

GOR-AG: Praxis der  
Mathematischen  
Optimierung  
Dr. Jens Schulz

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Herewith, we invite you to the 108<sup>th</sup> meeting of the GOR working group “Practice of Mathematical Optimization”. This meeting is planned to be held in person (or virtually if circumstances require) with the topic

## The World of Cutting, Packing and Placing

The workshop takes place in the physics center Bad Honnef (DPG – Deutsche Physikalische Gesellschaft) on **Thursday, April 11**.

The working language will be English to be inclusive for a non-German speaking audience.

Note that the participation in a GOR-AG-Workshop for non-members is subject to a registration fee, unless you are a speaker or a host. Given the uncertainty of Covid, travel restrictions, and company policies, we strongly advise you to book your stay and travel accordingly. Cancellation of the on-site event may occur on short notice, and the organizers will waive the registration fee but will not refund any other cost.

Participation in the workshop is subject to a minor registration fee of 30 Euro for GOR members and 150 Euro for non-GOR members. Bachelor and master students can participate at zero charge for GOR student members and 50 Euro for non-GOR student members.

For accommodation and food/drinks, a service charge needs to be paid at physics center on Thursday or Friday (breakfast included when staying overnight):

- Staying from Wednesday to Friday: 253 Euro
- Staying from Wednesday to Thursday: 164 Euro
- Staying from Thursday to Friday: 180 Euro
- Participation Thursday only (no overnight): 91 Euro

Please, register via [www.redseat.de/pmo108](http://www.redseat.de/pmo108) no later than March 20<sup>th</sup>.

The latest information on the meeting is available on the homepage of the GOR (<http://www.gor-ev.de/arbeitsgruppen/praxis-der-mathematischen-optimierung/real-world-optimization>).

Yours sincerely,

Jens Schulz, Julia Kallrath, Josef Kallrath

(GOR AG)

# The World of Cutting, Packing and Placing

## Specific aims

Cutting, packing and placing problems have been extensively studied for many years because of the vast amount of real-world applications they encompass. Application areas include logistics, manufacturing, clothing and material industries. Based on their dimensionality they can be solved in (pseudo-)polynomial time or maybe be NP-hard. One-dimensional problems include such as knapsack, bin packing, and cutting stock. Two-dimensional problems include packing of certain shapes such as circles, rectangles or general polygons, e.g., trim loss and strip packing problems. Three-dimensional geometric problems find applications in pallet or container loading, warehouse management etc. Most variants are NP-hard based on a reduction from knapsack or from bin packing. Here, a vast amount of heuristics and approximation algorithms have been developed to tackle real-world instances.

With the rise of CO<sub>2</sub>-awareness finding a best packing or minimizing resource consumption, such as in trim loss problems, have become standard considerations when designing logistics operations. A need for efficient transportation, such as considered in packing and loading problems for warehouses or container ships, has led to a variety of solution algorithms and techniques explored – from theoretical standpoint and also from a computational perspective. Besides (math-)heuristics, column generation and Benders decomposition are widely applied techniques to solve such real world problems.

The core of this 1-day workshop will consist of an attractive schedule of talks covering a broad range of mathematical techniques, theoretical considerations and real world applications around cutting, packing and placement problems. As usual, we will reserve plenty of time for informal exchange and networking.

In talks of 15+5min, 25+5min or 40+5min duration, experts from practice and research will address problems and solutions.

If you would like to contribute a talk, please feel free to contact any of the organizers.

Jens Schulz ([schulz-gor 'at' gmx.net](mailto:schulz-gor@gmx.net))

Julia Kallrath ([julia.kallrath 'at' h-da.de](mailto:julia.kallrath@h-da.de))

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**Vorstand**

Prof. Dr. Alexander Martin (Vorsitz)  
Prof. Dr. Stefan Ruzika (Arbeitsgruppen)  
Dr. Jens Schulz (Finanzen)  
Prof. Dr. Jutta Geldermann (Tagungen)

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## The venue & accommodation

### Venue

Deutsche Physikalische Gesellschaft (DPG)

<https://www.dpg-physik.de/ueber-uns/physikzentrum-bad-honnef/kontakt-anfahrt>

Physikzentrum Bad Honnef

Hauptstraße 5

53604 Bad Honnef

#### How to get there?

Bad Honnef has good train connection from Cologne, and a 10 minutes walk from the station to the venue.

