TU WIEN Informatics

dbai Database and Artificial Intelligence Group

Christian Doppler Forschungsgesellschaft

Seminari i parë shkencorë i Fakultetit të Inxhinierisë Elektrike dhe Kompjuterike

Artificial Intelligence and Optimization for Automated Planning and Scheduling

Nysret Musliu

Christian Doppler Laboratory for Artificial Intelligence and Optimization for Planning and Scheduling

Database and Artificial Intelligence Group

TU Wien

Research in Christian Doppler Laboratories

Application-orientated basic research

Cooperation between science and business

“A research group elaborates fundamental knowledge that flows into the development of new products and processes at commercial partners”

Industrial Partners

- Leading global supplier of technology and services

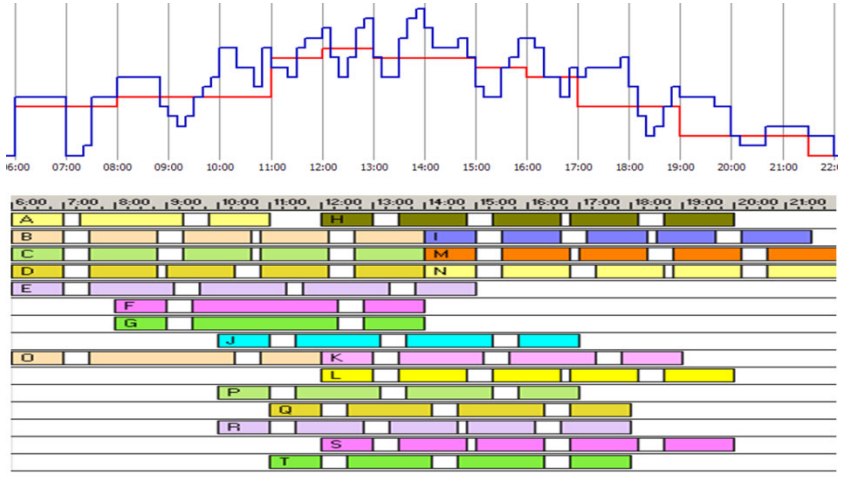
- Its core expertise is capacity and production planning and scheduling
- Rich expertise in heuristics

- It offers software and consulting services for workforce/working hours issues
- Spin-off of the TU Wien

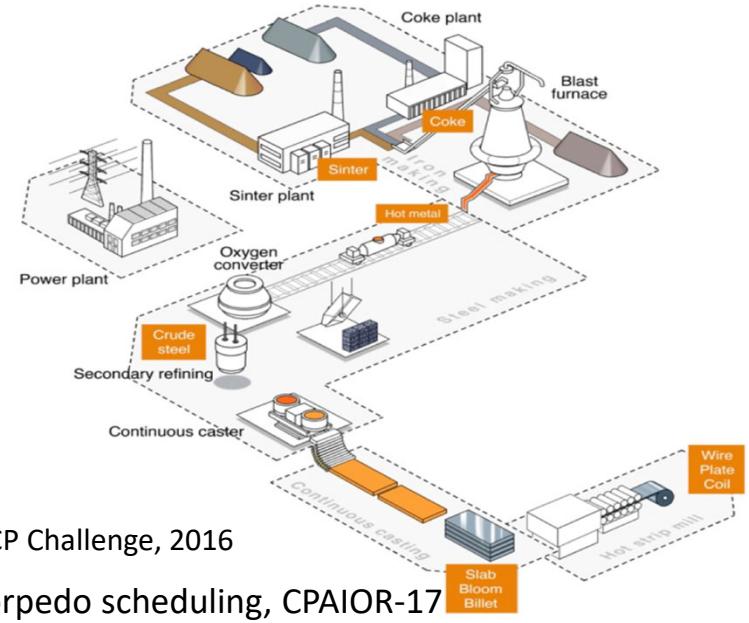
Planning and Scheduling Problems

	Mo	Di	Mi	Do	Fr	Sa	So
A	F	F	F	S	S		
B		N	N	N	N		
C		F	F	N	N	N	N
D			S	S	S	N	N
E	N			F	F	S	S
F	S			F	F	F	F
G	S	S				F	F
H	F	S	S			S	S
I	N	N	N				

Personnel scheduling, IJCAI-17



Break scheduling, IEEE Intelligent Systems (2010)



