EKC²+ACCESS *Smart Grids* Workshop

OBERÖSTERREICH

HeuristicLab

A Paradigm-Independent and Extensible Environment for Heuristic Optimization

Metaheuristic Open Source Power System Optimization and Analysis using HeuristicLab

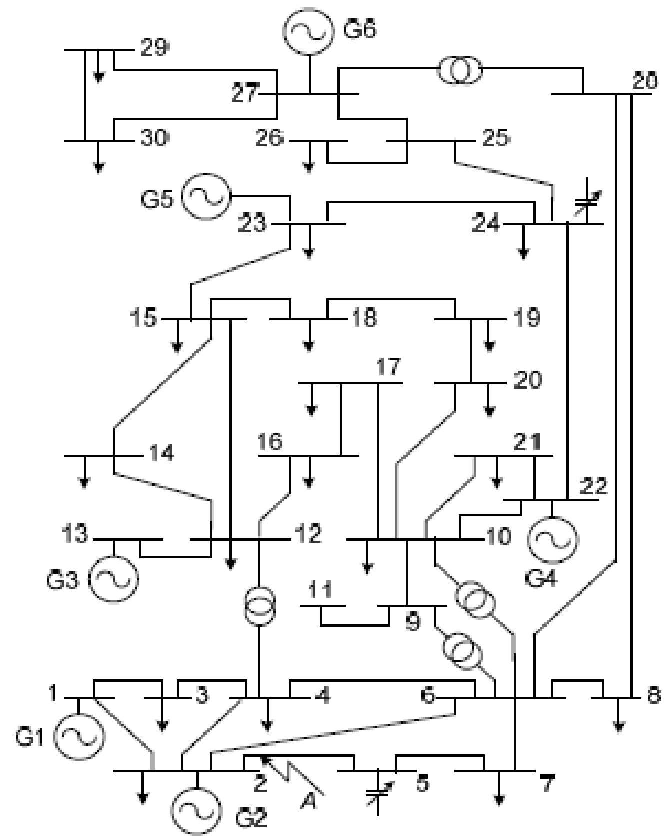
Stephan Hutterer

Content

- **Optimization in Smart Grids**
  - Original Problems
  - Investigation in Optimization Methods – why?
- **Simulation Based Approach - A Generic Optimization Framework**
  - Simulation- Based Optimization with Metaheuristics
  - The Principle of the Framework and its Abilities
- **A Powerful Use- Case: Planning With Uncertainty**
  - Stochastic Influences and Simulation- Based Sampling
  - Load Shifting in Smart Grids
  - Data Based Modelling
- **A Detailed View to HeuristicLab**
  - Algorithms, Problems and Experiments
  - Data Analysis

Optimization in Smart Grids
Original Problems

- **Optimal Power Flow / Economic Dispatch**
- **Unit Commitment**
- **Various Scheduling- Problems**
- **Layout- Problems**



Minimize some cost- function

$$F_i(P_G)$$

Subject to the constraints

$$\sum g(P_G) =)$$
$$\sum h(P_G) \leq)$$

Mostly Deterministic Techniques!

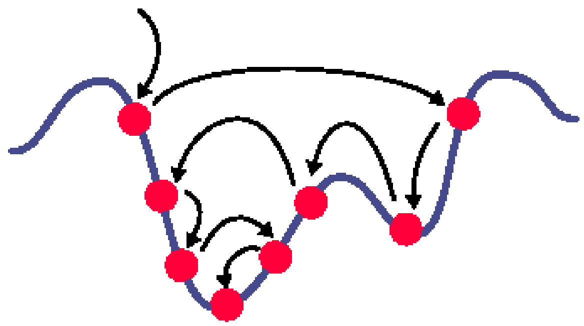
Optimization in Smart Grids

Investigation in Optimization Methods – why?

- „Intelligence“ → decision processes as optimization problems
- Standard optimization problems get more complex
  - More information
  - Better control abilities → higher number of decision variables
- Multiobjectivity
  - More than simple economic interests
  - Ecologic objectives get more important
  - Improved Reliability and Security as central Smart Grid Requirement!
- Computational advancements and parallelization techniques lead to new abilities in algorithmics

Metaheuristics

General class of algorithms which employ some degree of randomness to find (near-) optimal solutions to hard problems.



