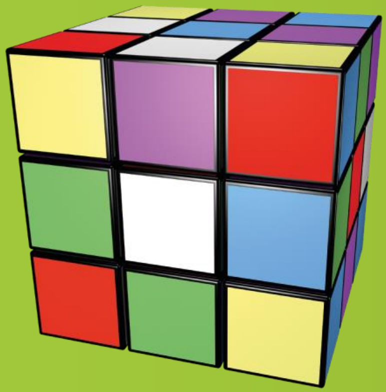


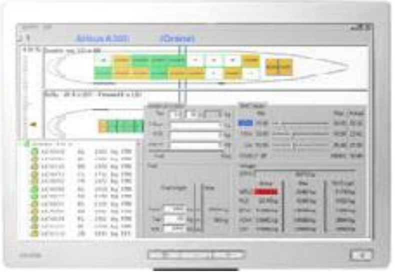
Modeling, learning and solving dynamic problems by meta- and hyper-heuristics in maintenance.

Patrick De Causmaecker
CODeS, Computer Science
KU Leuven

TC Ghent: Industrial Cooperation (Greet Vanden Berghe)

timetabling, rostering, scheduling, routing, cutting, packing

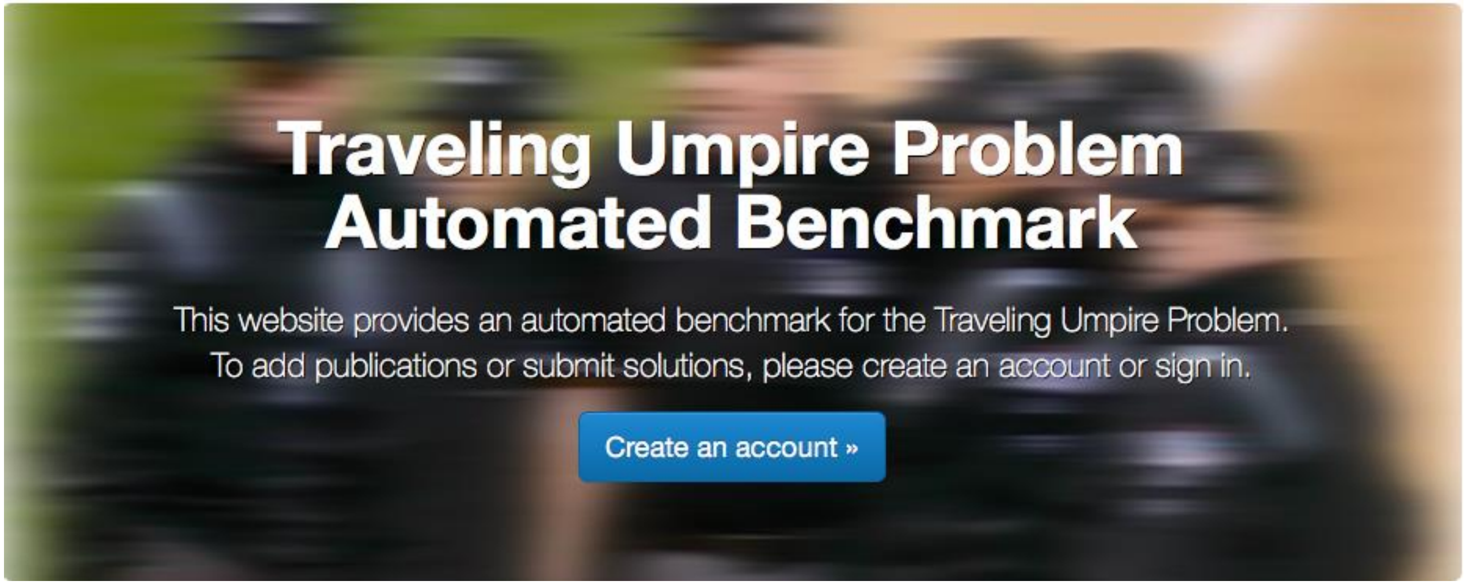




Themes at TC Ghent

- Vehicle routing, cutting and packing, (personnel) scheduling,…



Themes @ KULAK
Patrick De Causmaecker

- Data Science meets Optimization
  - New EURO Working Group (workshop)
  - Algorithm Selection
  - Algorithm Configuration

comex
combinatorial optimization:
metaheuristics & exact methods

LION
intelligent-optimization.org

Benelearn

COSEAL
COnfiguration and SElection of ALgorithms

So where are the data?