ACP Challenge, 2016

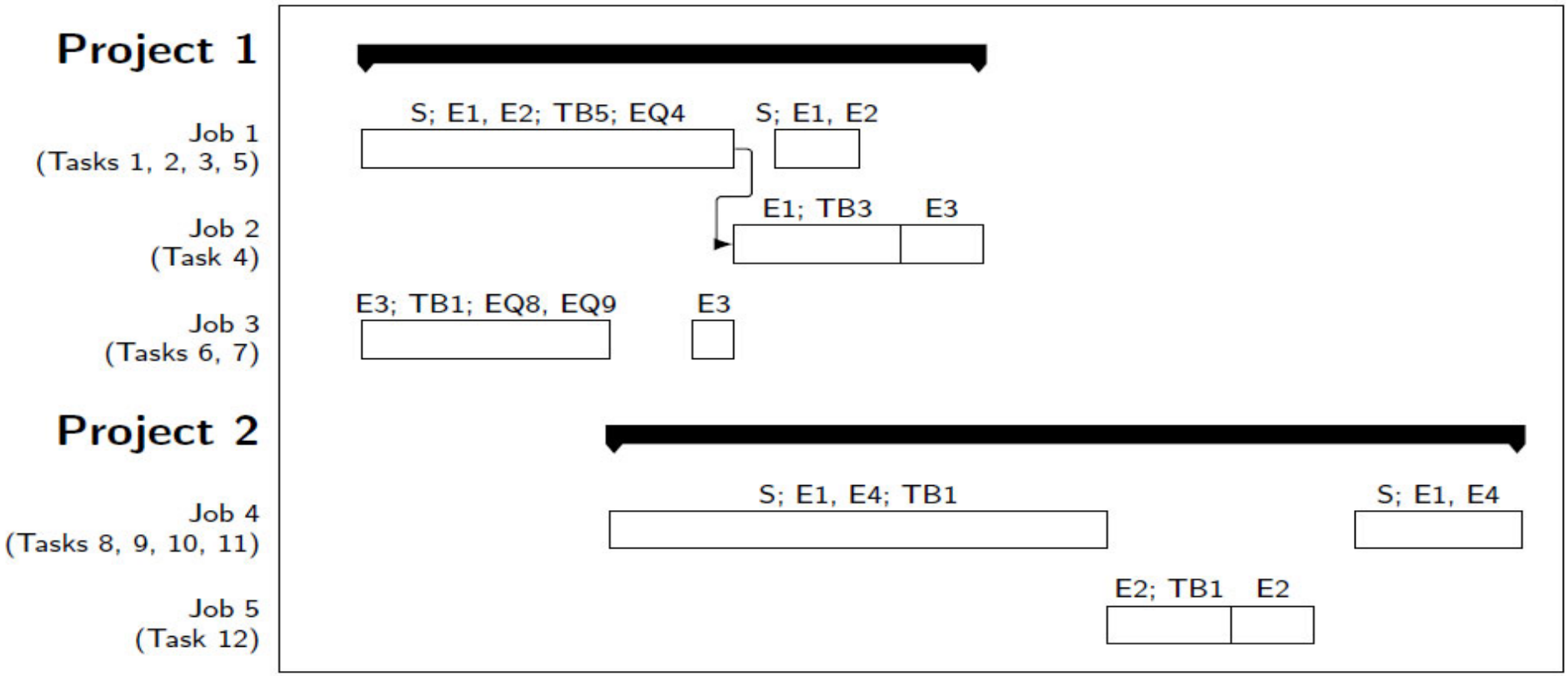
Torpedo scheduling, CPAIOR-17

More examples in health care, production, education, public transport, …

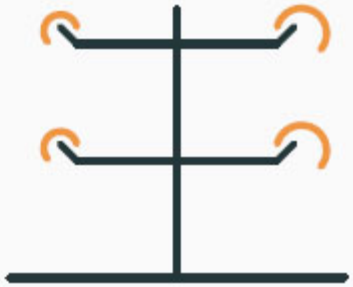
Very important problems

Their solutions impact people's everyday life and the efficiency of operations

Task Scheduling/Project Scheduling/Test Laboratory Scheduling

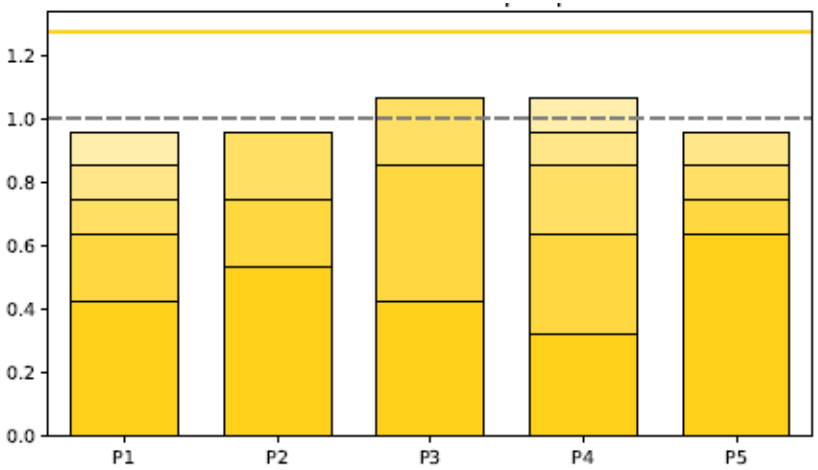


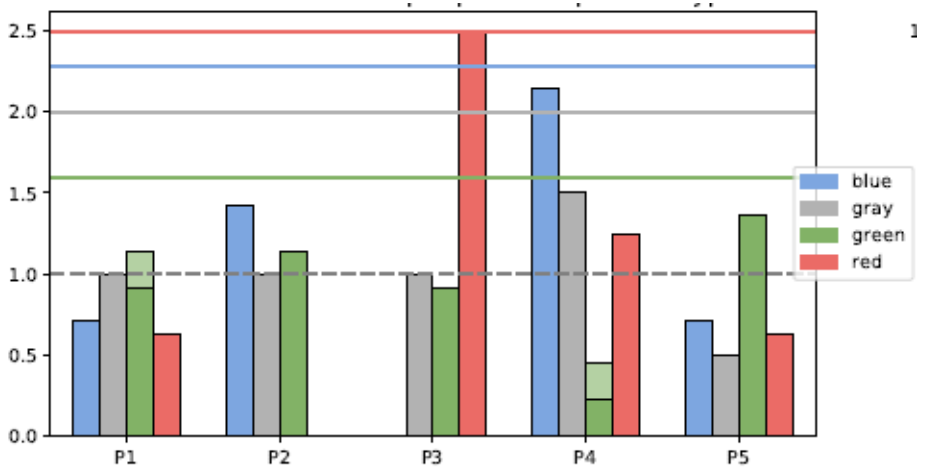
Automotive Paint Shop Scheduling Problem



