal{P}$, followed by Black's placement of their n points (this here being the one-round game). We assume that points cannot lie upon each other. Let W be the set of white points and B be the set of black ones. After all of the $2n$ points have been played, the arena is partitioned into the Voronoi diagram of $W \cap B$ using the l_1 metric and each player receives a score equal to the area of the Voronoi cells of their points, or rather their total market share.

The question we ask is "*What is each player's best strategy?*" We answer this question, determining whether it is still chivalrous to play last, or is first the worst, second the best.

References:

H.-K. Ahn, S.-W. Cheng, O. Cheong, M. Golin and R. van Oostrum, Competitive facility location: the Voronoi game, *Theoretical Computer Science* **310** (2004) 457–467.

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

S.P. Fekete and H. Meijer, The one-round Voronoi game replayed, *Computational Geometry* **30** (2005) 81–94.

Monotonic Representations of Outerplanar Graphs as Edge Intersection Graphs of Paths on a Grid

Thursday
15:00-15:20

Eranda Çela

Graz University of Technology, Austria

cela@math.tugraz.at

(*joint work with* Elisabeth Gaar)

A graph G is called an edge intersection graph of paths on a grid if there is a grid and there is a set of paths on this grid, such that the vertices of G correspond to the paths and two vertices of G are adjacent if and only if the corresponding paths share a grid edge. Such a representation is called an EPG representation of G. B_k is the class of graphs for which there exists an EPG representation where every path has at most k bends. The bend number $b(G)$ of a graph G is the smallest natural number k for which G belongs to B_k. B_k^m is the subclass of B_k containing all graphs for which there exists an EPG representation where every path has at most k bends and is monotonic, i.e. it is ascending in both columns and rows. The monotonic bend number $b^m(G)$ of a graph G is the smallest natural number k for which G belongs to B_k^m. Edge intersection graphs of paths on a grid were introduced by Golumbic, Lipshteyn and Stern [1] in 2009 and a lot of research has been done on them since then.

In this paper we deal with the monotonic bend number of outerplanar graphs. We show that $b^m(G) \leqslant 2$ holds for every outerplanar graph G. Moreover, we characterize in terms of forbidden subgraphs the maximal outerplanar graphs and the cacti with (monotonic) bend number equal to 0, 1 and 2, respectively. As a consequence we show that for any maximal outerplanar graph and any cactus, a (monotonic) EPG representation with the smallest possible number of bends can be constructed in a time which is polynomial in the number of vertices of the graph.

References:

[1] M.Ch. Golumbic, M. Lipshteyn and M. Stern, Edge intersection graphs of single bend paths on a grid, *Networks* **54(3)** (2009) 130–138.

A Tractable Network Game of Atomic Dynamic Flows[1]

Thursday
10:30-10:50

Bo Chen

University of Warwick, United Kingdom

B.Chen@warwick.ac.uk

(*joint work with* Zhigang Cao, Xujin Chen, and Changjun Wang)

Selfish routing, where agents compete in a network for traveling from their origins to destinations as fast as possible, is dynamic in nature. However, capturing such dynamics with a tractable model is challenging, especially when agents are atomic. We propose a network game model, which not only makes a good simulation of the dynamics, but also possesses some nice properties with theoretical and algorithmic tractability. Our edge-priority tie-breaking rule on congestion is key for tractability, which stands in contrast to previous related negative results in the literature.

We study Nash equilibrium (NE) for non-adaptive agents, who select and fix their own origin-destination paths simultaneously at the start. We constructively prove that an NE exists for multiple-origin single-destination networks. We characterize, supported by efficient algorithms, all NEs with many desirable properties, such as weak Pareto efficiency and global First-In-First-Out.

We further investigate an unexplored area of atomic dynamic routing games – the subgame perfect equilibrium (SPE) for adaptive agents, who make an online decision at each nonterminal vertex they reach as to which next edge to take. We prove that, in a single-destination network, an SPE always exists, and that every NE of non-adaptive agents is realizable by some SPE of adaptive agents. This allows us to build a bridge between non-adaptive and adaptive models.

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[1] An extended abstract of a preliminary version of this work appeared in the Proceedings of the ACM Conference on Economics and Computation EC'17 [Cao *et al.*, 2017].

Thursday
15:40-16:00

A mixed-integer programming model for the T-row Facility Layout Problem

Mirko Dahlbeck

University of Goettingen and TU Dortmund University, Germany

mirko.dahlbeck@tu-dortmund.de

We introduce a new shape of a facility layout problem, which we call T-Row Facility Layout Problem (TRFLP). The TRFLP consists of a set of one-dimensional departments with pairwise transport weights between them and two rows which are orthogonal to each other such that they form a T and such that two departments which lie in different rows cannot overlap. The aim is to find a non-overlapping assignment of the departments to the rows such that the sum of the weighted center-to-center distances measured in horizontal and vertical directions is minimized.

The TRFLP is related to the Single-Row (SRFLP) and the Double-Row Facility Layout Problem (DRFLP) where the departments are arranged on one or on two rows, respectively. All these problems are NP-hard and have broad applicability in factory planning where one advantage of the TRFLP is that it contains a crossroad, which is realistic for factory buildings.

We show that there always exists an optimal T-row layout where one department in the horizontal row lies directly opposite the vertical row. Thus we fix one department on this position and we set up a mixed-integer programming model which is based on ideas from the scheduling literature and makes use of betweenness variables which may in contrast to the literature also be equal to one if the departments lie in different rows. However, inequalities based on betweenness variables used for the SRFLP are still valid and we can separate them in our branch-and-cut algorithm.

Let n denote the number of the departments. In every step we arrange one department directly opposite the vertical row and thus we have to solve this mixed-integer programming model n times. We determine the order in which we solve these problems by a heuristic and we use the objective value of the current best layout as an upper bound. We present preliminary computational results.

Mathematical models for the Hospitals / Residents problem with Couples, Ties, and Incomplete lists

Thursday
17:50:18:10

Maxence Delorme

The University of Edinburgh, United Kingdom

mdelorme@ed.ac.uk

(*joint work with* Sergio García, Jacek Gondzio, Joerg Kalcsics, David Manlove, William Pettersson)

In the Hospitals / Residents problem with Ties (HRT), we are given a set of residents (junior Doctors) that have to be assigned to a set of hospitals based on their preferences over one another. The objective is to find a matching of maximum cardinality that ensures stability, i.e., a matching where no pair resident/hospital prefers to be matched together more than the hospital/resident they are currently assigned to. It is well known that the problem can be solved in polynomial time when the preferences are strictly ordered (see [2]), and that it becomes NP-hard when ties are allowed in the preference lists (see [3]). However, effective Integer Linear Programming (ILP) models were proposed recently and successfully solved instances of reasonable size (see [1]).

In this work, we are interested in the extension of HRT in which residents are allowed to make their applications in couples. We start by reviewing the extensions of stability constraints that were proposed in the literature for couples and we outline the main differences and resemblances that exists among them. We then introduce new ILP models for each stability constraints and propose some improvements to reduce their running times. We finally show how the different models behave both on real-world and randomly generated instances.

References:

[1] M. Delorme, S. García, J. Gondzio, J. Kalcsics, D. Manlove, W. Pettersson, Mathematical models for stable matching problems with ties and incomplete lists, *European Journal of Operational Research*, accepted for publication.

[2] R.W. Irving, Stable marriage and indifference, *Discrete Applied Mathematics* **48** (1994) 261–272.

[3] D.F. Manlove, R.W. Irving, K. Iwama, S. Miyazaki, and Y. Morita, Hard variants of stable marriage, *Theoretical Computer Science* **276** (2002) 264–279.

Friday
11:30-11:50

Formulations for the Capacitated Rank Pricing Problem

Concepción Domínguez

Université Libre de Bruxelles, Belgium
Universidad de Murcia, Spain

concepcion.dominguez@um.es

(*joint work with* Martine Labbé, Alfredo Marín)

Pricing optimization problems are widely present in the economic literature, and their aim is to determine the prices of a series of products in order to maximize the revenue of a company. These problems have a bilevel structure. They have an upper level problem, which is the maximization of the revenue of the company, and a subset of the constraints force the solution to be optimal to another optimization problem that satisfies the customers' choice rule.

The Rank Pricing Problem (RPP) was introduced in [2]. In this problem, customers are modeled by means of a budget and an ordered list of preferences including a subset of the products of the company. They are unit-demand, that is, they are interested in purchasing at most one product among the offered ones. Once the prices are established by the company, customers purchase the highest-ranked product of their list among the ones they can afford (if any). The so-called rank-buying objective was introduced in [2], where the authors show that the problem is NP-complete in the strong sense and introduce a heuristic approximation algorithm together with posterior performance bounds. The first bilevel and mixed-integer formulations and an in-depth analysis of its structure can be found in [1].

We present a generalization of the RPP considering limited supply of products and different reservation prices for each customer and each product of his list of preferences. We have named this problem the Capacitated Rank Pricing Problem, and we present a mixed-integer formulation along with valid inequalities added to the model in a branch-and-cut framework. To assess the performance, we have carried out extensive computational experiments.

References:

[1] H. I. Calvete, C. Domínguez, C. Galé, M. Labbé, and A. Marín, The Rank Pricing Problem: models and branch-and-cut algorithms, *Computers & Operations Research* **105** (2019) 12–31.

[2] P. Rusmevichientong, B. Van Roy, and P. W. Glynn, A nonparametric approach to multiproduct pricing, *Operations Research* **54** 1 (2006) 82–98.

The Defensive Domination Problem

Friday
10:50-11:10

Tınaz Ekim

Boğaziçi University, Turkey

tinaz.ekim@boun.edu.tr

(*joint work with* Andrzej Proskurowski, Arthur Farley, Mordechai Shalom)

Due to their numerous applications, domination problems are one of the most studied areas in graph theory. The classical domination problem deals with the selection of a set of vertices so that every other vertex has a neighbor in this set. Several variations of the classical domination problem have been studied in the literature. Some domination problems focus on security in networks, where a vertex in a dominating set can be viewed as a guard placed at that vertex having the ability to protect all its neighbors in the network. In this work, we study a version of domination related to security in networks: the defensive domination problem, which was introduced in [1].

A *k-attack* on a graph G is a set of k distinct vertices $\{a_1, ..., a_k\}$ which are said to be *under attack*. A k-attack A can be *countered* or *defended* by a subset of *defender* vertices X if and only if there exists an injective function f from A to X, such that either $f(a_i) = a_i$ or $(a_i, f(a_i))$ is an edge of G, for all i, $1 \leq i \leq k$. In other words, a k-attack can be seen as k vertices which are simultaneously attacked and each vertex under attack needs a distinct defender (which can also be itself). Given a graph G, a subset D of V is a *k-defensive dominating set* of G if and only if D can counter any k-attack in G. We consider the problem of deciding whether a given graph has a k-defensive dominating set of size at most K.

We start a systematic study on the complexity of the k-defensive dominating set problem. When k is not fixed, it is not known if the problem is in NP as there are exponentially many k-attacks. However, if k is fixed, then we show that the problem is NP-complete even in split graphs. Subsequently, we consider special graph classes, namely paths, cycles, co-chain graphs and threshold graphs. We show that in each of these graph classes, a k-defensive dominating set of minimum size can be found in linear time even for non-fixed k.

References:

[1] A. Farley, A. Proskurowski, Defensive domination, *Congressus Numerantium* **168** (2004) 97–107.

