Abstracts of the PhD presentations

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Supervisor(s) Etienne de Klerk

Title *On the convergence rate of the difference-of-convex algorithm (DCA)*
Abstract I discuss the non-asymptotic convergence rate of the Difference-of-Convex Algorithm (DCA), also known as the Convex–Concave Procedure. I introduce two distinct termination criteria suitable for smooth and non-smooth decompositions. The DCA is a widely used algorithm for solving Difference-of-Convex (DC) problems and is known to converge to a stationary point of the objective under specific assumptions. I provide an example demonstrating the exact convergence rate. Additionally, I delve into the convergence rate for the Proximal Gradient Method and explore the impact of regularization on DCA. Furthermore, I present a novel result on the linear convergence rate for DCA based on the Polyak–Lojasiewicz inequality assumption. Notably, our analysis incorporates semidefinite programming for performance estimation.

Joint work with Etienne de Klerk and Moslem Zamani

Mathijs Barkel
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Supervisor(s) Maxence Delorme, Renata Sotirov

Title *Bounding Procedures and Exact Arcflow Formulations for the Bin Packing Problem with Minimum Color Fragmentation*
Abstract The Bin Packing Problem with Minimum Color Fragmentation (BPPMCF) is a recently introduced extension of the well-known Bin Packing Problem (BPP). Given a set of weighted, colored items and a limited number of bins with identical capacity, the objective is to avoid color fragmentation by packing items of the same color as much as possible in the same bins. This problem has applications in several real-life problems in fields such as production planning, logistics, surgical scheduling and group event seating. To solve the BPPMCF, we introduce several BPP-based bounding procedures, one of which can solve all existing benchmark instances to optimality within a few seconds. Moreover, we introduce three exact methods based on the well-known arcflow formulation for the BPP, which we show to be effective, even on a new relevant benchmark of harder instances.

Joint work with Maxence Delorme, Enrico Malaguti, Michele Monaci

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Title *Structured learning of the optimal replacement rule beyond Markov settings*

Abstract In Markov decision processes, the archetypical point of departure is the Bellman optimality equations. For such problems, these equations rely on the underlying stochastic model being a Markov chain. However, the analysis and modelling of real data rarely produces a simple Markov chain model. Instead, it tends to result in history-dependent models (e.g., autoregressive models) or models with partial information. This necessitates two extensions of the current solution framework. Firstly, that the theoretical foundation of the Bellman optimality equations is extended non-Markovian settings. Secondly, that the learning of the underlying model is integrated with the decision analysis.

In this presentation we demonstrate how one can overcome these two challenges. Specifically, we focus on the replacement problem of an asset such as a technological device or component, and observe its condition, with the objective to determine when to optimally replace the asset so as to minimize cost. The key assumption is that the underlying condition (stochastically) renews when the asset is replaced by a good-as-new asset. In this case, the optimal replacement rule is much more complicated than in the Markovian case. Despite this complication, we present an algorithm which requires a relatively small number of iterations to converge to the optimal replacement rule. Furthermore, we show that this framework can be extended to the case where the underlying model is learned in real time whilst also learning the optimal replacement rule. Lastly, the proposed algorithm is also applicable for optimal stopping problems with a non-Markovian structure.

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Title *Predicting next week's bed census: combining medical expertise with data.*
Abstract Bed census predictions play a key role in hospital capacity management decisions, such as ward dimensioning, staffing decisions, patient-to-bed assignment and the development surgery schedules. Currently, predictions are typically solely based on the doctor's estimate of the Expected Discharge Date (EDD). In this paper, we propose two probabilistic models to combine the EDD with the LOS distributions retrieved from ERP data. Using the Poisson Binomial distribution and probabilistic convolution, we obtain the full census distribution. We apply our method on real world hospital data, and it turns out to be very accurate.

