Euro Gold Medal 2010
Laureate Lecture

Rolf Möhring

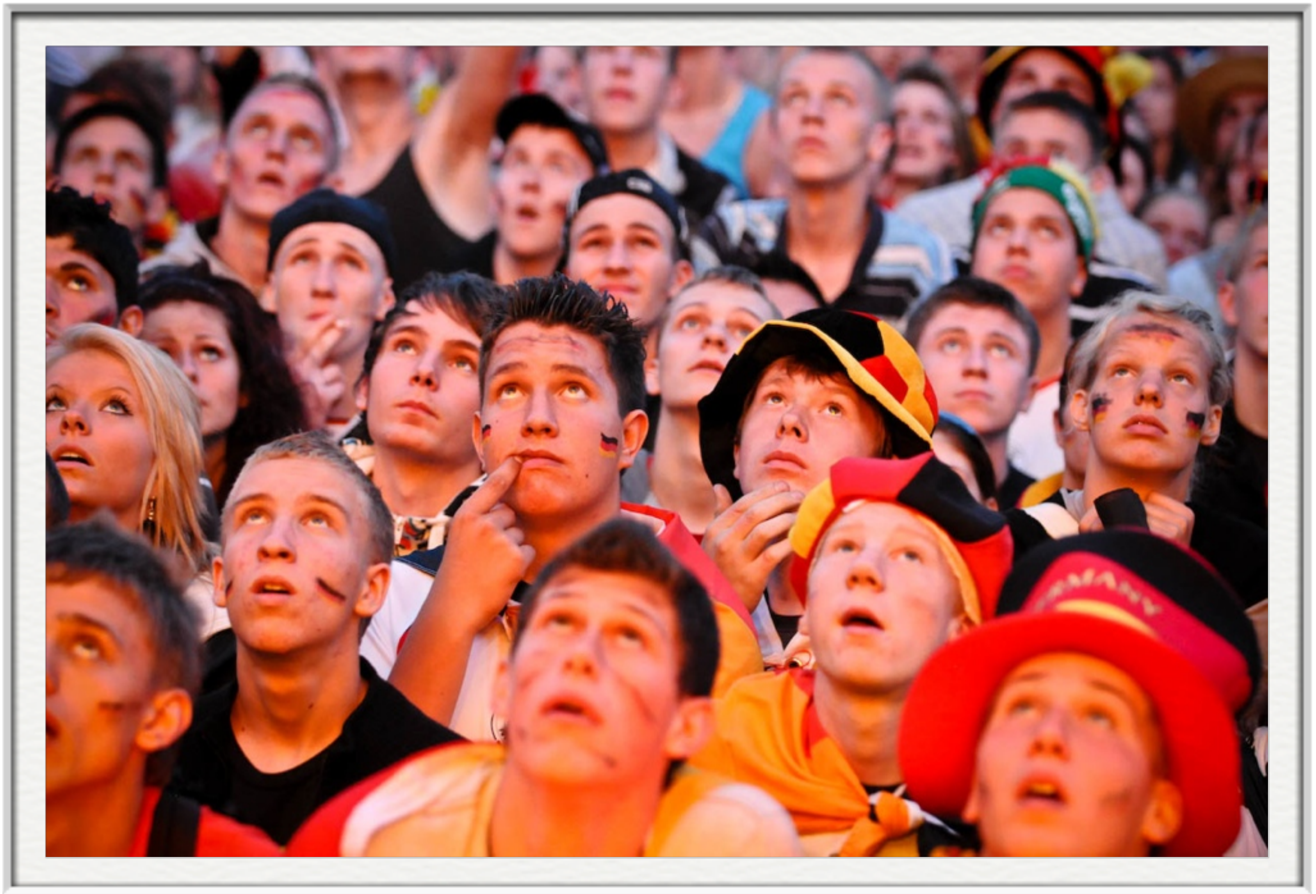
EURO XXIV LISBON

My feelings

Joy, thanks, and pride

Joy

This is better than winning the soccer world cup



Thanks

To my family

Catharina

Laura