Thursday
15:00-15:20

District Design via Diagrams

Peter Gritzmann

TU Munich, Germany

gritzmann@tum.de

(*joint work with* Andreas Brieden, Fabian Klemm)

We study the electoral district design problem where municipalities of a state have to be grouped into districts of nearly equal population while obeying certain politically motivated requirements. We develop a general framework for electoral district design that is based on the close connection of constrained geometric clustering and diagrams. The approach is computationally efficient and flexible enough to pursue various conflicting juridical demands for the shape of the districts. We demonstrate the practicability of our methodology for electoral districting in Germany.

Saturday
11:10-11:30

Modelling Masters Relay Swim Team Selection

Patrick Healy

University of Limerick, Ireland

patrick.healy@ul.ie

(*joint work with* Simona Mancini)

Masters swimming is a special class of competitive swimming for swimmers aged over 20 years. In addition to individual events, Masters "swim meets" host relay events, in which quartets of athletes perform as a team. Since several event types are generally proposed and rules prohibit overuse of the same personnel, providing an optimal line-up of relay teams quickly becomes a challenging combinatorial optimization problem.

In this paper we introduce the Relay Team Generation Problem (RTGP) whose goal is to maximize the competitiveness of the team while ensuring that the basic rules of relay participation are enforced. A crucial difference in Masters competitions is that, while competitiveness is very high in lower age categories – and an excellent chronometric performance is necessary to win a medal – in the older categories the degree of competitiveness is not so high, and it is possible to win a competition even with a squad performing very far from national records.

We present two different Integer Programming (IP) formulation to address the RTGP. In the first one, for each event and each age group, performances of the quartets are grouped in bands depending on their chronometric percentage distance with respect to some reference point, the national record, say. Higher bands are associated with a lower chrono, i.e. with a higher probability of winning a medal.

This is represented by a larger contribution to the objective function which we seek to maximize.

In the second formulation, the competitiveness of a quartet is determined by a linearly decreasing function of the difference between their chrono and the national record, so that it always takes values between 0 and 1. The parameters associated to these functions vary among age categories. The goal is to maximize the total competitiveness.

We provide a comparison of the effectiveness and of the robustness of the two formulations on real-life instances coming from the Irish National Championship, running a set of realization scenarios and computing the average number of medals achieved with the optimal line-ups provided by both models.

Resolving sets and integer programs for recommender systems

Friday
10:30-10:50

Alain Hertz

Polytechnique Montréal, Canada

alain.hertz@gerad.ca

Recommender systems make use of different sources of information for providing users with recommendations of items. Such systems are often based on collaborative filtering methods which make automatic predictions about the interests of a user by collecting taste information from many users. As an alternative approach, we propose to use the concept of resolving set that allows to determine the preferences of the users with a very limited number of ratings.

More precisely, consider a connected undirected graph G, and let $d(u, v)$ be the distance between two vertices u and v in G. A vertex x *resolves* two vertices u and v if $d(x, u) \neq d(x, v)$. A subset R of vertices is a *resolving set* for G if every two vertices in G are resolved by at least one vertex of R. The problem of determining a resolving set of minimum size is NP-hard. We show that when all users precisely indicate the distance between rated items and their expectations, then resolving sets for the n-cube correspond to small sets of recommendations that are sufficient to predict the preferences of all users.

We also show how to make recommendations when user ratings are imprecise or inconsistent, and we indicate how to take into account situations where users possibly do not care about the attribute values of some items. All recommendations are obtained in a few seconds by solving integer programs.

Thursday
10:30-10:50

New formulations for the multiple travelling repairmen problem with time windows

İmdat Kara

Başkent University, Turkey

ikara@baskent.edu.tr

(*joint work with* Gözde Önder Uzun)

The Travelling Repairman Problem (TRP) is one of the most important variants of the Travelling Salesman Problem (TSP). TRP is also known as Minimum Latency Problem, Deliveryman Problem or Cumulative Travelling Salesman Problem. In this problem, the objective is to find a Hamiltonian path or tour starting from the origin while minimizing the total latency (waiting time or delay time) of all customers. The latency of a customer is defined as the time passed from the beginning of the tour (or path) until this customer's service is completed. Multiple TRP (kTRP) finds k tours or paths, each starting at the depot and visiting the customers while minimizing total delay time. kTRP with time windows (kTRPTW) is a special variation of kTRP where earliest and latest time for visiting each customer are restricted by prescribed time windows. In this paper, we deal with kTRPTW in the homogeneous case, where travel times between nodes are the same for all repairmen, and in the heterogeneous case, where the travel times depend upon the travellers. As far as we are aware, there is only one formulation for homogeneous kTRPTW and one formulation for heterogeneous kTRPTW. We propose new formulations for homogeneous and heterogeneous kTRPTW with $O(n^2)$ decision variables and constraints. Then, we solve benchmark instances up to 150 node problems with our formulations and existing formulations with different number of repairmen by using CPLEX 12.5.0.1. We compare the performances of the formulations in terms of CPU times. We observe that our formulations can solve optimally more benchmark instances and are extremely faster than existing formulations for both types of kTRPTW.

References:

[1] N.Bjelic and D.Vidovic, Two-phase algorithm for solving heterogeneous travelling repairmen problem with time windows, *International Journal for Traffic and Transport Engineering*, **5** (2015) 64-73.

[2] J.Fakcharoenphol, C.Harrelson and S.Rao, The k-travelling repairman problem, *In Proc. 14th annual ACM-SIAM Symposium on Discrete Algorithms (SODA '03)*, Baltimore, (2003) 655-664.

[3] G.Heilporn, J.Cordeau and G.Laporte, The deliveryman problem with time windows, *Discrete Optimization*, **7** (2010) 269-282.

[4] J.N.Tsitsiklis, Special cases of travelling salesman and repairman problems with time windows, *Networks*, **22** (1992) 263-282.

[5] R.van der Meer, *Operational Control of Internal Transport*, PhD Thesis, Erasmus University Rotterdam, Rotterdam, Netherlands, (2000).

Integer programming formulations for the Frobenius problem

Friday
11:10-11:30

Halil İbrahim Karakaş

Başkent University, Turkey

karakas@baskent.edu.tr

(*joint work with* İmdat Kara)

The Frobenius number of a set of relatively prime positive integers $a_1, a_2, ..., a_n$ such that $a_1 < a_2 < ... < a_n$ is the largest integer that cannot be written as a nonnegative integer linear combination of the given set. Finding the Frobenius number is known as "The Frobenius Problem", which is also named as "The Coin Exchange Problem" or "The Money Changing Problem". This problem is closely related to "The Equality Constrained Integer Knapsack Problem". It is known that this problem is NP-hard. Extensive research has been conducted for finding the Frobenius number of a given set of positive integers. Exact formulas exist for the case $n \leq 3$. Various algorithms have been proposed for $n \geq 4$. As far as we are aware, there does not exist any integer programming approach for this problem, which is the main motivation of this paper. We present four integer linear programming formulations on the Frobenius number of a given set of positive integers. Our first formulation is used to check if a given positive integer is the Frobenius number of a given set of positive integers. The second formulation aims at finding the Frobenius number directly. The third formulation involves the residue classes with respect to the least member of the given set of positive integers, where a residue table is computed comprising all values modulo that least member, and the Frobenius number is obtained from there. Based on the same approach underlying the third formulation, we propose our fourth formulation which produces the Frobenius number directly. We demonstrate how to use our formulations with several examples. Some preliminary computational analysis is also presented. We hope that this paper will open a new window for the computation of the Frobenius number by using integer programming techniques.

References:

[1] K. Aardal and J. K. Lenstra, Hard Equality Constrained Integer Knapsacks, *Mathematics of Operations Research* **29(3)** (2004) 724-738.

[2] J. L. Ramirez Alfonsin, Complexity of the Frobenius Problem, *Combinatorica* **16(11)** (1996) 143-147.

[3] A. Brauer and J. E. Shockley, On a problem of Frobenius, *J. reine angew. Math* **211** (1962) 215-220.

[4] P. Hansen and J. Ryan, Testing integer knapsacks for feasibility, *European Journal of Operational Research* **88** (1996) 578-582.

[5] H. İ Karakaş, Parametrizing numerical semigroups with multiplicity up to 5, *International Journal of Algebra and Computation* **28(1)** (2018) 69-95.

[6] A. Tripathi, Formulae for the Frobenius number in three variables, *Journal of Number Theory* **170** (2017) 368-389.

Thursday
16:50-17:10

Efficient 3D Packing Without Vertical Overhanging

Philip Kilby

CSIRO Data61 and Australian National University, Australia

philip.kilby@csiro.au

(*joint work with* Dan Popescu)

We present a novel heuristic algorithm for the 3D packing problem with container loading constraints. The variant of the problem we study has multiple items, each with a notional value, which must be packed into a given number of containers. The objective is to minimise the value of items that cannot be packed. The motivation is to solve Vehicle Routing Problems (VRPs) with loading constraints, so our approach has two key elements. First, it is very fast, so can be called as a subroutine during tour construction within a VRP solver. Second, we constrain the solution so that boxes are not allowed to "overhang" – that is, one item can sit atop another only if every base point is supported from below. Such constraints are fairly common in logistics contexts, where stacked containers may fall if not properly supported. Ours is a very strict interpretation of this limitation.

We also support other elements of real-world vehicle packing problems: 90 degree rotations around the vertical axis are allowed, but rotations around any horizontal axis are not. Items can be labelled "top-load only", which prevents other items being placed on top. From the VRP context, items have weights, and containers have a maximum capacity. Finally, items have due dates, and containers have a pre-assigned departure date.

The solution procedure is based on Adaptive Large Neighbourhood Search, with multiple insert procedures derived from alternative orderings of items and containers. It has some similarities with the constrained packing methods proposed in [1] and [2]. We benchmark the packing efficiency of our proposed algorithm against the classical (exact) 3D packing algorithm described in [3], which does not prevent overhanging. We show that our additional constraint only results in minor losses in packing efficiency (typically between 0.5% to 3%) for most packing type scenarios. We also show that our method displays considerably better computational efficiency.

References:

[1] A. Bortfeld, G. Wascher, Constraints in Container Loading – A State-of-the-art Review, *European Journal of Operational Research* **229** (2013) 1–20.

[2] T. Linkosari, T. Urponen, H. Juvonen, M. Makela and Y. Nikulin, Three-dimensional Bin Packing Problem with a Stability Rejection Criterion, *ECOMAS Congress 2016* (2016) 1–25.

[3] S. Martello, D. Pisinger, D. Vigo, E. Den Boef and J. Korst, Algorithm 864: General and Robot-Packable Variants of the Three-Dimensional Bin Packing Problem, *ACM Transactions on Mathematical Software* **33** (2007) 1–7.

A branch-and-cut algorithm for the resource loading problem

Saturday
11:30-11:50

Tamás Kis

Institute for Computer Science and Control, Hungarian Academy of Sciences, Hungary

kis.tamas@sztaki.mta.hu

(*joint work with* Guopeng Song, Roel Leus)

In the resource loading problem, there is a set of jobs to be scheduled on a finite time horizon. In addition, there is a single resource with a finite capacity used by the jobs in each time period when they are processed. The processing intensities of the jobs may vary over time, and proportionally vary their resource requirement in each time period. A special feature of our problem is that for each job a time interval of the time horizon must be chosen such that in each time period of the selected interval the processing intensity must be between given lower and upper bounds, and must equal 0 outside the chosen time interval. The resource can be overused at the expense of purchasing extra capacity. The objective is to minimize the total job tardiness plus the total cost of extra capacity needed. This model generalizes that of [2].