### Conference dinner

The conference dinner will take place in physics center on Thursday evening.

### Accommodation

The physics center offers accommodation for up to 30 participants. You can choose to stay in a hotel nearby. Please, select the appropriate option during registration.

#### Pre-conference get-together

For arrivals on Wednesday, we have booked a table starting 7pm. Kitchen closes 8:30pm.

Restaurant Altes Standesamt & Altes Rathaus

Markt 6-7

53604 Bad Honnef

Please, inform the organizers in case you want to attend. Everyone pays their bill themselves.

### Excursion

An excursion to Konrad-Adenauer Haus in Bad Honnef is planned at no extra charge with a capacity for 40 visitors.

Adenauerhaus Rhöndorf - Führung durch Wohnhaus und Garten

Konrad-Adenauer-Straße 8c

16:30-17:30Uhr

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## The following speakers are confirmed:

**Stefan Hougardy**

The Bottom-Left Algorithm for the Strip Packing Problem

**Hedi Kiraly**

Combining computational geometry and operations research in order to solve two-dimensional irregular strip packing problems

**Stefan Irnich**

Packing with Irregular Shapes

**Klaus Jansen**

Algorithms for monotone moldable job scheduling

**Tetyana Romanova (University of Leeds, UK & IPMach, National Academy of Sciences of Ukraine)**

The phi-function technique for Packing and Cutting

**Guido Sand (Hochschule Pforzheim)**

Hyperparameter Optimization of Matheuristics for Hoist Scheduling

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## Abstracts and CVs

**Stefan Hougardy (Uni Bonn)**

### **The Bottom-Left Algorithm for the Strip Packing Problem**

The bottom-left algorithm is a simple heuristic for the Strip Packing Problem. It places the rectangles in the given order at the lowest free position in the strip, using the left most position in case of ties. Despite its simplicity, the exact approximation ratio of the bottom-left algorithm remains unknown. We will improve the more-than-40-year-old value for the lower bound from  $5/4$  to  $4/3$ . Additionally, we will show that this lower bound holds even in the special case of squares, where the previously known lower bound was  $12/11$ . These lower bounds apply regardless of the ordering of the rectangles. When squares are arranged in the worst possible order, we establish a  $3.17$  lower bound for the approximation ratio of the bottom-left algorithm. Finally, we show that the approximation ratio of a local search algorithm based on permuting rectangles in the ordering of the bottom-left algorithm is at least  $2$  and that such an algorithm may need an exponential number of improvement steps to reach a local optimum.

**Stefan Hougardy** received his Ph.D. in computer science in 1995 and completed his habilitation in 2004 at Humboldt-Universität zu Berlin. From 2002 to 2007, he served as a project leader at the DFG Research Center Matheon. During 2004-2006, he held positions as a visiting professor at Technische Universität Berlin and Humboldt-Universität zu Berlin. Since 2007, he is professor at the Research Institute for Discrete Mathematics at the University of Bonn. He specializes in combinatorial optimization, focusing on approximation and exact algorithms. For over 15 years, he has been involved in an applied project on chip design in close collaboration with IBM. Within this project, various types of (rectangle) packing problems need to be solved.