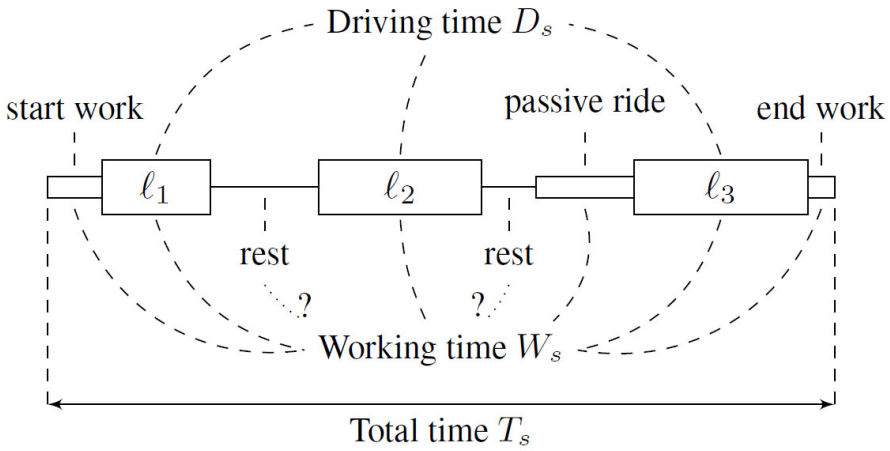
	R1	R2	R3	. . .
1	A	A	C	. . .
2	A	A	C	. . .
3	A	C	C	. . .
4	B	B	B	. . .
5	B	B	B	. . .

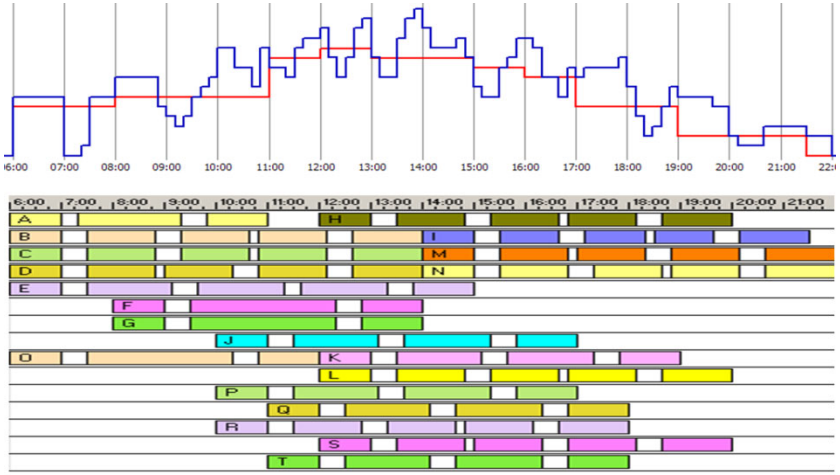
Production Leveling Problem





Personnel Planning and Scheduling





	Mo	Di	Mi	Do	Fr	Sa	So
A	F	F	F	S	S		
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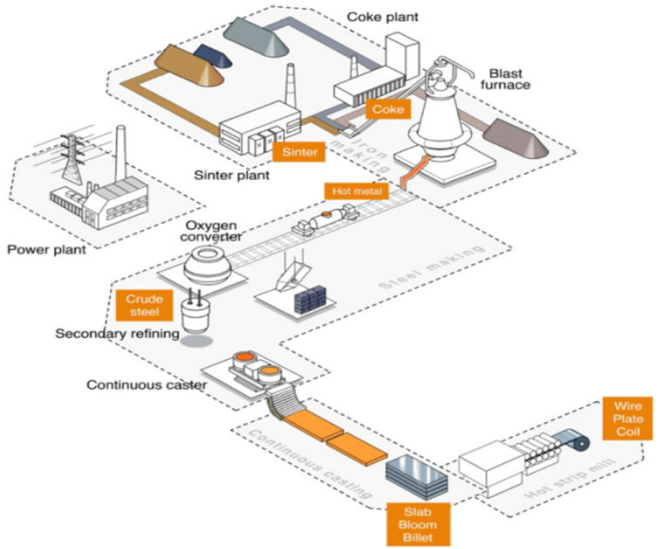
E	N			F	F	S	S
F	S			F	F	F	F
G	S	S				F	F
H	F	S	S			S	S
I	N	N	N				

Other real-life problems

Torpedo Scheduling Problem



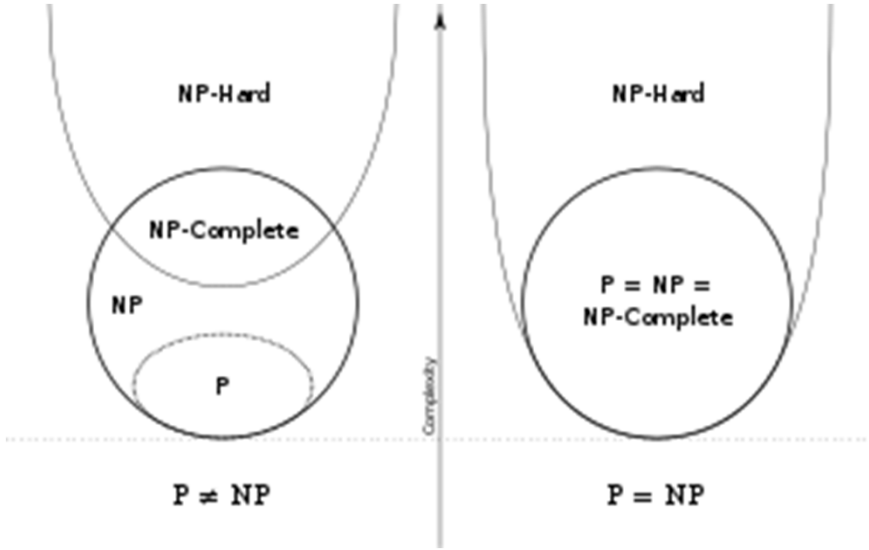
ACP Challenge, 2016

Parallel Machine Scheduling

Curriculum-based Course Timetabling

The General Obstacle

- NP-hard (intractable) problems
- No efficient algorithms could be found yet
- P problems can be solved efficiently (in polynomial time)
- P ≠ NP ? **(Millennium Prize Problem)**