We propose a couple of time-indexed MIP formulations based on the standard problem formulations of the resource-constrained project scheduling problem, and one in which we represent explicitly every feasible processing interval of each job. For the latter formulation we derive new polyhedral results by completely describing the convex hull of feasible intensity assignments for a job. The obtained polyhedral results generalize those of [1]. Extensive computation tests show that our branch-and-cut method based on the processing interval formulation and using the cutting planes derived from our polyhedral investigation can solve significantly more problem instances in a shorter time than other methods based on time-indexed formulations.

Acknowledgements: This work was supported by the National Research, Development and Innovation Office – NKFIH, Grant no. SNN 129178, and ED_18-2-2018-0006.

References:

[1] T. Kis, A branch-and-cut algorithm for scheduling of projects with variable-intensity activities. *Mathematical Programming* **103** (2005) 515–539.

[2] F. Talla Nobibon, R. Leus, K. Nip, and Z. Wang. Resource loading with time windows, *European Journal of Operational Research* **244** (2015) 404–416.

Thursday
17:10-17:30

Constrained Clustering via Voronoi Diagrams in General Topological Spaces

Fabian Klemm

Technical University of Munich, Germany

klemm@ma.tum.de

(*joint work with* Peter Gritzmann)

We are interested in finding clusterings that obey constraints, such as fixed cluster sizes or centroids, and have favorable shape properties, such as a high degree of consolidation. A correspondence between generalized Voronoi diagrams and clusterings under balancing constraints has been demonstrated in [3]. Optimizers of the underlying clustering problem can be embedded into the cells of the corresponding diagrams and thus inherit their geometric properties. Using different types of diagrams this has been successfully exploited in several applications such as the consolidation of farmland [2], electoral district design [3] or grain reconstruction [1].

We recall the theory from [3] and broaden the type of constraints that may be put on the clusters. Then we demonstrate the generality of the approach with respect to the underlying spaces. While in [3] the problem was restricted to the finite case, we show to what extent those results still hold for an arbitrary amount of data points in general topological spaces.

References:

[1] A. Alpers, A. Brieden, P. Gritzmann, A. Lyckegaard, and H. Poulsen, Generalized Balanced Power Diagrams for 3D Representations of Polycrystals, *Philosophical Magazine* **95(9)** (2015) 1016–1028.

[2] A. Brieden and P. Gritzmann, On optimal weighted balanced clusterings: gravity bodies and power diagrams, *SIAM Journal on Discrete Mathematics* **26(2)** (2012) 415–434.

[3] A. Brieden, P. Gritzmann, F. Klemm, Constrained clustering via diagrams: A unified theory and its application to electoral district design, *European Journal of Operational Research* **263(1)** (2017) 18–34.

Formulations for the K-partitioning problem

Saturday
10:30-10:50

Arnaud Knippel

INSA Rouen Normandie, France

arnaud.knippel@insa-rouen.fr

(*joint work with* Zacharie Ales)

We compare several formulations for the K-partitioning problem, where, given n elements and weights w_{ij} between them, we have to partition n elements in K sets so that the total weight over all the sets is minimized. Two formulations are variants of node-cluster formulations from the literature. One formulation is based on representative variables and has no symmetry [1]. We proposed an extended formulation of the latter [2]. We give valid inequalities for the representative formulation and its extended version and give conditions under which they are facet-defining.

We compare these formulations numerically, in terms of the quality of their linear relaxation and in terms of the resolution time. We also give bounds on the linear relaxation values that help to understand the numerical results.

References:

[1] Z. Ales, A. Knippel and A. Pauchet, Polyhedral combinatorics of the k-partitioning problem with representative variables, *Discrete Applied Mathematics* **211** (2016) 1–14.

[2] Z. Ales, A. Knippel, An extended edge-representative formulation for the K-partitioning problem, *Electronic Notes in Discrete Mathematics* **52** (2016) 333–342.

Saturday
10:50-11:10

On the Approximability of the Maximum k-Edge-Colored Clustering Problem

Alexander Kononov

Sobolev Institute of Mathematics, Novosibirsk, Russia
Novosibirsk State University, Novosibirsk, Russia

alvenko@math.nsc.ru

(*joint work with* Yousef M. Alhamdan)

We consider the Max k-Edge-Colored Clustering problem introduced by Angel *et al.* [2]. We are given an edge-colored graph with k colors. Each edge of the graph has a positive weight. It is required to color the vertices of the graph so as to maximize the total weight of the edges which have the same color as their extremities. As observed in [3], the Max k-Edge-Colored Clustering problem can be considered as an optimization counterpart of the Vertex-Monochromatic Subgraph problem or the Alternating Path Removal problem. The MAX-k-EC problem is also a natural generalization of Maximum Weight Matching Problem. Indeed, if each edge has its own color, the problem coincides with the edge packing problem which is equivalent to finding a maximum weight matching. Our problem can also be considered as an extension of the centralized version of the information-sharing model introduced by Kleinberg and Ligett [4] and a special case of the combinatorial allocation problem [5]. For the considered problem we present a new approximation algorithm with approximation ratio 0.34, improving the previous known ratio 0.3043 [1]. We also present the first upper bound of 0.972 for the inapproximability of the MAX-k-EC problem, even for the case when the given graph is bipartite and its edges are colored with at most three different colors.

References:

[1] A. Ageev and A. Kononov. Improved approximations for the max k-colored clustering problem. in: *Proceedings of the 12th International Workshop on Approximation and Online Algorithms, WAOA 2014* (2015) 1–10.

[2] E. Angel, E. Bampis, A. Kononov, D. Paparas, E. Pountourakis, and V. Zissimopoulos. Clustering on k-edge-colored graphs. *Discrete Applied Mathematics* **211** (2016) 15–22.

[3] L. Cai and O.-Y. Leung. Alternating path and coloured clustering. URL: arXiv:1807.10531 (2018).

[4] J. M. Kleinberg and K. Ligett. Information-sharing and privacy in social networks. *Games and Economic Behavior* **82** (2013) 702–716.

[5] U. Feige and J. Vondrak. Approximation algorithm for allocation problem improving the factor of $1 - \frac{1}{e}$. in: *Proceedings of the 47th Annual IEEE Symposium on Foundations of Computer Science* (2006) 667–676.

On the Mixed Set Covering and Packing Polytope

Friday
11:10-11:30

Janny M.Y. Leung

The Chinese University of Hong Kong, Shenzhen, Hong Kong

jannyleung@cuhk.edu.cn

(*joint work with* Yong-Hong Kuo)

We study the polyhedral structure of the mixed set covering and packing problem, which has not been studied much but has many real-life applications. By considering the interactions between the different types of edges of an induced graph, we develop new classes of valid inequalities. In particular, we derive the (generalized) mixed odd-hole inequalities, and identify sufficient conditions for them to be facet-defining. In the special case when the induced graph is a mixed odd hole, the inclusion of these new facets provides a complete polyhedral characterization of the polytope. Computational experiments indicate that these new valid inequalities may be effective.

Sectorization in elevator maintenance

Saturday
11:10-11:30

Cristina Lopes

CEOS.PP / ISCAP / P.PORTO and LEMA, Portugal

cristinalopes@iscap.ipp.pt

(*joint work with* Ana Maria Rodrigues, Cristina Oliveira, José Soeiro Ferreira, Maria João Cortinhal)

Sectorization problems consist in dividing a large region into smaller regions and can be interpreted as a particular case of graph partitioning problems [5]. This division usually aims at better organizing, or simplifying a large problem into smaller subproblems, or promoting groups with similar characteristics [1].

This problem has several applications, such as designing political districts, defining sales territories, assigning neighbourhoods to schools, locating health care services, and managing municipal waste collection [3]. This combinatorial optimization problem can be addressed with exact approaches, such as integer programming models based on graph theory, and also with specific heuristics and metaheuristics.

In order to evaluate the quality of the solutions, three criteria are commonly used: Equilibrium (the sectors should be identical portions of the whole), Compactness (regular forms like circles are preferred, avoiding sectors shaped with "tentacles"), and Contiguity (avoid sectors divided into portions) [2]. Depending on the application, other criteria can be considered. These criteria are often weighted differently by decision makers, and therefore multicriteria approaches should be used [4].

This presentation considers a specific sectorization problem that arises in an elevator company, which involves designating technicians for predetermined maintenance zones. The definition of these zones has a great impact on the company costs and therefore needs to be optimized. Preventive maintenance and also on call maintenance must be considered, in order to define the best sectorization and to obtain a better maintenance plan. We will discuss the efficient solution methods developed for this practical problem.

Acknowledgements: This work is financed by the ERDF - European Regional Development Fund through the Operational Programme for Competitiveness and Internationalisation - COMPETE 2020 Programme and by National Funds through the Portuguese funding agency, FCT - Fundação para a Ciência e a Tecnologia within project POCI-01-0145-FEDER-031671.

References:

[1] J. Kalcsics and S. Nickel and M. Schröder. Towards a unified territorial design approach - applications, algorithms and GIS integration. *Top*, **13**(1) (2005) 1–74.

[2] F. Ricca and A. Scozzari and B. Simeone. Political Districting: from classical models to recent approaches. *Annals of Operations Research* **204** (2013) 271-299.

[3] A.M. Rodrigues, and J.S. Ferreira. Waste collection routing - limited multiple landfills and heterogeneous fleet. *Networks*, **65**(2) (2015) 155–165.

[4] A.M. Rodrigues, and J.S. Ferreira. Measures in Sectorization Problems. In: A. P. F. D. Barbosa Póvoa and J. L. de Miranda (eds.), *Operations Research and Big Data, Studies in Big Data*, **15** Springer International Publishing, Switzerland (2015) 203–211.

[5] X. Tang and A. Soukhal and V. T'kindt. Preprocessing for a map sectorization problem by means of mathematical programming, *Annals of Operations Research* **222**(1) (2014) 551-569.

De novo computational based evaluation of Protein/RNA 3D models using consensus approach

Thursday
11:10-11:30

Piotr Łukasiak

Institute of Computing Science, Poznań University of Technology, Poland

Piotr.Lukasiak@cs.put.poznan.pl

(*joint work with* Tomasz Ratajczak, Thomas Villmann)

As the number of Protein/RNA structure prediction tools and methods is growing, selecting the best available model is a difficult challenge. Each tool can generate multiple candidate models that must be evaluated, usually through manual inspection. Even when a given tool provides estimated quality score or ranking, combining those values from multiple tools is impossible without a way to normalize them. The problem can be formulated as follows: given multiple models of a single 3D structure, the proposed method should provide a ranking ordering those models by their estimated quality. Each model should receive a unique position in the ranking. Model quality is calculated by comparing it with the reference structure using particular similarity measure. Models generated by different tools are assumed to be independent and generally well predicted. There should be more structures with high quality value than invalid structures. The proposed method is based on a consensus approach and ranks models by the similarity to other models. Because models are generated independently, common structural motifs shared by different models should indicate a well predicted region. Rankings generated with this consensus approach were evaluated on selected challenges from blind experiments (CASP and RNA-Puzzles) using common comparison measures [1,2]. The evaluation shows that the proposed methodology can be a good estimation of de novo assessment of 3D structures.

References:

[1] P. Łukasiak, M. Antczak, T. Ratajczak, J. Błażewicz, SphereGrinder - reference structure-based tool for quality assessment of protein structural models, *Proc. of the 2015 IEEE Int. Conf. on Bioinformatics and Biomedicine (BIBM), Washington D.C., USA* (2015) 665–668.