**Stefan Irnich**

### **Packing with Irregular Shapes**

The talk presents a new solution approach to Bin Packing (BP) with irregular shapes. We consider a version of BP with a given set of 2-dimensional, not necessarily rectangular items that have to be packed into a minimum number of bins. The size of a bin is given, and we also allow multiple types of bins. The solution approach is based on branch-and-price where the master program is the well-known Gilmore and Gomory formulation that also generalizes to the cutting stock problem (CSP), i.e., identical items must be produced a given number of times. The column-generation subproblem, i.e., the pricing problem, consists of finding a negative reduced cost packing (a.k.a. pattern). While the pricing problem is a knapsack problem in the 1-dimension case, it is a computationally much harder problem in the 2-dimensional case. It involves the selection and nesting/placement of items. We propose to solve this pricing problem with a combinatorial Benders algorithm. The Benders master is the 1-dimensional relaxation (a bounded knapsack problem), i.e., the items and bins are described by the area that they cover. Each solution to the Benders master is a selection of items that must be tested for feasibility using a placement algorithm. If no placement is possible, a no-good cut is added to the Benders master, which is then re-optimized and the process is repeated. Otherwise, the computed placement provides the pattern needed to continue the column-generation process. In our preliminary computational study, we use a grid/raster-based representation of items and bins so that a brute-force placement was easy to implement but effective. In general, however, the placement subproblem is a practically very difficult problem, so that we cannot expect to solve real instances from industry optimally. Therefore, the talk also discussed possible ways to accelerate the overall approach by using heuristic algorithmic components. The advantage of the branch-and-price approach is that it allows for heuristics at several points, e.g., in the branching, the pricing, and the placement.

**Stefan Irnich** is a full professor in logistics management at the Gutenberg School of Management and Economics, Johannes Gutenberg University Mainz, Germany. His research interests include the development and application of optimization methods to solve problems in logistics and transportation, network design, and algorithmic graph theory. In particular, his research focuses on mathematical programming decomposition methods and also on modeling and solving rich vehicle-routing problems.

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**Hedi Kiraly (University Duisburg-Essen)****Combining computational geometry and operations research in order to solve two-dimensional irregular strip packing problems**

In the realm of two-dimensional strip packing problems, both regularly and irregularly shaped polygons are arranged on a large material of fixed width and unlimited length, ensuring that the polygons do not overlap. The primary goal is to minimize the required length of the large material without exceeding its specified width. While heuristic-based nesting methods are often used in the literature to solve these problems, exact model formulations have also been presented in recent decades, which have been solved with commercial solvers. Most linear Mixed Integer Programming (MIP) models are based on the well-known No-Fit Polygons (NFPs). Until 2022, only two linear MIP models based on direct trigonometry had been introduced. By integrating geometrical insights into a mathematical model, we have developed another MIP model formulation that can handle industry-relevant aspects for the first time in the literature. In addition, the concept of "critical vertices" is explained and it is shown how this simplifies the calculations to avoid overlaps.

**Hedi Kiraly** is a PhD student at the Chair of Logistics and Operations Research, Mercator School of Management, University of Duisburg-Essen. Her research focuses on cutting and packing problems, in particular on two-dimensional irregular strip packaging problems. She considers both convex and non-convex items with or without holes and a limited number of rotation possibilities. She obtained her BSc in Economics from the University of Vienna and her MSc in Economics with a specialization in Supply Chain Management and Logistics from the University of Duisburg-Essen.

**Klaus Jansen (University of Kiel)****Algorithms for monotone moldable job scheduling**

A moldable job is a job that can be executed on an arbitrary number of processors, and whose processing time depends on the number of processors allotted to it. A moldable job is monotone if its work doesn't decrease for an increasing number of allotted processors. We consider the problem of scheduling monotone moldable jobs to minimize the makespan.

We argue that for certain compact input encodings a polynomial algorithm has a running time polynomial in  $n$  and  $\log m$ , where  $n$  is the number of jobs and  $m$  is the number of machines. We describe how monotony of jobs can be used to counteract the increased problem complexity that arises from compact encodings, and give tight bounds on the approximability of the problem with compact encoding: it is NP-hard to solve optimally, but admits a PTAS. The main focus of this work are efficient approximation algorithms. We describe different techniques to exploit the monotony of the jobs for better running times, and present a  $(3/2 + \epsilon)$ -approximate algorithm whose running time is polynomial in  $\log m$  and  $1/\epsilon$  and only linear in the number  $n$  of jobs.

This is joint work with my students Kilian Grage, Felix Land and Felix Ohnesorge.

**Klaus Jansen** is Professor in Algorithms and Complexity of the Department of Computer Science at the University of Kiel. His research focuses on scheduling and packing problems, in particular 2D and 3D packing problems and related scheduling problems with tasks that use several processors or resources in parallel. He obtained his Diploma in Computer Science at the RWTH Aachen and PhD and Habilitation in Mathematics at the University of Trier.