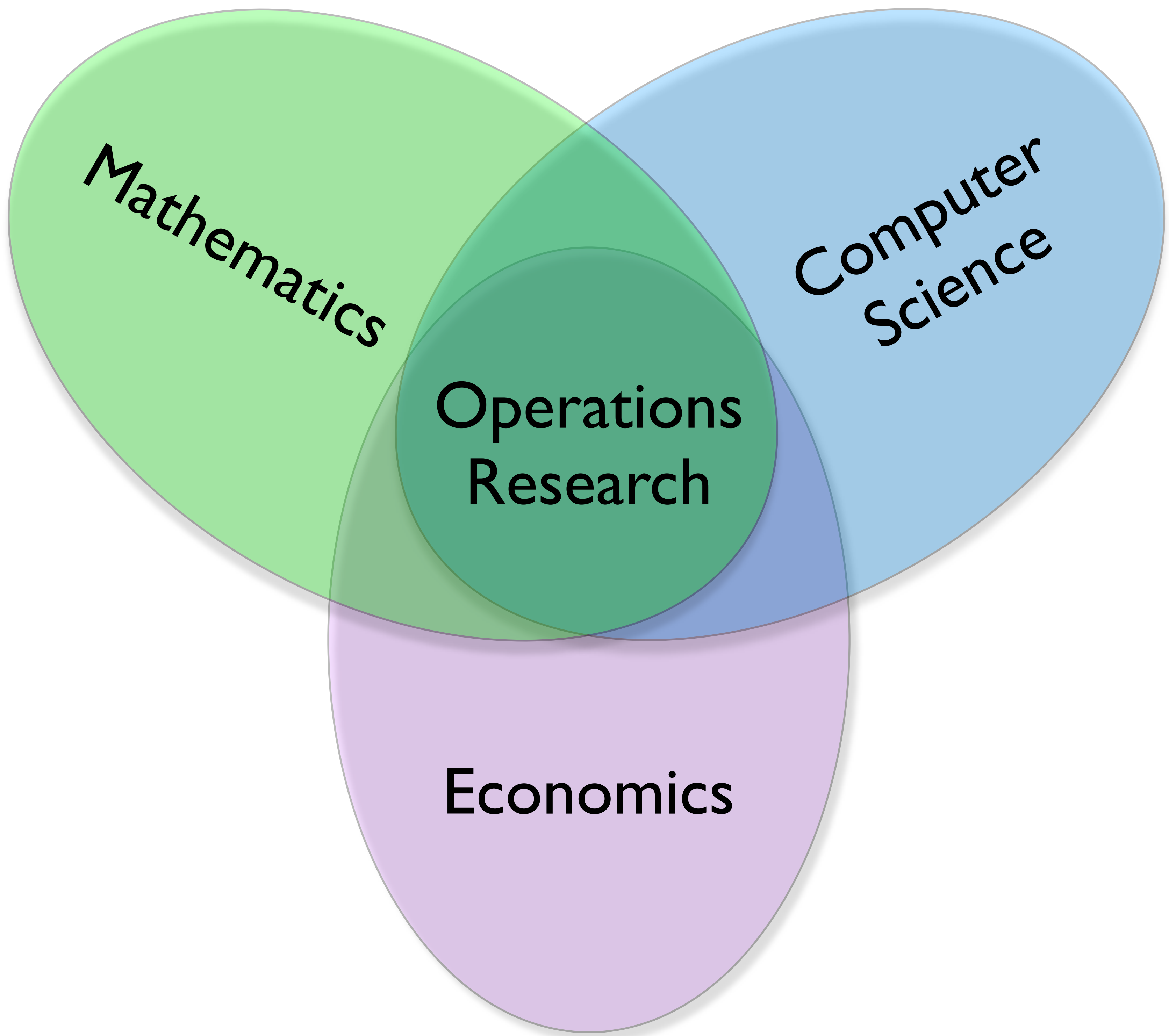
Raoul

Thanks to my group

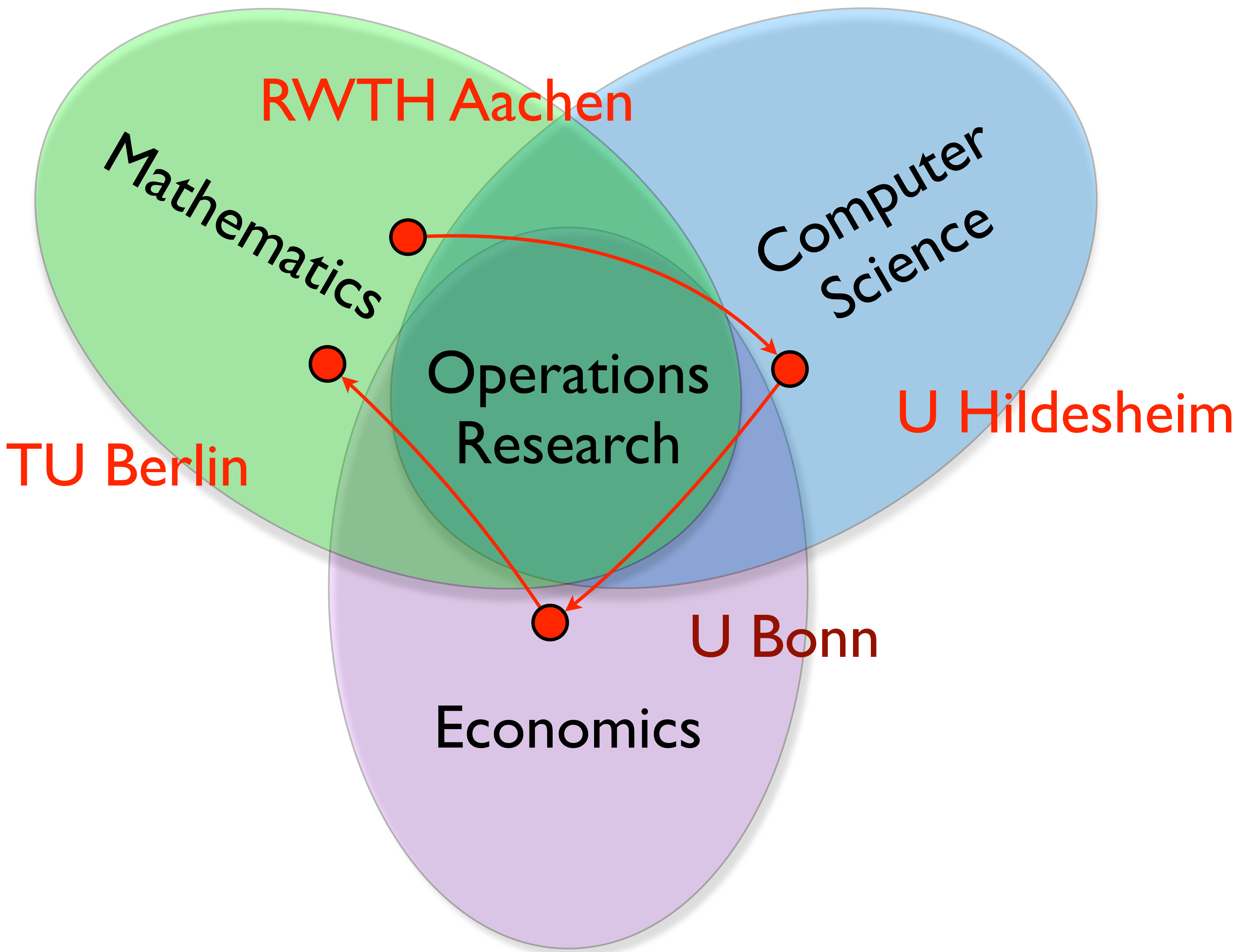
Thanks to my research environment

- 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



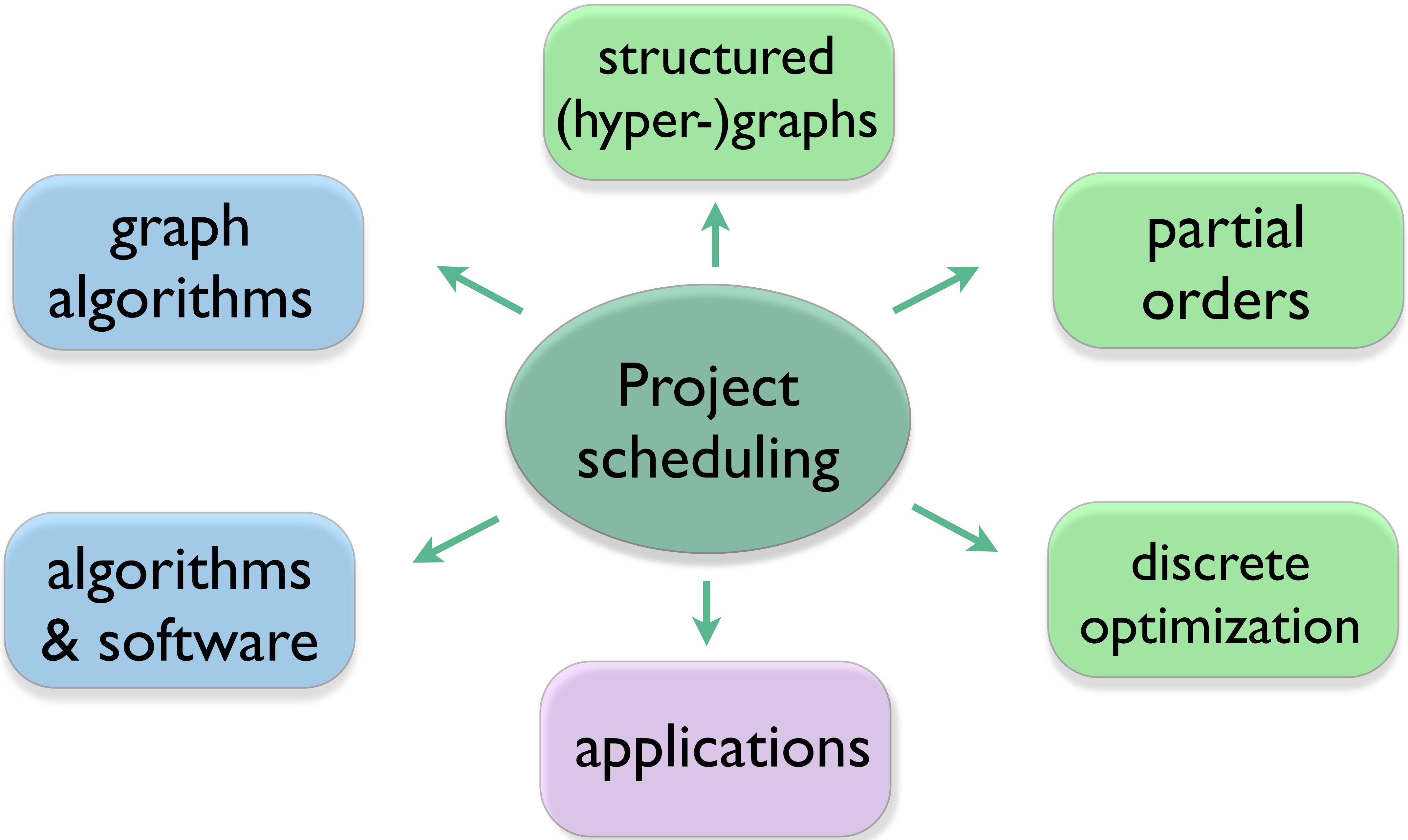
The early years in Aachen (73-82)