[2] P. Łukasiak, M. Antczak, T. Ratajczak, M. Szachniuk, M. Popenda, R.W. Adamiak, J. Błażewicz, RNAssess - a web server for quality assessment of RNA 3D structures, *Nucleic Acid Research* **43** (2015) 502–506.

Thursday
15:40-16:00

The moldable tasks in container port terminal

Maciej Machowiak

Poznań University of Technology, Poland

maciej.machowiak@cs.put.poznan.pl

The problem of the moldable task scheduling has been studied. In our model the quay cranes operating along the berths are processors and the vessels are tasks to be processed by the processors without preemption. We also take into account the fact that berthing time of a ship depends on the number of quay cranes allocated to it. This dependence is a processing speed function of a task and it is considered to be a non-linear strictly increasing and arbitrary. Our approach considers berth allocation together with quay crane allocation. From the port operator and the ship owners point of view the main goal is to increase utilization of the berths and minimize the turn-around time of the ships. In the moldable task scheduling, this will be achieved by minimizing the maximum completion time of all tasks, i.e., the schedule length.

To ensure the practical issues that appear at container terminals, we introduced additional assumptions:

1. Just as in other papers [1] we consider a lower bound and an upper bound on the number of quay cranes allocated to each ship.

2. In contrast with other models the berth is considered as continuous resource and there is no discretization of it. In this case the quay itself is treated as a berth and the berthing decision takes the form of where along the quay to assign incoming ships.

We present two approximation algorithms which solved problem with bounds starting from processors allocation given by lower bound. We conducted computational experiments to evaluate the performance of the algorithm. We made the worst case analysis and show that the algorithm gives solution not worst than 3 of lower bound for the problem.

References:

[1] J. Błażewicz, T. C. E. Cheng, M. Machowiak, C. Oguz, Berth and quay crane allocation: A moldable task scheduling model, *Journal of the Operational Research Society* **62(7)** (2011) 1189–1197.

The Vehicle Routing Problem with Heterogeneous Fleet and Draft Limits

Saturday
11:50-12:10

Simona Mancini

University of Cagliari, Italy

simona.mancini@polito.it

(*joint work with* Paolo Fadda, Gianfranco Fancello, Patrizia Serra)

In this paper, we introduce a Vehicle Routing Problem arising in Maritime Transportation in which a set of ports must be visited by a heterogeneous naval fleet. Each port is characterized by a demand to be served and a draft limit representing the maximum draft of a ship allowed to enter the port. The fleet is composed by different ships, each characterized in terms of: load capacity, fixed costs to enter each port, unitary travel costs and empty and full load draft values. The actual draft of a ship at a given time is calculated as the draft of the empty ship plus a linear function of the load on board at that time. Draft limits can prevent ships to enter some ports when they are fully loaded, thus imposing constraints on the sequence of ports visited. This problem, named Vehicle Routing with Heterogeneous Fleet and Draft Limits (VRPHFDL), extends the Traveling Salesman Problem with Draft Limit, introduced in [1], in which only one ship, serving all the ports in a single tour, is considered. The objective of the VRPHFDL is to minimize the total network cost given by the sum of fixed costs incurred at ports and travel costs. To solve the problem we propose a Mixed Integer Programming (MIP) model and several Valid Inequalities (VI) to strengthen the formulation and reduce computational times. Computational results carried on instances of different sizes show the benefit of the proposed VI. Furthermore, we introduce a real-life application in Liquefied Natural Gas (LNG) shipping, in which multiple visits are required and a minimum shift must be guaranteed between consecutive visits. Different modeling and methodological issues to handle this extension of the problem are discussed.

Acknowledgements: This research has been funded by the Project "SIGNAL Strategie transfrontaliere per la valorizzazione del Gas Naturale Liquido" which is part of the Interreg Italia-Francia Marittimo 2014-2020 cooperation program.

References:

[1] J.G. Rakke, M. Christiansen, K. Fagerholt, G. Laporte, The Traveling Salesman Problem with Draft Limits, *Computers & Operations Research* **39** (2012) 2161–2167.

Friday
11:30-11:50

Scheduling for the Growing of Crops to Meet Demand

Toni Martinez-Sykora

CORMSIS, University of Southampton, United Kingdom

a.martinez-sykora@soton.ac.uk

(*joint work with* Chris N. Potts)

A problem of scheduling the growing of crops to meet consumer demand as closely as possible is considered. The plants are to be assigned to growing locations of a given capacity, where all plant types in the same location at any time must have identical requirements for irrigation and lighting. Movement of plants between locations is allowed, although such movements should be minimized as far as is possible. A hierarchical decomposition math-heuristic is proposed, where the first phase minimizes the total weighted quantity of unsatisfied demand, and the second phase uses the satisfied demands from the first phase as input and aims to minimize plant movements. A computational evaluation of the math-heuristic using data from an industrial partner is reported.

Insights into an analysis of the intra- and intermolecular contacts in and between biomolecules

Thursday
15:00-15:20

Maciej Miłostan

Poznań University of Technology, Poland

Maciej.Milostan@cs.put.poznan.pl

(*joint work with* Jakub Wiedemann)

Intramolecular contacts depict interactions that occur between building blocks of a single biomolecule, e.g., between base pairs in DNA or RNA and between amino acids in proteins. On the highest level of details, the contacts are chemical bonds or electrostatic forces between single atoms. The precise definition of intramolecular contacts varies depending on the kind of the molecule and level of details. However, it is possible to generalize that definition by saying that two building blocks of the given molecule are in contact if some distinctive elements of their structures are in spatial proximity.

Intramolecular contacts are crucial for identification of the higher level of structural organization of a considered molecule, e.g., secondary structures or structural domains. The contacts patterns are in fact graphs of contacts, so the problem of identification of substructures is a graph clustering problem. Whatsmore, biomolecules can share domains or secondary structures even if their composition, described in the form of a sequence of nucleotides (for RNA or DNA) or amino acids, significantly differs. Thus there is a need for storing the information about relations between sequences and structures to be able to identify sequences that may correspond to the given structure and, vice versa, to identify structures that correspond to the given sequence. Besides storing the data, there is a need for efficient searching mechanisms. A search for similar structures can be depicted, for example, as the subgraph isomorphism problem.

The intermolecular contacts do not differ significantly from intramolecular ones, besides the fact that they occur between at least two independent molecules in complex or bound to each other. The analysis of the binding patterns often take into account the geometrical properties of the molecules, e.g., identification of the surface elements or fitting evaluation.

The talk will present selected problems for intramolecular and intermolecular contact analysis with potential solutions.

Friday
10:50-11:10

Flowshop scheduling with learning-effect and job-rejection

Baruch Mor

Ariel University, Israel

baruchm@ariel.ac.il

(*joint work with* Gur Mosheiov, Dana Shapira)

We study scheduling problems on a proportionate flowshop. Three objective functions are considered: minimum makespan, minimum total completion time and minimum total load. We consider a learning process, thus the processing time of a job processed later in sequence is reduced. The scheduler has the option of job rejection, i.e., he may process only a subset of the jobs, and be penalized for the rejected jobs. An upper bound on the total permitted rejection cost is assumed. Since the single machine versions of these problems were shown to be NP-hard, we focus on the introduction of pseudo-polynomial dynamic programming algorithms, indicating that the problems are NP-hard in the ordinary sense. We provide an extensive numerical study verifying that the proposed solution algorithms are efficient for medium size instances.

References:

[1] D. Biskup, Single-machine scheduling with learning considerations, *European Journal of Operational Research* **115** (1999) 173–178.

[2] S. Fiszman, G. Mosheiov, Minimizing total load on a proportionate flowshop with position-dependent processing times and job rejection, *Information Processing Letters* **132** (2018) 39–43.

[3] B. Mor, D. Shapira, Improved algorithms for scheduling on proportionate flowshop with job-rejection, *Journal of the Operational Research Society* (2019). DOI: 10.1080/01605682.2018.1506540.

[4] G. Mosheiov, Scheduling problems with a learning effect, *European Journal of Operational Research* **132** (2001) 687–693.

[5] L. Zhang, L. Lu, J. Yuan, Single-machine scheduling under the job rejection constraint, *Theoretical Computer Science* **411** (2010) 1877–1882.

On hard scheduling problems with generalized due-dates

Friday
10:30-10:50

Gur Mosheiov

The Hebrew University, Israel

msomer@huji.ac.il

(*joint work with* Enrique Gerstl)

In scheduling problems with generalized due-dates (gdd), the due-dates are specified according to their position in the sequence, and the j-th due-date is assigned to the job in the j-th position. In this paper, we study a number of problems with gdd. We focus first on the classical objective of minimizing the number of tardy jobs on parallel identical machines. This problem was proved by Hall (1986) to be NP-hard. In our knowledge, no solution procedure has been proposed in the literature. We introduce an efficient pseudo-polynomial dynamic programming (DP) algorithm, proving that the problem is NP-hard in the ordinary sense. Our numerical tests indicate that large instances are solved to optimality extremely fast. For example, the worst case running time required for solving a 2-machine 1000-job problem does not exceed 1 second.

The traditional version of the problem (that of minimizing the number of tardy jobs on parallel identical machines with job-specific due-dates) is clearly harder. We extend our proposed DP to this more complicated case, and compare the results. While the extended DP solves instances of medium size efficiently, we show numerically that it is quite limited compared to the performance of the algorithm introduced for the gdd setting.

We also extend our dynamic programming algorithm to a setting of uniform machines, i.e. to the case that machines have different speeds. Despite the fact that this setting is clearly more complicated, the modified DP appears to be fairly similar. This is reflected in the performance of the algorithm as the total computational effort remains almost unchanged. Another objective considered here is that of maximizing the number of jobs completed exactly on time on a single machine (max-on-time). We prove that this problem is NP-hard in the strong sense. In our knowledge, this is the only example of a scheduling problem, where the job-specific version has a polynomial time solution, and the gdd version is strongly NP-hard. An efficient heuristic and a branch-and-bound algorithm are introduced and tested. The branch-and-bound is shown to be able to solve problems of medium size in reasonable time, and the heuristic obtains the optimal schedule in most cases. We also study two special cases: max-on-time for a given job-sequence and max-on-time with unit-execution-time jobs. Both cases are shown to have polynomial time dynamic programming algorithms, and instances of up to 1000 jobs are easily solved.

References:

[1] Y. Gao, J. Yuan, Unary NP-hardness of minimizing the total deviation with generalized or assignable due dates, *Discrete Applied Mathematics* **189** (2015) 49–52.

[2] E. Gerstl, G. Mosheiov, Single machine scheduling problems with generalized due-dates and job-rejection, *International Journal of Operations Research* **55** (2017) 3164–3172.

[3] N. G. Hall, Scheduling problems with generalized due dates, *IIE transactions* **18** (1986) 220–222.

[4] N. G. Hall, S. P. Sethi, C. Sriskandarajah, On the complexity of generalized due date scheduling problems, *European Journal of Operational Research* **51** (1991) 100–109.

[5] Y. Yin, S. R. Cheng, T. C. E. Cheng, C. C. Wu, W. H. Wu, Two-agent single-machine scheduling with assignable due dates, *Applied Mathematics and Computation* **219** (2012) 1674–1685.

