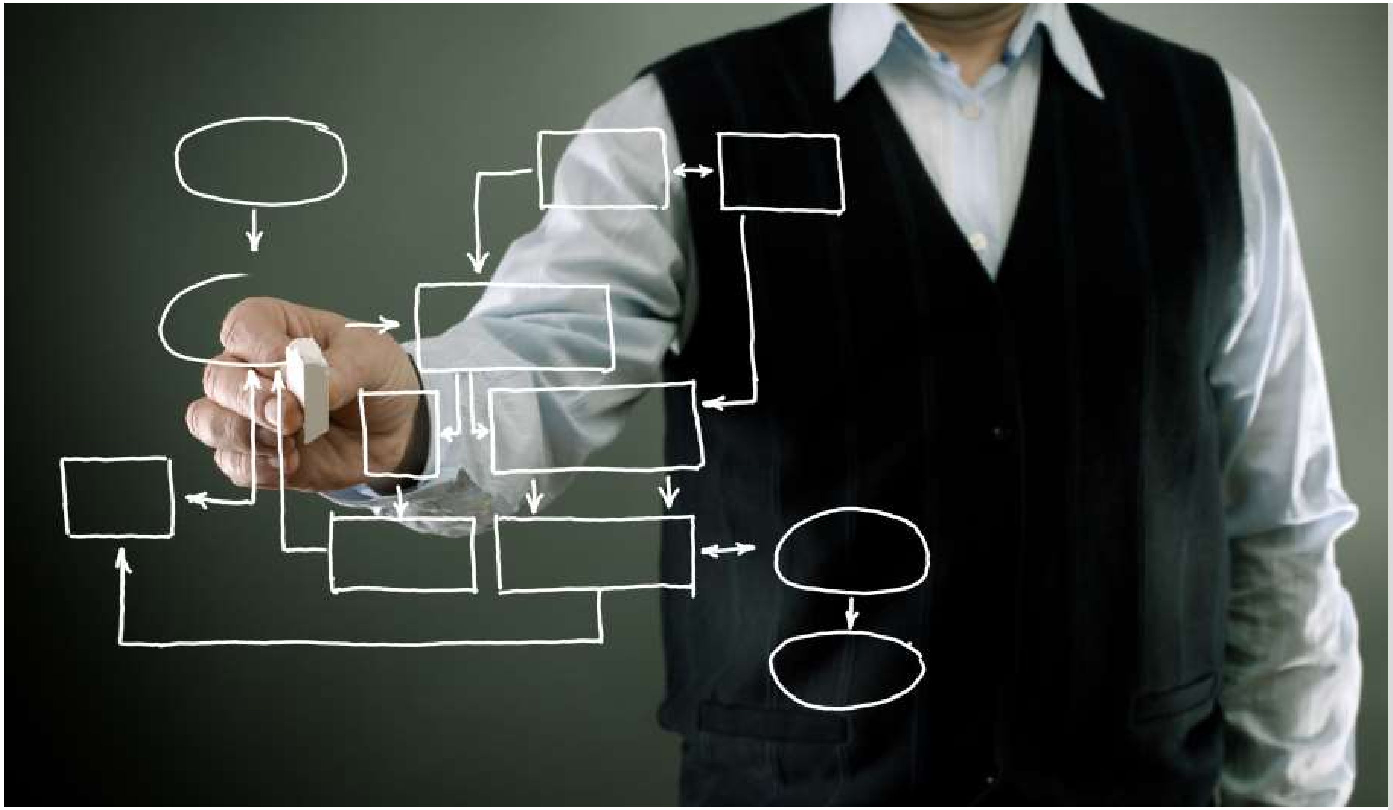


Research Group HEAL –
Heuristics and Evolutionary Algorithms Laboratory

2018

HEAL
HEURISTIC AND EVOLUTIONARY
ALGORITHMS LABORATORY

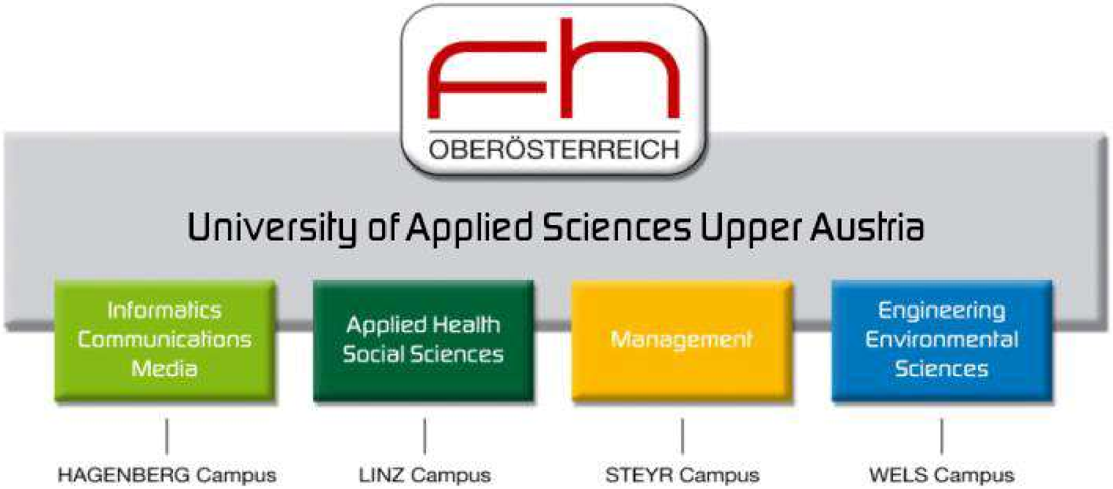
Contact:

Heuristic and Evolutionary
Algorithms Laboratory (HEAL)
FH OÖ University of Applied
Sciences Upper Austria
Softwarepark 11
A-4232 Hagenberg

WWW:
https://heal.heuristiclab.com
https://dev.heuristiclab.com

Largest University of Applied Sciences in Austria

- 4 schools
- 62 study programms
- 5.888 students
- 17.34 m€ R&D turnover (2016)



UNIVERSITY OF APPLIED SCIENCES UPPER AUSTRIA

Research Group
Heuristic and Evolutionary Algorithms Laboratory (HEAL)

HEAL
Heuristic and Evolutionary Algorithms Laboratory

Research Group

- since 2005 at FH OÖ
- 5 professors
- 12 research associates
- various interns, bachelor & master students

Research

- > 200 peer-reviewed publications
- 8 dissertations
- > 60 master and bachelor theses

Scientific partners

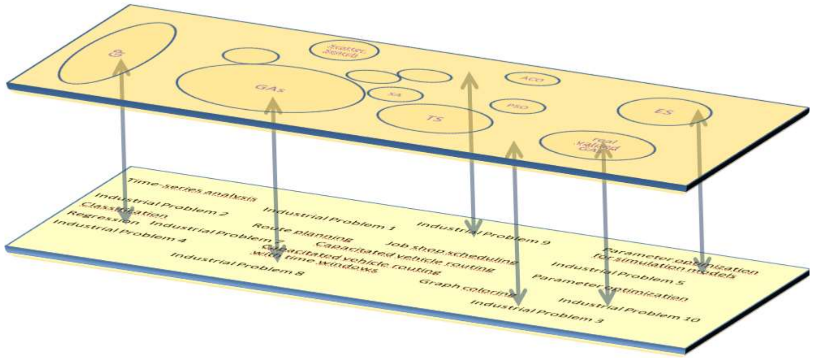
Industry partners (excerpt)

Metaheuristics

- intelligent search strategies
- can be applied to different problems
- explore interesting regions of the search space (parameter)
- tradeoff: computation vs. quality
  - good solutions for very complex problems
- must be tuned to applications

Challenges

- choice of appropriate metaheuristics
- hybridization



Finding needles in haystacks

Research Focus

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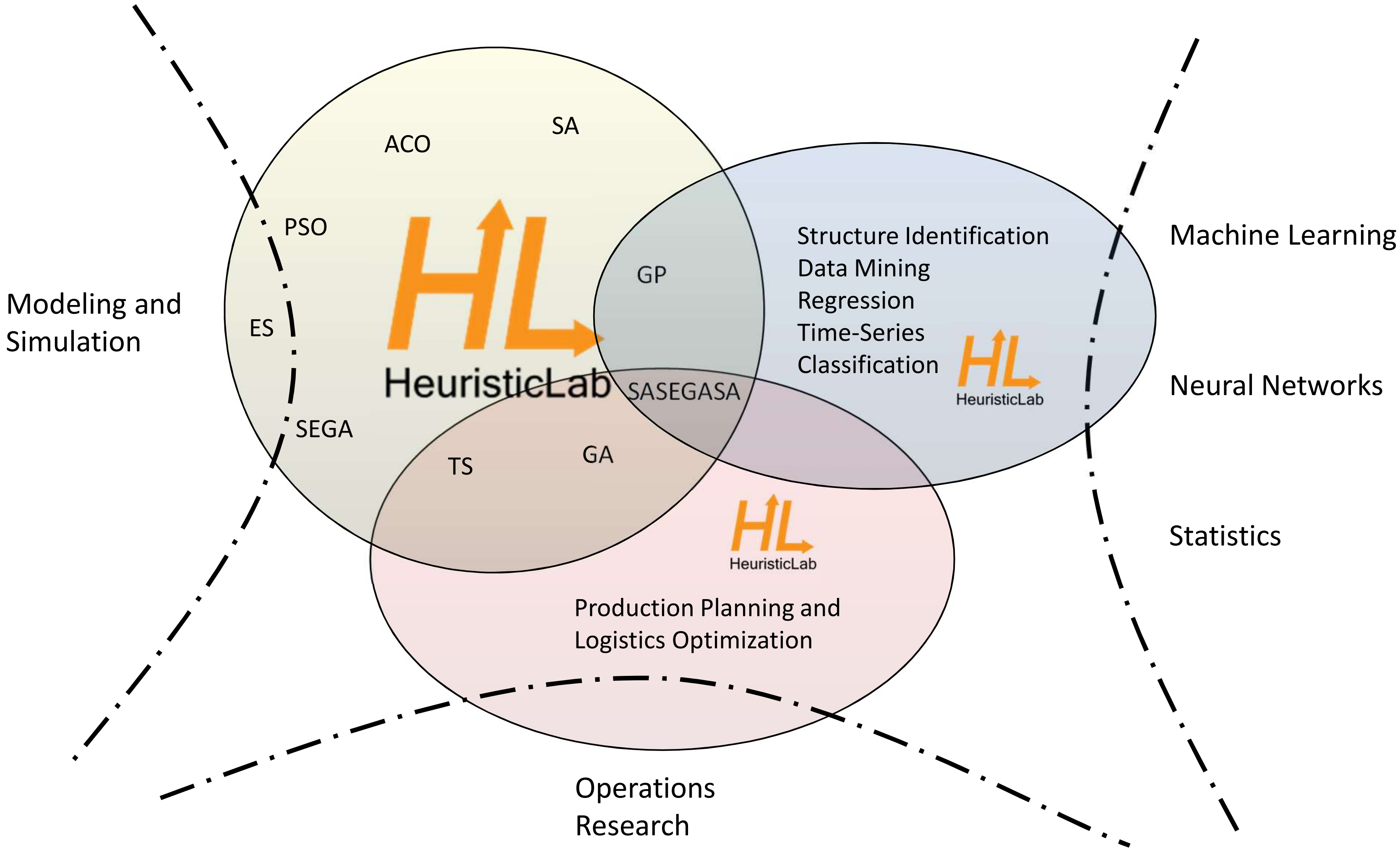

Research Projects

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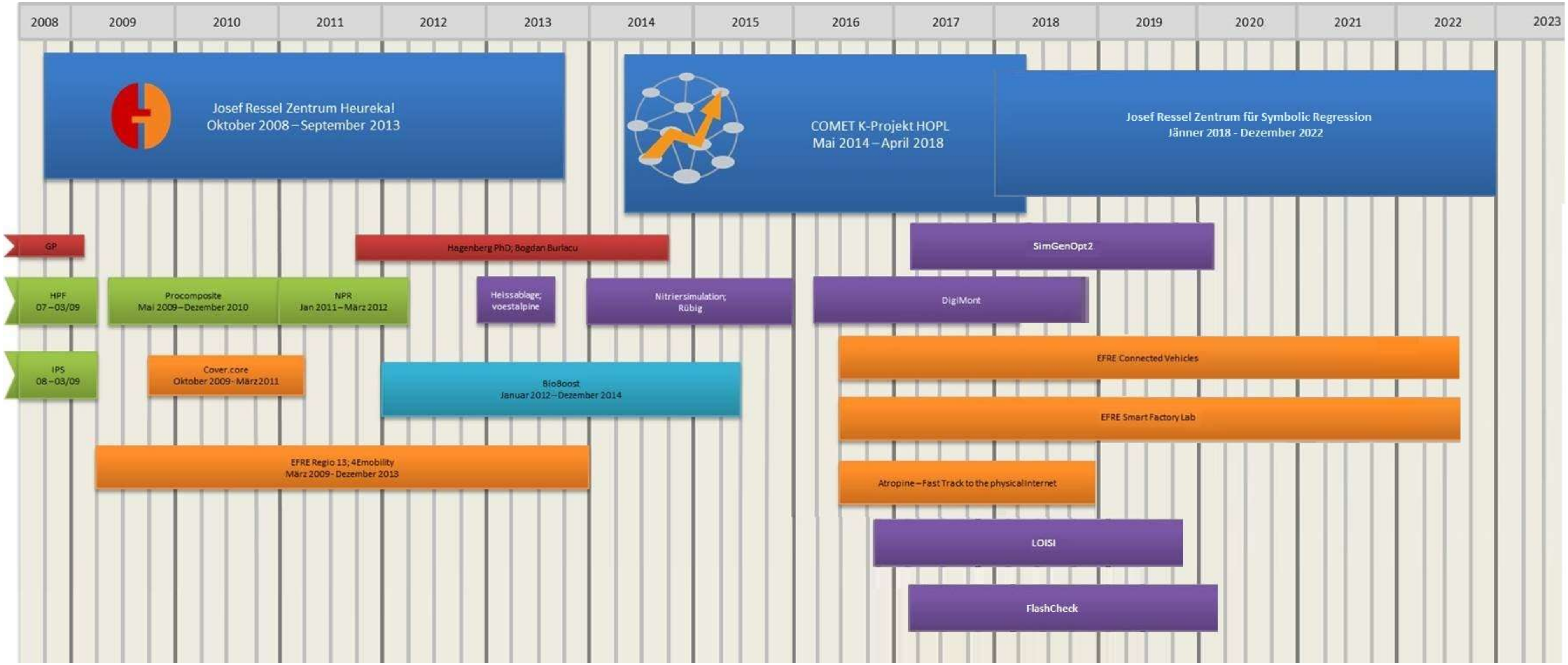

HeuristicLab

HEAL
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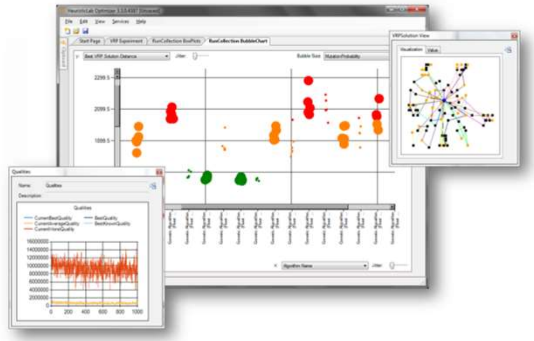
Open Source Optimization Environment HeuristicLab

- developed since 2002
- basis of many research projects and publications
- 2nd place at *Microsoft Innovation Award 2009*
- HeuristicLab 3.3.x since May 2010 under GNU GPL



Motivation and Goals

- graphical user interface for interactive development, analysis and application of optimizations methods
- numerous optimization algorithms and optimization problems
- support for extensive experiments and analysis
- distribution through parallel execution of algorithms
- extensibility and flexibility (plug-in architecture)

Distributed Computing with HeuristicLab Hive

- framework for distribution and parallel execution of HeuristicLab algorithms
- compute resources at Campus Hagenberg
  - 2006 – 2011: research cluster 1 (14 cores)
  - since 2009: research cluster 2 (112 cores, 448GB RAM)
  - since 2011: lab computers (100 PCs, on demand in the night)
  - since 2017: research cluster 3 (448 cores, 4TB RAM)

Available Algorithms

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Population-based
- CMA-ES
- Evolution Strategy
- Genetic Algorithm
- Offspring Selection Genetic Algorithm (OSGA)
- Island Genetic Algorithm
- Island Offspring Selection Genetic Algorithm
- Parameter-less Population Pyramid (P3)
- SASEGASA
- Relevant Alleles Preserving GA (RAPGA)
- Age-Layered Population Structure (ALPS)
- Genetic Programming
- NSGA-II
- Scatter Search
- Particle Swarm Optimization

Trajectory-based
- Local Search
- Tabu Search
- Robust Taboo Search
- Variable Neighborhood Search
- Simulated Annealing

Data Analysis
- Linear Discriminant Analysis
- Linear Regression
- Multinomial Logit Classification
- k-Nearest Neighbor
- k-Means
- Neighborhood Component Analysis
- Artificial Neural Networks
- Random Forests
- Support Vector Machines
- Gaussian Processes
- Gradient Boosted Trees
- Gradient Boosted Regression

Additional Algorithms
- User-defined Algorithm
- Performance Benchmarks
- Hungarian Algorithm
- Cross Validation
- LM-BFGS