- Technically
  - preventive maintenance
- Logistically:
  - Planned inspections
  - Unplanned replacements and repairs
  - Significant variation in workload

- Site characteristics
- Resources availability
- Process regulations

So where is the problem?

- *Core problem is planning*
  - Shunting (Routing Problem, Rush Hour Problem)
  - Parking (Multi-Knapsack Problem)
  - Services (Resource Constrained Multi-Project Scheduling Problem)
  - Splitting and combining of trains
  - Mapping of incoming trains to outgoing trains

So where is the challenge?

- Compare systematically with human planners' performance
- Improve and extend planning algorithms
- Better understanding of influencing factors
  - site layout
  - logistic problem characteristics
  - applied heuristics
- Empirical research to obtain more data on process variations and correlations

Modeling: Bin packing

minimize $B = \sum_{i=1}^{n} y_i$

subject to $B \geq 1$,

$$\sum_{j=1}^{n} a_j x_{ij} \leq V y_i, \quad \forall i \in \{1, \ldots, n\}$$

$$\sum_{i=1}^{n} x_{ij} = 1, \qquad \forall j \in \{1, \ldots, n\}$$

$$y_i \in \{0, 1\}, \qquad \forall i \in \{1, \ldots, n\}$$

$$x_{ij} \in \{0, 1\}, \qquad \forall i \in \{1, \ldots, n\} \, \forall j \in \{1, \ldots, n\}$$

where $y_i = 1$ if bin i is used and $x_{ij} = 1$ if item j is put into bin i.[5]

http://challenge-esicup-2015.org/Intro.htm

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Solving

- ‘Exact’ methods
  - MILP, Quadratic programming, Constraint programming
- Heuristics
  - E.g. Best Fit
- Metaheuristics
  - E.g. Genetic Algorithm, variable neighborhood
- Matheuristics
  - Hybridizing meta heuristic and exact mathematical ideas
- Hyperheuristics
  - Allowing layman designers to use advanced search

Solving: exact methods (MILP)

Progress in Algorithms Beats Moore's Law

December 23, 2010 by Noam Nisan

quantified. Here is just one example, provided by Professor Martin Grötschel of Konrad-Zuse-Zentrum für Informationstechnik Berlin. Grötschel, an expert in optimization, observes that a benchmark production planning model solved using linear programming would have taken 82 years to solve in 1988, using the computers and the linear programming algorithms of the day. Fifteen years later – in 2003 – this same model could be solved in roughly 1 minute, an improvement by a factor of roughly 43 million. Of this, a factor of roughly 1,000 was due to increased processor speed, whereas a factor of roughly 43,000 was due to improvements in algorithms! Grötschel

SOLVING REAL-WORLD LINEAR PROGRAMS:
A DECADE AND MORE OF PROGRESS

ROBERT E. BIXBY

ILOG, Inc. and Rice University, bixby@ilog.com or bixby@rice.edu

Solving: heuristics

Burke, E. K., Kendall, G., & Whitwell, G. (2004). A new placement heuristic for the orthogonal stock-cutting problem. *Operations Research*, *52*(4), 655–671.

Imahori, S., & Yagiura, M. (2010). The best-fit heuristic for the rectangular strip packing problem: an efficient implementation and the worst-case approximation ratio. *Computers and Operations Research*, *37*(2), 325–333.

Production, Manufacturing and Logistics

A two-dimensional heuristic decomposition approach to a three-dimensional multiple container loading problem

Túlio A. M. Toffolo[a,b,*], Eline Esprit[a], Tony Wauters[a], Greet Vanden Berghe[a]

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Solving: Metaheuristics

- The two-dimensional decomposition:
- Until **stop criterion** is reached:
  - Order unhandled items
  - Until all items have been handled
    - Pack equal height items at the bottom layer
    - Stack two layers on top
  - Keep **“best”** packed containters