Project scheduling

- Deterministic Scheduling
  - time-cost tradeoff
  - decomposition
  - scarce resources
- Stochastic Scheduling
  - classes of policies
  - optimality
  - stability

Franz-Josef Radermacher
Computer Science, Ulm

Getting broader (80-96)



PhD Gallery 1

of PhD students still in academia

Dorothea Wagner
1986
CompSci Karlsruhe

Stefan Felsner
1992
Math, Berlin

Jens Gustedt
1992
CompSci, Nancy, F

Rudolf Müller
1993
OR, Maastricht, NL

Andreas Schulz
1996
OR, MIT, USA

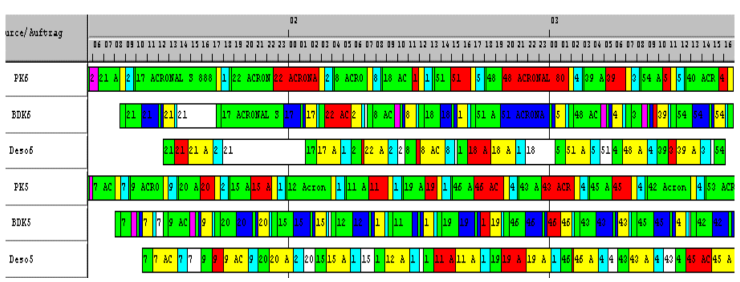
Markus Schäffter
1996
CompSci, Ulm

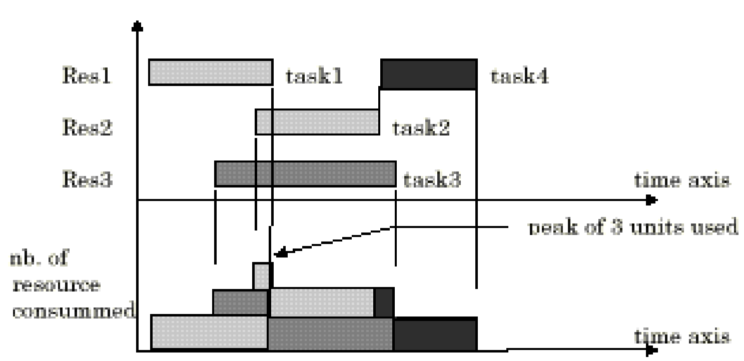
Research Topics (80-96)

- 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

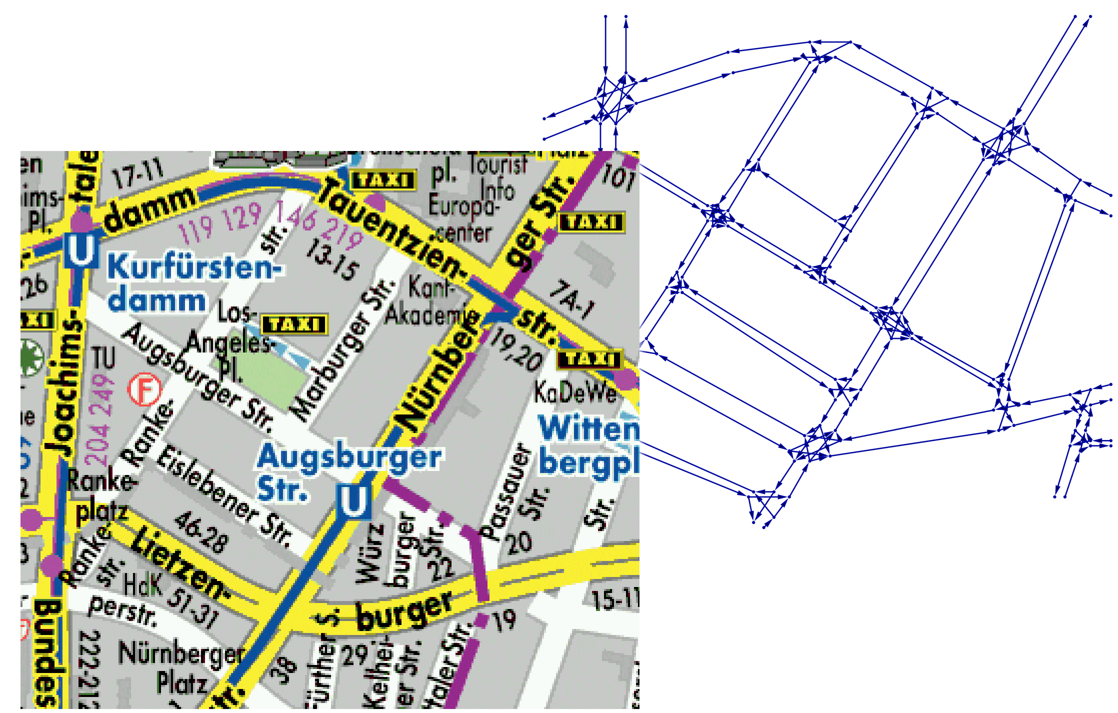
Back to Operations Research (1997 - now)

Scheduling in production and traffic





Routing in traffic, logistics and telecommunication



PhD Gallery 2

of PhD students still in academia

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

DaimlerChrysler Navigation und Verkehrsdienste

Bundesministerium für Bildung und Forschung

- Constructing periodic timetables in public transport

ptv traffic mobility logistics.

Die Bahn DB

BVG

S Bahn Berlin Deutsche Bahn Gruppe

- Coordinated traffic light control in networks

Bundesministerium für Bildung und Forschung

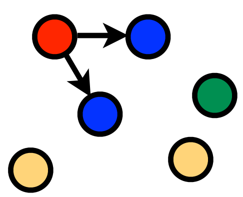
ptv traffic mobility logistics.

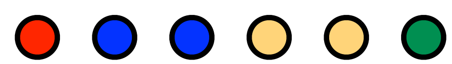
Projects in scheduling and logistics

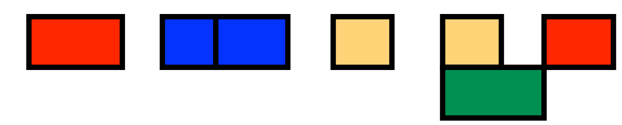
- Routing of AGVs in the Hamburg harbor
- Ship Traffic Optimization for the Kiel Canal
- Turnaround scheduling in chemical plants
- Scheduling and logistics in steel production
- Optimizing throughput at a dairy filling line