Joint work with Stef R. P. Baas, Richard J. Boucherie, Erwin W. Hans, Gréanne Leeftink

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Title *Large-scale Appointment Scheduling via Robust Convex Optimization with Polyhedral Uncertainty Sets*
Abstract The efficient management of appointments is crucial in enhancing high overall operational efficiency and service quality in many sectors, with healthcare as leading example. The Appointment Scheduling Problem (ASP) revolves around determining an optimal time allocation of appointments, such that it minimizes customers' waiting time and the doctor's overtime. From a Robust Optimization (RO) perspective, we assume the service times are uncertain and fall within some given polyhedral

uncertainty set, and look for the schedule that minimizes the worst-case costs over this full set. Although this leads to a very complicated RO problem that is convex in the uncertain parameters, recent work of Bertsimas et al. (2023) gives rise to new opportunities. We deduce an approximate linear problem that results in an upper bound for the total costs. Additionally, we develop a scenario selecting procedure to generate a lower bound, that can even be improved to solve the problem to optimality. Where state-of-the-art literature on the ASP is limited to very small problems, this new methodology enables us to generate lower and upper bounds for problems with more than 100 customers, and study exact schedules for approximately 50 customers. We discuss specific choices of polyhedral uncertainty sets and find patterns in the optimal robust schedules, which we compare with those reported in the literature.

Joint work with Dick den Hertog, Johan van Leeuwaarden

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Title *Strategic placement of defibrillators*
Abstract Volunteer responder systems (VRS) alert and guide nearby lay rescuers towards the location of an emergency. An application of such a system is to out-of-hospital cardiac arrests, where early cardiopulmonary resuscitation (CPR) and defibrillation with an automated external defibrillator (AED) are crucial to increase survival chances. However, numerous AEDs are barely used due to poor location choices, while many areas lack appropriate AED coverage instead. We present a comprehensive data-driven algorithmic approach to optimize deployment of (additional) public-access AEDs. Using real-world instances from the Netherlands we show that coverage can be increased substantially by relocating existing AEDs, or by strategically placing a handful of additional AEDs.

Joint work with dr. Derya Demirtas, prof. Erwin Hans, prof. Erik Koffijberg

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Pedro José Correia Duarte
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Supervisor(s) Dennis Huisman, Luuk Veelenturf

Title *A Cyclic Timetabling Approach to Determine Optimal ERTMS Rollout*
Abstract The enhancement of European Railway Traffic Management Systems (ERTMS) can lead to shorter headway requirements between trains and faster connections for passengers. However, the deployment of ERTMS or other digital infrastructure in a railway network is a lengthy and costly process subject to many constraints. Consequently, infrastructure decisions must be strategically planned over time to maximize passenger benefits.

This research introduces a novel model aimed at optimizing the deployment of infrastructure upgrades in a railway network over a given planning horizon. We propose a Mixed Integer Linear Programming formulation based on the Periodic Event Scheduling Problem formulation for cyclic timetabling. Furthermore, we develop heuristics to tackle this new problem and present results on a set of real-life instances from the Netherlands.

Joint work with Dennis Huisman, Luuk Veelenturf

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Supervisor(s) Bernd Heidergott, Joost Berkhout, Caroline Jagtenberg

Title *A Pseudo-Gradient Approach for Model-free Markov Chain Optimization*
Abstract We develop a first-order gradient approach for optimizing a function of the stationary distribution of a discrete-time Markov chain (DTMC) based on Simultaneous Perturbation Stochastic Approximation (SPSA). We give insights into why solving this optimization problem is challenging and show the necessary adaptations to the SPSA algorithm. The resulting algorithm scales well and avoids the use of projections.

We compare our algorithm to a benchmark algorithm in the case of linear and quadratic objective functions. Moreover, we show that, in contrast to the benchmark, our algorithm can also be used in the case of general objective functions and, for example, for optimizing the ranking of web pages in larger internet networks. Our approach is model-free in the sense that we allow for differentiating with respect to the entries of the Markov chain transition matrix and do not require an explicit model of the interdependence of the row elements of the Markov chain transition matrix.

Joint work with Bernd Heidergott and Joost Berkhout

Tim Engels
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Supervisor(s) Ivo Adan, Onno Boxma, Jacques Resing

Title *Batch sojourn times in polling systems on a circle*
Abstract Polling models are important queuing models, in which servers are responsible for the service of customers in multiple queues. In this talk we consider a particular class of polling systems, where the customers instead arrive on a circle. A single server on this circle serves these customers in a clock-wise manner. The talk is devoted to a mean-value approach for the analysis of the waiting time in this system.