Available Problems

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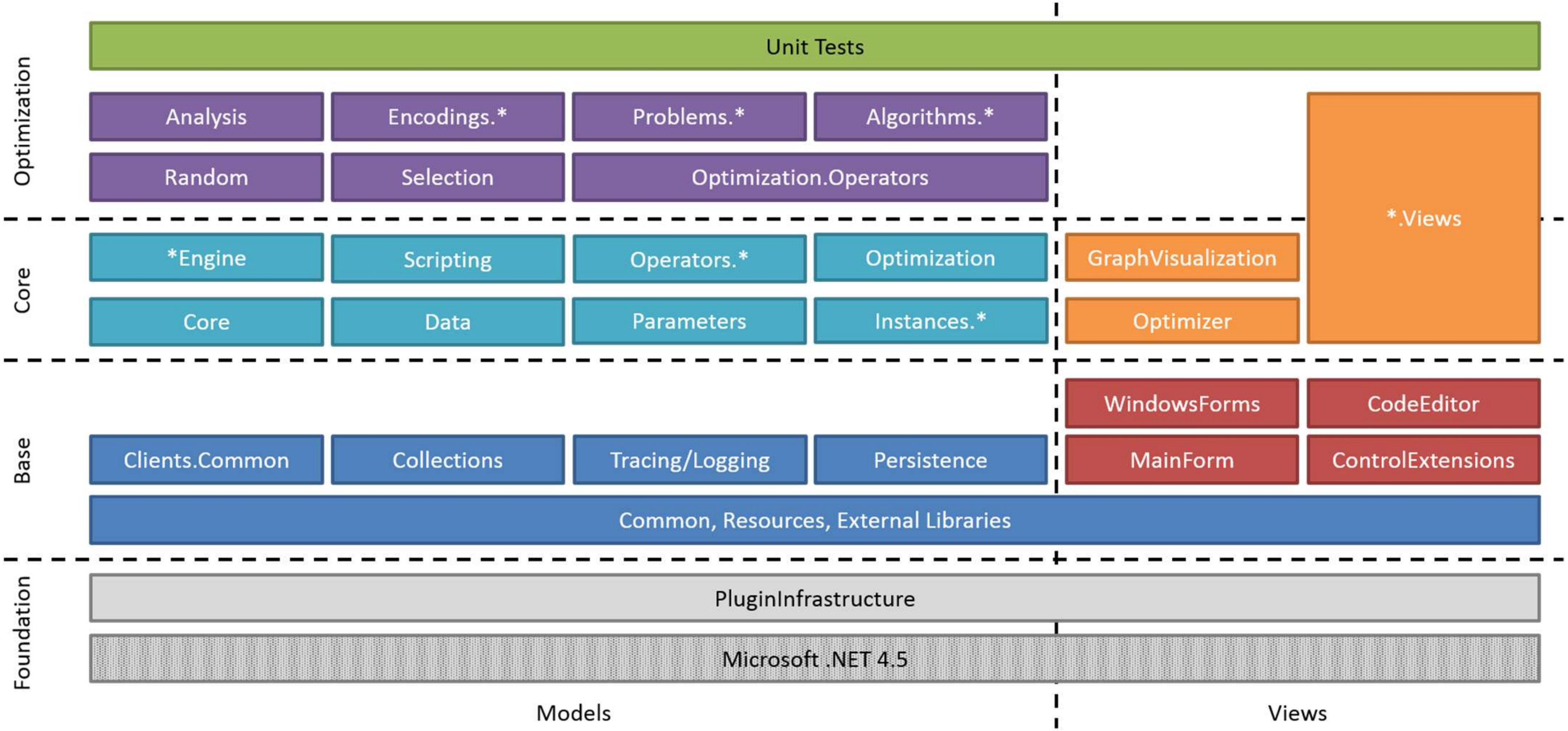
Combinatorial Problems
- Traveling Salesman
- Probabilistic Traveling Salesman
- Vehicle Routing
- Knapsack
- Bin Packing
- NK[P,Q]
- Job Shop Scheduling
- Linear Assignment
- Quadratic Assignment
- OneMax
- Orienteering
- Deceptive Trap
- Deceptive Trap Step
- HIFF

Genetic Programming Problems
- Test Problems (Even Parity, MUX)
- Symbolic Classification
- Symbolic Regression
- Symbolic Time-Series Prognosis
- Artificial Ant
- Lawn Mower
- Robocode
- Grammatical Evolution

Additional Problems
- Single-/Multi-Objective Test Function
- User-defined Problem
- Programmable Problem
- External Evaluation Problem (Anylogic, Scilab, MATLAB)
- Regression, Classification, Clustering
- Trading

Plugin Architecture



How to get HeuristicLab?

Download binaries

- deployed as ZIP archives
- latest stable version 3.3.14 "Denver"
  - released on July 24th, 2016
- daily trunk builds
- https://dev.heuristiclab.com/download

Check out sources

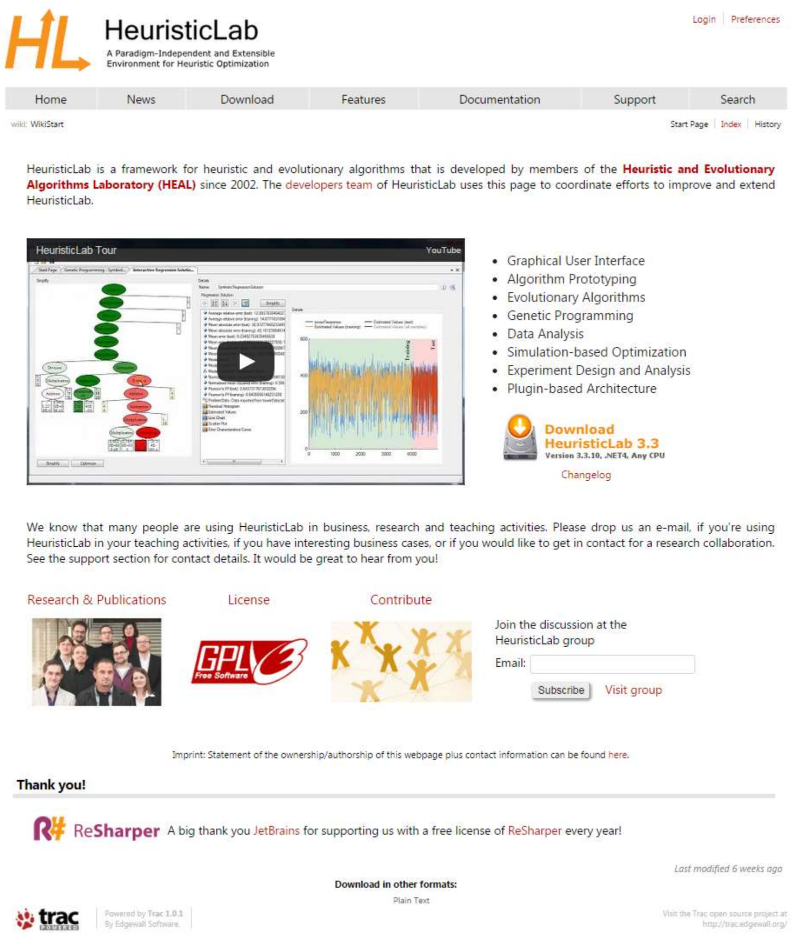
- SVN repository
- HeuristicLab 3.3.14 tag
  - https://src.heuristiclab.com/svn/core/tags/3.3.14
- Stable development version
  - https://src.heuristiclab.com/svn/core/stable

License

- GNU General Public License (Version 3)

System requirements

- Microsoft .NET Framework 4.5
- enough RAM and CPU power ;-)



HeuristicLab Video

Some Additional Features

HeuristicLab Hive

- parallel and distributed execution of algorithms and experiments on many computers in a network

Optimization Knowledge Base (OKB)

- database to store algorithms, problems, parameters and results
- open to the public
- open for other frameworks
- analyze and store characteristics of problem instances and problem classes

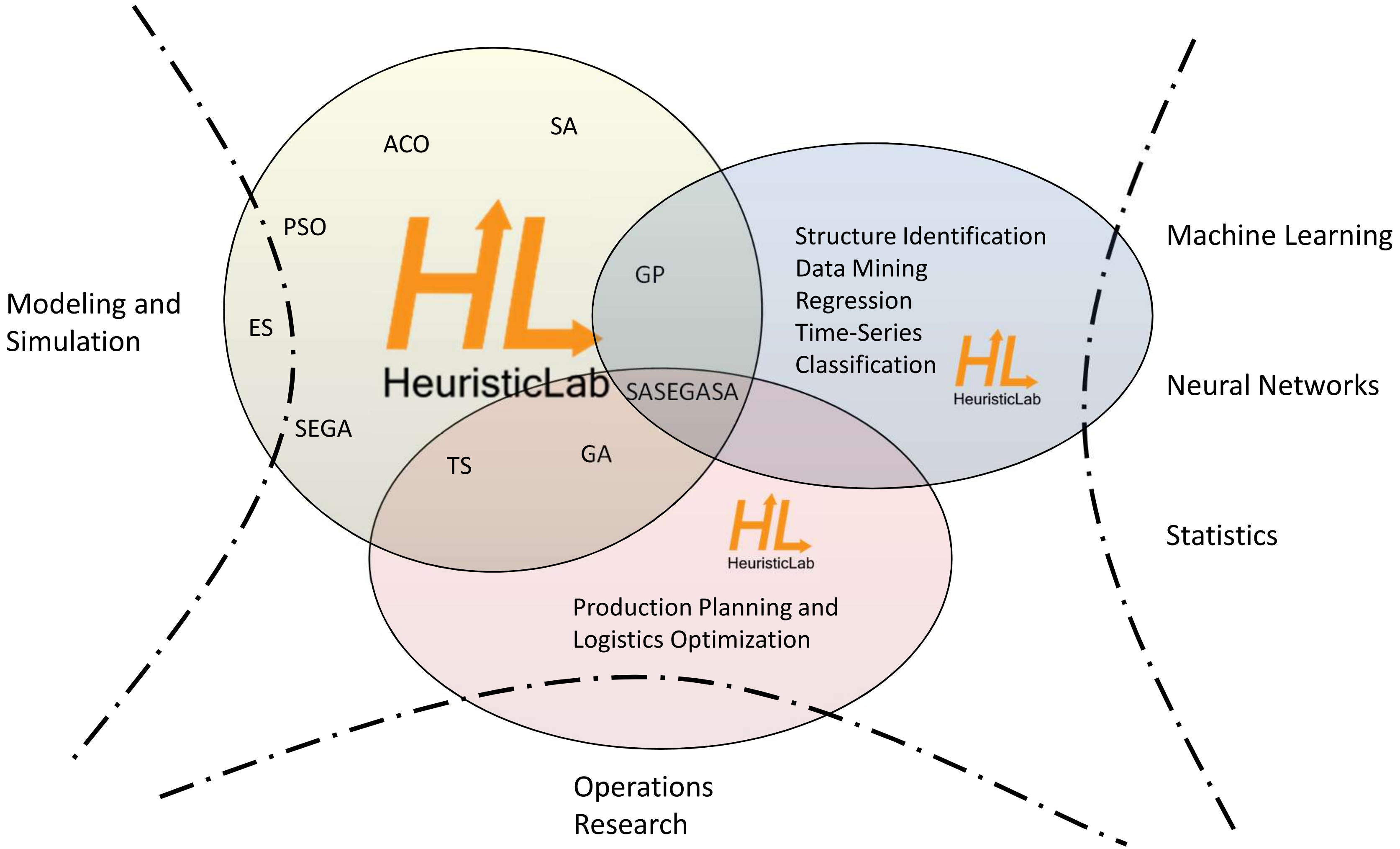
External solution evaluation and simulation-based optimization

- interface to couple HeuristicLab with other applications (MATLAB, Simulink, SciLab, AnyLogic, …)
- supports different protocols (command line parameters, TCP, …)

Parameter grid tests and meta-optimization

- automatically create experiments to test large ranges of parameters
- apply heuristic optimization algorithms to find optimal parameter settings for heuristic optimization algorithms

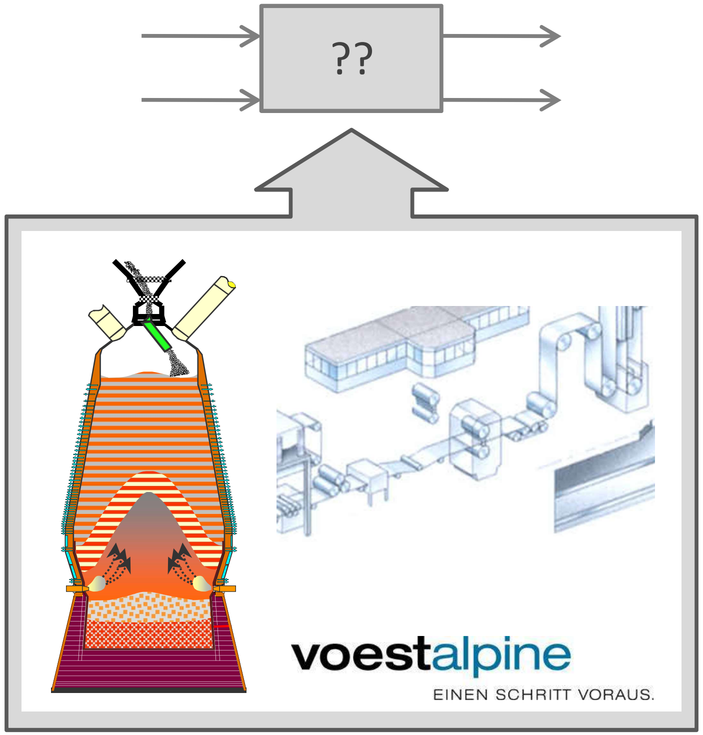
Research Focus



Data Based Modeling: Starting Point

Goal: Mathematical models that describe system behavior

System = Engine, human body, financial data etc.



Analysis of steel production processes

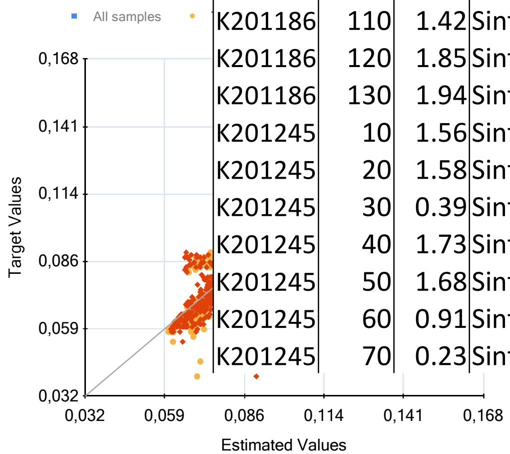
Medical data analysis

Data Based Modeling: Process

Test No.	engagements	Pressure			
K201186	10	1.31			
K201186	20	0.34	Sinter	Shell Donax TX	Radial
K201186	30	1.43	Sinter	Shell Donax TX	Radial
K201186	40	1.66	Sinter	Shell Donax TX	Radial
K201186	50	0.27	Sinter	Shell Donax TX	Radial
K201186	60	1.02	Sinter	Shell Donax TX	Rad
K201186	70	0.83	S	ax TX	Rad
K201186	80	0.29	Sinter	Shell onax TX	Rad
K201186	90	0.32	Sinter	Shell Donax TX	Radial
K201186	100	0.26	Sinter	Shell Dor	
K201186	110	0.55	Sinter	Shell Dor	
K201186	120	0.84	Sinter	Shell Dor	
K201186	130	0.97	Sinter	Shell Dor	
K201245	10	1.77	Sinter	Shell Dor	
K201245	20	1.72	Sinter	Shell Dor	
K201245	30	0.18	Sinter	Shell Dor	
K201245	40	0.82	Sinter	Shell Dor	
K201245	50	0.76	Sinter	Shell Dor	
K201245	60	0.39	Sinter	Shell Dor	
K201245	70	0.6	Sinter	Shell Dor	

Linear Regression, Genetic Programming, Rand
Neural Networks, Support Vector Machines, …

Modeling
(Training)



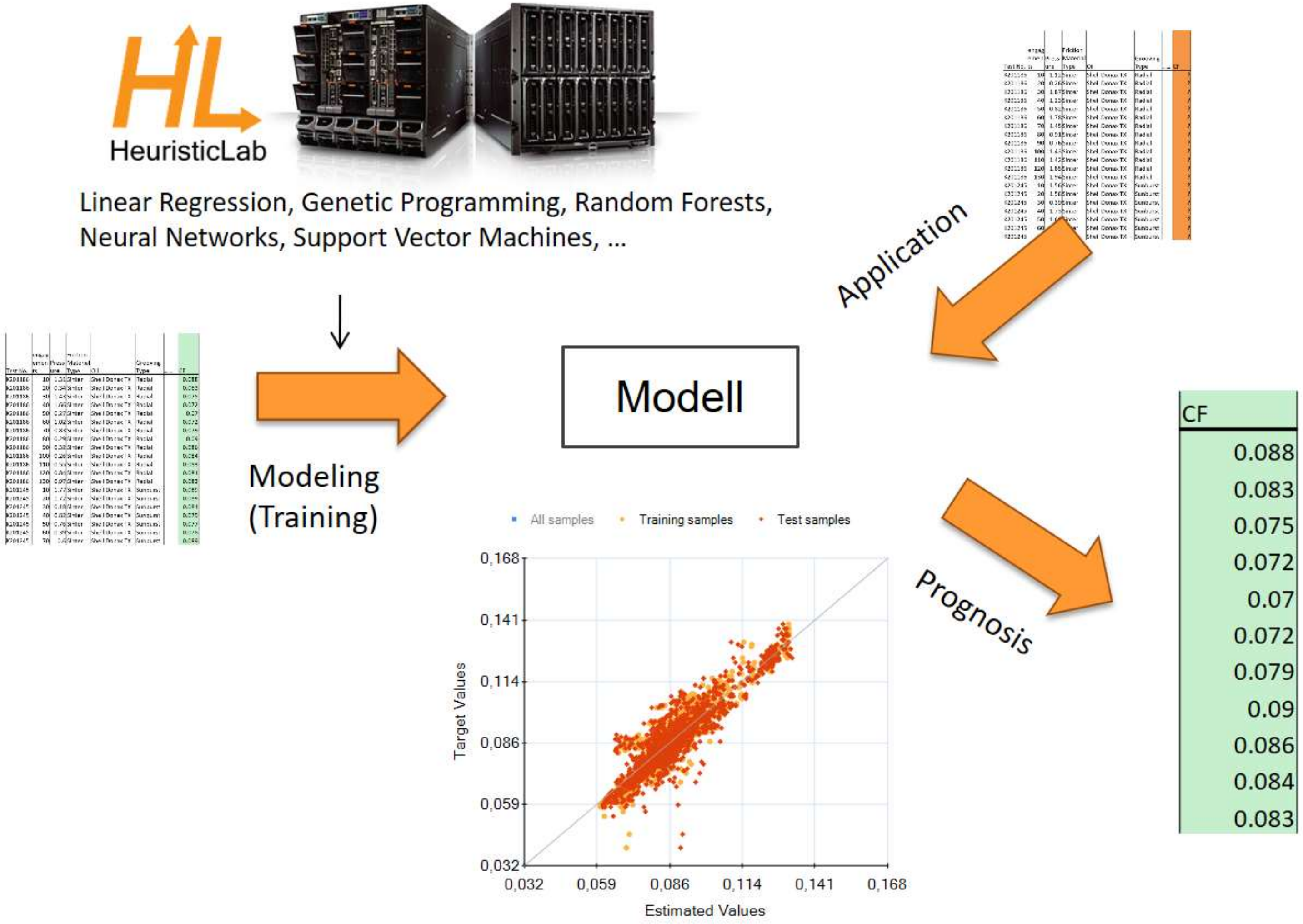
Application

Prognosis

Test No.	engagements	Pressure	Friction Material Type	Oil	Grooving Type	......	CF
K201186	10	1.12	Sinter	Shell Donax TX	Radial		?
K201186	20	0.26	Sinter	Shell Donax TX	Radial		?
K201186	30	1.87	Sinter	Shell x TX	Radial		?
K201186	40	1.2	Sinter	onax TX	Radial		?
K201186	50	0.82	Sinte	ll Donax TX	Radial		?
K201186	60	1.78	Sinte	hell Donax TX	Radial		?
K201186	70	1.45	Sinter	Shell Donax TX	Radial		?
K201186	80	0.91	Sinter	Shell Donax TX	R		?
K201186	90	0.76	Sinter	Shell Donax TX	R		?
K201186	100	1.43	Sinter	Shell Donax TX	R		?
K201186	110	1.42	Sinter	Donax TX	R		?
K201186	120	1.85	Sinter	Sh TX	R		?
K201186	130	1.94	Sinter	Shell D TX	R		?
K201245	10	1.56	Sinter	Shell Donax TX	S		?
K201245	20	1.58	Sinter	Shell Donax TX	S		?
K201245	30	0.39	Sinter	Shell Donax TX	S		?
K201245	40	1.73	Sinter	Shell Donax TX	S		?
K201245	50	1.68	Sinter	Shell Donax TX	S		?
K201245	60	0.91	Sinter	Shell Donax TX	S		?
K201245	70	0.23	Sinter	Shell Donax TX	S		?