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

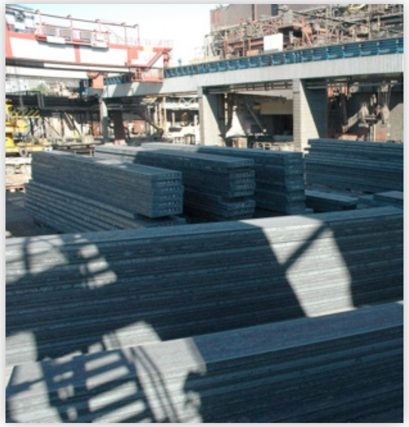
Example 1: Slab logistics

[König, Lübbecke, Möhring, Schäfer, Spenke 2007]

different orders

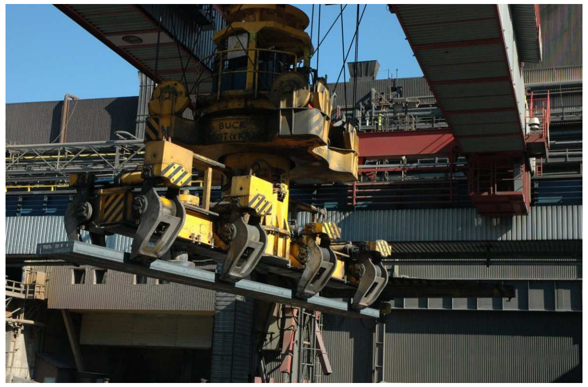
steel slabs arrive from casting

intermediate storage on stacks



further processing or delivery

scheduling = sorting with stacks



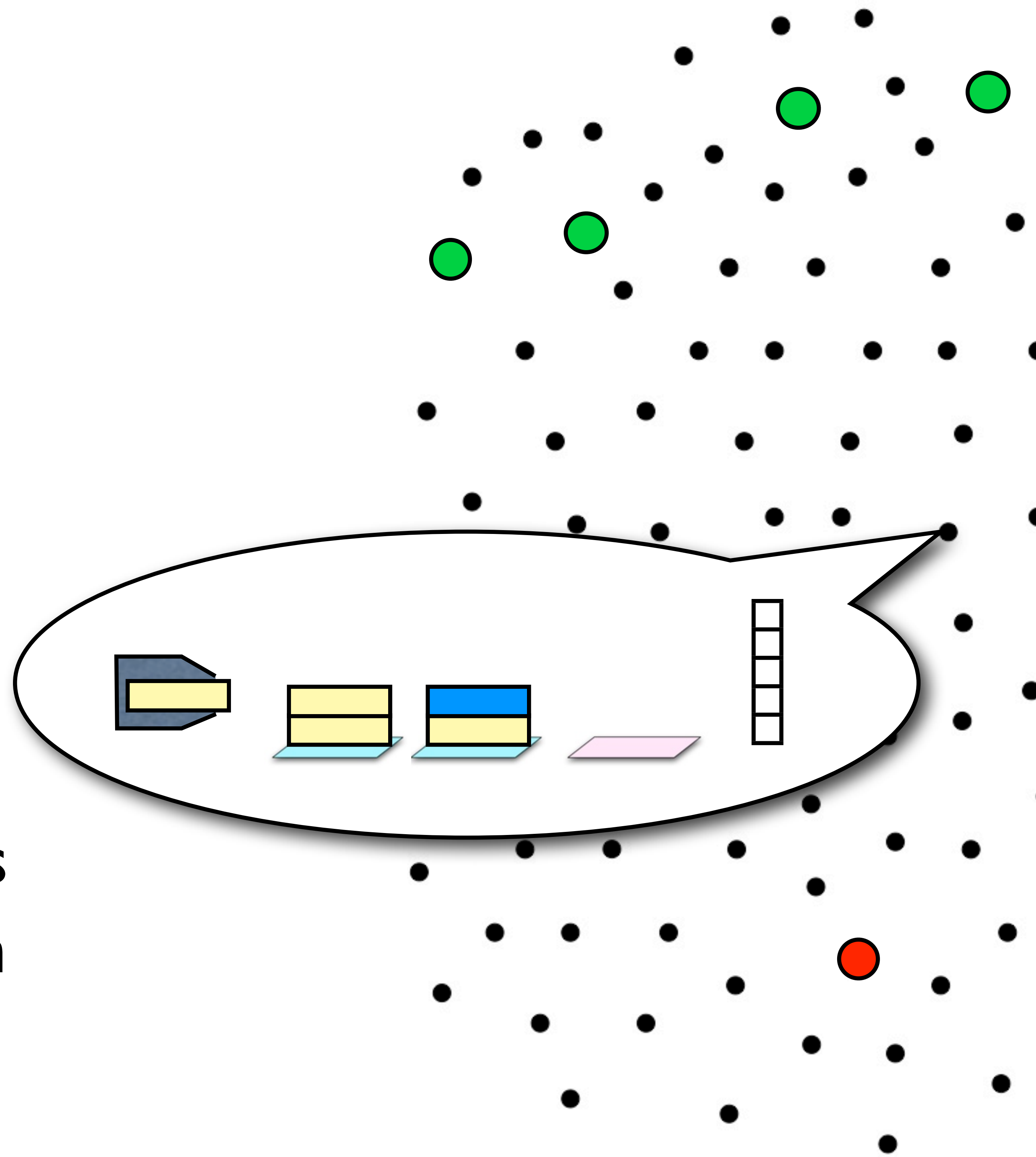
transport by cranes or vehicles