Tree search based approaches for scheduling flexible job shops incorporating machine operator restrictions

Saturday
11:10-11:30

David Müller

University of Siegen, Management Information Science, Germany

david.mueller@uni-siegen.de

(*joint work with* Dominik Kress, Erwin Pesch)

The job shop scheduling problem (JSP) is a well-known scheduling setting that arises in many traditional manufacturing systems (see, for example, [1]). Modern real-world manufacturing systems, however, are usually more complex as they oftentimes feature multiple machines of the same type as well as multi-purpose machines that allow for processing different types of operations. This is taken account of in a generalization of the JSP, referred to as the flexible job shop scheduling problem (FJSP, see [2]). Additionally, workforce planning plays an important role in real-world manufacturing systems, especially in the presence of differently skilled machine operators. In this talk, we therefore address a FJSP that aims at makespan minimization and that incorporates a heterogeneous workforce. We present two heuristic approaches. They are based on a filter-and-fan procedure and combine a local search procedure with a tree search procedure to enable a multi-stream neighborhood search strategy. For the design of our neighborhood structure, we propose two different decomposition based procedures. In a computational study, we evaluate the performance of our proposed heuristic approaches against a state-of-the-art constraint programming solver on randomly generated instances and show that our approaches are able to outperform existing metaheuristic approaches on benchmark instances from the literature.

Acknowledgements: This work has been supported by the European Union and the state North Rhine-Westphalia through the European Fund for Regional Development (EFRD). It has been conducted as part of the project "EKPLO: Echtzeitnahes kollaboratives Planen und Optimieren" (EFRE-0800463).

References:

[1] J. Błażewicz, K.H. Ecker, E. Pesch, G. Schmidt and J. Węglarz, *Handbook on scheduling: from theory to applications*, Springer, Berlin (2007).

[2] P. Brucker and R. Schlie, Job-shop scheduling with multi-purpose machines, *Computing* **45(4)** (1990) 369–375.

Thursday
11:10-11:30

Vertex adjacencies in the traveling salesperson polytope by simulated annealing

Andrei Nikolaev

P. G. Demidov Yaroslavl State University, Russia

andrei.v.nikolaev@gmail.com

(*joint work with* Anna Kozlova)

We consider the 1-skeletons of the symmetric and asymmetric traveling salesperson polytopes whose vertices are all possible Hamiltonian tours in the complete directed or undirected graph, and the edges are geometric edges or one-dimensional faces of the polytope. It is known that the question whether two vertices of the symmetric or asymmetric traveling salesperson polytopes are nonadjacent is NP-complete [1]. A sufficient condition for nonadjacency can be formulated as a combinatorial problem: if from the edges of two Hamiltonian tours we can construct two complementary Hamiltonian tours, then the corresponding vertices of the traveling salesperson polytope are not adjacent [2].

We consider a heuristic simulated annealing algorithm to solve this problem. Let x and y be two Hamiltonian tours. We denote by $x \cup y$ a multigraph that contains all edges of both tours x and y. We generate the candidate state z and w as two complementary vertex-disjoint cycle covers of the multigraph $x \cup y$. The energy function to minimize is the total number of connected components in z and w. If it equals 2, then z and w are two Hamiltonian tours. We construct a neighbor candidate state by finding an edge of w with endpoints in two different connected components of z, or vice versa, and adding it to the queue of fixed edges of z.

The algorithm has a one-sided error: the answer "not adjacent" is always correct. The largest instance that was solved by the algorithm had random Hamiltonian tours on 5 000 vertices and required 2 797 275 ms.

Acknowledgements: The research is supported by the grant of the President of the Russian Federation MK-2620.2018.1.

References:

[1] C. H. Papadimitriou, The adjacency relation on the traveling salesman polytope is NP-Complete, *Math. Program.* **14** (1978) 312–324.

[2] M.R. Rao, Adjacency of the traveling salesman tours and 0-1 vertices. *SIAM J. Appl. Math.* **30** (1976) 191–198.

A Matheuristic for the Order Acceptance and Scheduling Problem

Thursday
17:30-17:50

Ceyda Oğuz

Koç University, Turkey

coguz@ku.edu.tr

(*joint work with* İstenç Tarhan)

Firms operating on a make-to-order basis may not satisfy the entire demand due to capacity limitations and tight delivery time requirements. This necessitates selecting only part of customer orders to maximize the total revenue, which gives rise to the order acceptance and scheduling (OAS) problems. Herein, we propose a matheuristic for the OAS problem consisting of a hybrid of mixed integer programming (MIP) and constraint programming (CP).

In the OAS problem, we are given a single machine and a set of independent orders at the beginning of the planning period. For each order, there is an associated release time, processing time, due date, deadline, sequence dependent setup times, revenue and unit tardiness penalty cost. Each order should be processed between its release time and its deadline; however, satisfying all orders may not be possible due to the capacity limitations. Therefore, the problem can be defined as a joint decision of which orders to accept and how to schedule the accepted orders. The manufacturer may complete an accepted order until its deadline, but for each time unit beyond its due date, she incurs a tardiness penalty. Although commercial solvers can handle moderate size problems, they fail as the problem size (i.e. the number of orders and the length of the planning horizon, accordingly) increases.

In the proposed algorithm, we developed an MIP model and a CP model that are communicated iteratively. The original planning horizon is decomposed into predefined number of segments. MIP uses a relaxed time-indexed model formulation for the OAS problem without setup times to assign orders to those time segments; unaccepted orders are not assigned to any time segments. After MIP finds the optimal assignment of orders to time segments, CP, starting from the first segment, solves the OAS problem of each segment sequentially and generates a feasible solution to the original problem which is improved by a variable neighborhood search algorithm. Since MIP assigns orders to time segments without considering the setup times, CP may not schedule all of the assigned orders within the respective time segment, and such a segment is called "overloaded". To cope with overloaded segments, we add in the next iteration a compensation term to the objective function of MIP to create idle times and define a decision variable for the amount of respective idle time in that segment. MIP is resolved after adding the compensation term and iterations continue until the termination criterion is satisfied.

This is an ongoing study and preliminary runs show that the proposed algorithm can reach near optimal solutions of large size problems in minutes while commercial solvers cannot find competitive solutions in much more time.

Saturday
10:30-10:50

A novel MILP model for cyclic scheduling with interlacing

Olivér Ősz

Széchenyi István University, Hungary

osz.oliver@sze.hu

(*joint work with* Máté Hegyháti)

Cyclic scheduling is a widely used technique for long-term scheduling of production systems. Exact solution methods are practically inapplicable for the long planning periods (several months) used in the industry. With cyclic scheduling, a shorter (1-5 days) schedule, a cycle is determined, which will be repeated along the longer time period.

The objective of cyclic scheduling is to maximize hourly profit, which is the profit of a cycle divided by the cycle time. The non-linear nature of the objective is difficult to handle by most scheduling methods. To simplify the problem, and to separate planning decisions of demand and production, the product quantities of a cycle are assumed to be fixed in the scheduling problem. Then the simplified objective is to minimize the cycle time.

In this work, the cyclic variant of the well-known job-shop problem is investigated, where products are produced through a given sequence of operations. A solution of the regular job-shop problem can also be used as a cycle with the cycle time equal to the completion time. However, better cycle times can be achieved if cycle boundaries are defined individually for each machine. This way, the cycle time can be decreased to the length of the longest schedule among the machines. While this technique eliminates the idle times of machines at the start and end of their schedules, interlacing methods can utilize intermediate idle periods in machine cycles.

Interlacing allows the machines to start operations from their next cycle before finishing the current cycle. Allowing interlacing between cycles can lead to higher throughput over time, but can also increase the flow time of products, which raises concerns about material storage. This problem is usually solved in the literature by limiting the number of cycles that can interlace. For cyclic scheduling with limited interlacing, only non-linear models have been published, which use heuristic search methods. In this work, an exact, linear formulation is presented for the problem. The MILP solution performance was tested on literature examples.

Acknowledgements: This work was financially supported by the ÚNKP-18-3 New National Excellence Program of the Ministry of Human Capacities of Hungary.

Equilibrium Colorings and the Four Color Theorem

Thursday
17:10-17:30

Panagiota Panagopoulou

University of Patras, Greece

panagopp@upatras.gr

The well-known Four Color Theorem states that four colors suffice to color the vertices of a planar graph so that no pair of adjacent vertices get the same color. The theorem first appeared as a conjecture in 1852 and, after several false proofs and disproofs that appeared in the 20th century, a proof was finally given in 1976. The proof however is computer-assisted and cannot be verified by hand, and it remains a challenging open problem to find a purely mathematical proof of the Four Color Theorem (if one exists).

The approach we propose is based on the fact that there exist proper colorings (which we call *equilibrium colorings*) with the property that *every* vertex is connected to a vertex of *each* color class of equal or greater cardinality than its own color class. In fact, starting with an arbitrary proper coloring, we can always find an equilibrium coloring that uses at most as many colors as the original coloring.

Now, every planar graph is known to admit a proper coloring using 5 colors (this fact is known as the Five Colour Theorem). We start with such a 5-coloring and compute an equilibrium coloring that uses no more than 5 colors. Such a coloring partitions the vertices of the graph into 5 independent sets of vertices (the color classes). We focus on the special case where the two smallest color classes have each cardinality equal to 1. For this case, we show how to transform the equilibrium coloring into a proper coloring that uses at most 4 colors. We are able to do so by exploiting the fact that planar graphs do not have K_5 or $K_{3,3}$ as minors.

This special case where the two smallest color classes are singletons is the furthest we could get towards proving the Four Color Theorem; however, we point out that, if one could use this case as the induction base to prove (by induction on the size of the second smallest color class) that *"if a planar graph admits an equilibrium 5-coloring such that the smallest color class is a singleton, then the graph is 4-colorable"*, then this would immediately imply the Four Color Theorem, i.e., that any planar graph is 4-colorable.

Thursday
16:50-17:10

Complex precedence constraints for flexible job shop scheduling problems

Dimitris Paraskevopoulos

Cass Business School, City, University of London, United Kingdom

dimi@city.ac.uk

(*joint work with* Greg Kasapidis, Panagiotis Repoussis, Christos D. Tarantilis)

In Flexible Job Shop Scheduling problems (FJSSP) there is a set of job operations that need to be executed on a set of machines. The main difference with Job Shop Scheduling problems is that the job operations can be executed by more than one machine, while having a different processing time per machine. Even if the FJSSP can be used to model various shop scheduling challenges, real-world applications require a more detailed description of the production environment that allow for more complex operational constraints. Inspired by this need to model more realistic shop scheduling settings, in this paper, we extend the FJJSP by introducing complex precedence constraints among the operations. In particular, we assume that the precedence constraints of each job are not sequential, and an operation may have multiple predecessor and successor operations. To solve the problem, we developed a scatter search algorithm that uses path relinking principles to combine multiple solutions and produce offspring. Efficient local search mechanisms are presented that perform a fast exploration of the solution space, without compromising solution quality. A new benchmark generator is proposed, based on well known problems of the literature, to generate new benchmark FJSSP instances with complex precedence constraints. Extensive computational experiments are conducted to prove the efficiency of the proposed SS, both on the new problem instances and on well known benchmark FJSSP instances. Our SS was able to produce 11 new best solutions on large scale FJSSP instances of the literature, while being highly competitive with regards to the remaining problems. To assess the complexity of the new benchmark instances with complex precedence constraints, a MIP and Constraint Programming solver of a commercial optimiser were used, and computational results and comparisons to results produced by our SS are presented.

Heuristics for the Quadratic TSP

Thursday
10:50-11:10

Ulrich Pferschy

University of Graz, Austria

pferschy@uni-graz.at

(*joint work with* Rostislav Stanek, Peter Greistorfer, Klaus Ladner)

The classical travelling salesman problem (TSP) asks for a shortest tour through all vertices of a graph with respect to the sum of edge costs. The quadratic travelling salesman problem (QTSP) associates a cost value with every two edges traversed in succession. After reviewing exact ILP-models for the general QTSP based on fractional and integral separation of subtours, we will concentrate on the geometric case where vertices correspond to points in the Euclidean plane and the quadratic costs implied by two successive edges represent the turning angle at the enclosed vertex. This setting occurs e.g. in robotics, where turning may be more critical than moving on a straight line.