CF
0.088
0.083
0.075
0.072
0.07
0.072
0.079
0.09
0.086
0.084
0.083

Data Based Modeling: Process



Data Based Modeling: Results

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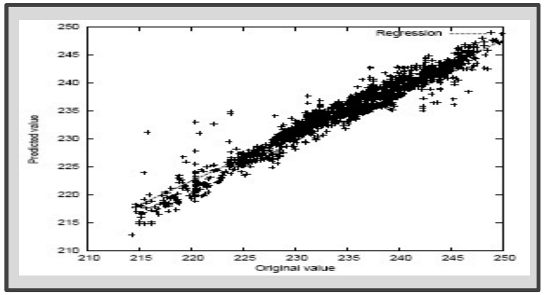
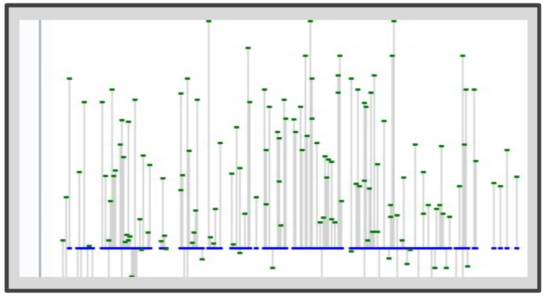
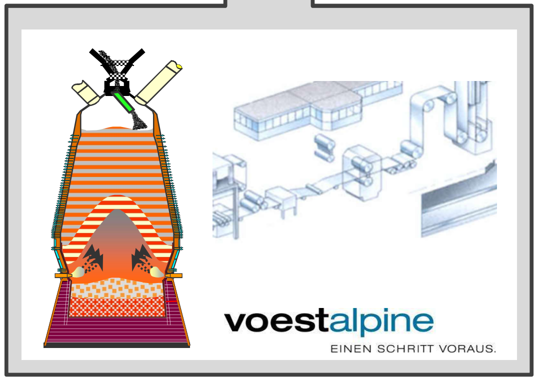
Results:

MeltingRate(t)= f(x3$_{(t-2)}$, x1$_{(t-3)}$, …)

C125(p780641) = (chol, GGT, x58, …)







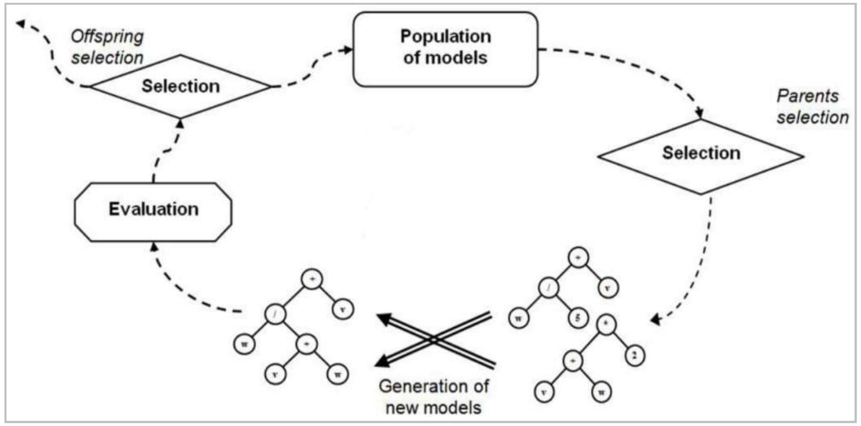
Improved process understanding for steel production

Virtual tumor markers for cancer diagnosis

Data Based Modeling: Methods

Modeling Methods

- linear regression, random forests
- support vector machines, neural networks
- nearest neighbor, k-means



Genetic Programming

- implicit feature selection
- optimizes model structure and parameters
- generates interpretable formulas
- results directly applicable
- assessment of variable relevance

$$y = c_0 \cdot x_1 \cdot (\log(c_1 \cdot x_2) + c_2) + c_3$$

$$c_0 = 0.500331886126962$$

$$c_1 = 2.3702293890766$$

$$c_2 = 1.28570833399083$$

$$c_3 = 4.91856540837157$$

Black-Box vs. White-Box Modeling

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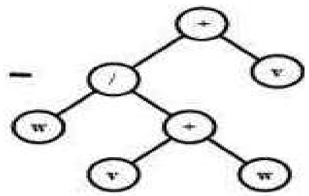
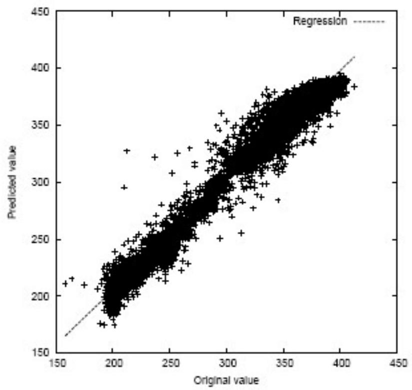
- Instead of **black box models** (ANN, SVM, etc.) identification of model structure, i.e. **white box models**
(symbolic regression/classification with Genetic Programming)

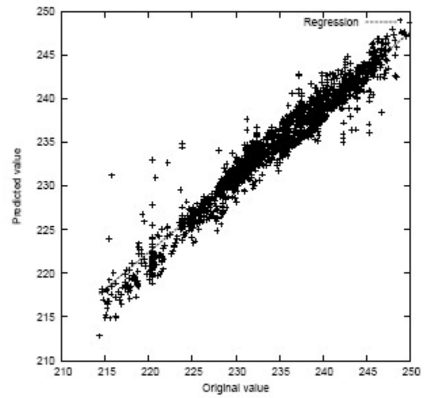
Black Box Model

?

White Box Model

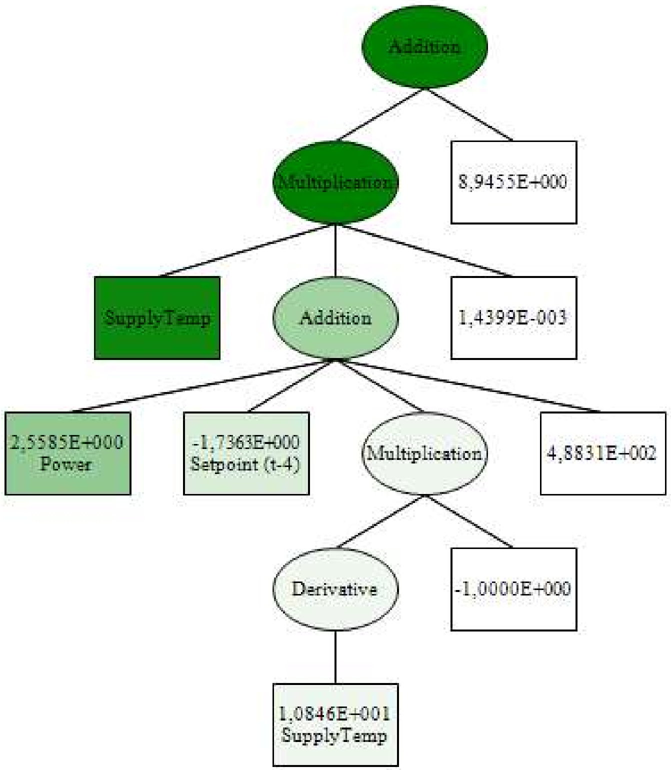




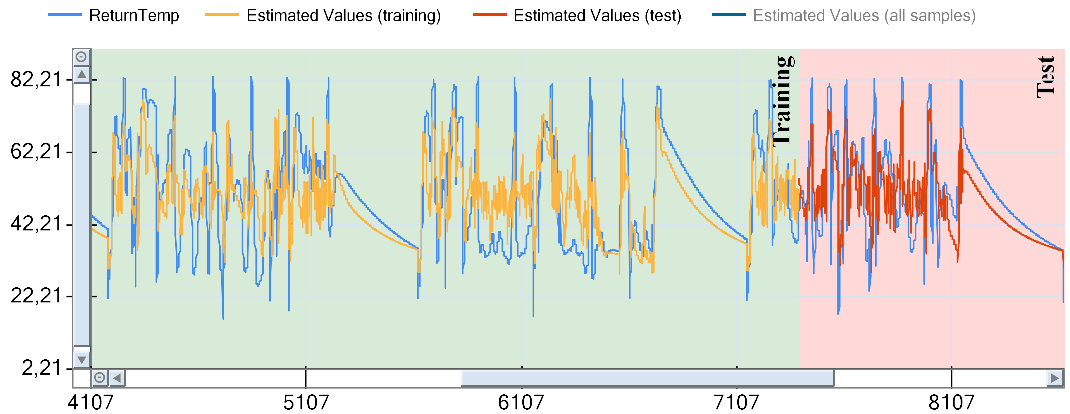


White-Box Modeling

$$\text{ReturnTemp}(t) = \text{SupplyTemp} \cdot \left(c_0 \cdot \text{Power} + c_1 \cdot \text{Setpoint}(t-4) + \frac{d(c_2 \cdot \text{SupplyTemp})}{dt} \cdot c_3 + c_4 \right) \cdot c_5 + c_6$$



$$\begin{aligned} c_0 &= 2.5585 \\ c_1 &= -1.7363 \\ c_2 &= 10.846 \\ c_3 &= -1.0 \\ c_4 &= 488.31 \\ c_5 &= 0.0014399 \\ c_6 &= 8.9455 \end{aligned}$$



Model Simplification

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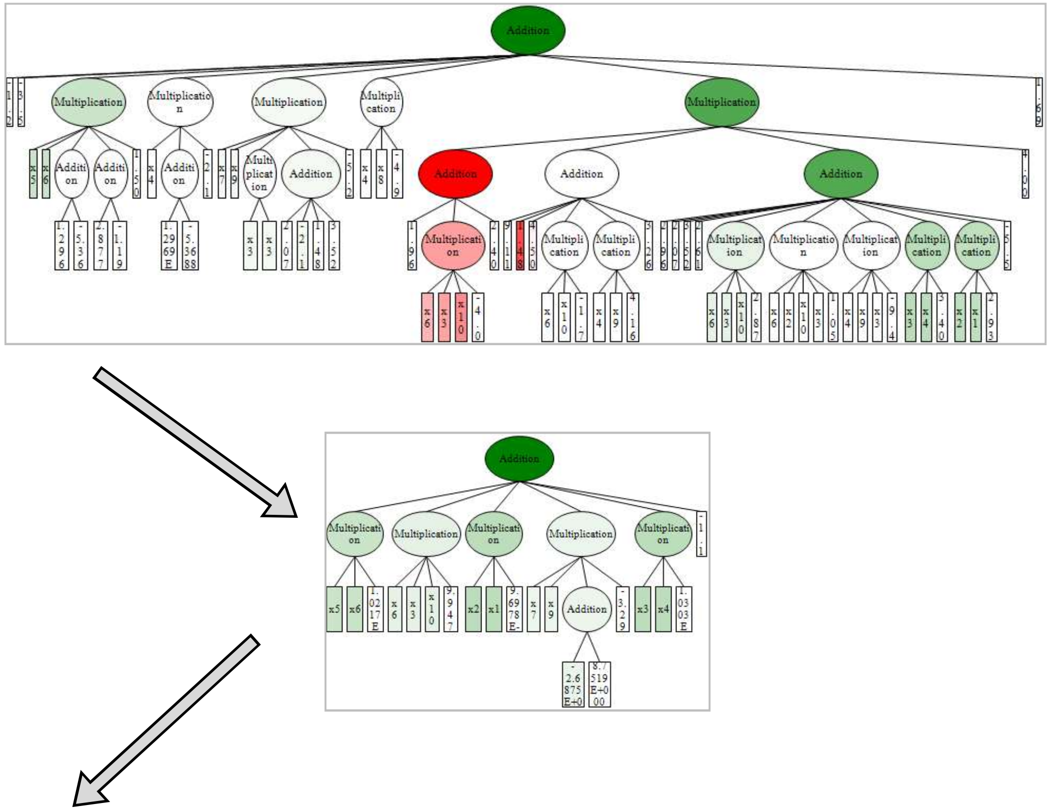
Simplification Methods

- mathematical transformation
- remove nodes
- constant optimization
- external optimization

Export

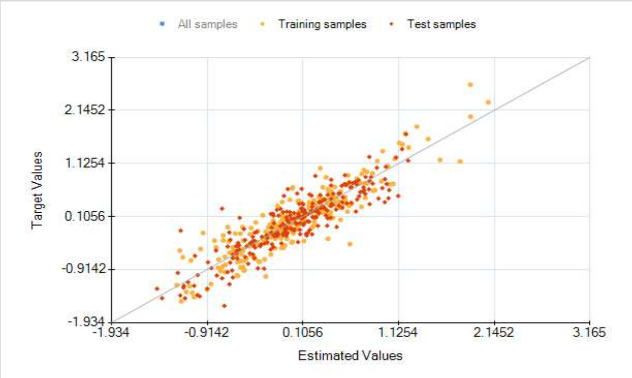
- textual export
- LaTeX, MatLab
- graphical export

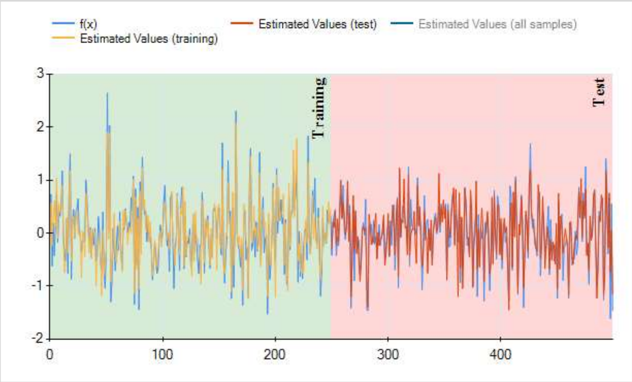


$$y = x_1 \cdot x_2 + x_3 \cdot x_4 + x_5 \cdot x_6 + x_1 \cdot x_7 \cdot x_9 + x_3 \cdot x_6 \cdot x_{10}$$

Model Evaluation

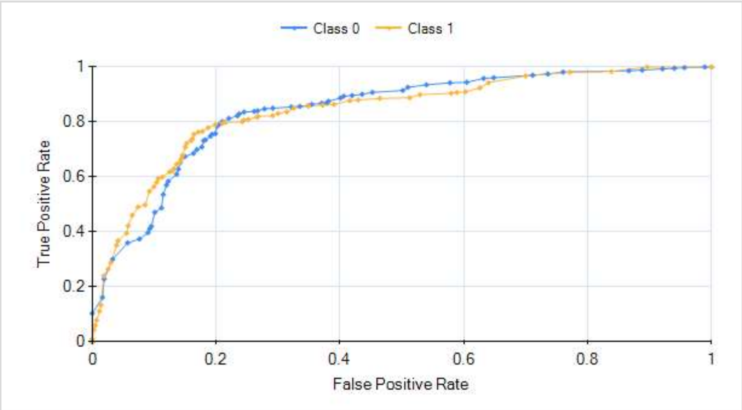
Regression





Classification

	Id	Target Variable	Estimated Values (all)	Absolute Error (all)	Relative Error (all)
Row 1	0	-0.051247964	-0.244931259696236	0.193683295696236	0.790765931373734
Row 2	1	0.727691161	0.566948971537046	0.160742189462954	0.283521441139877
Row 3	2	-0.623794992	-0.235158714563106	0.388636277436894	1.65265522121487
Row 4	3	0.184169363	0.312577120202989	0.128407757202989	0.410803443065828
Row 5	4	-0.425409255	0.607464911486624	1.03287416648662	1.70030259683463
Row 6	5	0.13440877	0.135008413403134	0.000599643403133...	0.00444152618358...
Row 7	6	0.723969158	1.02967884646345	0.305709688463453	0.296898095472629
Row 8	7	-0.175618484	-0.096476538290749	0.079141945709251	0.820323232066462
Row 9	8	0.412736644	0.559935700149158	0.147199056149158	0.262885642244183
Row 10	9	0.321465414	0.391061335521024	0.0695959215210236	0.177966766845663
Row 11	10	0.492008676	0.412907348968929	0.0791013270310709	0.191571613410599



Visual Model Exploration

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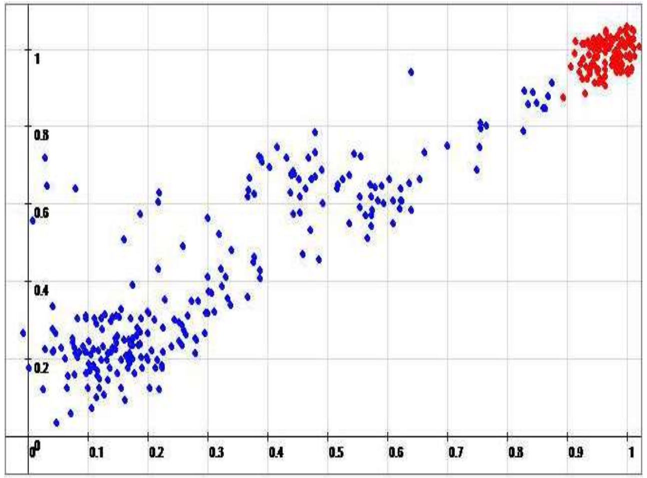
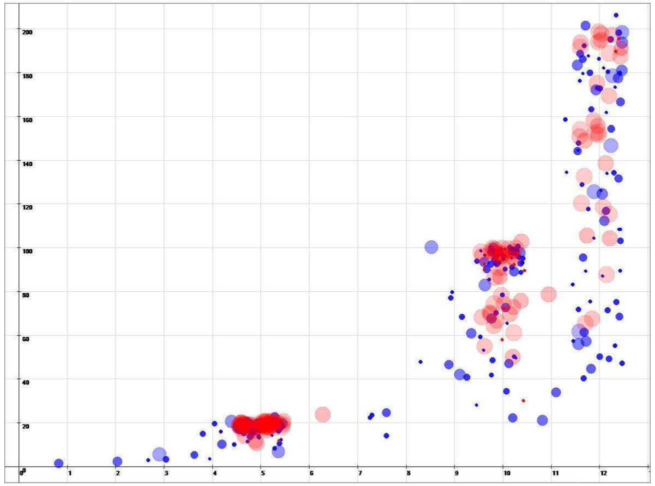
Training Quality