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

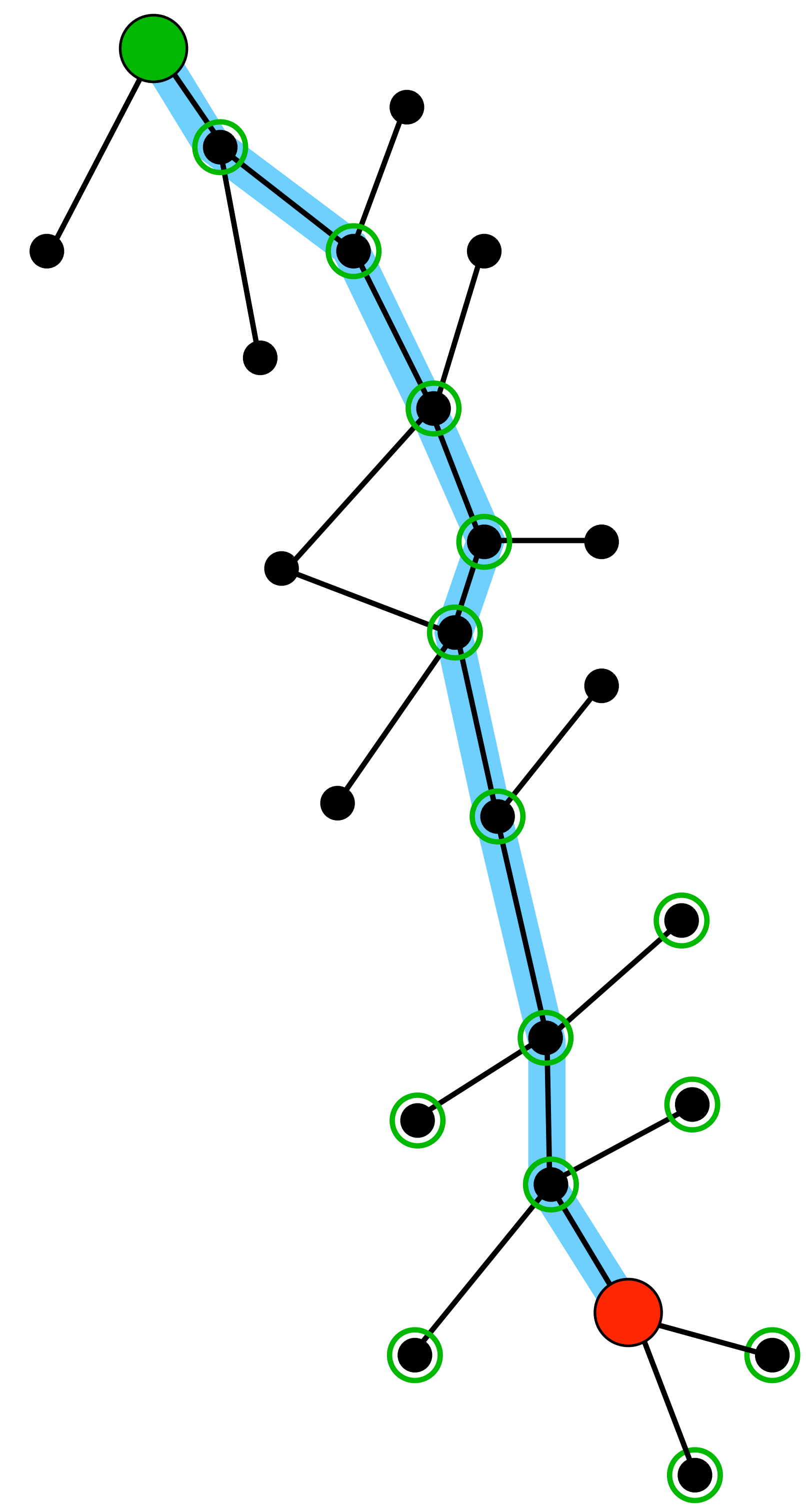
... but rather easy in practice

- 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

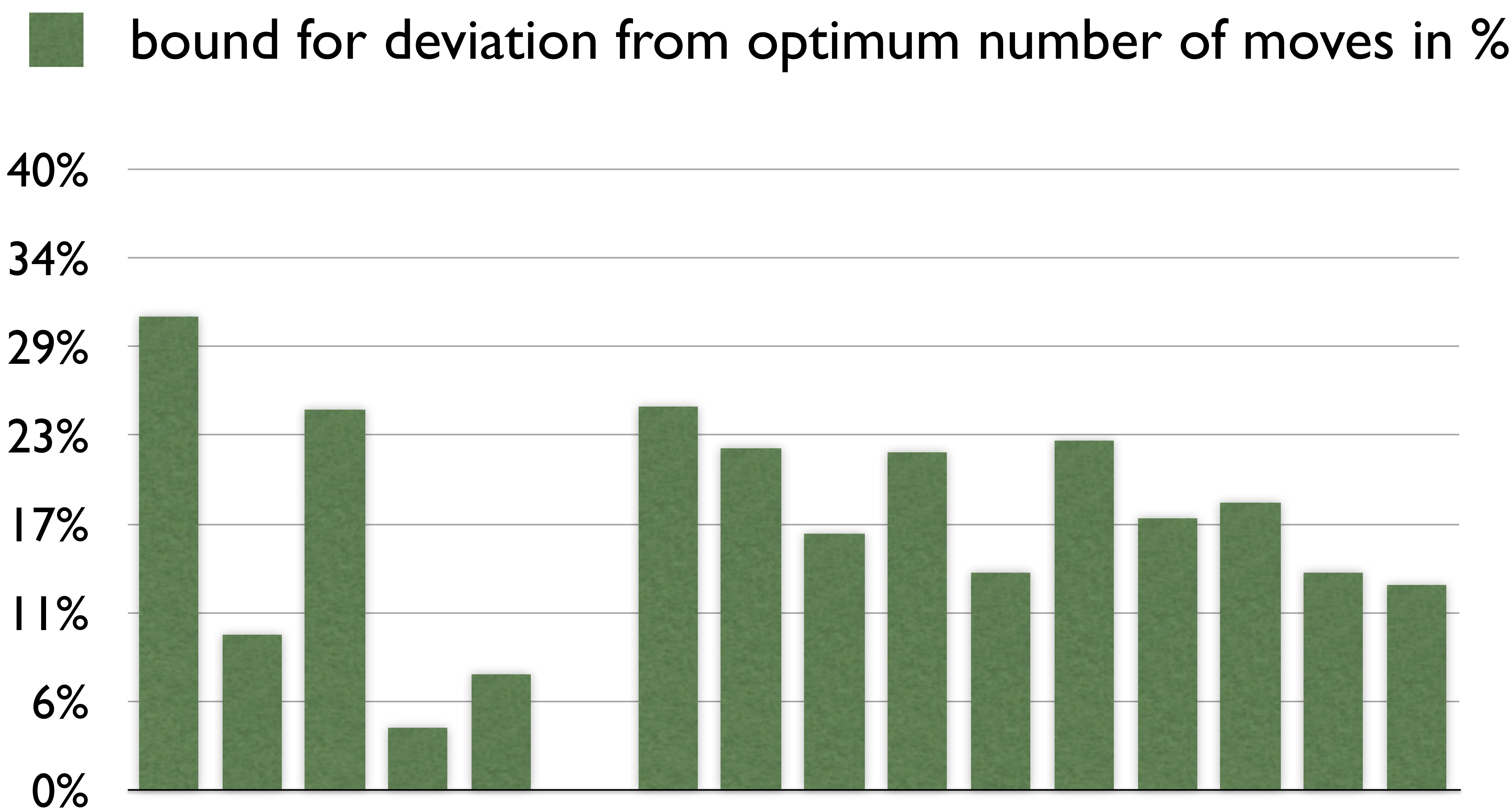


Greedy search in the state space

- generate start state
- generate all neighbors
- evaluate them
- go to the best



Greedy is fast and gives good quality



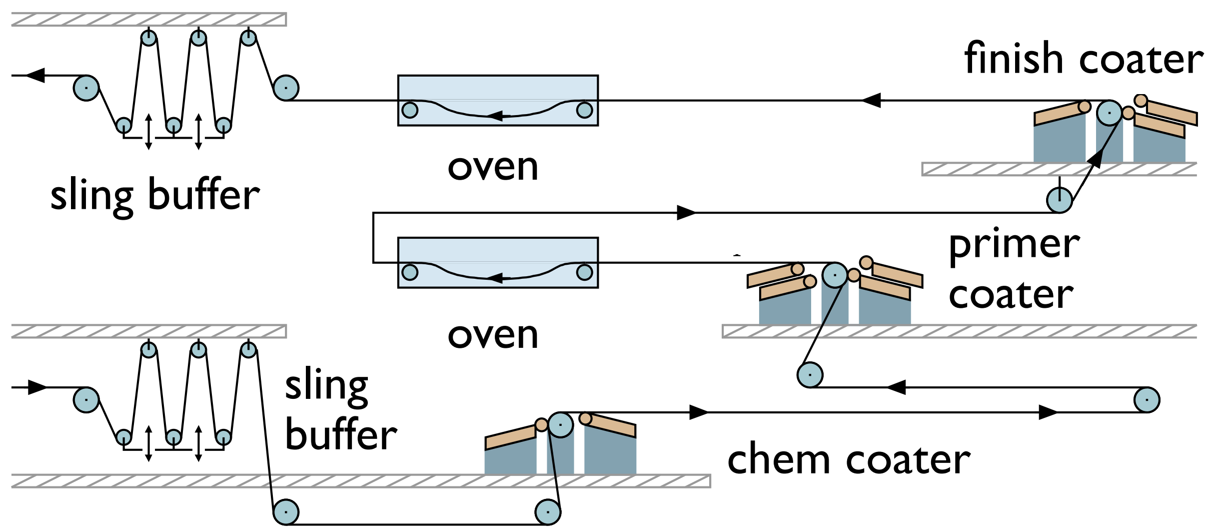
- lower bound obtained from relaxation solved by IP