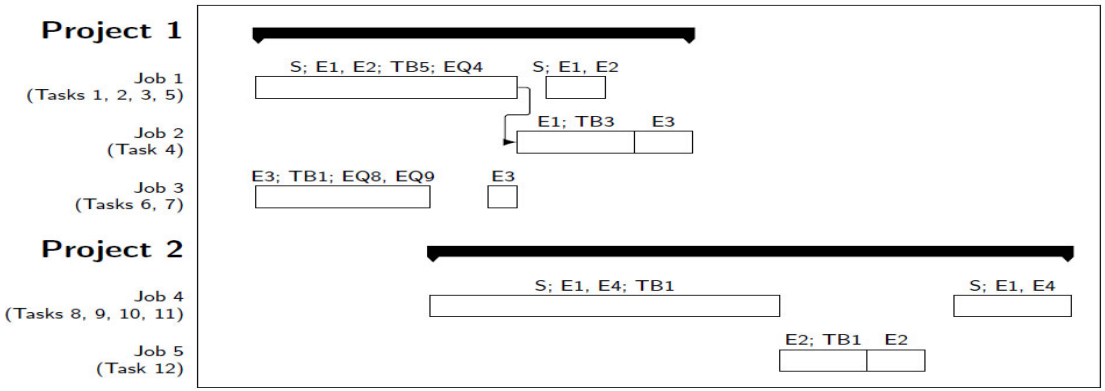
https://en.wikipedia.org/wiki/NP-hardness

Tremendous size of the search space of possible candidate solutions

Search Space

	Mo	Di	Mi	Do	Fr	Sa	So
A	F	F	F	S	S		
B		N	N	N	N		
C		F	F	N	N	N	N
D			S	S	S	N	N
E	N			F	F	S	S
F	S			F	F	F	F
G	S	S				F	F
H	F	S	S			S	S
I	N	N	N				

10^{84}



10^{3000}

State-of-the-art methods

Complete approaches

Mathematical programming
Constraint programming
Answer set programming
SAT/SMT
…

Metaheuristics

Tabu Search
Simulated Annealing
Evolutionary Strategies
Memetic Algorithms
…

Solvers and constraint languages: IBM (CPLEX, CP Optimizer), Gurobi, Google (OR-Tools), Chuffed, MiniZinc …

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- Domain specific solutions
- For many problems optimal solutions are not known
- New challenging problems that cannot be optimally solved (e.g., problems from our industrial partners)

State-of-the-art methods

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Solvers Gurobi,
Goolge

New algorithms/techniques needed

- Domain specific solutions
- For many problems optimal solutions are not known
- New challenging problems that cannot be optimally solved (e.g., problems from our industrial partners)

Goals and Methods

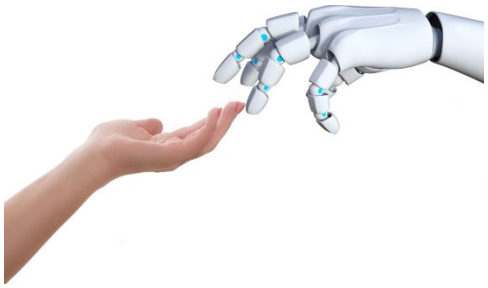
Overall goal: New generation of planning and scheduling algorithms

- Scalable in practice
- Domain independent
- Online adaptive

Methods

- Novel modeling approaches for state-of-the art solvers
- Hybrid techniques
- Machine learning and automated algorithm selection
- Automated algorithm design

Hybrid Algorithms



Methods of Artificial Intelligence (Machine Learning…)

Methods of Logic

Mathematical Optimization

$$S_{i,d,t} \leftrightarrow \bigwedge_{x=1}^{sl_t} U_{i,d,x} \bigwedge_{y=sl_t}^{sl_{max}} \neg U_{i,d,y}$$

$$\begin{aligned} minimize\ f = \quad & 30 * \sum_{\substack{s \in S \\ k \in K \\ d \in \{1 \ldots 7\}}} C_{skd}^{S1} \\ & +15 * \sum_{\substack{n \in N \\ s \in S \\ d \in \{1 \ldots 7\}}} (C_{nsd}^{S2a} + C_{nsd}^{S2b}) \\ & +30 * \sum_{\substack{n \in N \\ d \in \{1 \ldots 7\}}} (C_{nd}^{S2c} + C_{nd}^{S2d}) \end{aligned}$$

Parallel Machine Scheduling

minimise $Lex(\Sigma_{j\in J}(T_j), C_{max})$, subject to

$$\Sigma_{m\in M}(Y_{j,m}) = 1, \forall j \in J$$

$$\Sigma_{i\in J_0, i\neq j}(X_{i,j,m}) = Y_{j,m}, \forall j \in J, m \in M$$

$$\Sigma_{j\in J_0, i\neq j}(X_{i,j,m}) = Y_{i,m}, \forall i \in J, m \in M$$

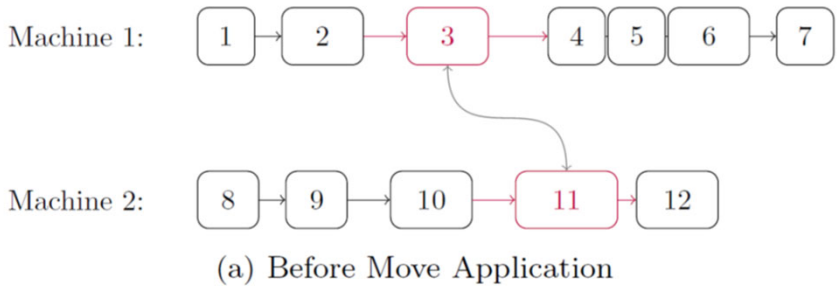
$$C_j \geq C_i + s_{i,j,m} + p_{j,m} + V \cdot (X_{i,j,m} - 1), \quad \forall i \in J_0, j \in J, m \in M$$