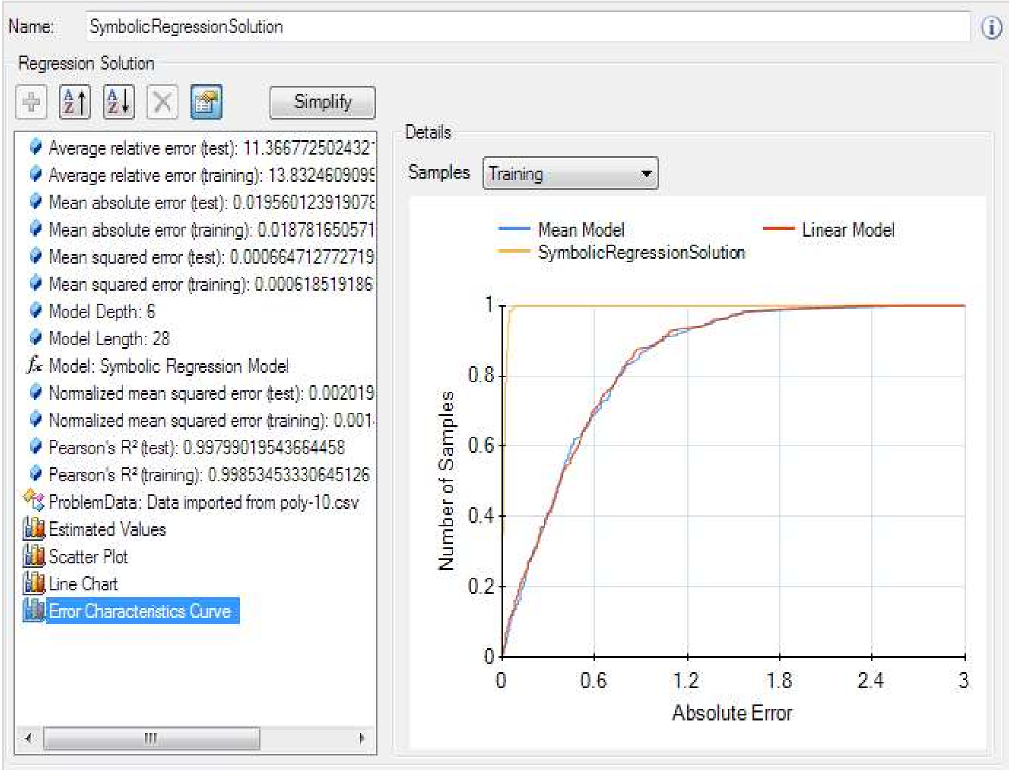


Validation Quality

Model Size



Model Height



Selected Model

Example:
Virtual Sensors for Modeling Exhaust Gases

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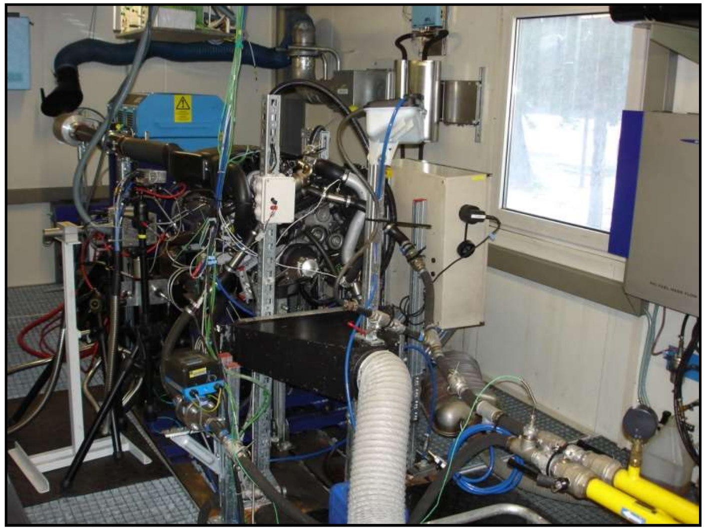
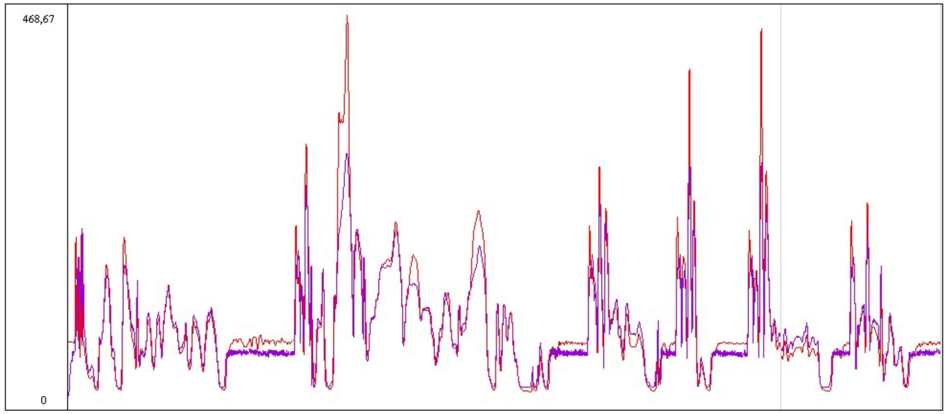
Motivation

- high quality modeling of emissions (NO_x and soot) of a diesel engine
- **virtual sensors:** (mathematical) models that mimic the behavior of physical sensors
- advantages: low cost and non-intrusive
- identify variable impacts:
  - injected fuel, engine frequency, manifold air pressure, concentration of O_2 in exhaustion etc.

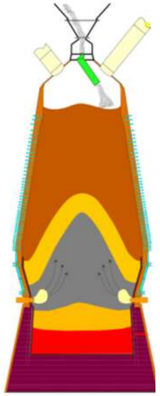


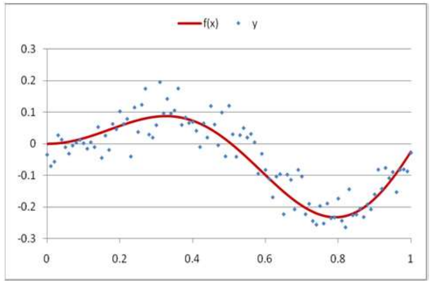
$NO_x(t) = f(x1_{(t-7)}, x2_{(t-2)}, \ldots)$



Example:
Blast Furnace Modeling

x1	x2	x3	x4	x5	y
28.07845	13.93902	87.63394	20.07777	63.00267	250.4028
27.95657	12.75236	87.05083	19.95878	63.00894	440.0825
25.43135	23.03532	88.32881	21.98374	74.99575	292.6644
28.5034	36.71041	87.59461	20.55528	75.01106	100.8683
23.03413	46.5804	79.38985	18.67402	80.31421	435.7738
20.97957	41.52231	73.32074	21.49193	79.98517	288.5032
28.07431	28.49076	106.4166	27.38095	79.97826	?
28.00494	36.33813	104.7173	27.99428	75.00266	?
28.0274	31.84306	102.277	28.81878	78.1752	?
26.503	27.67078	93.81539	21.29002	62.99904	?
23.869	27.25298	93.67531	24.54099	80.00291	?

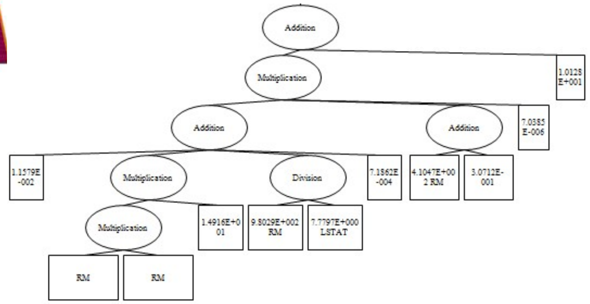




f(***x***)

Model

Prognosis



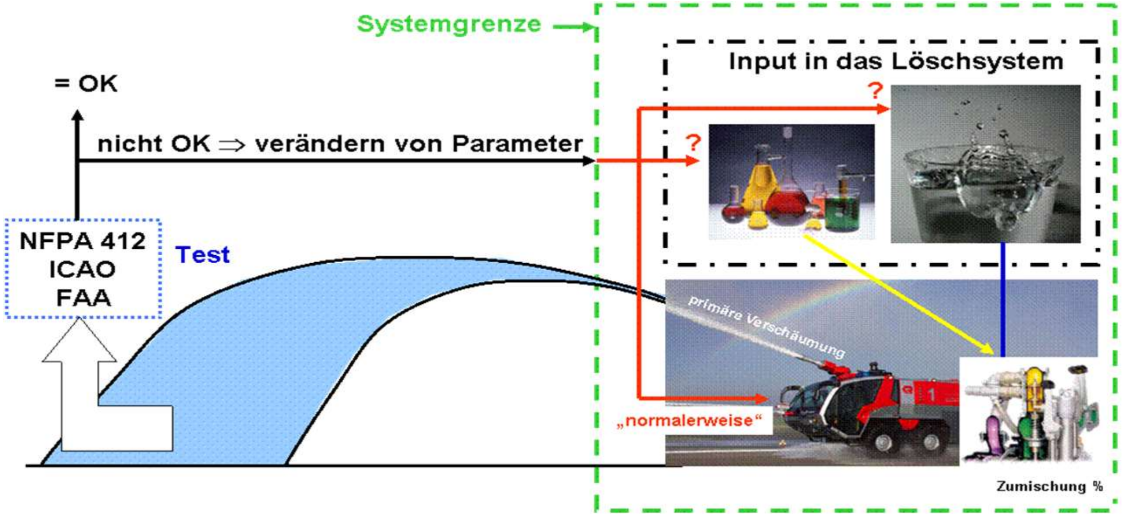
Innovations

- results as formulas → domain experts can analyze, simplify and refine the models
- integration of prior physical knowledge into modeling process
- powerful data analysis tools: model simplification and variable impact analysis

Example:
Foam Quality of Firefighting Vehicles

Goals

- detect **relevant impact factors** and potential relationships between foam parameters with respect to throw range and foam quality
- **model throw range and foam quality**
- configure extinguishing systems for optimal throw range and foam quality



Example:
Plasma Nitriding Modeling

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Motivation

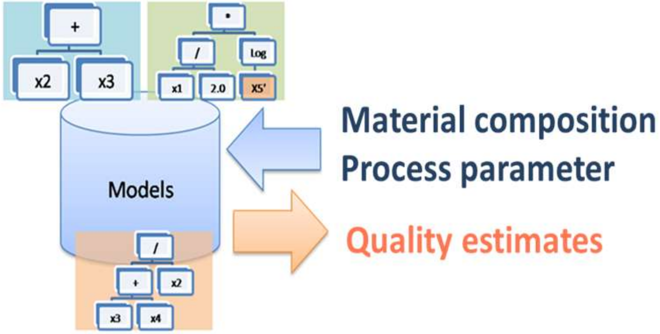
- hardening of materials (e.g. transmission parts)
- process parameter settings based on expert knowledge

Modeling Scenarios

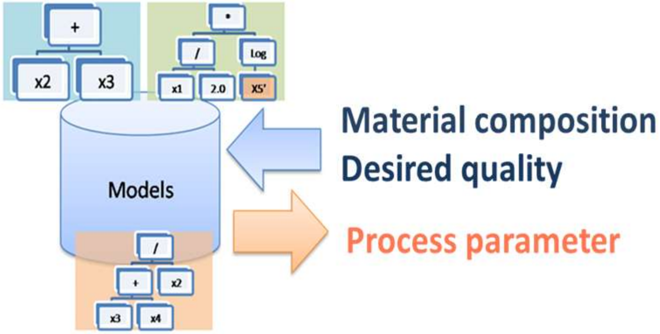
a) prediction of quality values based on process parameters and material composition

b) propose process parameter settings to reach the desired material characteristics

a)



b)



Example:
Modelling Tribological Systems

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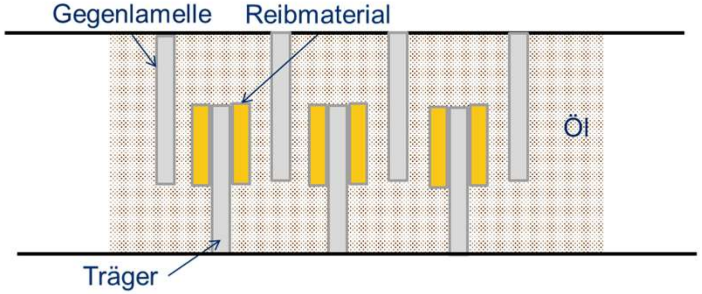
Goals

- virtual design and prototyping
- support design & dimensioning process

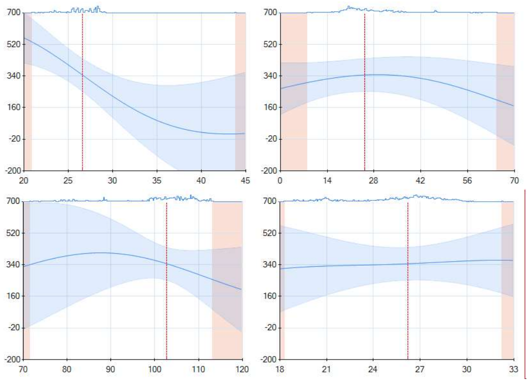
Methods

- model friction coefficient, wear, noise & vibration
- integrate domain knowledge
- reuse and formalize existing test data

Tribological System

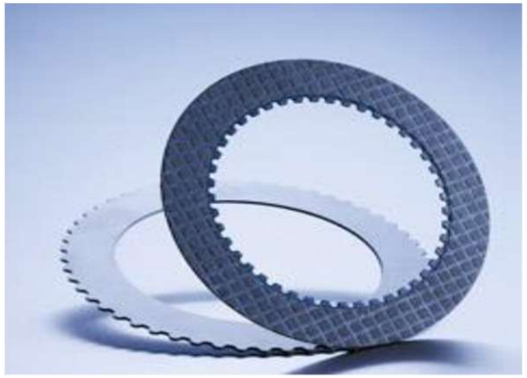


Virtual Design



Testing

Final Product



Example: Medical Diagnosis

Motivation

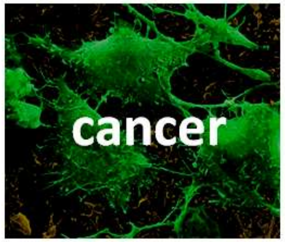
- **research goal:** identification of mathematical models for cancer diagnosis
- **tumor markers:** substances found in humans (especially blood and / or body tissues) that can be used as indicators for certain types of cancer

Data

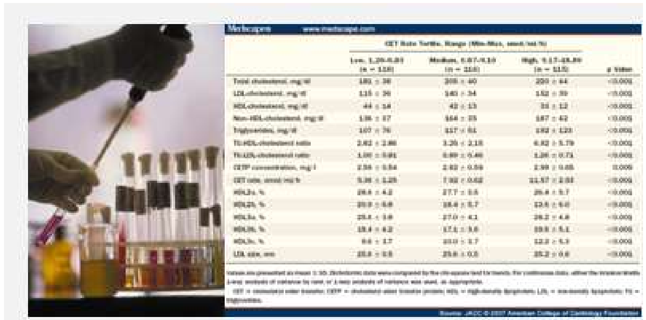
- medical database compiled at the central laboratory of the General Hospital Linz, Austria, in the years 2005 – 2008
- total: blood values and cancer diagnoses for 20,819 patients

Modeling Scenarios

- model virtual tumor markers using normal blood data
- develop cancer diagnosis models using normal blood data
- develop cancer diagnosis models using normal blood data and (virtual) tumor markers



effects seen in data (blood examinations, tumor markers)



Cancer Diagnosis Estimation

Integration of Expert Knowledge

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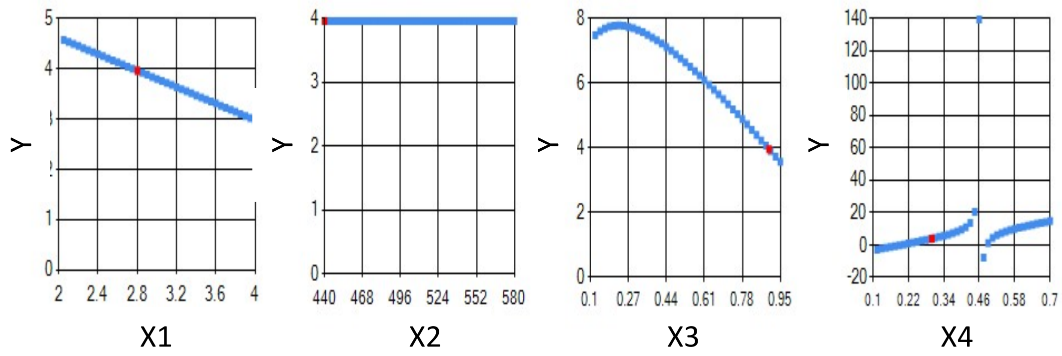
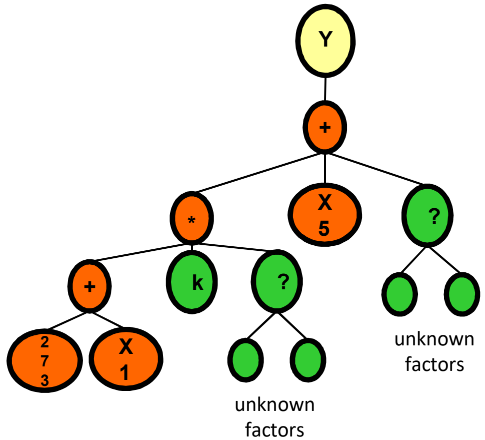
Model Analysis