Observing that optimal tours usually have the form of large "circles" or "spiral" shapes, we first develop a number of heuristic algorithms introducing a lens-shaped neighborhood of edges and a decomposition of the vertex set into layers of convex hulls. These layers are then merged into a tour either by a greedy-type procedure or by an auxiliary ILP model.

Secondly, we consider an ILP model for a standard linearization of QTSP and compute fractional solutions of a relaxation. By rounding we obtain a collection of subtours, paths and isolated points which are combined into a tour by various strategies, all of them involving auxiliary ILP models. Finally, different improvement heuristics are proposed, most notably a matheuristic which locally reoptimizes the solution for rectangular sectors of the given point set by an ILP approach. Extensive computational experiments for benchmark instances from the literature and extensions thereof are reported. It turns out that the best-known heuristic approach from the literature [2] can be improved significantly.

References:

[1] O. Aichholzer, A. Fischer, F. Fischer, J.F. Meier, U. Pferschy, A. Pilz, R. Stanek, Minimization and maximization versions of the quadratic traveling salesman problem, *Optimization* **66** (2017) 521–546.

[2] A. Fischer, F. Fischer, G. Jäger, J. Keilwagen, P. Molitor, I. Grosse, Exact algorithms and heuristics for the quadratic traveling salesman problem with an application in bioinformatics, *Discrete Applied Mathematics* **166** (2014) 97-114.

[3] R. Stanek, P. Greistorfer, K. Ladner, U. Pferschy, Geometric and LP-based heuristics for angular travelling salesman problems in the plane, *Computers & Operations Research*, to appear (2019).

Thursday
15:40-16:00

Graceful difference labelings of disjoint directed cycles

Christophe Picouleau

CEDRIC - CNAM, Paris, France

christophe.picouleau@cnam.fr

(*joint work with* Alain Hertz)

A graceful difference labeling of a directed graph G with vertex set V is a bijection $f : V \to \{1, \ldots, |V|\}$ such that, when each arc uv is assigned the difference label $f(v) - f(u)$, the resulting arc labels are distinct. We are interested in the case of a disjoint unions of directed cycles. When $G = n\overrightarrow{\mathbf{C_3}}$, i.e. a collection of n directed triangles, $n \geq 1$, we show that G has a graceful difference labeling if and only if $n \neq 1$.

Our proof is constructive. We consider four subcases depending on the remainder of $n/7$. It uses a recurrence where the base is from $n = 2$ to $n = 9$.

Then we use this result to prove some more general cases.

References:

[1] J.A. Gallian, A Dynamic Survey of Graph Labeling, *The Electronic Journal of Combinatorics* **69** (2011) 245–253.

Thursday
11:50-12:10

Solving the multi-objective shortest path problem using local search methods

Yi Qu

Newcastle Business School, Northumbria University, United Kingdom

yi.qu@northumbria.ac.uk

This research concerns the multi-objective shortest path problem (MSPP) and novel methods for solving it. The problem is an extension of the classical shortest path problem and has a wide range of practical applications, particularly in passenger transportation. Two, fast, local search algorithms are presented for solving MSPP. To evaluate these algorithms and other methods, four performance indicators are proposed and applied. Computational results demonstrate that the local search algorithms are faster than other heuristic methods for the MSPP presented in literature and are also able to produce good-quality solutions.

Knockout-based analysis in Stochastic Petri Net models of complex biological systems on the example of atherosclerosis process

Thursday
10:50-11:10

Marcin Radom

Institute of Computing Science, Poznań University of Technology, Poland
Institute of Bioorganic Chemistry, Polish Academy of Sciences, Poland

Marcin.Radom@cs.put.poznan.pl

(*joint work with* Dorota Formanowicz, Piotr Formanowicz)

Petri nets and their numerous extensions are well known tools, used for example in the systems biology for the purpose of modeling both simple and complex biological processes. Stochastic Petri Nets (SPN) seem to be especially well suited for modeling biological systems which, on a molecular level, are stochastic in nature. SPN can be analyzed using the same approaches that are available for the classical nets, while it can also offer new ways of analysis based on the probability theory, which can greatly enhance the simulation of the model behavior under different conditions. In our study we have investigated different interesting problems connected with the atherosclerosis process, its creation and progression. Its complexity makes it particularly difficult to fully understand; thereby having its detailed stochastic model greatly contributes to the discovery of new facts about this complex phenomenon. In our study we used SPN model of atherosclerosis combined with the so called knockout analysis. Such an analysis was used for investigating both structural and dynamic properties of the net. The simulation based analysis connected with the knockout approach gives especially interesting results about the model dynamics and the interactions between seemingly distant sub-processes and reaction included in the model.

Thursday
11:10-11:30

Minimum-Cardinality Balanced Edge Addition in Polarized Networks

Celso Ribeiro

Universidade Federal Fluminense, Brasil

celso@ic.uff.br

(*joint work with* Ruben Interian)

Polarization is the division into sharply contrasting groups or sets of opinions or beliefs. The issue of polarization has been discussed by politicians, media, and researchers. Fake news spread faster in polarized networks or groups. At the same time, fake and tendentious news can accentuate polarization within already existing echo chambers in the social networks. Polarized networks are divided into two or more strongly connected groups, with few edges between vertices belonging to different groups. In order to reduce polarization, networks can be treated by minimal external interventions consisting of the addition or the removal of vertices and edges. A new optimization problem addressing the issue of polarization reduction by edge additions is presented in this work. We formulate the Minimum-Cardinality Balanced Edge Addition Problem. Next, we discuss its complexity and we propose integer programming approaches for its solution.

Reducing the domination number of graphs via edge contractions

Friday
10:30-10:50

Bernard Ries

University of Fribourg, Switzerland

bernard.ries@unifr.ch

(*joint work with* Esther Galby, Paloma T. Lima)

We study the following problem: given a connected graph G, can we reduce the domination number of G by at least one using k edge contractions, for some fixed integer $k \geq 0$? More formally, we are interested in the following problem.

k-Edge Contraction(γ)
Instance: A connected graph $G = (V, E)$
Question: Can G be k-edge contracted into a graph G' such that $\gamma(G') \leq \gamma(G) - 1$?

We prove the (co)-NP-hardness of k-Edge Contraction(γ) for $k = 1, 2$. We further show that 1-Edge Contraction(γ) is W[1]-hard parameterized by the size of a minimum dominating set plus the mim-width of the input graph, and that it remains NP-hard when restricted to P_9-free graphs, bipartite graphs and $\{C_3, \ldots, C_l\}$-free graphs for any $l \geq 3$. Finally, we present some positive results; in particular, we show that for any $k \geq 1$, k-Edge Contraction(γ) is polynomial-time solvable for P_5-free graphs and that it can be solved in FPT-time and XP-time when parameterized by tree-width and mim-width, respectively.

Acknowledgements: The results presented here were obtained while Paloma T. Lima was visiting the University of Fribourg with a research grant from that same institution. This support is gratefully acknowledged.

Saturday
11:30-11:50

Sectorization applied to Routing Problems

Ana Maria Rodrigues

INESC TEC / CEOS.PP / ISCAP-P.Porto, Portugal

ana.m.rodrigues@inesctec.pt

(*joint work with* José Soeiro Ferreira, Cristina Lopes, Cristina Oliveira, Maria João Cortinhal)

Sectorization Problems (SP) appear in a wide context and are often associated with the geographical partition. A certain territory is divided into small parts or, alternatively, a set of elementary units, which belong to a large territory, are grouped according to certain characteristics and criteria. Applications are as diverse as political districting, the design of sales territory or waste collection management [1]. Various approaches, namely, exact and metaheuristics, are proposed in the literature to deal with SP [2].

Different applications of SP involving routes will be presented in this talk. One is related to the collection and distribution of donated food and its distribution to non-profit organizations. The objective is to ensure the sustainability of the activity by reducing food waste and emissions of CO_2, while the economic efficiency is improved. The other practical example considers the transportation of patients with a mental disability between their homes and a hospital center (HC). Every morning, from Monday to Friday, several vehicles of the HC transport a different group of patients between their homes and the HC. At the end of the day, at different moments, patients return to their houses. Transportation is done considering a set of particularities peculiar to this type of situation including the knowledge of drivers and caregivers.

Acknowledgements: This work is financed by the ERDF - European Regional Development Fund through the Operational Programme for Competitiveness and Internationalisation - COMPETE 2020 Programme and by National Funds through the Portuguese funding agency, FCT-Fundação para a Ciência e a Tecnologia within project POCI-01-0145-FEDER-031671.

References:

[1] A.M. Rodrigues and J.S. Ferreira, Sectors and Routes in Solid Waste Collection, in: J. P. Almeida *et al.* (ed.), *Operational Research, CIM Series in Mathematical Sciences 4*, Springer International Publishing, Switzerland (2015) 353–375.

[2] M.J. Cortinhal *et al.*, Local search heuristics for sectoring routing in a household waste collection context, *European Journal of Operational Research* **255** (2016) 68–79.

Lagrangian duality as a tool to relate approaches for robust problems

Saturday
11:50-12:10

Filipe Rodrigues

University of Aveiro, Portugal

fmgrodrigues@ua.pt

(*joint work with* Agostinho Agra, Erick Delage, Cristina Requejo)

In this paper we consider a class of min-max robust problems that includes many practical problems such as the lot-sizing problem under demand uncertainty. By considering a Lagrangian relaxation of the uncertainty set we derive a tractable approximation that we relate with the classical dualization approach introduced by Bertsimas and Sim (2004) and also with the exact min-max approach. Moreover we show that the dual Lagrangian approach coincides with the affine approximation of the uncertainty set.

The theoretical study is applied to a lot-sizing problem where demands are assumed to be uncertain and to belong to the uncertainty set with a budget constraint for each time period introduced by Bertsimas and Sim (2004).

Computational experiments based on medium size instances are carried out to evaluate the performance of the approaches discussed when setup costs are considered in the lot-sizing problem. For large size instances, we design two heuristic strategies based on the interpretation of the Lagrangian multipliers in the proposed dual model. The computational experiments show the efficiency of the designed heuristics to obtain solutions with low cost in a short time.

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References:

[1] D. Bertsimas and M. Sim, The price of robustness, *Operations Research* **52** (2004) 35–53.

[2] D. Bertsimas and A. Thiele, A robust optimization approach to inventory theory, *Operations Research* **54** (2006) 150–168.

Thursday
10:30-10:50

The role of YRNA-derived small RNAs in atherosclerosis development and progression modeled and analyzed using stochastic Petri nets

Agnieszka Rybarczyk

Institute of Computing Science, Poznań University of Technology, Poland
Institute of Bioorganic Chemistry, Polish Academy of Sciences, Poland

arybarczyk@cs.put.poznan.pl

Non-coding RNAs are involved in a multitude of cellular processes and for many of them it has been demonstrated that they have a key role in regulating diverse aspects of development, homeostasis and diseases. Among them, YRNA-derived fragments are now of clinical interest and have attracted much recent attention as potential biomarkers for disease, since they are highly abundant in cells, tissues and body fluids of humans and mammals, as well as in a range of tumors.