$$\Sigma_{j\in J}(X_{0,j,m}) \leq 1, \forall m \in M$$

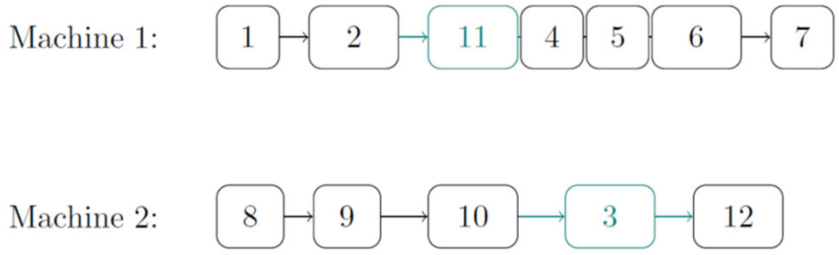
$$\Sigma_{i\in J_0, j\in J, i\neq j}(s_{i,j,m} \cdot X_{i,j,m}) + \Sigma_{i\in J}(p_{i,m} \cdot Y_{i,m} + s_{i,0,m} \cdot X_{i,0,m}) \leq C_{max}, \quad \forall m \in M$$

$$T_j \geq C_j - d_j, \forall j \in J$$

$$T_j \geq 0, \forall j \in J$$



(a) Before Move Application



(b) After Move Application

Test Laboratory Scheduling

$$\xi(\xi(a)) = \xi(a) \qquad a \in A^* \qquad (1)$$

$$p_a = p_{\xi(a)} \wedge f_a = f_{\xi(a)} \qquad a \in A^* \qquad (2)$$

$$\texttt{all\_equal}(\{\xi(a) \mid a \in \dot{A}_j^F\}) \qquad j \in J^0 \qquad (3)$$

$$\xi(a) \leq a \qquad a \in A^* \qquad (4)$$

$$s_{\xi(a)} \geq \alpha_a \wedge n_{\xi(a)} \leq \omega_a \qquad a \in A^* \qquad (5)$$

$$d_a = n_a - s_a \qquad a \in J \qquad (6)$$

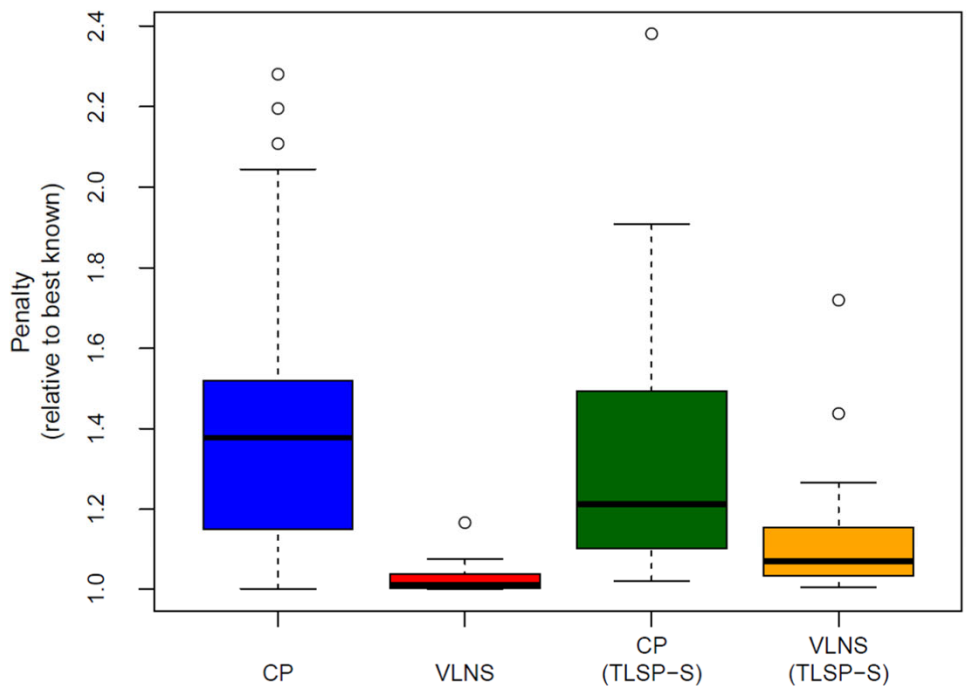
$$d_a \cdot \mathcal{M} \geq \sum_{\substack{a' \in A^* \\ \text{s.t. } \xi(a')=a}} d_{a'm_a} + st(a) \qquad a \in J \qquad (7)$$

$$(d_a - 1) \cdot \mathcal{M} < \sum_{\substack{a' \in A^* \\ \text{s.t. } \xi(a')=a}} d_{a'm_a} + st(a) \qquad a \in J \qquad (8)$$

$$\xi(a) = \xi(a') \vee n_{\xi(a')} \leq s_{\xi(a)} \qquad a \in A^*, a' \in \mathcal{P}_a \qquad (9)$$