Knowledge Integration

- specification of known correlations
- model extension through algorithm



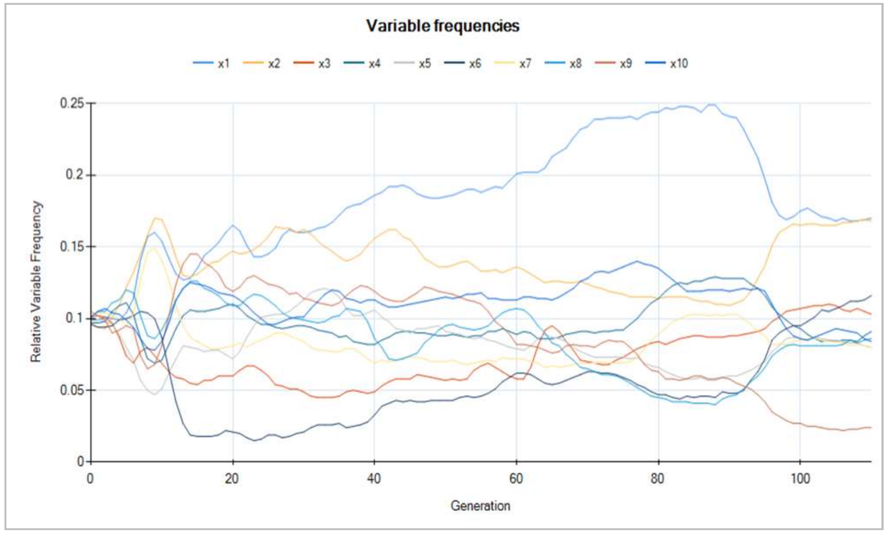
Holistic Knowledge Discovery

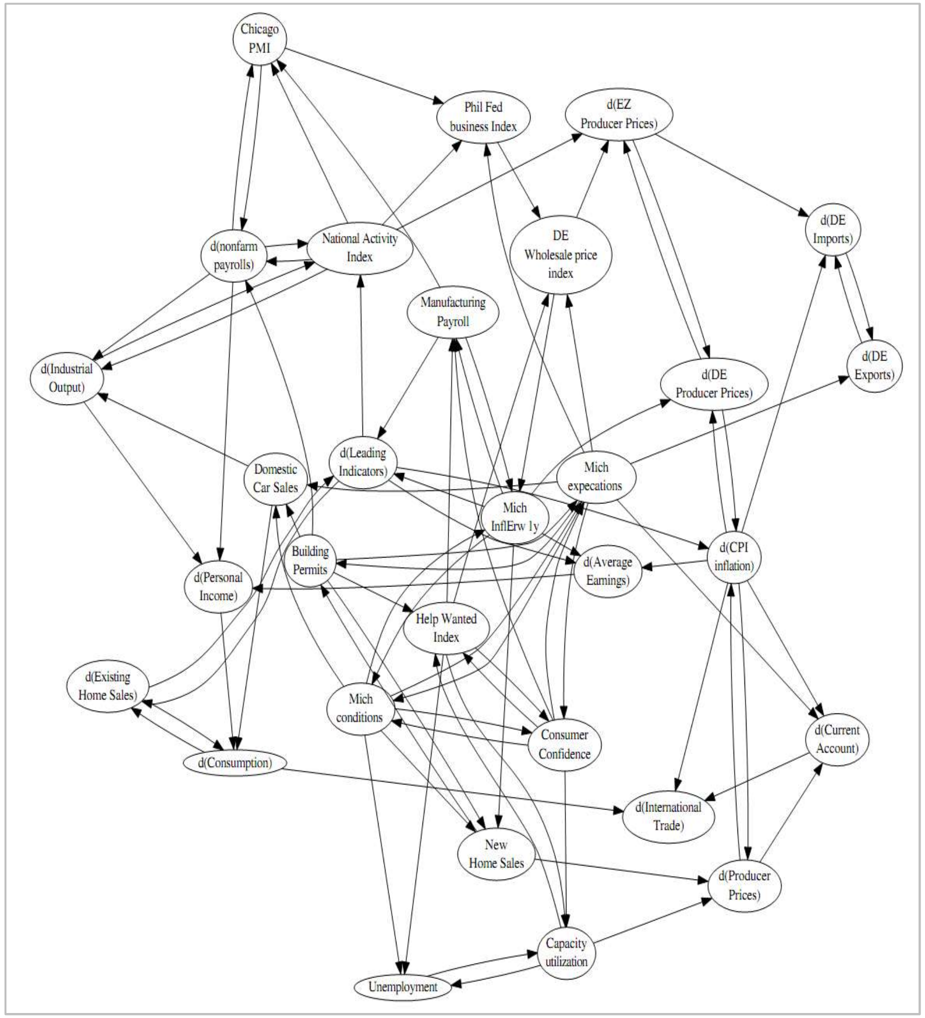
Variable interaction networks

- reveals non-linear correlations

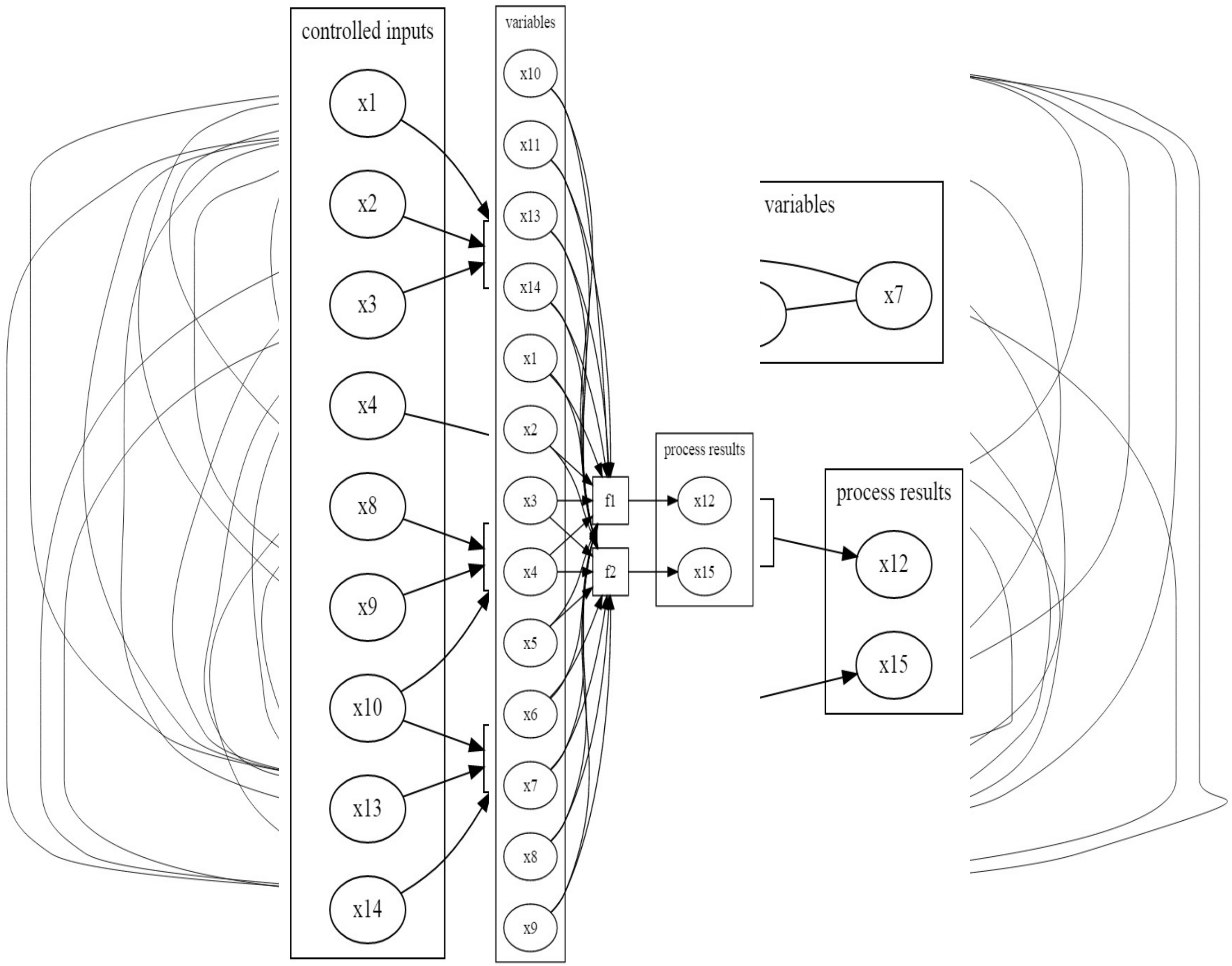
Variable frequencies

- analyzed during the algorithm run



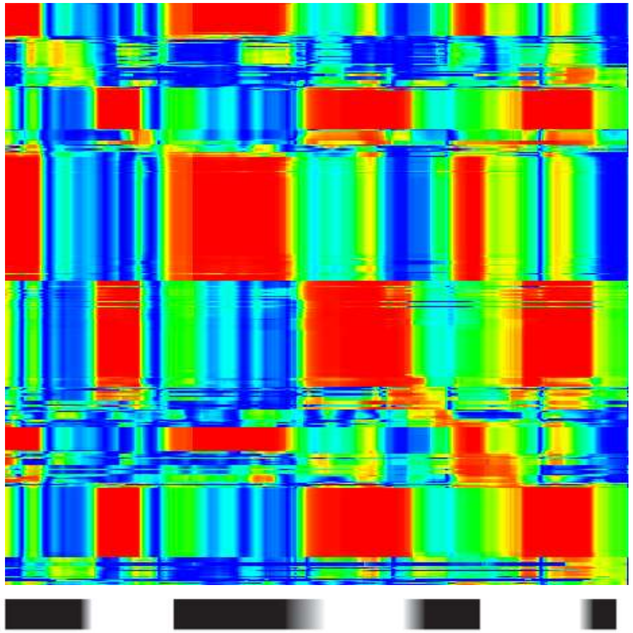


Model Networks for Structuring Systems

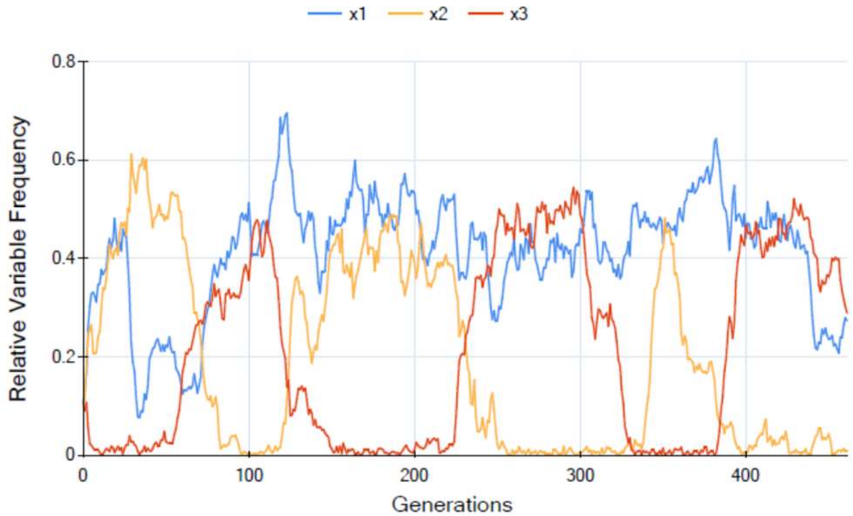


Detection of Regime Shifts

- **Real-time Analytics (Streaming Data)**
- **Analysis of Variable Frequencies**
  - clearly shows that algorithm is able to detect which variables are relevant



$$f_1(x,h) = x_1 * (h * x_2 + (1-h) * x_3)$$



Smart Factory Lab

- „Smart Factory Lab EFRE/IWB 2014–2020“ – Technology Lab for Intelligent Production along the Product Lifecycle
- Project Locations: Hagenberg, Steyr, Wels
- Time Frame: 01.01.2016 – 31.12.2021

- Research Focus in the Industry 4.0 Field

- Infrastructure Investments
  - high performance compute cluster
  - VR/AR technology
  - laser cladding and milling system

Preemptive Maintenance

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Real-Time Identification of Maintenance Needs with Machine Learning

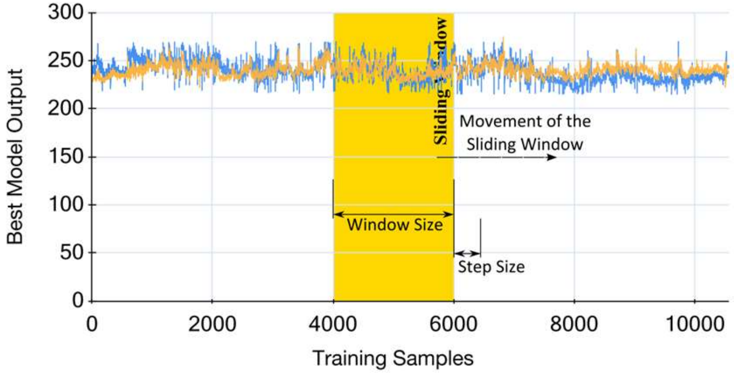
- prevention of production downtimes, early detection of quality problems, scrap prognosis

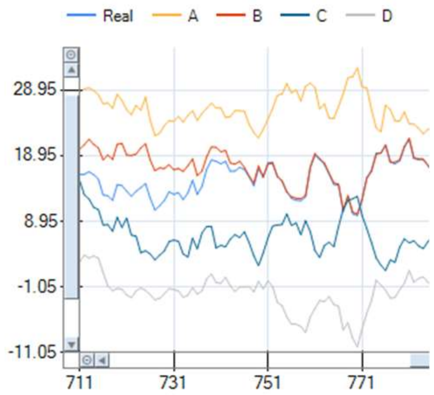
Time Series Analysis / Data Stream Analysis

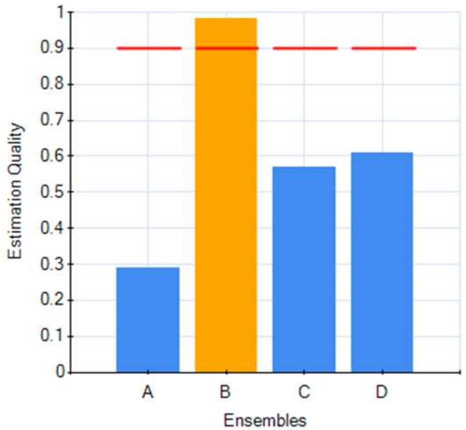
- consecutive data from sensors for monitoring production facilities

Sliding Window Regression

- online and real-time capabilities
- ensembles for state detection







Research Focus

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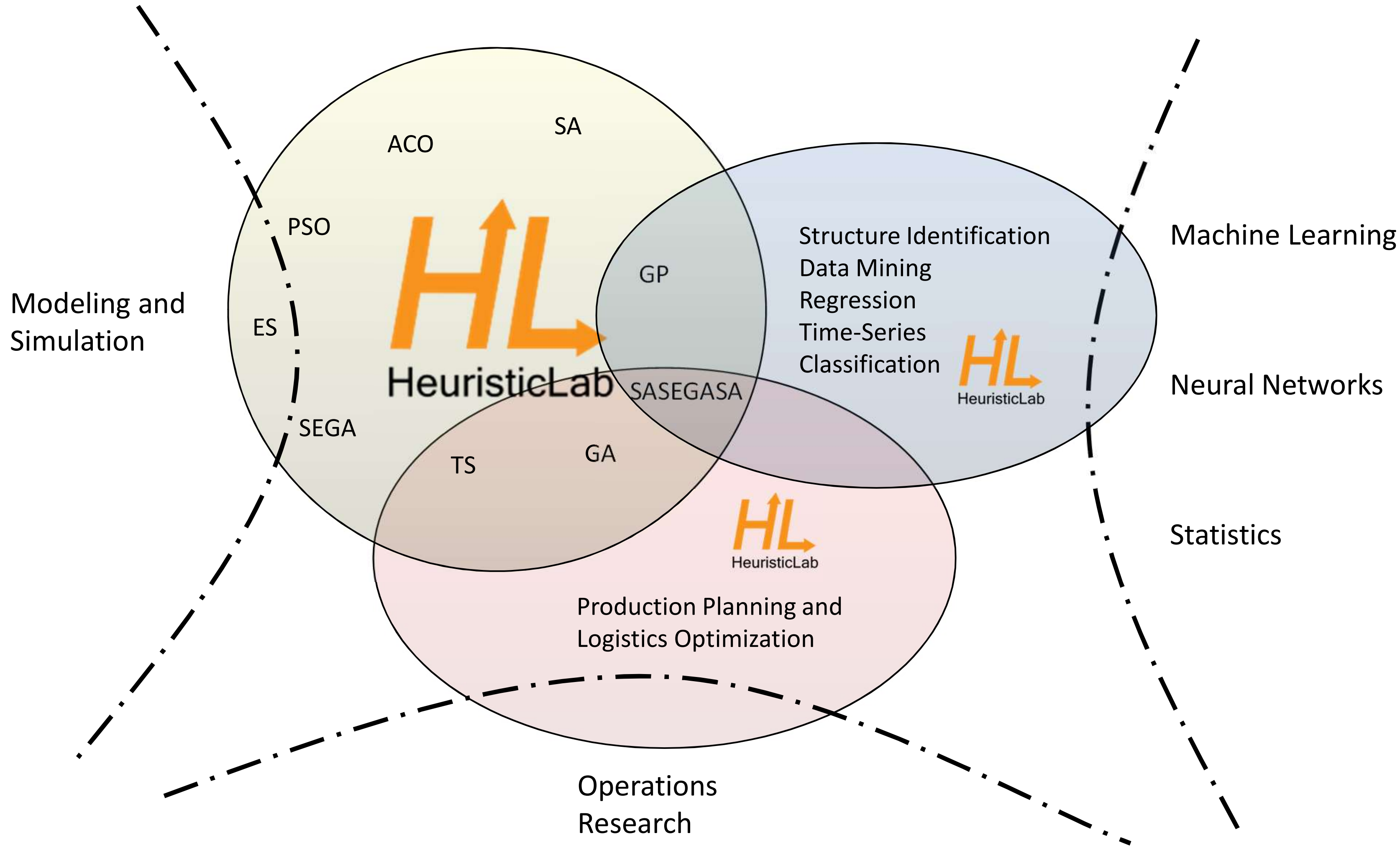
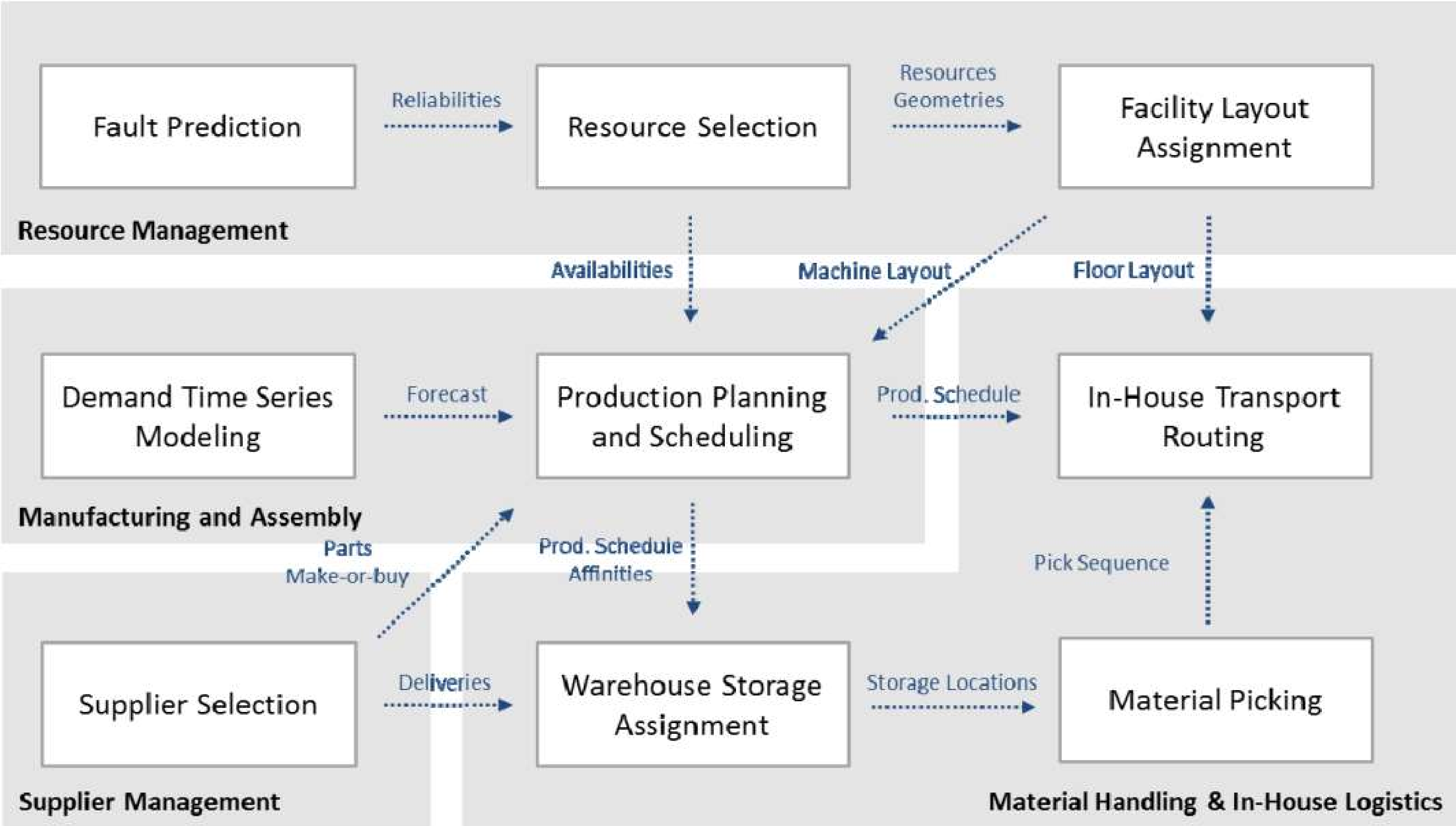
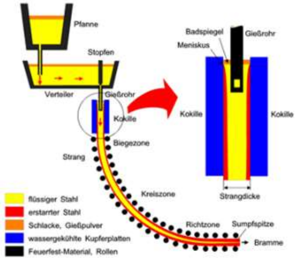