Joint work with Ivo Adan, Onno Boxma, Jacques Resing

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Title *Learning from scenarios in the context of stochastic scheduling*

Abstract In many decision-making processes parameters are uncertain and can only be estimated with help of historical data. Decision-focused learning focuses on end-to-end learning in such situations. While decision-focused learning benefits optimization with uncertainty in linear objectives, researchers emphasize the need for further explorationin cases with uncertain coefficients in constraints. This is particularly challenging as inaccurate estimates can lead to infeasible solutions requiring adjustments when true values are revealed. We are interested in a resource-constrained stochastic scheduling problem, in which processing times are uncertain. In practice, when the realisation of uncertain parameters invalidates a schedule, adaptations are made, such that the work can continue. A methodology based on stochastic smoothing using score function gradient estimation seems most promising for extending the scope of decision-focused learning to stochastic scheduling. We make the assumption that historical data is only available in the form of realisations of the stochastic processing times. We show here that it can already be useful to train a model based on scenarios for a specific instance, and show when this outperforms the state of the art for such situations: scenario-based stochastic optimisation.

Joint work with Mathijs de Weerdt, David M.J. Tax, Esteban Freydell

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Rolf van der Hulst
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Title *A row augmentation algorithm for graph realization*
Abstract Given a binary matrix A, the graph realization problem asks to determine if there exists a tree T such that the columns of A are incidence vectors of paths in T, or to show that no such T exists. Although there exist nearly-linear time algorithms for the graph realization problem, they exclusively work in a column-wise fashion, by incrementally determining if a column subset of A admits a graphic realization, and then growing this submatrix by a single column, simulatenously deciding if this larger new matrix admits a graphic realization. In this talk, we present a fast algorithm that decides whether a matrix is graphic, but does so in a row-wise fashion.

Joint work with Matthias Walter

Purva Joshi
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Title *Efficiently Navigating Autonomous Vehicles through Intersections*
Abstract The anticipated launch of fully autonomous vehicles presents an opportunity to develop and implement novel traffic management systems. Intersections are one of the bottlenecks for urban traffic, and thus offer tremendous potential for performance improvements of traffic flow if managed efficiently. Platoon-forming algorithms, in which vehicles are grouped together with short inter-vehicular distances just before arriving at an intersection at high speed, seem particularly promising in this aspect. In this work, we present an intersection access control system based on platoon-forming for heterogeneous autonomous traffic. The heterogeneity of traffic arises from vehicles with different

acceleration capabilities and safety constraints. We focus on obtaining computationally fast and interpretable closed-form expressions for safe and efficient vehicle trajectories that lead to platoon formation, and show that these trajectories are solutions to certain classes of optimisation problems. Additionally, we conduct a numerical study to obtain approximations for intersection capacity as a result of such platoon formation.

Sophie Klumper
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Title *To Trust, or Not to Trust: Truthful Mechanisms for Maximum Weighted Matching Problems in Private Bipartite Graphs with Predictions*
Abstract Recently, a lot of work has focused on the design and analysis of algorithms with predictions, where the algorithm can use predictions to improve performance. For instance, a common goal is to achieve better approximation guarantees when the predictions are correct (consistency), and ideally maintain worst-case approximation guarantees when the predictions are incorrect (robustness). This promising idea has only been applied to a few mechanism design problems, in which the predictions regard the private information of the agents. This motivates the question that we address in this paper: what approximation guarantees can truthful mechanisms achieve for the maximum weighted matching problem in private bipartite graphs with predictions?

We study the problem in the setting without money, so payments cannot be used to incentivise agents to be truthful. One needs to sacrifice optimality, and Dughmi and Ghosh (2018) show that without predictions this results in a tight approximation guarantee of 2. Can predictions be used to improve on this tight guarantee? First, we give a characterisation of truthful mechanisms. Then, we give a deterministic truthful mechanism with a consistency of $1 + \frac{1}{\gamma}$ and a robustness of $2 + \gamma$, with $\gamma \ge 1$. Here, γ can be viewed as a parameter of trust and can be set accordingly. A high value corresponds to high trust and will lead to a better consistency, but a worse robustness. Finally, we prove that no deterministic truthful mechanism can do better than $(1 + \frac{1}{\gamma})$-consistency and $(1 + \gamma)$-robustness.