$$s_{\xi(a)} = 1 \qquad j \in J^{0S}, a \in \dot{A}_j \qquad (10)$$

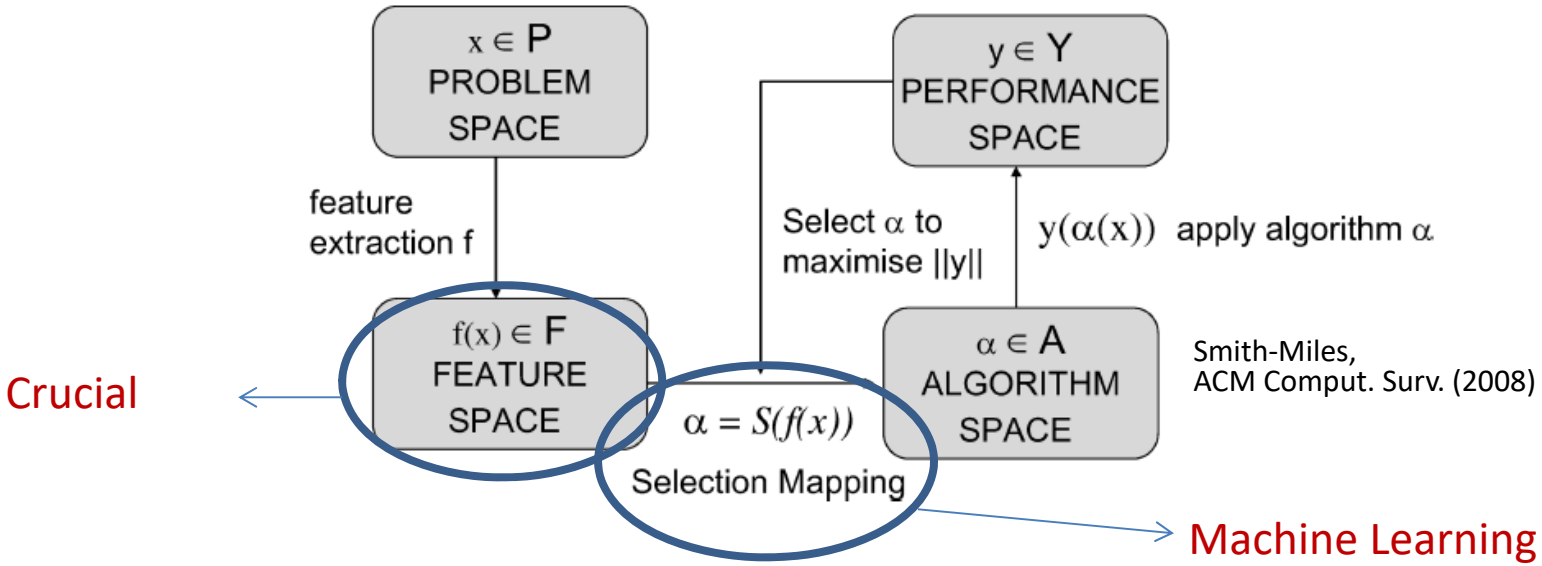
$$\texttt{cumulative}((s_a)_{a \in A^*}, (d_{m_a a})_{a \in A^*}, (a_{ea}^{Em})_{a \in A^*}, 1) \qquad e \in E \qquad (11)$$



Automated Algorithm Selection

No free lunch theorem

"…for any algorithm, any elevated performance over one class of problems is offset by performance over another class" (Wolpert & Macready, IEEE Trans. Evo. Comp., 1997)