In this study, to investigate the participation of the YRNA-derived small RNAs in the development and progression of the atherosclerosis, a stochastic Petri net model has been build and then analyzed. First, MCT-sets and t-clusters were generated, then knockout and simulation based analysis was conducted. The application of systems approach that has been used in this research has enabled for an in-depth analysis of the studied phenomenon and has allowed drawing valuable biological conclusions.

On split B_1-EPG graphs

Thursday
17:30-17:50

David Schindl

Department of Informatics, University of Fribourg, Switzerland

david.schindl@unifr.ch

(*joint work with* Zakir Deniz, Simon Nivelle, Bernard Ries)

A graph belongs to B_1-EPG if one can associate to each vertex a path on a rectangular grid with at most one bend, such that two vertices in G are adjacent if and only if their corresponding paths share at least one grid edge. This class is a natural extension of the class of interval graphs and was first introduced in [1]. We focus on graphs in B_1-EPG when restricted to split graphs. We first give some inclusion results on subclasses defined by restricting the paths to some orientations. Then we further concentrate on the subclass where only L-shaped paths are allowed. For this class, a 9 forbidden induced subgraphs characterization was conjectured in [2]. We disprove it by providing about 20 additional forbidden subgraphs, and provide an alternative characterization. The complexity status of recognizing graphs in this class, as well as a complete forbidden induced subgraphs characterization remain unknown.

References:

[1] M. Golumbic, M. Lipshteyn, M. Stern, Edge intersection graphs of single bend paths on a grid, *Networks* **54** (2009) 130–138.

[2] K. Cameron, S. Chaplick, C.T. Hoang, Edge intersection graphs of L-shaped paths in grids, *Discrete Applied Mathematics* **210** (2016) 185–194.

Thursday
11:30-11:50

On a Threshold Graph Model for Complex Networks

Irene Sciriha

University of Malta, Malta

irene.sciriha-aquilina@um.edu.mt

(*joint work with* Johann Briffa)

In the last twenty years, a number of different classes of graphs have been proposed to model real–world networks. The questions we ask are:

(i) Given a network G, is there a threshold graph that is sufficiently close to G that it can be used instead of G for the purposes of computing network statistics, parameters and spectral properties?

(ii) How can computation time be reduced by drawing on the nice geometric properties of threshold graphs?

Real–world networks often display topological features that require exponential–time algorithms. On the other hand, threshold graphs display a nested split graph (NSG) structure that can reduce the complexity of algorithms to determine network invariants. The vertex set of a NSG can be partitioned into cliques and co–cliques that give an equitable vertex–partition [1]. The reason that NSGs are so nice to work with is that all connected NSGs on n vertices correspond to a unique binary string of length $n-2$. Many graph invariants can be computed directly from it. For instance the string 0110001101, of length 10, corresponds to the NSG, shown in Figure 1, on 13 vertices, with vertex partition 2,2,3,2,1,2, where the first and last parts of the 0–1 string are increased by one. The entries 0 in the string correspond to the addition of isolated vertices and the entries 1 to dominating vertices in the construction of the NSG. An edge between two parts of the vertex partition indicates that each vertex of one part is adjacent to each vertex of the other part.

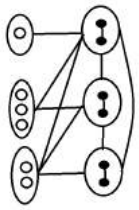

Figure 1: The NSG with creation sequence 0110001101

We are using Markov chains and simulated annealing to determine a NSG close enough to a given graph G. The problem centres on the best distance functions to use for reasonable computation times and reliable values of graph invariants of the NSG to which the process converges.

References:

[1] I. Sciriha and S. Farrugia, On the spectrum of threshold graphs, *ISRN Discrete Mathematics International Scholarly Journal* **108509** (2011).

Tabu Search for Multi-Period Sales Districting Problem

Thursday
15:20-15:40

Saranthorn Phusingha

University of Edinburgh, United Kingdom

saranthorn.phusingha@ed.ac.uk

(*joint work with* Joerg Kalcsics)

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.

In a recent extension of the problem, we consider 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 will present a mixed integer linear programming formulation for the problem. As only small data sets can be solved optimally, we propose a tabu search algorithm to solve instances of a size that are practically relevant. We will present our algorithm applied on the model and discuss its performance.

Saturday
10:50-11:10

Simulated Annealing Algorithm for 1-M-1 Pickup and Delivery Problem

Aydin Sipahioglu

Eskisehir Osmangazi University, Turkey

asipahi@ogu.edu.tr

(*joint work with* Islam Altin, Ahmet Yazici)

The Pickup and Delivery Problem (PDP) is a significant part of the Vehicle Routing Problem (VRP). In 1-M-1 PDP, while some materials are delivered from the warehouse to the customers, others are picked up by the customers from the warehouse. There are four kinds of solution models in the literature, namely General, Hamiltonian, Lasso and Double Path. The Hamiltonian solution model, also known as the simultaneously pickup and delivery method, satisfies pickup and delivery demand of each customer at the same time. Recently, Autonomous Robots (ARs) and Automated Guided Vehicles (AGVs) routing that became more important within the scope of Industry 4.0, are being modeled as 1-M-1 Hamiltonian PDP especially in-plant logistics. In this study, in-plant ARs routing is considered as 1-M-1 Hamiltonian PDP. Due to the NP-Hardness of the 1-M-1 PDP, a Simulated Annealing (SA) algorithm is developed to obtain a good solution in a reasonable computation time. Besides, five different neighborhood search methods are applied in each iteration probabilistically with regard to the scale of the problem. In order to evaluate the performance of the proposed algorithm, test problems with different scales from the literature were used. The computational results indicate that the proposed algorithm is efficient to solve 1-M-1 PDP and improves several best known solutions.

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Social Enterprise Tree Network Game

Thursday
10:50-11:10

Darko Skorin-Kapov

Adelphi University, USA

skorin@adelphi.edu

(*joint work with* Jadranka Skorin-Kapov)

We investigate the cost allocation strategy associated with the problem of providing service between network users residing at nodes of a social network. It is assumed that the social network platform is established in a symmetric complete network. There is a cost associated with each link and the service between any pair of nodes can be delivered via a directed path. The most cost efficient solution for such network is a minimum cost directed spanning tree. The network cost is distributed among users who might have conflicting interests. The objective of this work is to formulate the above cost allocation problem as a cooperative game, to be referred to as a Social Enterprise Tree Network (SETN) game, and develop a "fair" and efficient cost allocation scheme. The SETN game is related to minimum cost spanning tree games. The profound difference is that in the minimum cost spanning tree games the service is delivered from some common source node to the rest of the network, while under the social network platform there is no source and the service is established through the interaction between all participating nodes. The input to our cost allocation problem is the optimal SETN. We propose the associated SETN cooperative game in characteristic function form and show the existence of a cost allocation solution in the core of the SETN game.

Thursday
15:20-15:40

Approximation algorithms for early work maximization on two identical machines

Malgorzata Sterna

Poznań University of Technology, Poland

malgorzata.sterna@cs.put.poznan.pl

(*joint work with* Jacek Błażewicz, Xin Chen, Xin Han)

Scheduling problems with the early work criterion allow for maximizing the size of jobs executed before their due dates. We summarize studies on approximation algorithms proposed for the problem with two identical machines and a common due date, which is NP-hard [1].

We proposed a list algorithm, called Extended First Fit (EFF) due to its similarity to the approach proposed for the bin packing problem. We analyzed its behavior in the worst case and proved its finite approximation ratio [1]. Moreover, we proposed the polynomial time approximation scheme (PTAS) based on the features of optimal solutions of the considered problem [2] and on the dynamic programming approach (DP) solving it in pseudo-polynomial time [1].

The theoretical studies were completed with the extended computational experiments. The test results allowed for comparing the theoretically proved worst case efficiency of EFF and PTAS with their average performance. The solution quality and time efficiency were compared to the efficiency of DP and other simple list heuristics. As it could be observed for other scheduling models, approximation algorithms with the worst case guarantee are often outperformed by other approaches, with unknown approximation ratios, in the mean case (i.e. when the average behavior in experiments is considered).

Acknowledgements: This work was partially supported by the part of Poznan University of Technology grant No. 09/91/DSPB/0649 designated to the Poland-China Scientific & Technological Cooperation.

References:

[1] X. Chen, M. Sterna, X. Han, J. Błażewicz, Scheduling on parallel identical machines with late work criterion: offline and online cases, *Journal of Scheduling* **19(6)** (2016) 729–736.

[2] M. Sterna, K. Czerniachowska, Polynomial time approximation scheme for two parallel machines scheduling with a common due date to maximize early work, *Journal of Optimization, Theory and Application* **174(3)** (2017) 927–944.

Scheduling with controllable processing times and a common deadline to minimize maximum compression cost

Thursday
16:30-16:50

Vitaly A. Strusevich

University of Greenwich, London, United Kingdom

V.Strusevich@gre.ac.uk

(*joint work with* Akiyoshi Shioura, Natalia V. Shakhlevich)

We consider a range of scheduling problems either on a single machine or on parallel machines (identical and uniform). The processing times of jobs are controllable, i.e., they have to be chosen from given intervals. The jobs must be completed by a common deadline by compressing appropriately their processing times. Preemption is allowed. The jobs either are released simultaneously or have individual release dates. The objective is to minimize the maximum compression cost.

The problems in which the job deadlines can be different for different jobs have been studied within an area of Scheduling with Imprecise Computation. A recent survey [1] links these problems to the problems with controllable processing times and presents fast algorithms for their solution, typically based on the ideas of submodular optimization and/or parametric flow problems. These techniques cannot be fully used in the case of a common deadline if a goal is to design a fast algorithm. We present a number of algorithms based on common general principles adapted with a purpose of reducing the resulting running times.

References:

[1] A. Shioura, N.V. Shakhlevich and V.A. Strusevich, Preemptive models of scheduling with controllable processing times and of scheduling with imprecise computation: A review of solution approaches, *European Journal of Operational Research* **266** (2018) 795–818.

Searching for patterns in genes during integration of gene expression and copy number variation data

Thursday
11:50-12:10

Aleksandra Świercz

Poznań University of Technology, Poland

aswiercz@cs.put.poznan.pl

(*joint work with* Giovanni Felici, Agnieszka Zmienko)

Copy number variation (CNV) strongly affects the expression of the genes in the cells. It has been observed in the literature that CNV influences gene expression and can lead to several diseases. In this study we analyzed publicly available datasets of the plant *Arabidopsis thaliana*, composed of DNA sequencing datasets of 1060 samples, which were transformed into vectors of copy numbers for each gene (CNV), and transcriptomic dataset of 728 samples, which are represented as vectors of gene expression.

Genes were first clustered according to the values of the expression and the number of copies each gene appears in the genome. Automatic clustering method was not accepted by the biological experts because standard methods for measuring the distance of CNV vectors did not take into account the difference of duplication and deletion signals. Therefore, we classified genes on the base of the threshold levels of copy numbers, which gave us only 9 groups differing in the number of deletions or duplications of those genes in different plants. In the 9 groups, we analyzed the correlation of CNV and gene expression with the significance of the p-value. We searched for the dependencies of the deletion of the gene and its lower expression in the tissue.

The conclusions are to be confirmed by the biological experiments.

Acknowledgements: Grant Canaletto PO16MO04.

