Euro Gold Medal 2010
Laureate Lecture

Rolf Möhring

EURO XXIV LISBON
My feelings

Joy, thanks, and pride
Joy

This is better than winning the soccer world cup
Thanks

To my family

Catharina
Laura
Raoul
Thanks to my group
Thanks to my research environment

- **Study programs**
  Business Mathematics, Industrial Mathematics

- **Graduate programs (Graduiertenkollegs)**
  - Combinatorics, Geometry and Computation
  - Berlin Mathematical School

- **DFG Research Cluster (SPP)**
  Algorithm Engineering

- **BMBF Program**
  Mathematics for Innovations in Industry

- **EU Project Arrival**
  Algorithms for Robust and Online Railway Optimization

- **DFG Research Center MATHEON**
  Mathematics for Key Technologies
Proud to be an Operations Researcher
My personal road in OR

Mathematics

Operations Research

Economics

TU Berlin

Computer Science

U Bonn

U Hildesheim

RWTH Aachen
The early years in Aachen (73-82)

Franz-Josef Radermacher
Computer Science, Ulm

- Deterministic Scheduling
  - time-cost tradeoff
  - decomposition
  - scarce resources

- Stochastic Scheduling
  - classes of policies
  - optimality
  - stability

Project scheduling
Getting broader (80-96)

- structured (hyper-)graphs
- partial orders
- discrete optimization
- applications
- algorithms & software
- graph algorithms

Project scheduling
Matrix Permutation Problems

Given: A 0-1 (net-gate) matrix $M$

Problem: Find a permutation of the columns and an assignment of the augmented rows (nets) to tracks, such that the number of tracks is minimum.

Related Graph Problems

• Interval Graph Augmentation
  Given a Graph $G$, find an augmentation of $G$ to an interval graph $H$ whose clique size $\omega(G)$ is as small as possible.

• Node Searching
  Find a node search of a Graph $G$ that minimizes the number of searchers.

• Path Width
  Find a path decomposition of a graph $G$ of minimum width.

Theorem [Bodlaender & Möhring]
The track number of a cograph $G$ (given in 'decomposed' form or by its parse tree) and an optimal layout can be obtained in $O(|V(G)| + |E(G)|)$ time.
Research Topics (80-96)

- An algebraic decomposition theory
- Interval orders: recognition, structure, jump number
- Treewidth, pathwidth, chainminors of networks
- Polyhedral structure of scheduling polytopes
- Complexity of rescheduling
- Scheduling with communication delays
Back to Operations Research (1997 - now)

Scheduling in production and traffic

Routing in traffic, logistics and telecommunication
Finite-Elemente-Netzgenerierung mit Flüssen und Matchings

Matthias Müller-Hannemann: 1987
CompSci, Halle

Martin Skutella: 1998
Math, Berlin

Ekkehard Köhler: 1999
Math, Cottbus

Marc Uetz: 2001
Math, Twente, NL

Martin Oellrich: 2008
CompSci, Berlin
Postdocs

Christian Liebchen  
2006  
DB Schenker

Nicole Megow  
2006  
CompSci, Saarbrücken

Sebastian Stiller  
2008  
OR, MIT, USA

Felix König  
2009  
Math, Berlin
Research Topics (97-now)

- Quadrilateral mesh generation
- Resource constrained project scheduling (RCPSP)
  - Lagrangian relaxation
  - LP-based approximation, also for stochastic case
  - Discrete time-cost tradeoff
- Routing problems and flows over time
- Acceleration of shortest path calculations
- Train Timetabling
- Robust optimization
- Algorithmic game theory
Projects in traffic and telecommunication

- Embedding VPNs into the base net of the German Telecom
  T·Systems·Nova

- Traffic management and flows over time

- Constructing periodic timetables in public transport

- Coordinated traffic light control in networks
Projects in scheduling and logistics

- Routing of AGVs in the Hamburg harbor
  ![HHLA](image)

- Ship Traffic Optimization for the Kiel Canal

- Turnaround scheduling in chemical plants
  ![T.A.Cook](image) ![INEOS](image)

- Scheduling and logistics in steel production
  ![PSI](image) ![voestalpine](image)

- Optimizing throughput at a dairy filling line
  ![SACHSEN Milch](image) ![müller](image)
Sequencing and Scheduling

input of \( n \) items → sequence them → schedule them w.r.t. the sequence

conditions may depend on entire subsequences

cost depends on both
Example 1: Slab logistics
[König, Lübbecke, Möhring, Schäfer, Spenke 2007]

- Steel slabs arrive from casting
- Intermediate storage on stacks
- Further processing or delivery

**Different orders**

**Scheduling = sorting with stacks**

- Transport by cranes or vehicles
Sorting with stacks is hard ...

- Natural side constraints
  - stacking restrictions (size, temperature)
  - limited number of stacks
  - limited stack heights
- lead to PSPACE-complete problem in general
... but rather easy in practice

- Use local search on state space
  - every node corresponds to a state of the pile yard
  - start node = current state
  - targets = deliveries to next production stage
Greedy search in the state space

- generate start state
- generate all neighbors
- evaluate them
- go to the best
Greedy is fast and gives good quality

- lower bound obtained from relaxation solved by IP
Example 2: Coil coating
[Höhn, König, Lübbecke, Möhring 2009]

Coils need to be sequenced. Run through coating line. Complex scheduling with shuttle coaters.

Setups in the scheduling phase:
- Roller change
- Roller change
- Cleaning & roller change
- Cleaning
- Cleaning

2 color tanks.
Details about the scheduling phase

- **Subproblem:**
  - given fixed-order coil sequence, find tank assignment with minimum total idle time

- **Setup work necessary if**
  - color changes $\rightarrow$ cleaning
  - coil has larger width than predecessor $\rightarrow$ roller change

- $\rightarrow$ concurrent setup work on idle tank saves idle time
Graph model for the scheduling phase

- k shuttle coaters
- no parallel concurrent setup

Practice
Tank Assignment Problem with k coaters

Theory
Max Weight Indep. Set in special 2-union graphs

new ideas for efficient algorithm
far too slow, even for small instances

polynomial-time algorithm for fixed k
↔ dynamic programming

strongly $NP$-hard
Combining sequencing and scheduling

Sequence generation with a fast genetic algorithm

Scheduling based on the insights from dyn. prog.

Quality testing by an IP relaxation
Example 3: Dairy production filling line

[Gellert, Höhn, Möhring 2010]

charges of products need to be sequenced

run through a filling line

complex scheduling due to cleaning

- Jobs specified by
  - base, e.g. yoghurt, cream, ...
  - fruit (optional) package
  - number of pallettes duration

- Setup/waiting due to
  - package/fruit/base change or cleaning
  - regular cleaning of line and tanks
  - limited size of tanks
  - minimum time lags
Details about the scheduling phase

- Guarantee maximum distance $d_{\text{clean}}$ between cleanings:
  - preempt jobs
  - replace setup already in the schedule

Respect limited size of cream tank
Solving the two classes of constraints

- Can solve cleaning conditions fast via shortest paths

- Can solve sequence and job dependent minimum distances by a simple greedy scan

- Not clear how to do both together
Combining sequencing and scheduling

<table>
<thead>
<tr>
<th>Sequence generation with a fast genetic algorithm</th>
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<tbody>
<tr>
<td>Scheduling based on the insights from analysis</td>
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Quality testing by an TSP lower bound show optimality gap of 2% for a weekly production
Combining sequencing and scheduling is at the core of many applications

- We can help with a good analysis and good algorithms

But

- We do not understand the integration well yet
- Good IP models for lower bounds are very hard to obtain

There is much work left to be done