Interrelated Production and Logistics Processes



Steel Production Processes

Casting

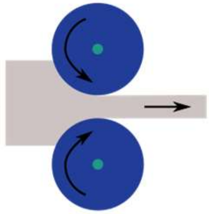


Stacking

Transport

Storage

Transport



Rolling

Integrated Modeling, Simulation & Optimization

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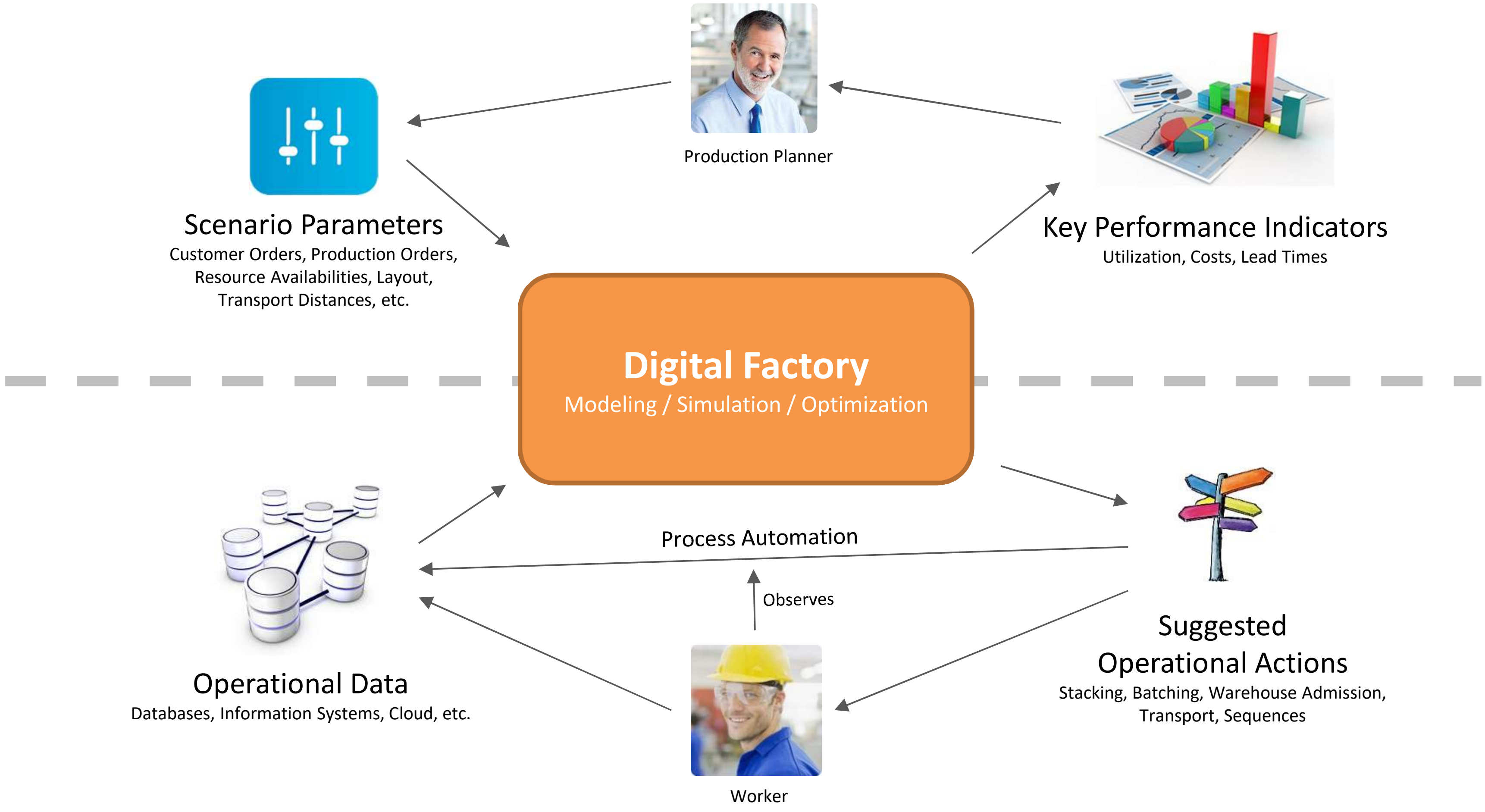
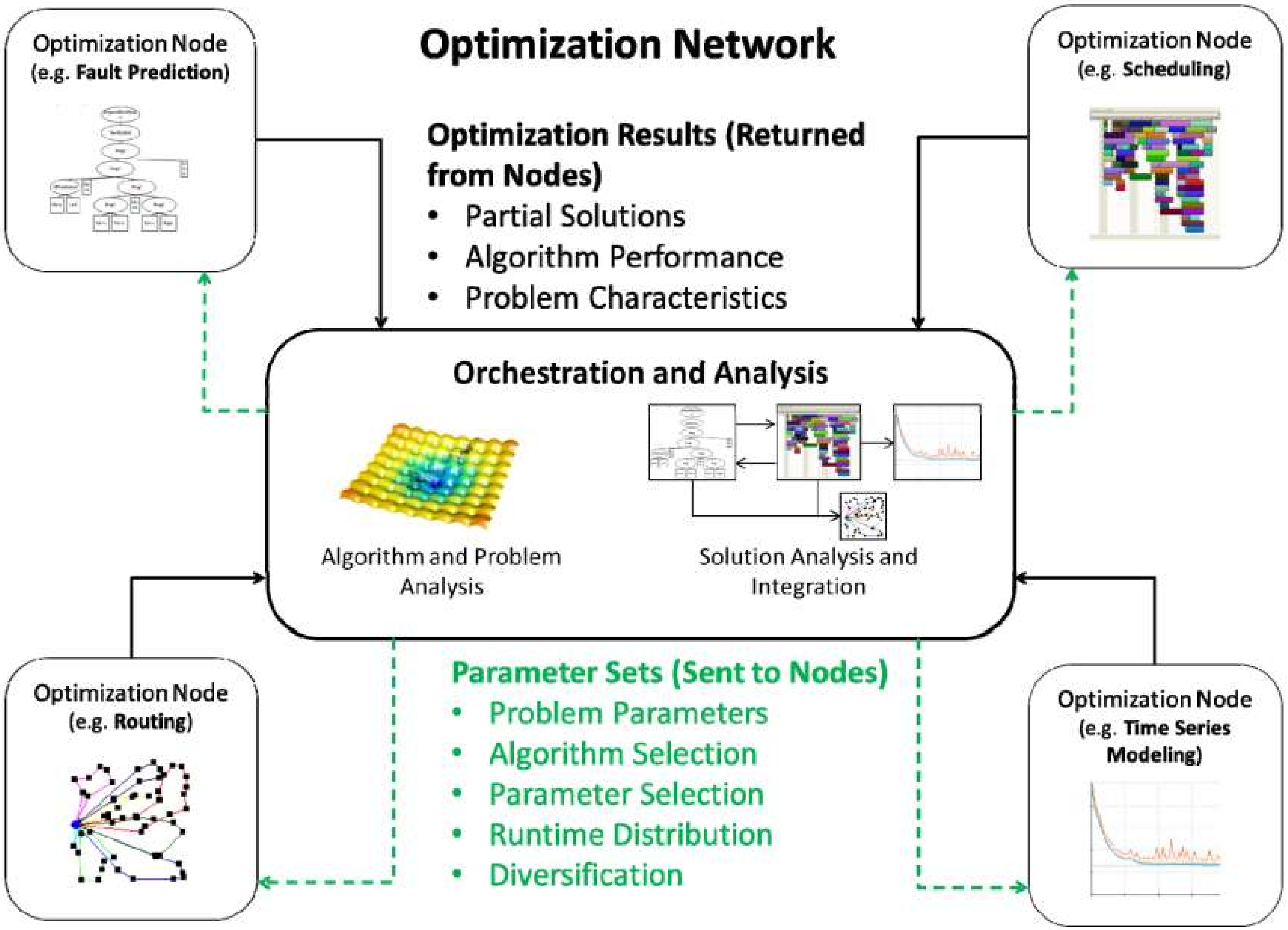
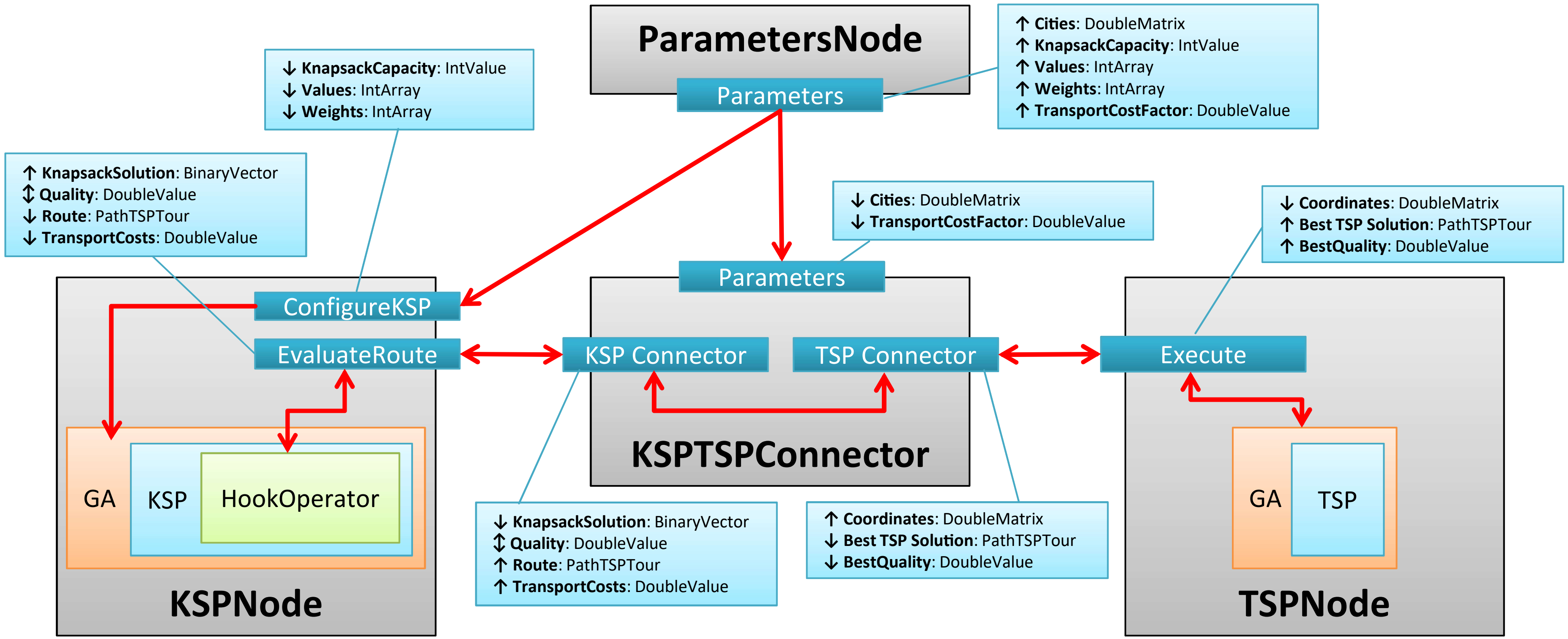


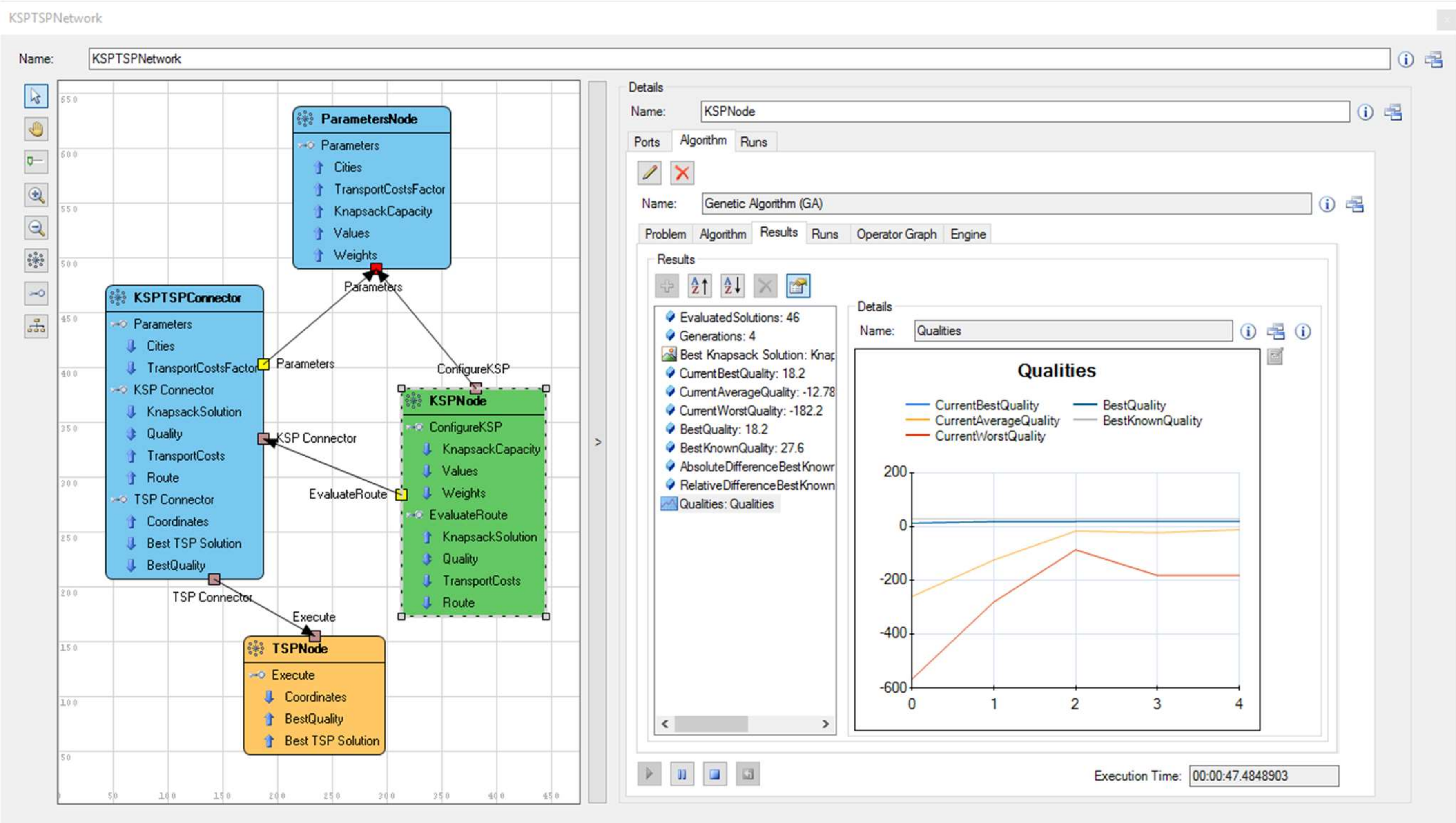
Optimization Networks – Synchronized Planning and Control