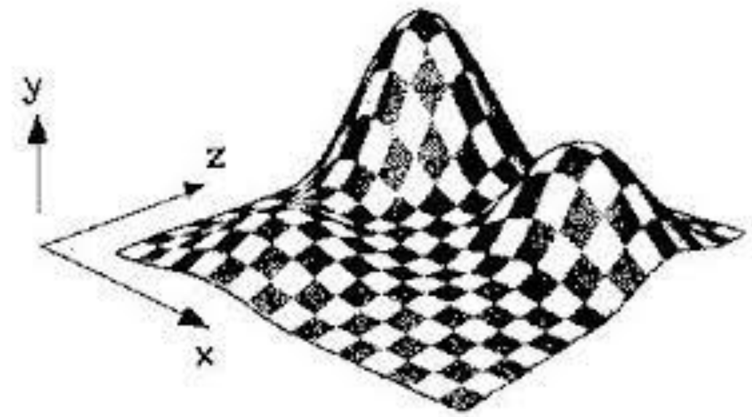
Solving: Metaheuristics

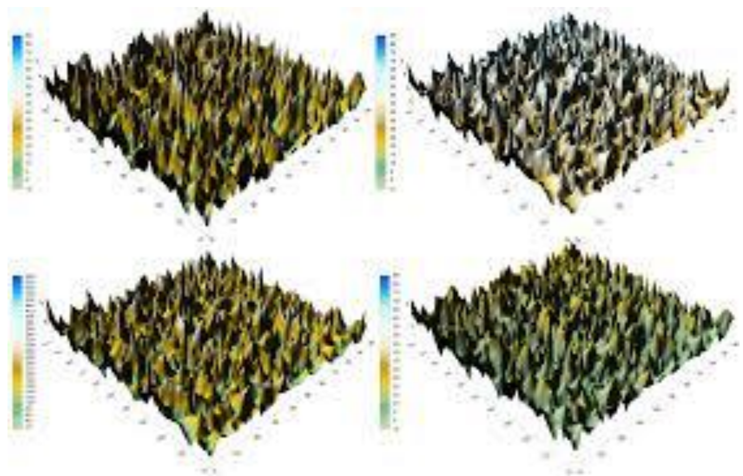
- "best":
  - Space left in container
  - Fragmentation
  - Algorithm effectiveness
  - …
- Stop criterion
  - Time
  - Iterations
  - Time since last improvement
  - …

http://challenge-esicup-2015.org/Intro.htm

Solving: Metaheuristics

- E.g. local search of solution space
- Neighborhoods ("best")
- Guided walk
- Escaping from local optima
  - Good results when exact methods break down
  - Fast design
  - No guarantees for optimality

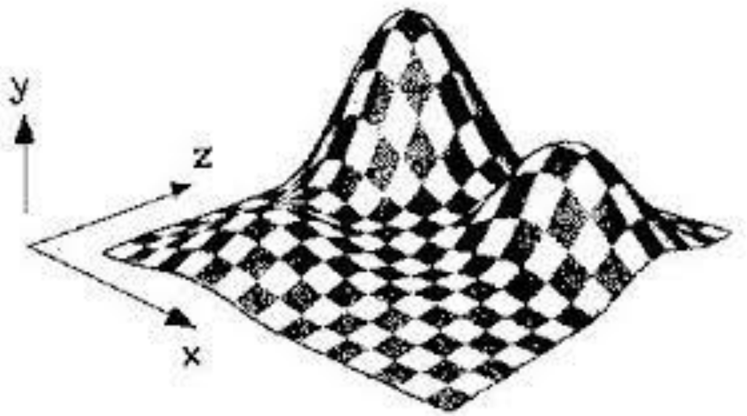


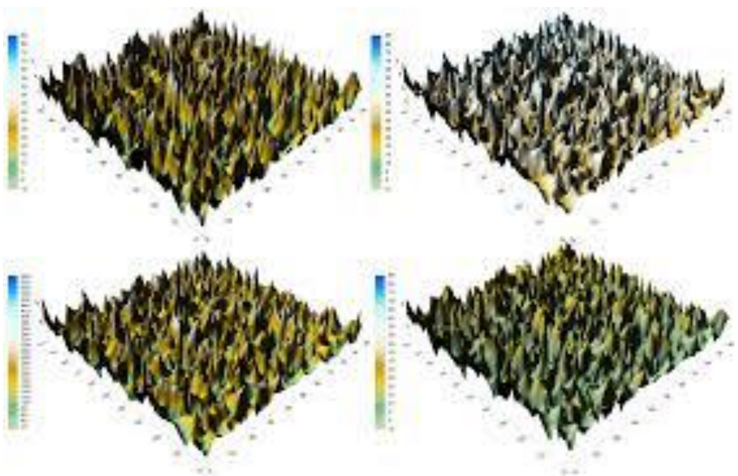


http://branchandbound.net/blog/architecture/2015/06/on-microservices-monoliths-and-critical-thinking/
http://file.scirp.org/Html/2-2730045_49864.htm