An Iterated Local Search approach for course timetabling with block lectures

Thursday
17:50:18:10

Kadri Sylejmani

University of Prishtina, Kosovo

kadri.sylejmani@uni-pr.edu

(*joint work with* Gresa Neziri, Artina Gashi, Kaltrina Zeqiri, Adrian Ymeri)

We consider the Curriculum Based - Course Timetabling (CB-CTT) problem, which was used in the 2nd International Timetabling Competition (ITC2007 [1], Track 3). The CB-CTT formulation can be used to model the problem of course timetabling at the universities, where a number of entities are considered, such as: time-slots (available for teaching over a week), courses and the respective teachers, rooms, and curriculum (i.e. study program) defined as a set of courses taken by a group of students. A feasible solution to this problem would be assigning all lectures of all courses in the available teaching time-slots, subject to the constraints, such that teachers are not assigned to teach multiple courses in the same time, the rooms should not be used to serve multiple courses at the same time, and the students of the same curriculum can not attend multiple courses at the same time. There are four soft components used for measuring the quality of the derived solutions, which are: the lectures must be spread into a minimum number of days, lectures belonging the same curricula should be adjacent to each other, the number of students that attend a given course must be less or equal to the number of seats in the assigned room, all lectures of the course must be assigned to the same room.

In this paper, with the aim of remodeling the CB-CTT problem to adhere to the particularities of the course timetabling needs at the University of Prishtina (specifically for three of its engineering faculties), we amend the original CB-CTT problem by adding an additional hard constraint that enforces the rule that all lectures of any given course should be taught in block (i.e. without breaks in between). For this variant of CB-CTT problem, we propose an approach based on Iterated Local Search (ILS) algorithm, which was also applied, in the form of an hybrid solution, for solving the original problem in the literature [2]. Our ILS approach explores the search space by means of two operators, developed to specifically deal with the new proposed variant of CB-CTT problem. The first operator comes in two variants, where it either changes the room of a single selected course, or it swaps the rooms of any two selected courses, whereas the second operator changes the assigned time-slot of any single course. Both operators enforce heuristic values (in respect to the soft constraints of the problem) and randomness features when selecting courses at a given iteration.

Further, based on the original format proposed in the literature [1], we develop a test set (consisting of eight new test instances) that comes out of real timetabling data from the three engineering faculties at the University of Prishtina, namely the Faculty of Electrical and Computer Engineering, Faculty of Mechanical Engineering, and Faculty of Civil Engineering and Architecture. The first two faculties are

represented with two instances each, for the autumn and the spring semesters, respectively, whereas the last one had four instances, two for the autumn and spring semester, respectively. This test set is used for evaluation purposes, to compare the results of our ILS approach against the timetables that are produced manually by the experts at these faculties (usually vice deans for teaching affairs).

Acknowledgements: This work was partially supported by the program of HERAS (Higher Education, Research and Applied Science) with funding from Austrian Development Cooperation Agency and Ministry of Education, Science and Technology of Republic of Kosovo.

References:

[1] B. McCollum, A. Schaerf, B. Paechter, P. McMullan, R. Lewis, A. J. Parkes, L. D. Gaspero, R. Qu, E. K. Burke, Setting the research agenda in automated timetabling: The second international timetabling competition, *INFORMS Journal on Computing* **22-1** (2010) 120–130.

[2] Zh. Lü,J. K. Hao, Adaptive tabu search for course timetabling, *European Journal of Operational Research* **200-1** (2010) 235–244.

Consensus-based approach to ranking similar objects

Friday
10:50-11:10

Marta Szachniuk

Poznań University of Technology, Poland

mszachniuk@cs.put.poznan.pl

(*joint work with* Tomasz Zok, Maciej Antczak)

Let us define the following problem. There is a set of n objects which are different models (approximations, images) of the same real object. We want to evaluate the approximation quality of these models, create their ranking, and select the best model or subset of models. However, the modeled object is not precisely described. Its structure is not fully recognized, and we only know its general characteristics. In fact, one of the main goals of the problem is to discover the properties of the modeled object itself. Therefore, the evaluation and ranking cannot be based on model comparison to the approximated object and their similarity assessment.

Such an issue arises in many fields of life and science where new phenomena or patterns are discovered. One of such areas is contemporary structural bioinformatics, in which our instance of the above-defined problem is rooted. As developers of the RNA 3D structure prediction system and participants in projects aimed at modelling of unknown RNA structures, we often face the question of ranking the RNA models generated computationally. There exist several measures and algorithms used to assess the accuracy and quality of predicted 3D models of biomolecules. However, they are based on model comparison to the reference structure. In the case when the reference RNA molecule is absent, new solutions are needed to sort out the evaluation and ranking problem.

Here, we present the new algorithm to address the ranking of RNA structures. It can be applied to evaluate RNA models predicted computationally or determined experimentally. The method is based on a consensus approach. It uses a virtual approximation of the modeled structure built upon the network of base-base interactions. Each RNA model from the considered set is analyzed, and its canonical and non-canonical base pairs are treated as separate votes. After processing of all candidates, the method creates a consensus. It is built from all base pairs which received m votes, where m, being the acceptance threshold, is a parameter of the method. Next, the algorithm performs the comparison of all considered models to the consensus and evaluates them. As a result, models are ranked and supplemented with details about the predicted correctness of their base pairing pattern.

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Thursday
11:50-12:10

Analyzing the performance of Traveling Salesman Problem solver methods

Boldizsár Tüű-Szabó

Széchenyi István University, Hungary

tuu.szabo.boldizsar@sze.hu

(*joint work with* Péter Földesi, László T. Kóczy)

In this work we analyze the efficiency of three Traveling Salesman Problem (TSP) solver methods: the best-performing exact Concorde algorithm [1], the state-of-the-art inexact Helsgaun's Lin-Kernighan heuristic [2] and our Discrete Bacterial Memetic Evolutionary Algorithm (DBMEA) [3]. The mean run times and the average tour lengths were compared testing the methods on VLSI benchmark instances up to 20000 nodes. Three models (polynomial, exponential, square-root exponential) were fitted to the mean run times. The Lin-Kernighan heuristic was the fastest method (e.g. for the polynomial model the time complexities are: Lin-Kernighan ($O(n^{1.82})$, DBMEA ($O(n^{1.98})$ and Concorde ($O(n^{2.12})$) and it produced the lowest tour lengths. The DBMEA also produced high-quality near-optimal solutions (the gaps are much below 1% compared to the solutions of the Lin-Kernighan heuristic). The Concorde was not able to solve instances with more than 2000 nodes within two CPU days. For each fitting model the DBMEA produced the highest fitting accuracy with close to 1 R-squared values, which indicates that the run time of the DBMEA is well predictable. The Concorde has poor fitting properties, the R-squared values were lower than 0.4 for each model.

Acknowledgements: This work was supported by the National Research, Development and Innovation Office (NKFIH) K124055 and by the NKP-18-3 New National Excellence Program of the Ministry of Human Capacities.

References:

[1] D.L. Applegate, R.E. Bixby, V. Chvátal, W.J. Cook *The Traveling Salesman Problem: a computational study* (second edition), Princeton University Press, Princeton (2006) 489–530.

[2] K. Helsgaun, An effective implementation of the Lin-Kernighan traveling salesman heuristic, *European Journal of Operational Research* **216** (2000) 106–130.

[3] L.T. Kóczy, P. Földesi, B. Tüű-Szabó, Enhanced Discrete Bacterial Memetic Evolutionary Algorithm-An efficacious metaheuristic for the traveling salesman optimization, *Information Sciences* **460** (2017) 389–400.

The Fast Searching Problem on Cartesian Products of Graphs

Thursday
16:30-16:50

Boting Yang

University of Regina, Canada

boting@uregina.ca

(*joint work with* Yuan Xue)

Given a graph that contains an invisible fugitive, the fast searching problem is to find the minimum number of searchers required to capture the fugitive in the fast search model. In this talk, we give a lower bound on the fast search number. Using the lower bound, we show the fast search number of the Cartesian product of an Eulerian graph and a path. We also present results on the fast search number of hypercubes, toroidal grids, and variants of the Cartesian product.

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Thursday
16:50-17:10

Modeling and solving job shop scheduling problems with graphs and clique search

Bogdan Zavalnij

Renyi Alfred Institute of Mathematics, Hungarian Academy of Sciences, Hungary

bogdan@renyi.hu

(*joint work with* Sandor Szabo)

The job sequencing problem is an optimization problem. Certain products are to be produced on given machines satisfying predetermined technological order. The objective is to determine the sequence of jobs in which the various products are processed on the machines in the least possible time. The well-known standard approach recasts the problem by means of mixed integer linear program. Here we experiment with a more combinatorial idea.

Given a positive number T we construct an integer k and an auxiliary graph G. The graph G encodes the constraints of the job sequencing problem. If the graph G contains a k-clique (a clique with k vertices), then there is a feasible job sequencing whose completion time is at most T. So, instead of an optimization problem we are dealing with a decision problem.

The practical utility of the clique search framework is three fold. A greedy sequencing procedure can be used to locate a feasible but typically far from optimal job sequencing. The difficulty of the clique search problem depends on the parameter T. If T is near to completion time of the greedy schedule, then the k-clique problem is relatively easy. As T gets closer and closer to the completion time of the optimal schedule, the clique search problem gets computationally harder and harder. The k-clique search version of the job sequencing problem can be used to locate a not optimal but feasible solution that outperforms the simply greedy sequencing. The k-clique search can be carried out in a parallel fashion in a relatively straight-forward manner. Finally, there is a technique due D. Knuth which allows to estimate the size of the search tree of a k-clique locating algorithm. So we have an indication of whether the clique search we are attempting is cost effective or not.

It must be clear that the k-clique search version of the job sequencing problem will not always be a competitor of the standard mixed integer programming reformulation. Rather it is a complementary technique which may be useful when one needs a not necessarily optimal feasible solution.

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Scheduling two-stage jobs processing with limited storage

Friday
11:10-11:30

Yakov Zinder

University of Technology, Sydney, Australia

yakov.zinder@uts.edu.au

(*joint work with* Alexander Kononov)

Publications on the two-stage scheduling systems, such as two-machine flow shops, job shops and open shops, single machine with coupled tasks, and their various generalisations such as flexible and parallel shops and systems with batch processing, constitute a significant part of the scheduling literature. Many of these publications consider a limited storage (normally referred to in the scheduling literature as a buffer) or an additional limited resource. The majority of publications on scheduling with a buffer consider the buffer as a storage that limits the number of jobs that have completed their first operation and are waiting for the commencement of the second one, whereas the majority of publications on scheduling with an additional resource (resource constrained scheduling) assume that the resource is used only during the processing on a machine [2, 3, 6]. Despite numerous possible applications that include, for example, supply chains [4], multimedia systems [5] and data gathering networks [1], much less research has been done on the models where the resource (storage space, buffer) is allocated to a job from the start of its first operation till the end of its second operation and where storage requirement varies from job to job. The talk addresses this gap in the scheduling literature by presenting new NP-hardness proofs, particular cases amenable for polynomial-time algorithms, and polynomial approximation schemes.

References:

[1] J. Berlińska, Scheduling data gathering with limited base station memory, in: *Proceedings of the 16th International Conference on Project Management and Scheduling*, Rome (2018) 42–45.

[2] P. Brucker and S. Knust, *Complex Scheduling* (second edition), Springer (2012).

[3] H. Emmons and G. Vairaktarakis, *Flow shop scheduling*, Springer (2013).

[4] J. Fung, G. Singh and Y. Zinder, Capacity planning in supply chains of mineral resources, *Information Sciences* **316** (2015) 397–418.

[5] F.C. Lin, J.S. Hong and B.M. Lin, A two-machine flow-shop problem with processing time-dependent buffer constraints – an application in multimedia presentations, *Computers & Operations Research* **36** (2009) 1158–1175.

[6] M. Pinedo, *Scheduling: Theory, Algorithms, and Systems* (fourth edition), Springer (2012).

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