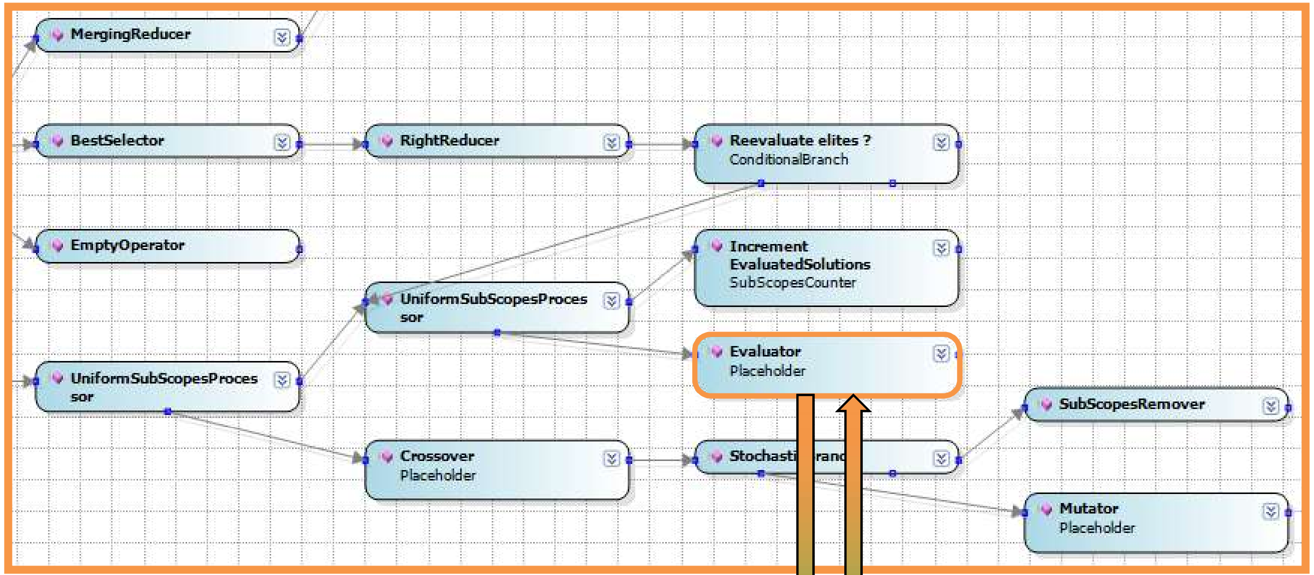
Academic Example: Knapsack + TSP



Optimization Networks in HeuristicLab

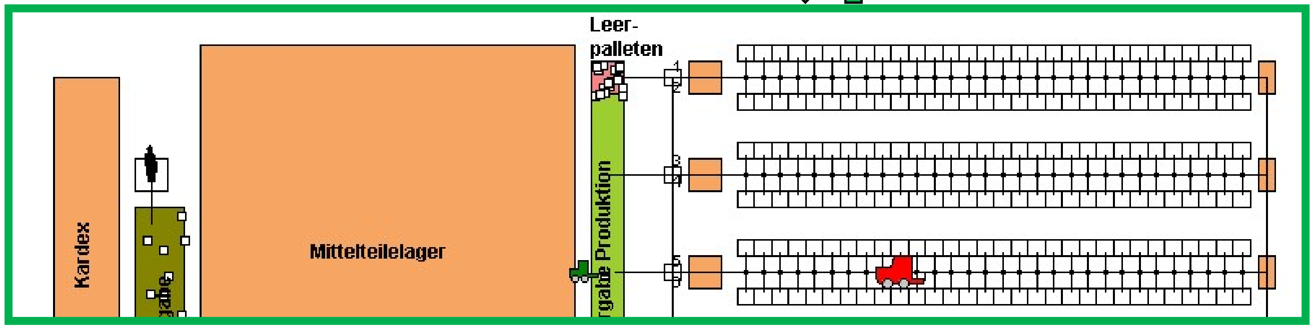


Interaction with Simulation Software



Configurable and extensible data exchange using protocol buffers

e.g.



Interaction with Simulation Software

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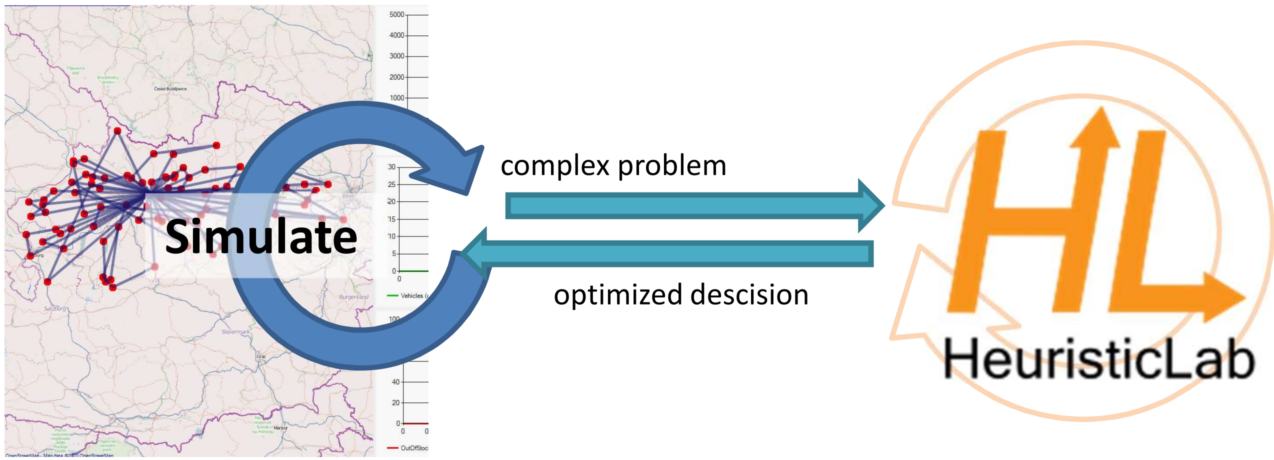
Integration into Simulation Process

- complex decisions may need to be made inside a simulation
  - e.g. which customers should be served by which trunk in what tour?
- HeuristicLab can be used to optimize these decisions
  - exisiting problem models can be parameterized (e.g. VRP) and solved
  - new problem models can be implemented and added



Interaction with Simulation Software

Google Protocol Buffers

- originally developed at Google but has been released to the public
- reference implementations still maintained by Google
- used to describe messages that are exchanged between HeuristicLab and simulation software
- very **small and fast** serialization format
- protocol buffers can be **extended and customized**

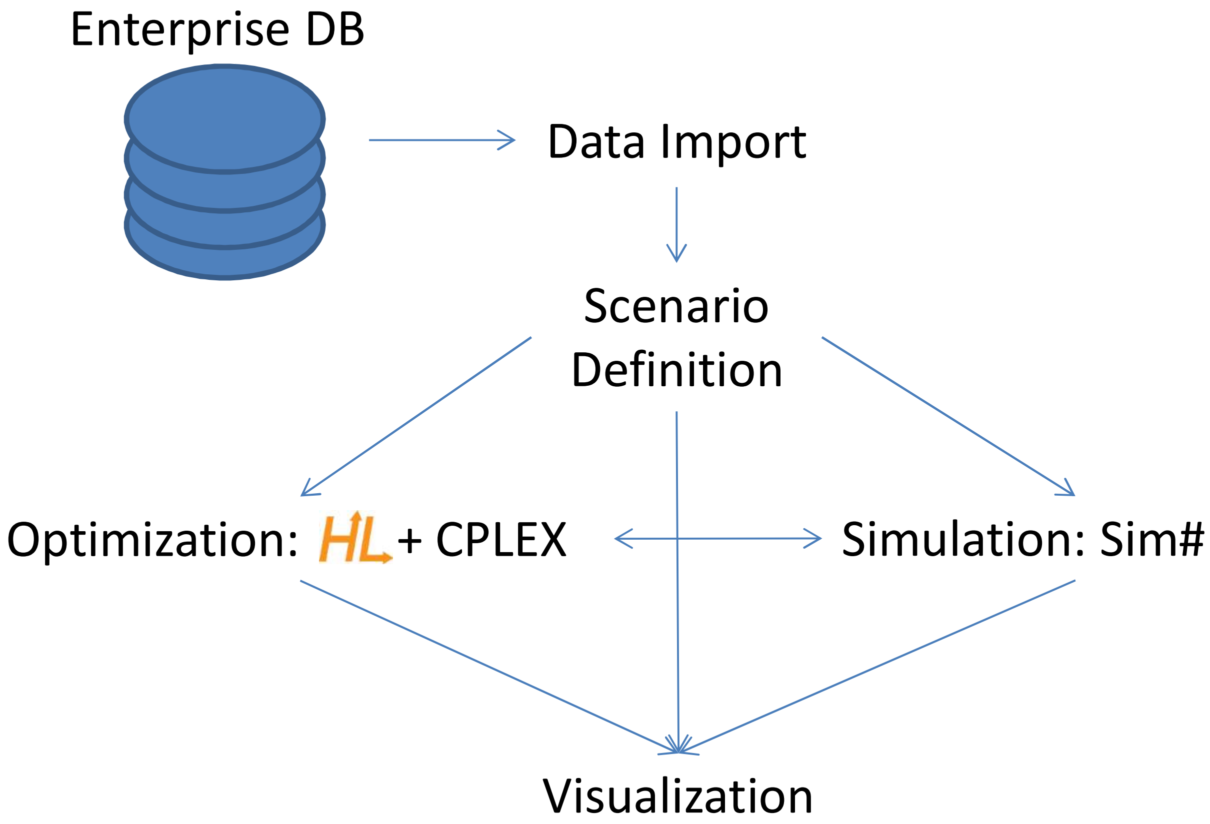
Serializer	Larger than best	Slower than best
Microsoft DataContractSerializer	4.68x	6.93x
Microsoft JsonDataContractSerializer	2.24x	9.31x
Microsoft BinaryFormatter	5.62x	9.21x
NewtonSoft.Json	2.30x	7.83x
ProtoBuf.net	**1x**	**1x**
ServiceStack TypeSerializer	1.77x	2.23x
ServiceStack JsonSerializer	2.09x	2.58x

Protobuf is among the fastest and smallest serializers for many programming languages

Source: http://www.servicestack.net/benchmarks/NorthwindDatabaseRowsSerialization.100000-times.2010-08-17.html

Production Planning Optimization & Visualization Cockpit

- software frontend for applying optimization and simulation methods on company data



HeuristicLab PPOVCockpit

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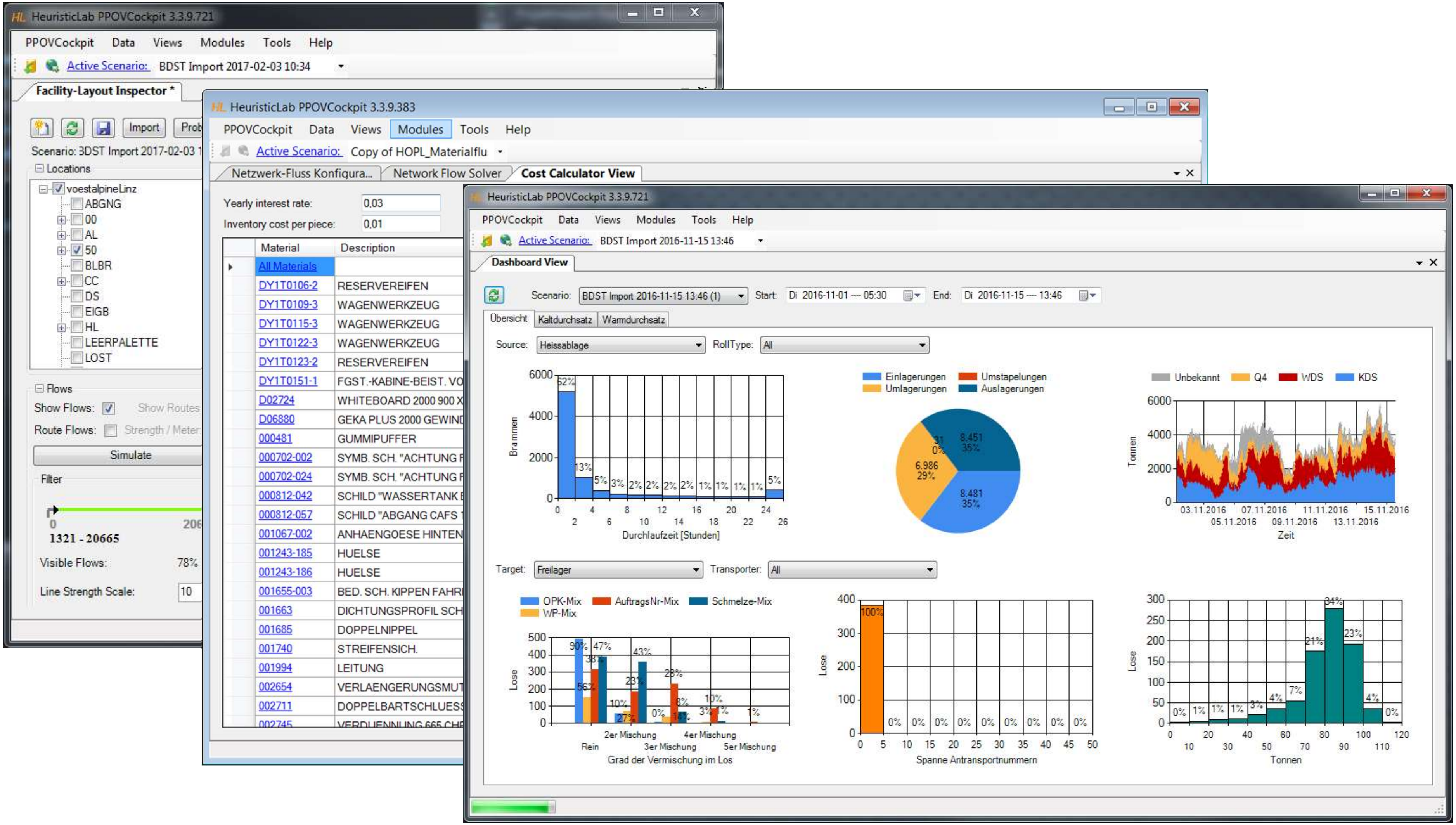
Heuristic and Evolutionary
Algorithms Laboratory



Example:
Material Flow and Layout Optimization

Goal

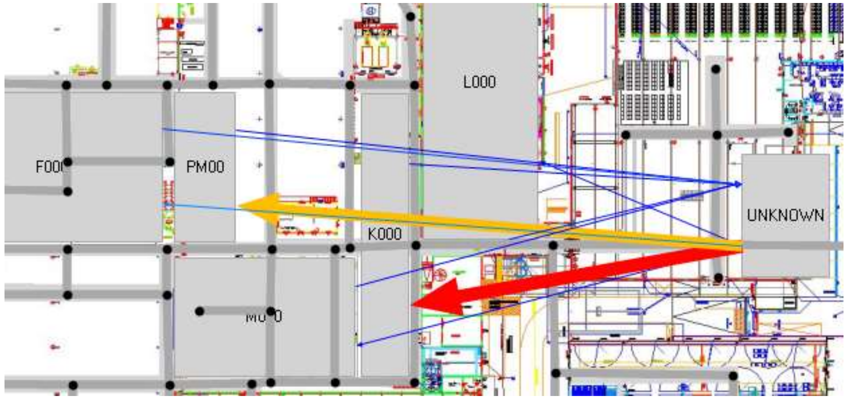
- the layout of an automotive production partner should be optimized
- material flows are to be simulated and used to rearrange workcenters

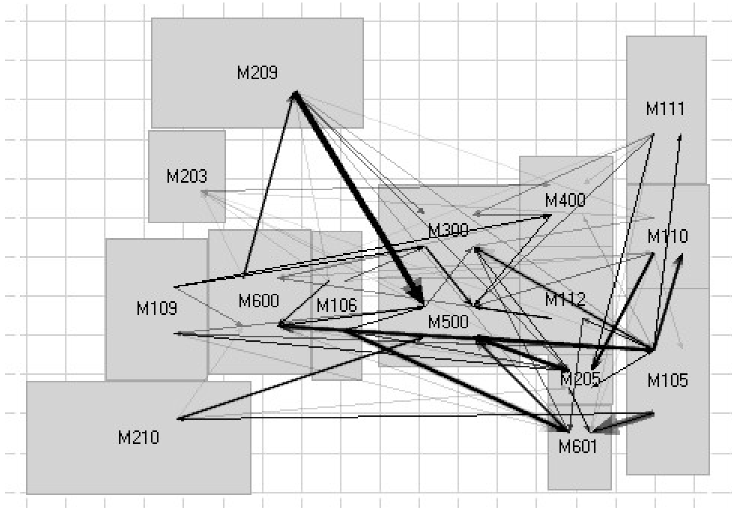
Simulation Model

- the simulation runs with the historical data of the production plant
- production flows are identified as either sequential, parallel or material demands that are satisified from different sources

Optimization

- a rearrangement of workcenters shows significant potential in reducing transportation requirements
- the company currently builds a new facility and adapts the layout of the existing plant





Example:
Steel Slab Logistics

Goal

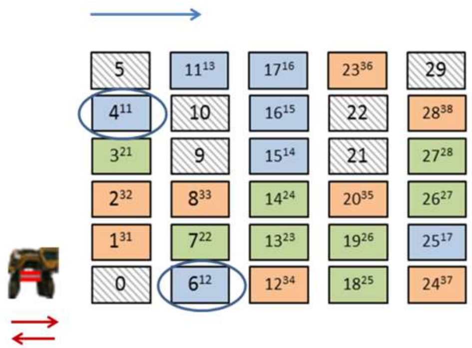
- the transportation of steel slabs should be improved and a better utilization of the capacities achieved

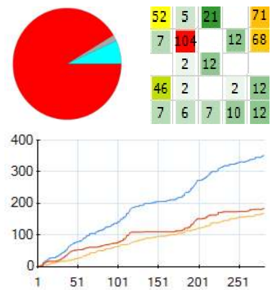
Simulation Model

- straddle carriers transport steel slabs between the continuous caster, the designated storage areas, processing facilities and the rolling mill

Optimization

- determine which straddle carrier picks up which slabs in which order
- a 4% improvement in lead time in dispatching of the straddle carriers was identified
- major bottlenecks (e.g. stacking of slabs) in the process have been identified and led to subsequent projects





Example:
Fork Lift Routing

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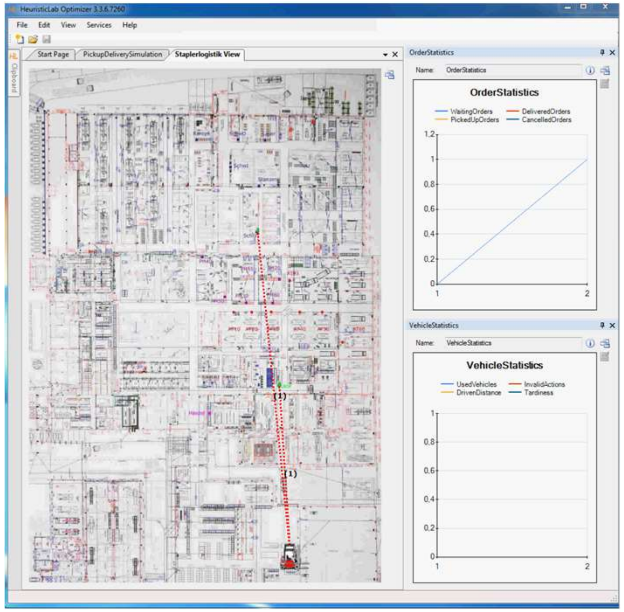