Solving: Matheuristics

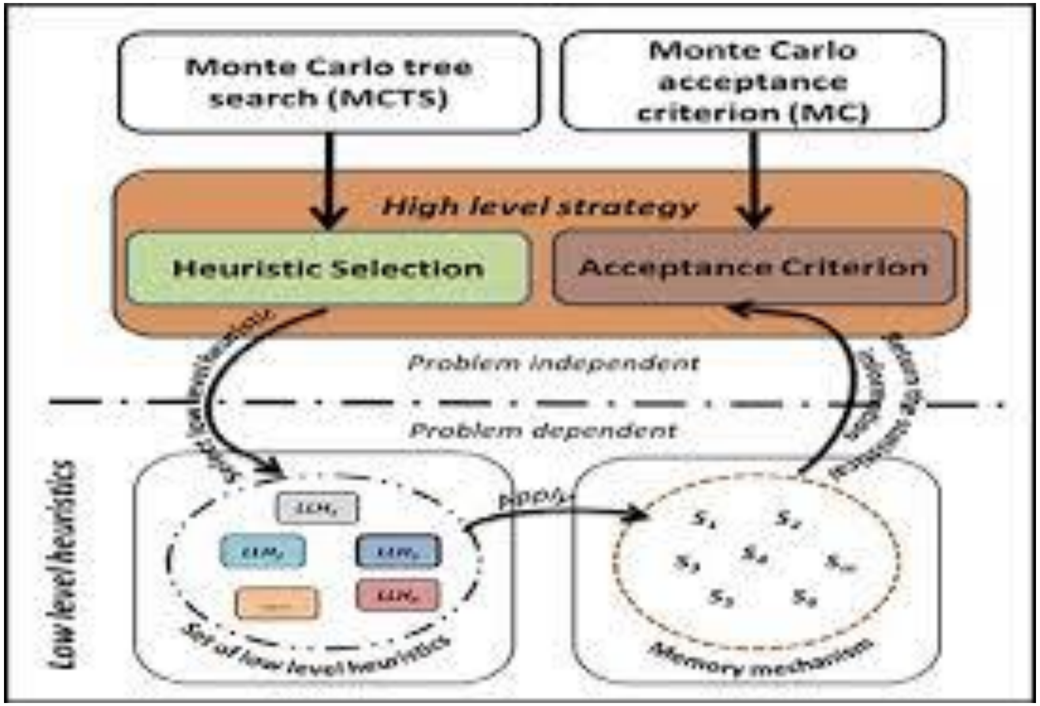
- Metaheuristics use simple 'heuristic' ingredients
- Matheuristics incorporate mathematical devices
    - E.g. define a neighborhood using an MILP model
    - Neighborhood search becomes MILP search
- Combine power of metaheuristics and mathematical methods





Solving: Hyperheuristics

- Domain independent technique:
  - E.g. metaheuristic
  - E.g. genetic algorithm
  - …
- Domain dependent sector: domain expert
  - Heuristics
  - Neighborhoods
  - ...



- Population based Monte Carlo tree search hyper-heuristic for combinatorial optimization problems, Nasser R. Sabar, Graham Kendall, Information Sciences 2015

An intelligent hyper-heuristic framework for chesc 2011
M Mısır, K Verbeeck, P De Causmaecker, GV Berghe, Learning and Intelligent Optimization, 461-466

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Solving: Active learning

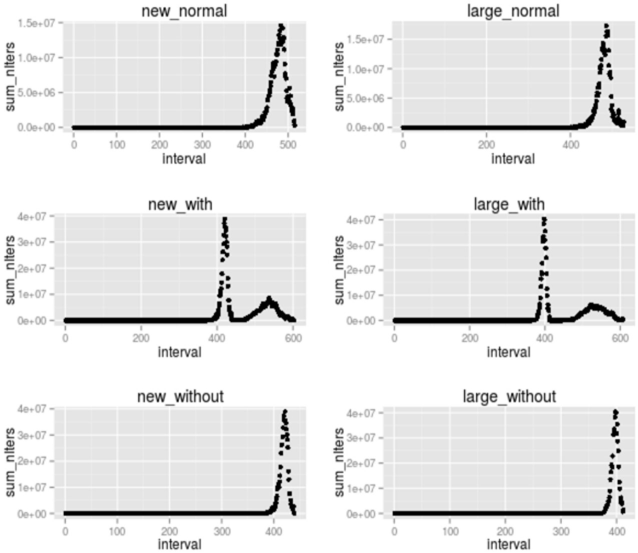
- Algorithm selection
- Behavior of the algorithm depends on the instance
- Instance features can be used to decide on which algorithm
- Which algorithm?
- Multi armed bandit learns to decide the algorithm

https://en.wikipedia.org/wiki/Multi-armed_bandit

Automatic Online Algorithm Selection, Hans Degroote, Patrick De Causmaecker, Benelearn 2016