Example 2: Coil coating

[Höhn, König, Lübbecke, Möhring 2009]

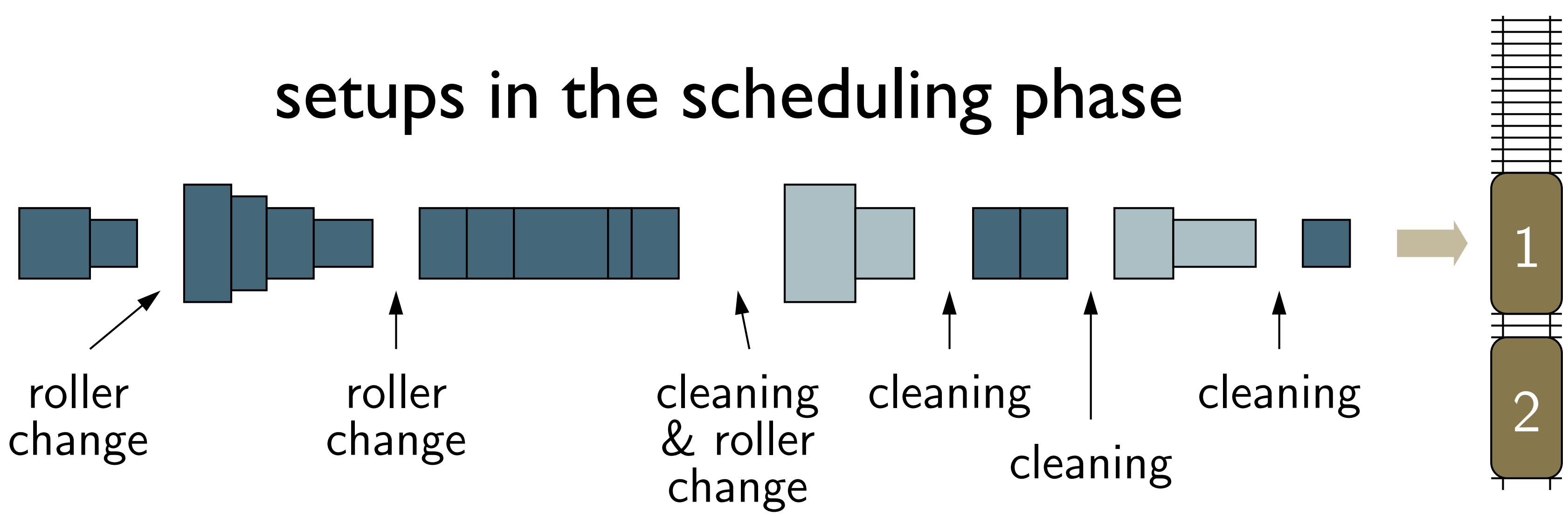
coils need to be sequenced

run through coating line



complex scheduling with shuttle coaters

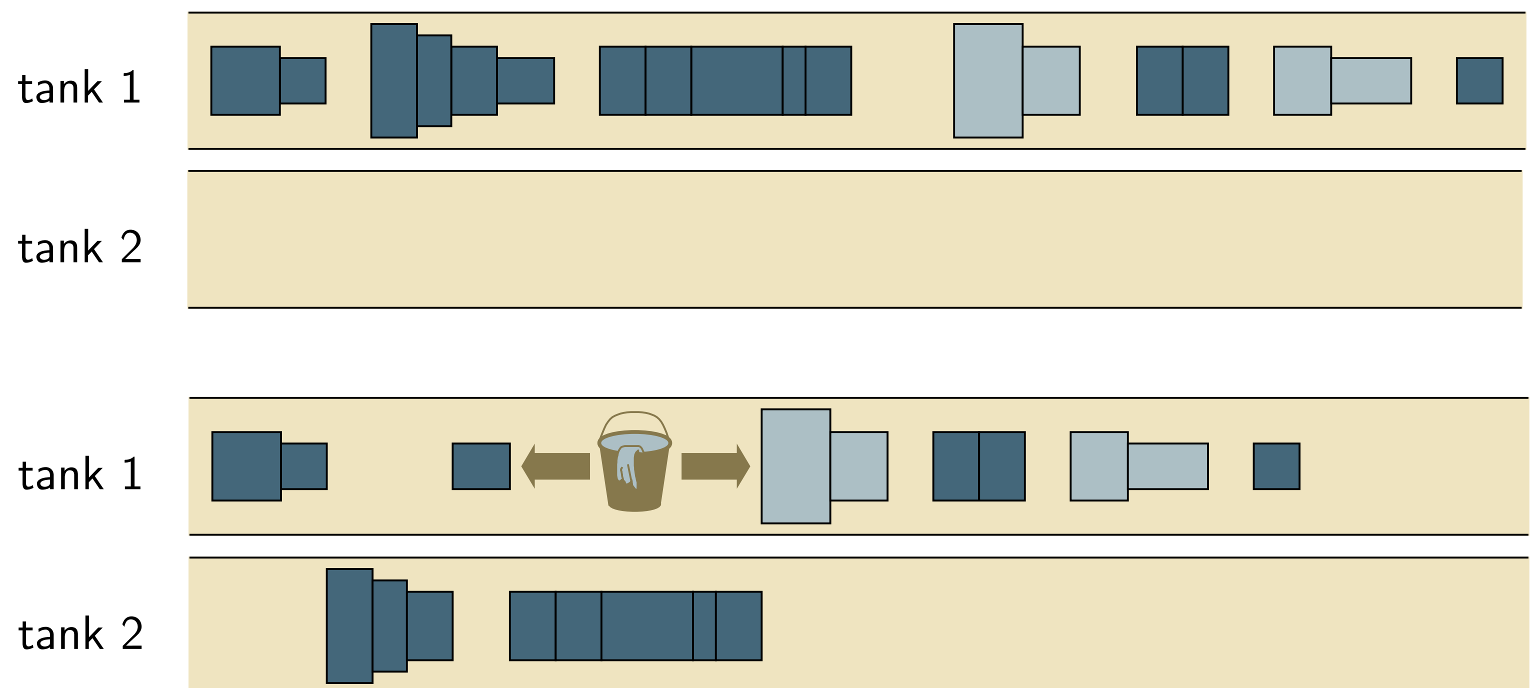
setups in the scheduling phase



2 color tanks

Details about the scheduling phase

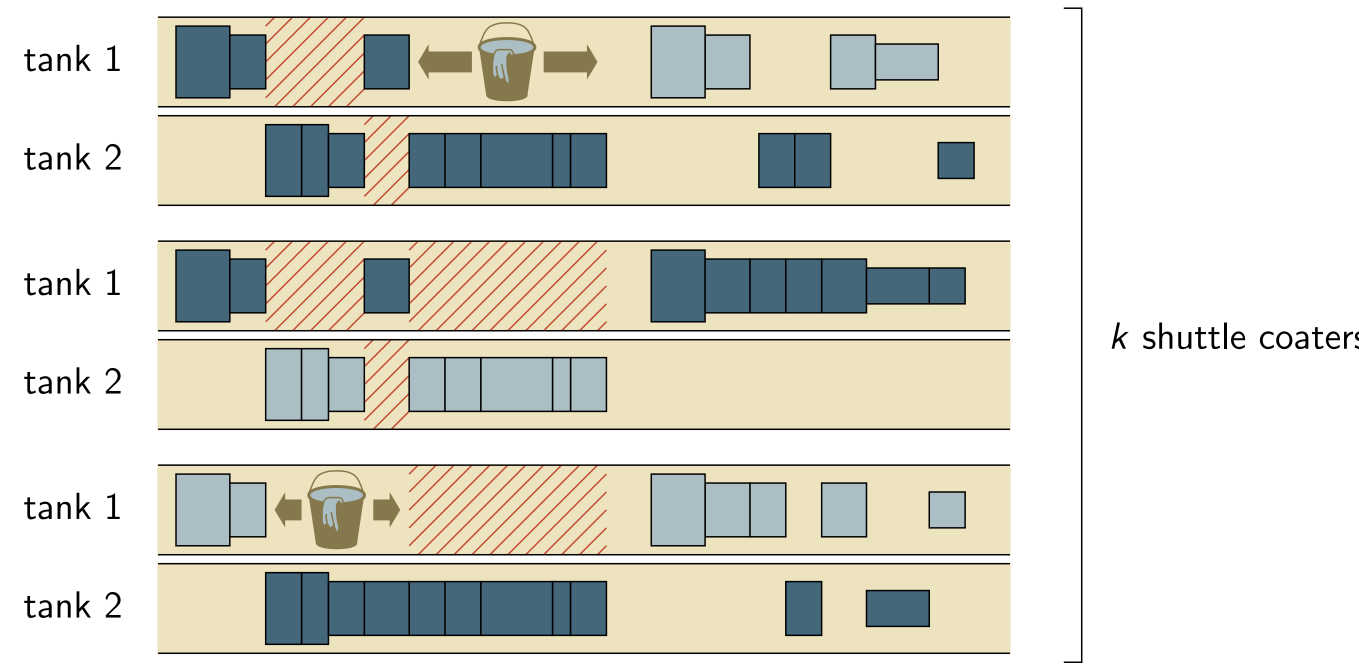
- Subproblem:
  - given fixed-order coil sequence, find tank assignment with minimum total idle time



- Setup work necessary if
  - color changes → cleaning
  - coil has larger width than predecessor → roller change
- → concurrent setup work on idle tank saves idle time