**Tetyana Romanova (University of Leeds, UK & IPMach, National Academy of Sciences of Ukraine)****The phi-function technique for Packing and Cutting**

Cutting and Packing (C&P) problems have many and diverse applications including: additive manufacturing, biology, nanotechnology, medicine, robotics, logistics, materials science, space engineering. The phi-function technique provides an analytical description of the placement constraints (e.g., non-overlapping, containment, distance constraints) to solve C&P problems. It deals with arbitrary shaped 2D & 3D objects (these include disconnected objects, non-convex objects, regions with holes and cavities, oblique objects), which can be free translated and continuously rotated subject to homothetic and stretching transformations. It may take into account variable metric characteristics of objects and target domains. Using the phi-function technique reduces C&P problem to a mathematical programming model (Nonlinear Programming or Mixed Integer Nonlinear Programming). Mathematical

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models, solution strategies and computational results are discussed for several classes of C&P problems (such as sparse packing, quasi packing, ratio packing, packing soft objects, packing clusters of objects, balance packing) motivated by actual applications. Some future research areas are identified.

**Tetyana Romanova** (Professor) received her M.Sc. degree in Applied Mathematics from Kharkiv National University of Radio Electronics (KNURE), Ukraine; Ph.D. and Dr.Sci. (Habilitation) in Mathematical Modeling and Computational Methods from the Institute of Cybernetics of the National Academy of Sciences of Ukraine, Kyiv. She is a leading scientist of the Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine and visiting professor of the University of Leeds. She is an author of numerous research papers focused on the development of geometric tools, mathematical models and optimization algorithms for solving packing, cutting, layout and covering problems.

### **Hyperparameter Optimization of Matheuristics for Hoist Scheduling Sophie Hildebrandt & Guido Sand (Pforzheim University of Applied Science)**

Matheuristics combine mathematical programming with heuristic methods to solve real-world decision problems. The construction of a matheuristic requires to optimize a set of hyperparameters which may be continuous, integer, ordinal or categorial in nature. This paper describes a new approach to construct matheuristics based on Bayesian optimization applied to hoist scheduling problems. First numerical studies compare this approach to the state of the art and quantify their pros and cons.

**Guido Sand** is German professor in industrial automation, in particular optimization technologies. He received his diploma and doctoral degree in chemical engineering from Technical University of Dortmund in 1998 and 2003, respectively. After his doctoral studies in the DFG priority programme "Real time optimization of large scale systems", he joined the DFG special research area "Computational intelligence" as a project leader. From 2006 to 2016, Guido worked for ABB's corporate research organization as research project manager, group manager and research strategy analyst. Since then, he is holding a professorship at Pforzheim University of Applied Science and heading the transfer center "OptiKon" for optimization technologies.

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108<sup>th</sup> meeting of the GOR working group "Practice of Mathematical Optimization"

## The World of Cutting, Packing and Placing

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Thursday, Apr 11, 2024: 09:00 – 16:00

- 09:00-09:30 *Welcome coffee, take a seat and have first chats*
- 09:30-09:45 **Opening and Welcome** (Jens Schulz & Julia Kallrath)
- 09:45-10:30 **Stefan Hougardy**  
The Bottom-Left Algorithm for the Strip Packing Problem
- 10:30-11:00 **Hedi Kiraly**  
Combining computational geometry and operations research in order to solve two-dimensional irregular strip packing problems
- 11:00-11:45 **Stefan Irnich**  
Packing with Irregular Shapes
- 11:45-13:00 ----- Lunch Break -----
- 13:00-13:45 **Klaus Jansen**  
Algorithms for monotone moldable job scheduling
- 13:45-14:30 **Tetyana Romanova**  
The phi-function technique for Packing and Cutting
- 14:30-15:00 ----- coffee break -----
- 15:00-15:45 **Guido Sand**  
Hyperparameter Optimization of Matheuristics for Hoist Scheduling
- 15:45-16:00 Closing & discussion  
----- Taking a Group Photo for the OR News and Press -----
- 16:00-18:00 ----- Excursion to Konrad-Adenauer Haus -----
- 18:00-21:00 **Conference Dinner at physics center**