Joint work with Riccardo Colini-Baldeschi, Guido Schäfer & Artem Tsikiridis

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Title *Railway line planning for varying demand with focus on stop planning, frequency setting, and asymmetric lines*
Abstract The aim of the line planning problem in railways is to determine a set of lines that is going to be operated. Each line has a certain route, a stopping pattern determining at which stations a train is going to stop, and a frequency at which the line will be operated. This line plan is an important aspect of the quality of the service that a railway undertaking provides to its passengers. For example, it determines which origin-destination pairs are connected by a direct trip and which pairs need a transfer between lines. Although the railway demand is varying throughout the day in volume and

direction, the line plan is still often constant throughout the day. To better match the supply with this varying railway demand, we present a mixed integer linear programming model for multi-period line planning. With this model, we intent to determine a line plan for each period with different demand, that provides a low generalised journey time to the passengers. At the same time, the amount of changes over the day between the different line plans are limited to keep it practically feasible. Furthermore, we include the possibility of having asymmetric lines to deal with spatially unbalanced (peak hour) demand. Gurobi is used to test the proposed model on a case study based on real data of part of the Dutch railway network.

Joint work with Niels van Oort, Menno de Bruyn, Rob M.P. Goverde

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Title *Cooperative Locker Location Games*
Abstract More and more people are ordering products online, having their parcels delivered to their homes. This leads to more congestion, which negatively impacts the environment as well as public health and safety. To reduce these negative impacts, carriers can use parcel lockers to consolidate and serve their customers. The implementation of a locker network can, however, be financially challenging. To overcome this, carriers can decide to collaborate and invest in parcel lockers together. In this presentation, we introduce a stylized model in which a group of carriers can decide to position parcel lockers collectively. In this model opening a locker comes at a cost, while serving a customer via close-by lockers generates a customer-specific profit. By introducing and studying the associated cooperative game, we then investigate whether the carriers can allocate the joint profit in a stable way. For this game, we prove that a stable allocation is guaranteed for a particular class of networks. Generating a large set of instances, we furthermore conduct a number of numerical experiments, showing that a stable profit allocation is possible in most situations.

Joint work with Loe Schlicher, Sonja U.K. Rohmer, Tom Van Woensel

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Jelle Oostveen
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Title *The Parameterised Complexity of Integer Multicommodity Flow*
Abstract The Integer Multicommodity Flow problem has been studied extensively in the literature. However, from a parameterised perspective, mostly special cases, such as the Disjoint Paths problem, have been considered. Therefore, we investigate the parameterised complexity of the general Integer Multicommodity Flow problem. We show that the decision version of this problem on directed graphs for a constant number of commodities, when the capacities are given in unary, is XNLP-complete with pathwidth as parameter and XALP-complete with treewidth as parameter. When the capacities are given in binary, the problem is NP-complete even for graphs of pathwidth at most 13. We give related results for undirected graphs. These results imply that the problem is unlikely to be fixed-parameter tractable by these parameters.In contrast, we show that the problem does become fixed-parameter

tractable when weighted tree partition width (a variant of tree partition width for edge weighted graphs) is used as parameter.

Joint work with Hans L. Bodlaender, Isja Mannens, Sukanya Pandey, Erik Jan van Leeuwen

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Linda Punt
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Supervisor(s) Yashar Ghiassi-Farrokhfal; Gar-Goei Loke

Title *Integrating EV Fleet Flexibility into Robust Optimal Planning of Local Power Grids*
Abstract The unpredictable and flexible nature of electric vehicle (EV) demand poses both a challenge and an opportunity to distributed power networks. Accounting for this flexibility during the planning phase is critical to prevent overprovisioning. This requires supply-demand matching at all nodes and at all times, where decisions are the link capacities and per-node storage capacity. However, the stochastic nature of EV demand in time, space, and quantity complicates this task. We address this problem by modeling the aggregate of EVs and presenting a two-stage multi-period moments uncertainty robust optimization model. Using real data from a local grid, we demonstrate that our model can reduce grid investment costs by taking advantage of EV fleet flexibility.