Solving: Off line analysis

- Behavior of the algorithm depends on the instance
- Instance features can be used to decide on which algorithm



- ➔ DATA ANALYSIS
  - Parameter tuning
  - Characterisation of components
  - Helping the designer

[Dang, Nguyen Thi Thanh; De Causmaecker, Patrick. Characterization of neighborhood behaviours in a multi-neighborhood local search algorithm, Festa, Paola; Sellmann, Meinolf; Vanschoren, Joaquin (eds.), Learning and Intelligent OptimizatioN Conference, Ischia Island (Napoli), Italy, 29/5 - 1/6 2016, Springer]

Maintenance

- Metaheuristics for Production Scheduling, Jarboui, Siarry, Teghem, Wiley 2013 (Chapter 11. Multi-Objective Metaheuristics for the Joint Scheduling of Production and Maintenance, BERRICHI, YALAOUI)
- Maintenance for Industrial Systems, Manzini, Regattireri, Pham, Ferrari, 2010
- Maintenance scheduling in the electricity industry: A literature review, Froger, Gendreau, Mendoza, Pinson, Rousseau, EJOR 2016
- The scheduling of maintenance: A resource-constraints mixed integer linear programming model, Manzini, Accorsi, Cennerazzo, Ferrari, Maranesi, Computers and Industrial Engineering, 2015

Model

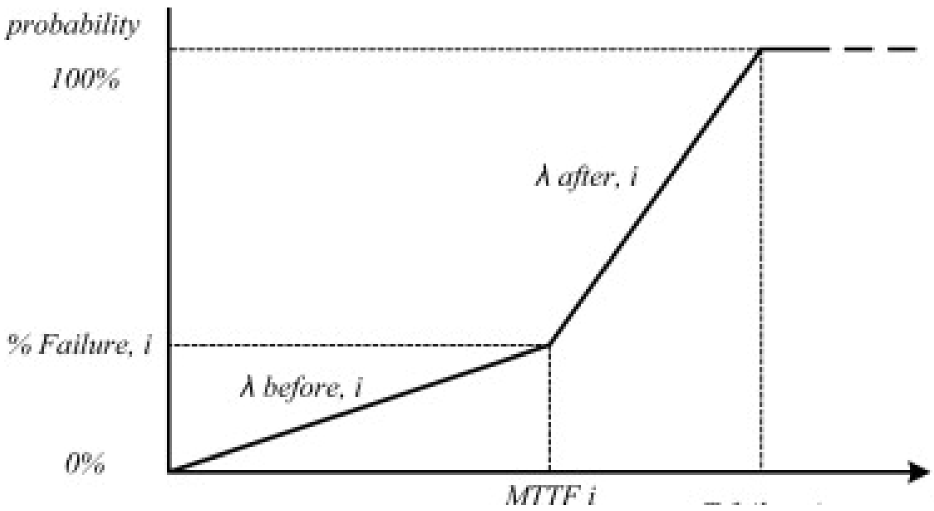
- Reliability
- Cost
- Reliability & Cost
- Resources
- Downtime
- MTTF
  - Failure prediction
  - Uncertainty
- Product specifications
- Complex systems

Algorithms

- Mathematical programming
- Matheuristics
- Heuristics/metaheuristics
  - GA
  - PSO
  - Other population based
  - LS
  - Tabusearch
  - ACO
  - CP
  - …

A linear model

- Service takes place in ‘time buckets’ ➔Bin packing problem.
- the set of tasks to be scheduled is known
- the number of time buckets is pre-defined
- the duration of a specific task is constant
- the unit costs (e.g. spare parts, personnel, additional failure cost) are known and deterministic.



$T_{failure}$, f_i and $\%_{failure,i}$
➔ On field monitoring

Open problems

- Strategic planning
  - Exact methods
  - Metaheuristics
- Fast algorithms for online decision support
  - (Meta)heuristics/matheuristics

The role of data

- Behaviour of the machinery ➔ fault sensitivity
- Production data ➔ fault tolerance, criticality
- Schedule robustness
- Model accuracy and uncertainty
  - Constraint learning
  - Parameter tuning
  - On-line learning

Thanks for the invite

1st COST Conference on Mathematics for Industry in Switzerland

September 15, 2016 - ZHAW Winterthur, Technikumstrasse 9, 8400 Winterthur

Well …
this is only the
1st!

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