Graph model for the scheduling phase

- k shuttle coaters
- no parallel concurrent setup



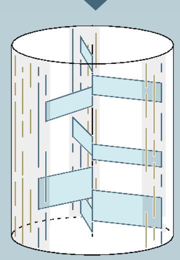
Practice

Tank Assignment Problem with k coaters

new ideas for efficient algorithm

far too slow, even for small instances

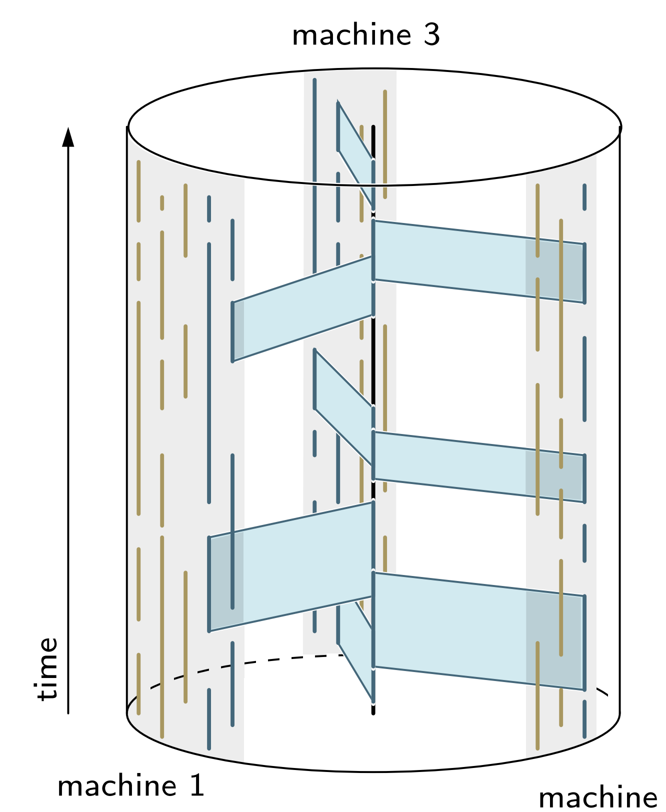
Theory



Max Weight Indep. Set in special 2-union graphs

polynomial-time algorithm for fixed k
$\rightsquigarrow$ dynamic programming

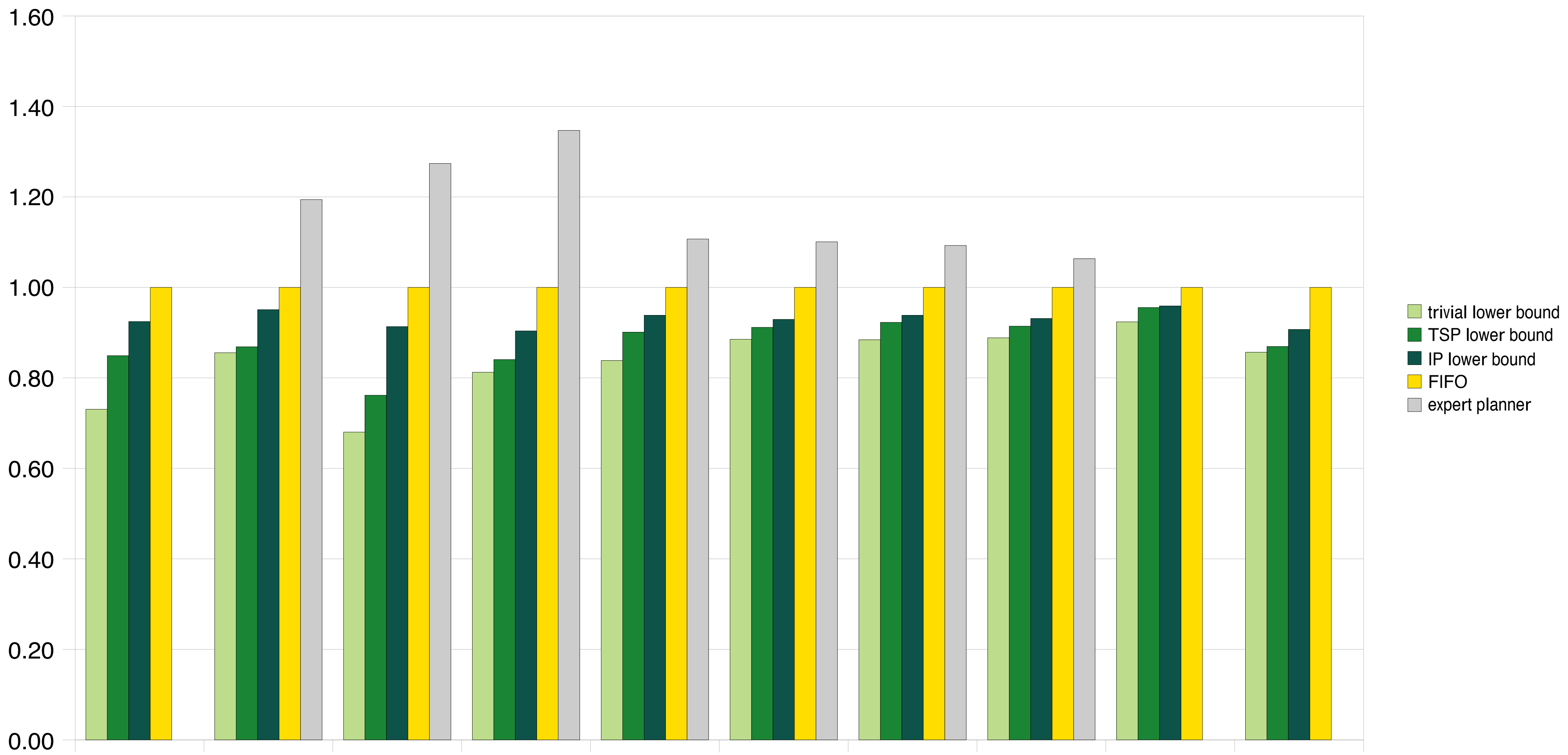
strongly NP-hard



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

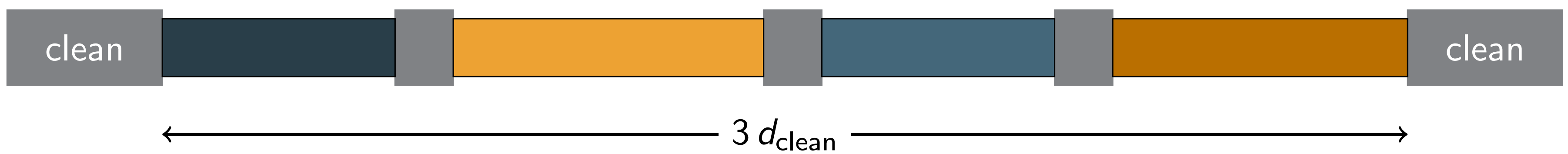
run through a filling line

complex scheduling due to cleaning

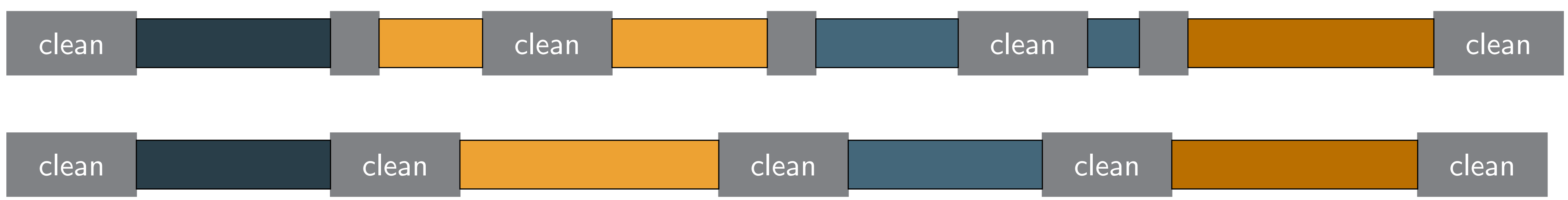
- Jobs specified by
  - base, e.g. yoghurt, cream, . . .
  - fruit (optional) package
  - number of pallettes duration
- Setup/waiting due to