Joint work with Yashar Ghiassi-Farrokhfal, Gar-Goei Loke

Jesse van Rhijn
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Supervisor(s) Bodo Manthey

Title *Some new Results on Hartigan's Method for k-Means Clustering*
Abstract Hartigan's method is an old local search algorithm for the k-means clustering problem. Although not as widely known or used as the almost-ubiquitous Lloyd's method, Telgarsky and Vattani showed in 2010 that Hartigan's method is more powerful than Lloyd's method, while it has a similar running time on practical instances. Due to its relative obscurity, theoretical knowledge on Hartigan's method is sparse. This talk presents some new results pertaining to the heuristic, including an explicit construction of a linear instance on which the algorithm can have exponential running time, a smoothed analysis, and a computational complexity result.

Joint work with Bodo Manthey, Nils Morawietz, Frank Sommer

Arman Rouhani
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Supervisor(s) Andre Berger

Title *An improved bound for the price of anarchy for related machine scheduling*

Abstract In this paper, we introduce an improved upper bound for the efficiency of Nash equilibria in utilitarian scheduling games on related machines. The machines have varying speeds and adhere to the Shortest Processing Time (SPT) policy as the global order for job processing. The goal of each job is to minimize its completion time, while the social objective is to minimize the sum of completion times. Our main result provides an upper bound of $2-\frac{1}{2\cdot(2m-1)}$ on the price of anarchy for the general case of m machines. We improve this bound to 3/2 for the case of two machines, and to $2-\frac{1}{2\cdot m}$ for the general case of m machines when the machines have divisible speeds.

Joint work with Andre Berger, Marc Schröder

Ashkan Safari
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Supervisor(s) Lars Rohwedder and Tjark Vredeveld

Title *A k-swap Local Search for Makespan Scheduling*
Abstract Local search is a technique for tackling challenging optimization problems, offering significant advantages in terms of computational efficiency and exhibiting strong empirical behavior across a wide range of problem domains.
In this talk, we address a scheduling problem on two identical parallel machines with the objective of makespan minimization. For this problem, we consider a local search neighborhood, called k-swap, which is a more generalized version of the widely-used swap and jump neighborhoods.
The k-swap neighborhood is obtained by swapping at most k jobs between two machines in our schedule.
First, we propose an algorithm for finding an improving neighbor in the k-swap neighborhood which is faster than the naive approach, and prove an almost matching lower bound on any such an algorithm.
Then, we analyze the number of local search steps required to converge to a local optimum with respect to the k-swap neighborhood. For the case k = 2 (similar to the swap neighborhood), we provide a polynomial upper bound on the number of local search steps, and for the case k = 3, we provide an exponential lower bound.
Finally, we present computational experiments on various families of instances, and we discuss extensions to more than two machines in our schedule.

Joint work with Lars Rohwedder and Tjark Vredeveld

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Title *Improving Congestion in an Efficient & Robust manner using smart Virtual Queuing at Airport Security*
Abstract We show that the efficiency of the security process at airports can be significantly improved by adoption of a virtual queue where passengers are able to book a time slot. This time slot allows passengers to get priority access at the given time for security. We show that a simple load balancing

heuristic already guarantees that participants have minimal waiting time while at the same time reducing the average waiting time of all passengers.

Our proposed method is able to reduce the waiting time even further. Furthermore, our approach specifically takes into consideration the uncertainty in the arrival pattern and security capacity at the moment the time slots need to be allocated. Therefor, it can guarantee minimal waiting time in all scenarios for participating passengers. Furthermore, this approach leads to significantly lower wait time for non-participants than the baseline heuristic or having no virtual queuing at all in almost all scenarios.

Our numerical experiments show that our approach reduces the sensitivity to the uncertainty in the arrival behavior of passengers and the security capacity.

Joint work with Roman Kazus, Bruno van Beek

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Title *The good stuff: Matching supply and demand by introducing an opaque product: Pricing, learning, fun.*
Abstract In this project we help a retailer increase his revenue and decrease his waste by introducing a new selling strategy. Instead of offering his original, fixed priced assortment, he will additionally sell an 'opaque product' with a dynamic price as he sees fit. As he does not now how his clientele will respond to this new product and its price, we help him to find the right balance between earning (by optimizing his revenue) and learning (by gathering enough information to be able to estimate the effect of the new product). An interesting problem with many mathematical challenges.