Goal

- dispatching of fork lifts to serve the assembly of trucks should be improved
- interaction with warehouse operations should be investigated to determine interrelated effects

Simulation Model

- fork lifts transport materials to the assembly stations
- finished assembly parts have to be transported back

Optimization

- results indicate that a combined view of picking and in-house transport is able to reduce makespan more than optimizing storage and transport independently

Example: Warehouse Operations

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Goal

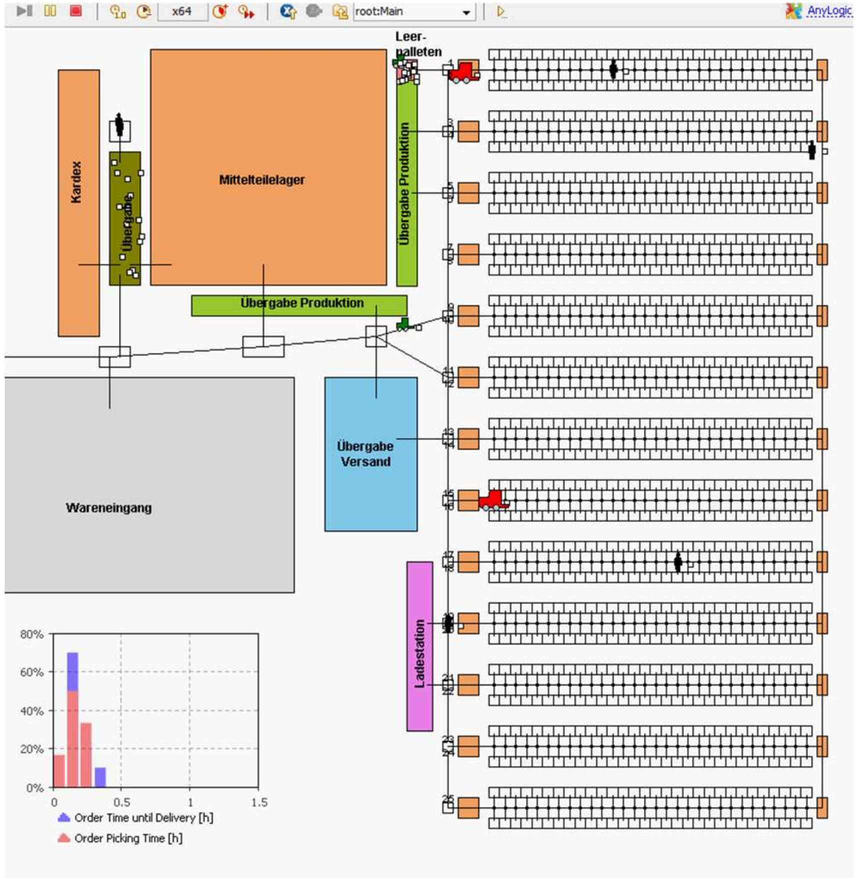
- automate the decision of where to place items in a high rack storage
- simulate the effects of the automation

Simulation Model

- the high rack contains the assigned items
- what is the effect on the picking process?

Optimization

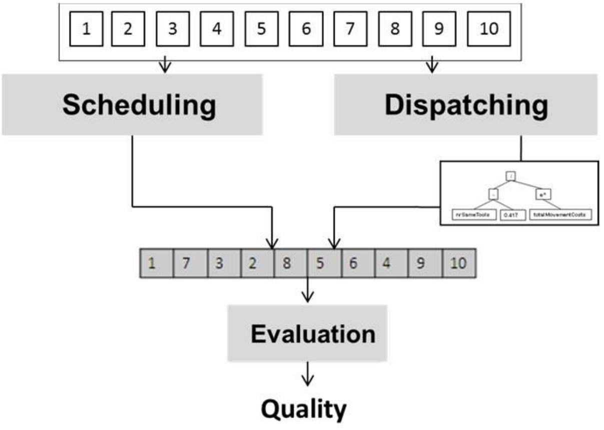
- optimize the assignment of items to storage locations
- several constraints are considered such as storage box capacity, different location capacities, aspects of certain parts (FIFO) and more
- a 10% reduction of the travel distances could be achieved if the whole high rack was to be reorganized
- reduction of 10km of travel distance in the first month of the automation



Example:
Setup Cost Minimization

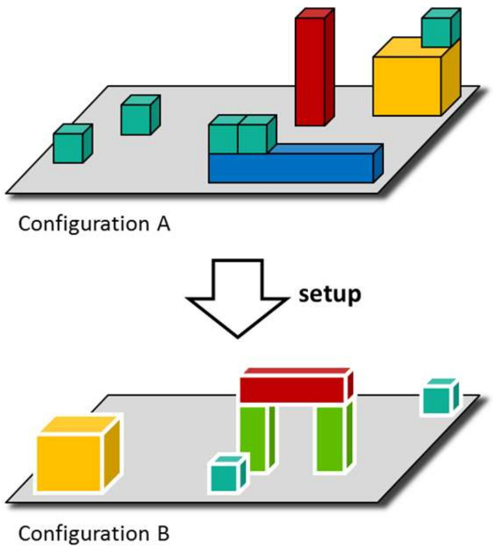
Motivation

- shift from mass production to customized products in small lot sizes
- more frequent setups to prepare machines or tooling
- 40% - 70% spent on setup in some manufacturing environments
- in many cases: constantly changing product portfolio
  (especially for toll manufacturers)



Setup Costs

- setup times are a crucial factor in many branches of industry
- setup costs are frequently sequence-dependent



Goal

- no measurements but approximation of setup costs
- optimization of total setup costs for production planning
- evaluation of scheduling vs. dispatching rules

Example:
Product Mixture Simulation and Optimization

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Goal

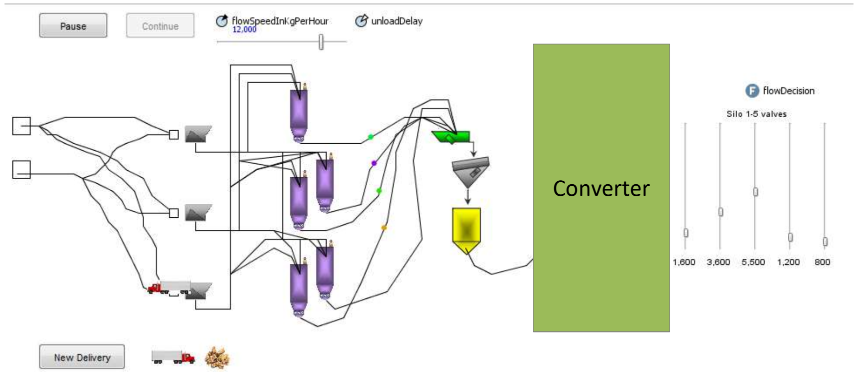
- for creating a product with a stable quality multiple raw materials stacked in several containers must be mixed together
- the mixing descision is complex and has to take into account product restrictions
- an existing optimization only considers the bottom raw material in the container

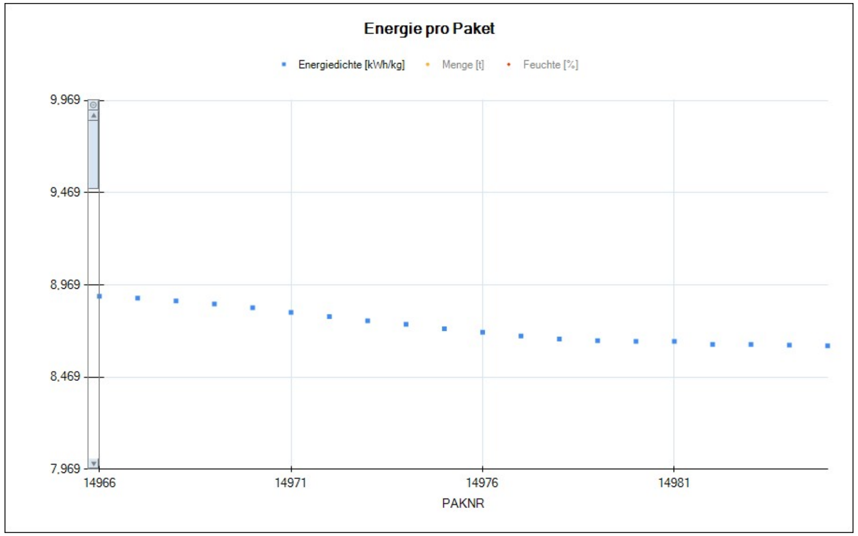
Simulation Model

- given a certain mixing plan the simulation model calculates the properties of future products
- trucks bring in new raw material

Optimization

- the optimization finds mixtures that result in stable qualities of the products over time and reduces fluctuations





Example: Scheduling vs. Dispatching in Production Planning

Motivation

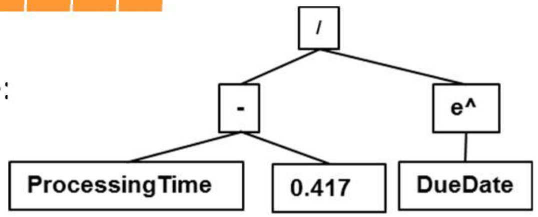
- challenges in the optimization of a real-world production plant: data quality, problem size, constraints
- **scheduling**: long-term planning, „big picture“ (global optimization)
- **dispatching**: rule-based, local strategies, real-time capable, for volatile environments

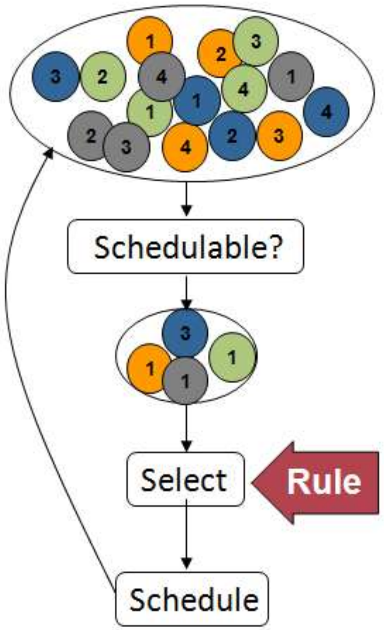
Variants

- simple dispatching rules: FIFO, EarliestDueDate, NrOfOperations, etc.
- rule per group/machine:

5	7	3	0	2	2	7	4	9	4	5	1

- complex dispatching rule:





Evaluation via Simulation

- robustness, stochastic variability, additional key figures

Example:
Logistics Network Design

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BioBoost – EU FP7 Project

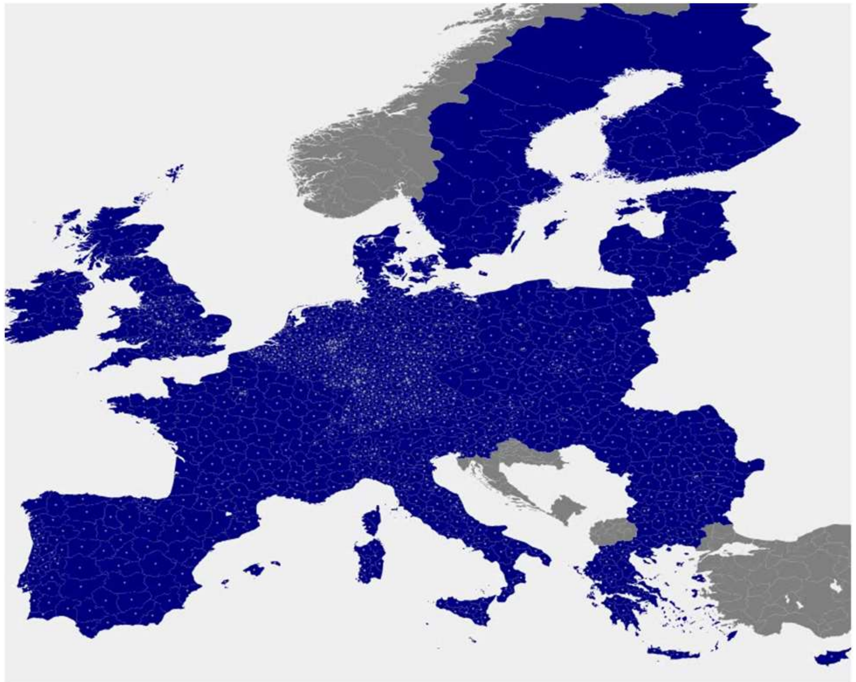
- agricultural waste should be converted to BioFuel
- however waste has little energy density and is inefficient to transport
- the project develops plants to compress waste into intermediate and final products
- question: what would an efficient logistic network to support this process look like and what would it cost to build and run?

Simulation Model

- regions supply certain types of waste in different degrees
- regions have transportation infrastructure that influences cost and speed
- a high demand influences the price of waste

Optimization

- determine which regions get a converter
- determine which region contributes which type of waste to which degree to which converter



Example:
Dial-a-Ride Transportation Model

Goal

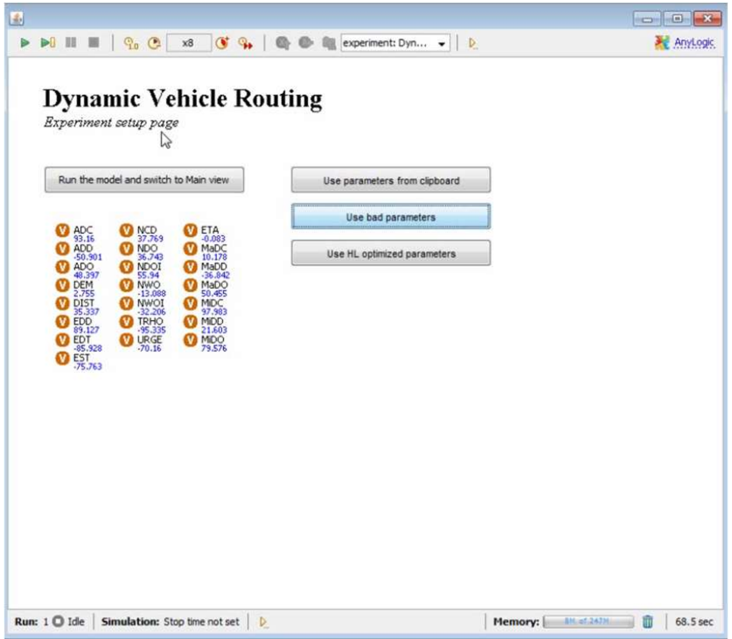
- what would a more efficient public transport look like that is based on dynamic routes and small buses
- a control strategy should be identified which performs bus dispatching

Simulation Model

- customers appear at bus stops and demand a ride to their destination
- buses frequent the stops and pick up as well as drop off the customers
- the control strategy decides where the bus heads next and which customers to be picked up

Optimization

- the control strategy consists of several parameters that need to be optimized
- a reduced lead time is the main goal such that customers do not wait too long



Example:
Vendor Managed Inventory

Goal

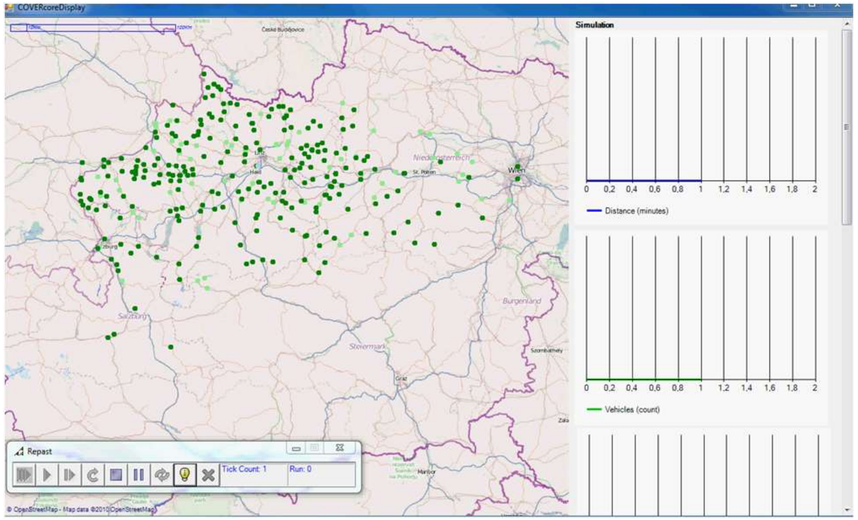
- build a tool to evaluate and compare the case of order-based and vendor-managed inventory
- determine the expected improvements and potential return on investment

Simulation Model

- supermarkts have several thousand product groups in stock
- customers have demands and consume the stock
- the central warehouse needs to continuously restock the supermarkets

Optimization

- determine which supermarkts will be restocked with which truck in what tour on which day with which products
- compare this case to an order-based case where only tours need to be determined
- the demands have been smoothened over the week and peek demands could be avoided
- consideration of mixed scenarios where only some markets adopted VMI



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HEAL: https://heal.heuristiclab.com

HeuristicLab: https://dev.heuristiclab.com

Specific Strengths and USPs

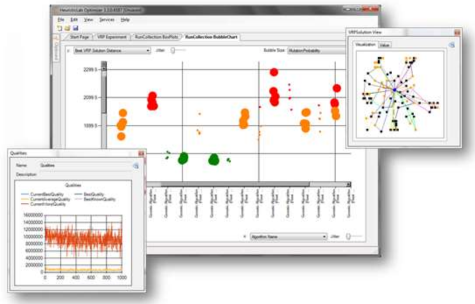
Own Framework, Own Algorithms and Methods

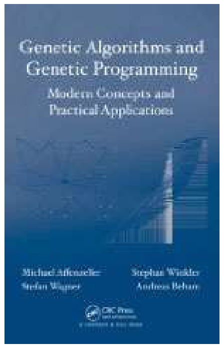
- long-term experience in algorithm development, analysis and application
- tailored solutions

HeuristicLab
http://dev.heuristiclab.com

Well-Known and Reputable in the Scientific Community

- first invitation of an European group to GPTP
- organization of annual GECCO workshop since 2012
- other workshop and conference organizations (APCase, I3M, EuroCAST, LINDI)
- excerpts of CRC Press book proposal about GA & GP
  - Reviewer 1: “I know most of the authors and have very high opinion about their professionalism. They are from one of the LEADING groups in the field.”
  - Reviewer 2: “Affenzeller’s group is probably the best academic organization with respect to symbolic regression and industrial applications.”
- numerous publications in journals, books and conference papers





Specific Strengths and USPs

Own Framework, Own Algorithms and Methods

- long-term experience in algorithm development, analysis and application
- tailored solutions

http://dev.heuristiclab.com

Long-Term Cooperation with Leading Local Industrial Partners such as voestalpine, Rosenbauer, MIBA, AVL, Rübig

- first Josef Ressel Centre of Excellence in Austria
- first COMET project in Hagenberg campus
- close personal and individual cooperation