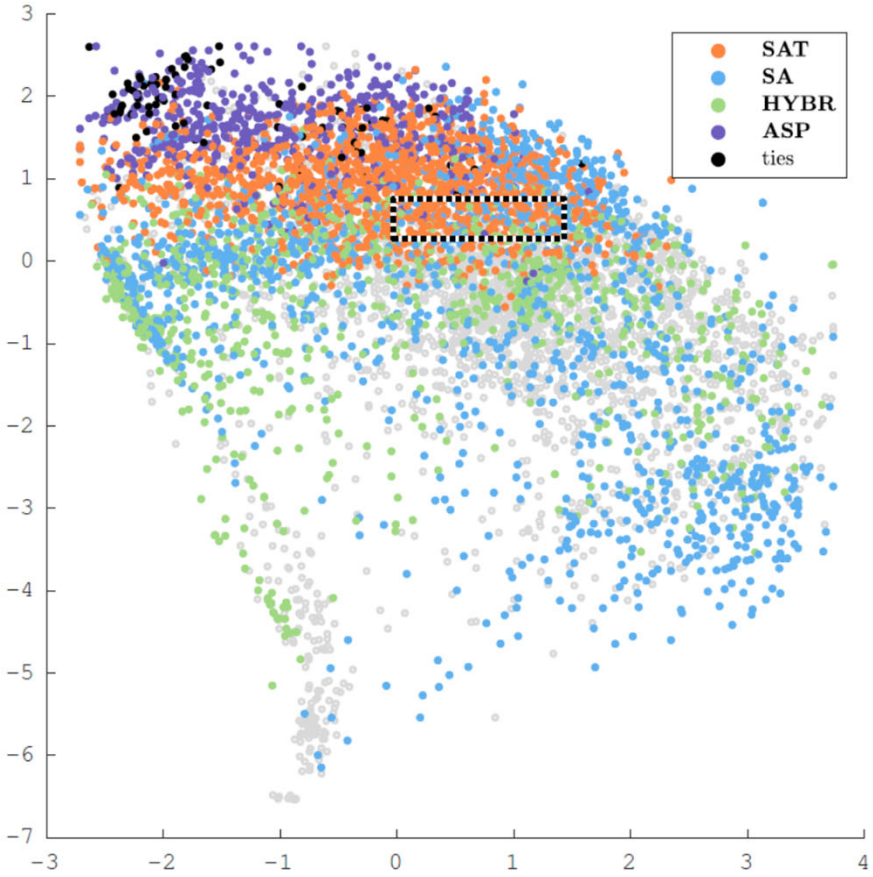


Success Stories

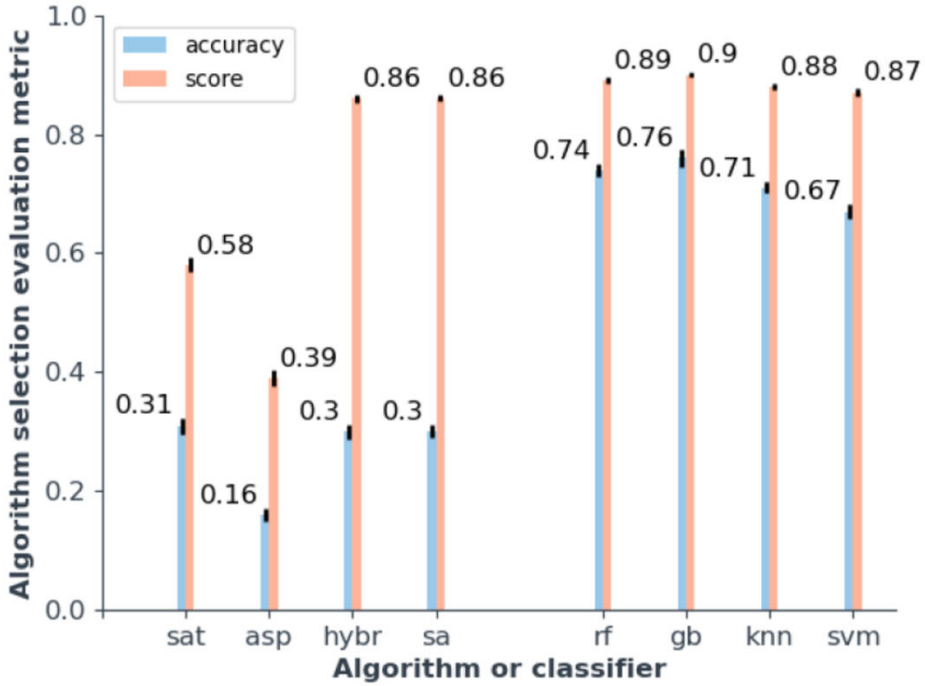
SAT, TSP, Graph Coloring, Combinatorial Auctions,…

⚠ Problem specific features

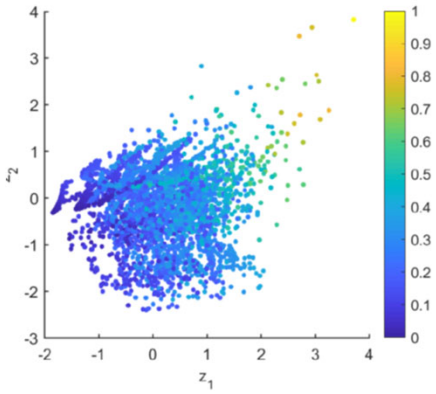
Curriculum-based Course Timetabling



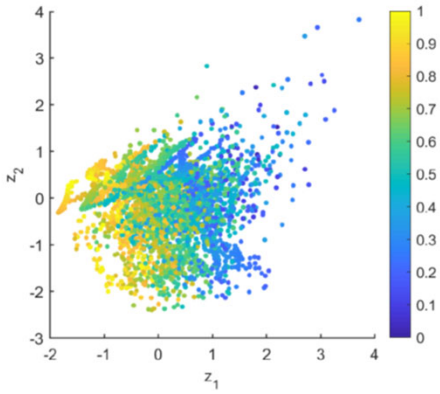
(b) Best performance (with time)



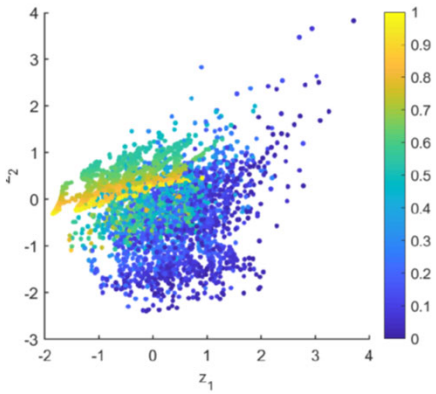
Personnel Scheduling



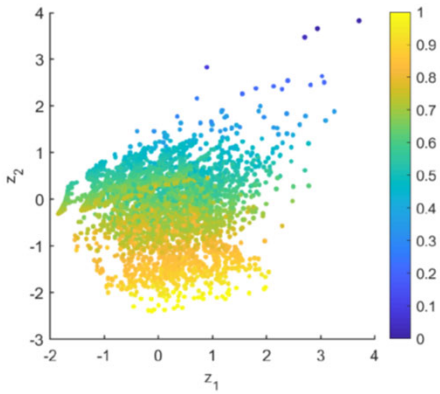
(a) *minAvgBlockLength*



(b) *maxAvgBlockLength*



(c) *minDayFraction*



(d) *maxDayFraction*

Fig. 5: Selected features for the extended instance set

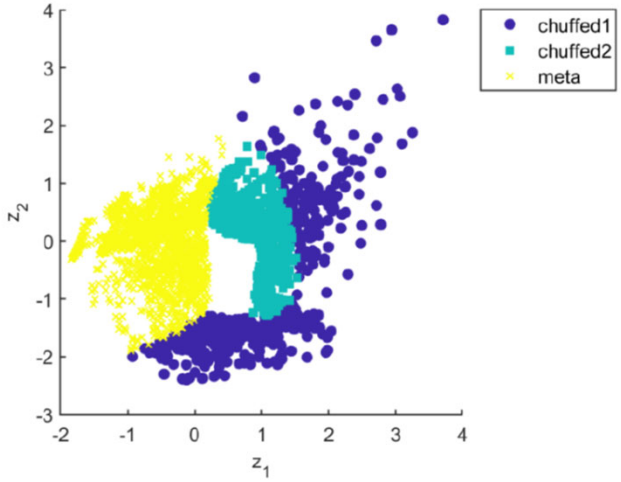
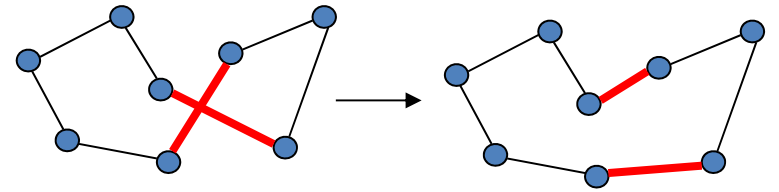