  - package/fruit/base change or cleaning
  - regular cleaning of line and tanks
  - limited size of tanks
  - minimum time lags

Details about the scheduling phase

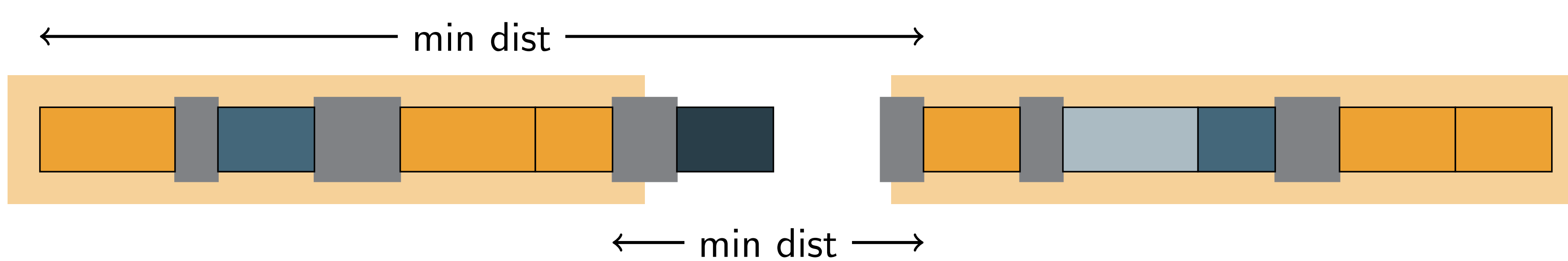
- Guarantee maximum distance d_{clean} between cleanings:



  - preempt jobs
  - replace setup already in the schedule

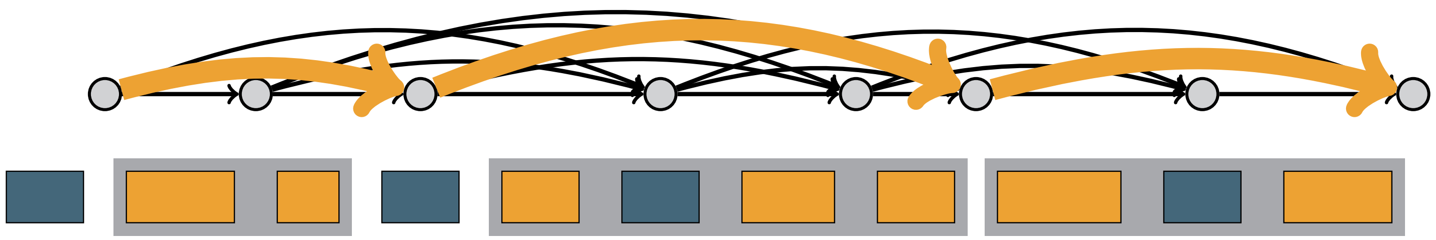


- Respect limited size of cream tank

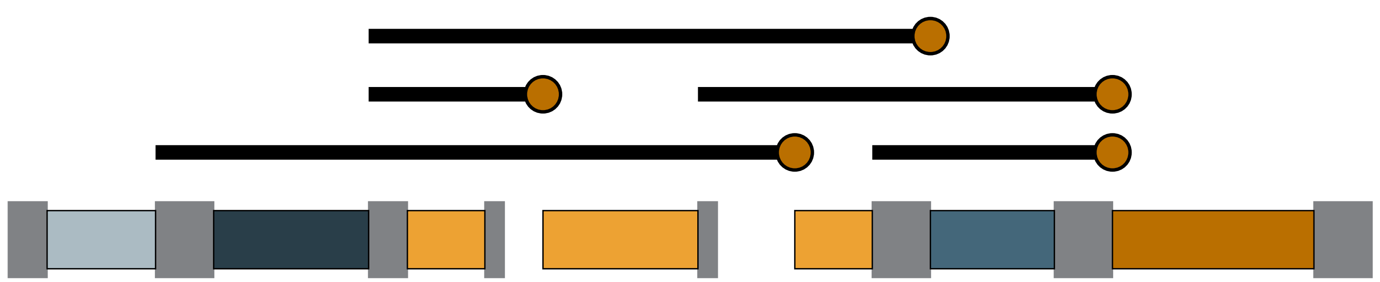


Solving the two classes of constraints

- 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

Sequence generation with a fast genetic algorithm

Scheduling based on the insights from analysis

Quality testing by an TSP lower bound show optimality gap of 2% for a weekly production

Summary

- 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

$\boxed{\text{There is much work left to be done}}$