Joint work with Arnoud den Boer, Ivo Adan, Zümbül Atan

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Supervisor(s) Ilker Birbil, Reza Mohammadi, Marit Schoonhoven

Title *Bayesian Structure Learning in Undirected Gaussian Graphical Models*
Abstract Gaussian graphical models are graphs that represent the conditional relationships among multivariate normal variables. The process of uncovering the structure of these graphs is known as structure learning. Bayesian methods in structure learning offer intuitive and well-founded ways to measure model uncertainty and integrate prior information. However, frequentist methods are often preferred due to the computational burden of the Bayesian approach. Over the last decade, Bayesian methods have seen substantial improvements, with some now capable of generating accurate estimates of graphs up to a thousand variables in mere minutes. Despite these advancements, a comprehensive review or empirical comparison of all cutting-edge methods has not been conducted. I will present the most relevant Bayesian approaches used in structure learning and provide directions for future research.

Joint work with Ilker Birbil, Reza Mohammadi and Marit Schoonhoven

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Title *Edge recovery in geometric random graphs*
Abstract Given a geometric random graph on n nodes, where an edge between two nodes exist if the distance is smaller than a given radius r. Suppose we do not know anything about this graph, and we want to exactly recover all edges in the graph. We can perform queries on two nodes to obtain the shortest path distance between these two nodes. The SIMPLE algorithm (Mathieu & Zhou, 2023) provides a method that recovers edges with O(n^{5/3}) queries for general bounded-degree graphs. In ongoing work, we aim to show that for these geometric random graphs, it is sufficient to do O(n log(n)) queries to exactly recover the edges by leveraging the geometry of these graphs.

Joint work with Clara Stegehuis

Sten Wessel
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Supervisor(s) Frits Spieksma, Christopher Hojny

Title *Fairness in Graph-Theoretical Optimization Problems*
Abstract There is arbitrariness in optimum solutions of graph-theoretic problems that can give rise to unfairness. We show how existing approaches that deal with this unfairness are connected to well-known graph-theoretic properties.
In this work, we analyze in detail two fairness measures that are based on finding a probability distribution over the set of solutions.
One measure guarantees uniform fairness, i.e. entities have equal chance of being part of the solution when one is sampled from this probability distribution.
The other measure maximizes the minimum probability for every entity of being selected in a solution.
In particular, we reveal that computing these individual fairness measures is in fact equivalent to computing the fractional covering number and the fractional partitioning number of a hypergraph.
In addition, we show that for a general class of problems that we classify as independence systems, these two measures coincide.
Finally, we analyze how not only fairness can be described for individuals, but also for how for groups of individuals we can achieve fairness by requiring representation of the group in a solution.

Joint work with Christopher Hojny, Frits Spieksma

Leoni Winschermann
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Supervisor(s) Johann Hurink

Title *Relating Electric Vehicle Charging to Speed Scaling with Job-Specific Speed Limits*
Abstract Due to the ongoing electrification of transport in combination with limited power grid capacities, efficient ways to schedule electric vehicles (EVs) are needed for intraday operation of, for example, large parking lots. Common approaches like model predictive control repeatedly solve a corresponding offline problem.
We present and analyze the Flow-based Offline Charging Scheduler (FOCS), an offline algorithm to derive an optimal EV charging schedule for a fleet of EVs that minimizes an increasing, convex and differentiable function of the corresponding aggregated power profile. To this end, we relate EV charging to mathematical speed scaling models with job-specific speed limits. The FOCS algorithm is provably optimal.

Joint work with Marco E.T. Gerards, Antonios Antoniadis, Gerwin Hoogsteen, Johann Hurink

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Niels Wouda
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Supervisor(s) Evrim Ursavas and Ward Romeijnders

Title *Optimising Groningen's waste collection*
Abstract In this talk we present some recent work solving a large, practical case of urban waste collection in the municipality of Groningen. We model this problem as a daily prize-collecting vehicle routing problem, which we solve using a tailored hybrid genetic search metaheuristic based on PyVRP. We discuss acceleration techniques to efficiently and repeatedly solve the daily routing problem. We also present managerial insights derived from a large scale simulation study, and show that our method can substantially improve operational performance.

Joint work with Nicky van Foreest and Marjolein Aerts-Veenstra

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