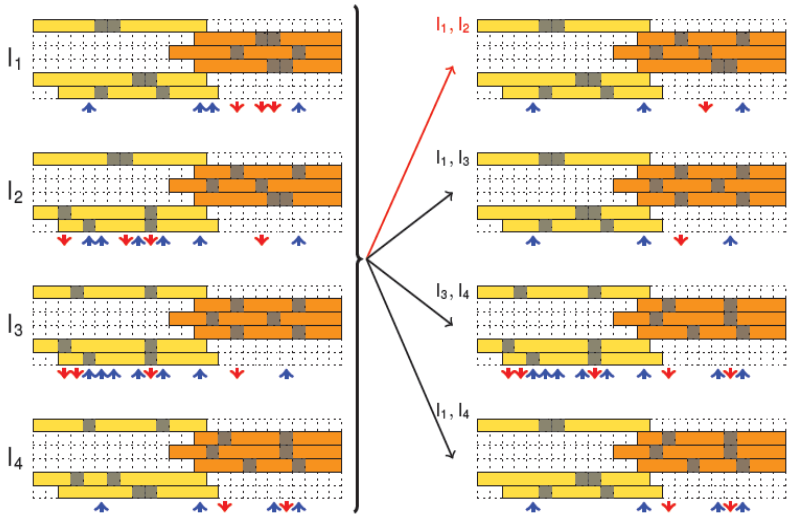
Fig. 9: Algorithm portfolio

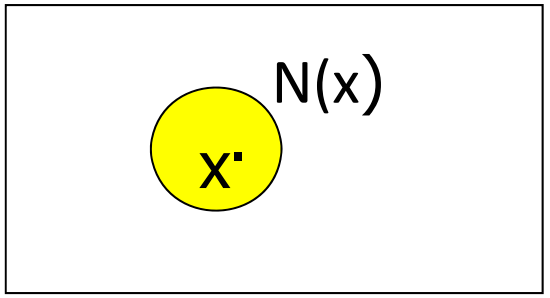
Future Work: Automated Algorithm Design

Automated generation of low-level heuristics and operators

Algorithm design by hyper-heuristics





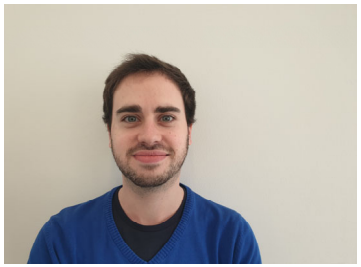


CD-Laboratory: Researchers







CPAIOR 2021

18th International Conference on the Integration of Constraint Programming, Artificial Intelligence, and Operations Research, July 5-8, 2021, Vienna, Austria.

Program Chair: Peter Stuckey
Conference Chair: Nysret Musliu

CONFERENCE WEBSITE

Selected References

- Lucas Kletzander, Nysret Musliu, Pascal Van Hentenryck. Branch and Price for Bus Driver Scheduling with Complex Break Constraints. ***The Thirty-Fifth AAAI Conference on Artificial Intelligence (AAAI-21).***
- Tobias Geibinger, Florian Mischek, Nysret Musliu. Constraint Logic Programming for Real-World Test Laboratory Scheduling. ***The Thirty-Fifth AAAI Conference on Artificial Intelligence (AAAI-21).***
- Felix Winter and Nysret Musliu. Constraint based scheduling for paint shops in the automotive supply industry. ***ACM Transactions on Intelligent Systems and Technology, 2021.***
- Lucas Kletzander, Nysret Musliu, Kate Smith-Miles. Instance space analysis for a personnel scheduling problem. ***Annals of Mathematics and Artificial Intelligence (2020).***
- Lucas Kletzander, Nysret Musliu. Solving the general employee scheduling problem. ***Computers and Operations Research, Volume 113, January 2020.***
- Lucas Kletzander, Nysret Musliu. Solving Large Real-Life Bus Driver Scheduling Problems with Complex Break Constraints**. *In Proceedings of the 30th International Conference on Automated Planning and Scheduling, ICAPS 2020, Nancy, France, 2020***
- Philipp Danzinger, Tobias Geibinger, Florian Mischek and Nysret Musliu. Solving the Test Laboratory Scheduling Problem with Variable Task Grouping**. *In Proceedings of the 30th International Conference on Automated Planning and Scheduling, ICAPS 2020, Nancy, France, 2020.***
- Felix Winter, Nysret Musliu, Peter Stuckey. Explaining Propagators for String Edit Distance Constraints. ***In Proceedings of the Thirty-Fourth AAAI Conference on Artificial Intelligence, New York, United States, 2020.***
- Martin Josef Geiger, Lucas Kletzander, Nysret Musliu: Solving the Torpedo Scheduling Problem. ***Journal of Artificial Intelligence Research. Vol 66: 1-32, 2019.***
- Florian Mischek and Nysret Musliu. A Local Search Framework for Industrial Test Laboratory Scheduling. ***Submitted to Annals of Operations Research.***
- Maximilian Moser, Nysret Musliu, Andrea Schaerf, Felix Winter. Exact and Metaheuristic Approaches for Unrelated Parallel Machine Scheduling. ***Submitted to Journal of Scheduling.***
- *Johannes Vass, Marie-Louise Lackner, Christoph Mrkvicka, NysretMusliu, Felix Winter. Exact and Meta-Heuristic Approaches for the Production Leveling Problem.* ***Submitted to Journal of Scheduling.***
- *Arnaud De Coster , Nysret Musliu, Andrea Schaerf, Johannes Schoisswohl, Kate Smith-Miles. Algorithm Selection & Instance Space Analysis for Curriculum-based Course Timetabling.* ***Submitted to Journal of Scheduling.***

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