- Able to handle high Dimensionality
- Multiobjective Optimization Enabled
- Simultanous handling of Continuous and Discrete Variables
- Tradeoff Solution Time vs. Quality

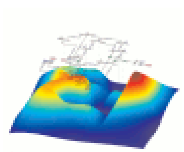
High Variety of different Algorithms with varying Abilities

Simulated Annealing, Evolution Strategy, Genetic Algorithm,
Particle Swarm Optimization, etc.
→ No Free Lunch Theorem

Simulation Based Approach
A Generic Optimization Framework

Quality of Solution

Simulation Software



PSAT

Optimization Software

HL

Candidate Solution
(vector with control variables)

Genericity:

Fast modelling of power grid through easy-to-use Simulation Software

Optimization with various Metaheuristic Algorithms as Part of the HeuristicLab Optimization Software

Simulation Based Approach
Central Abilities

- General abilities of metaheuristics as mentioned before
- Genericity:
  - Simple formulation of optimization problems
    - Definition of target variable computed by simulation
    - Definition of constraints → consideration with penalty term
    - Definition of solution vector (vector of control variables)
  - Independent of simulation- tool and specific simulation- model
- Applicable to systems where no closed-form mathematical model is available / possible, like
  - Uncertain systems
  - Systems with discontinuities in state space

A Powerful Use- Case:
Planning With Uncertainty

Scenario: Dispatch of charging load caused by electric vehicle fleet

Problem: stochastic influences:
- uncertain individual traffic
- intermittent energy supply through renewables

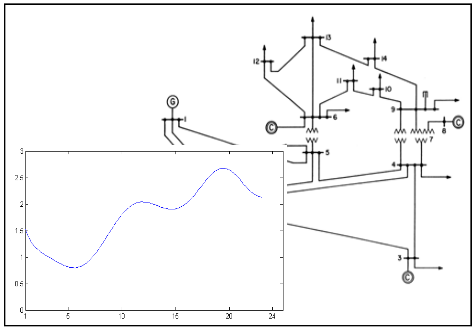
Target: optimal power schedule for supplying battery charging

Solution: include stochastic influences per probabilistic model
- discrete-event model describes individual traffic
- stochastic supply approximated by probability density function

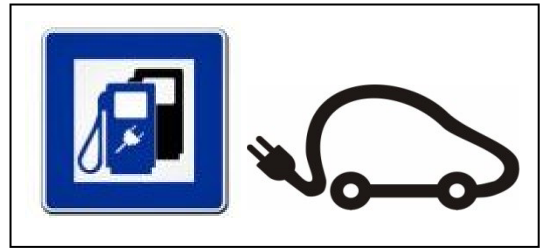
→ compute fitness of candidate schedule by random sampling

A Powerful Use- Case: Planning With Uncertainty

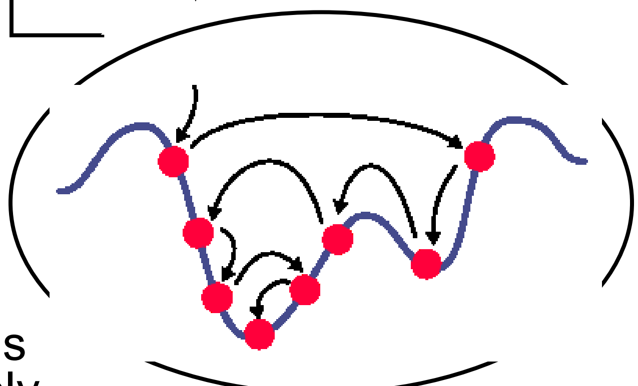
Power Grid Simulation



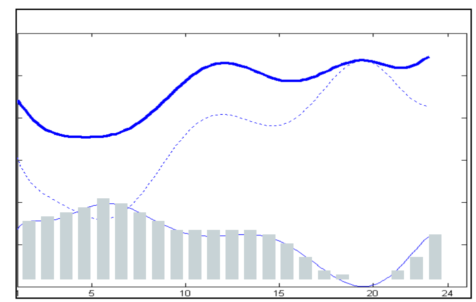
Traffic Simulation



Probabilistic Models of Intermittent Supply

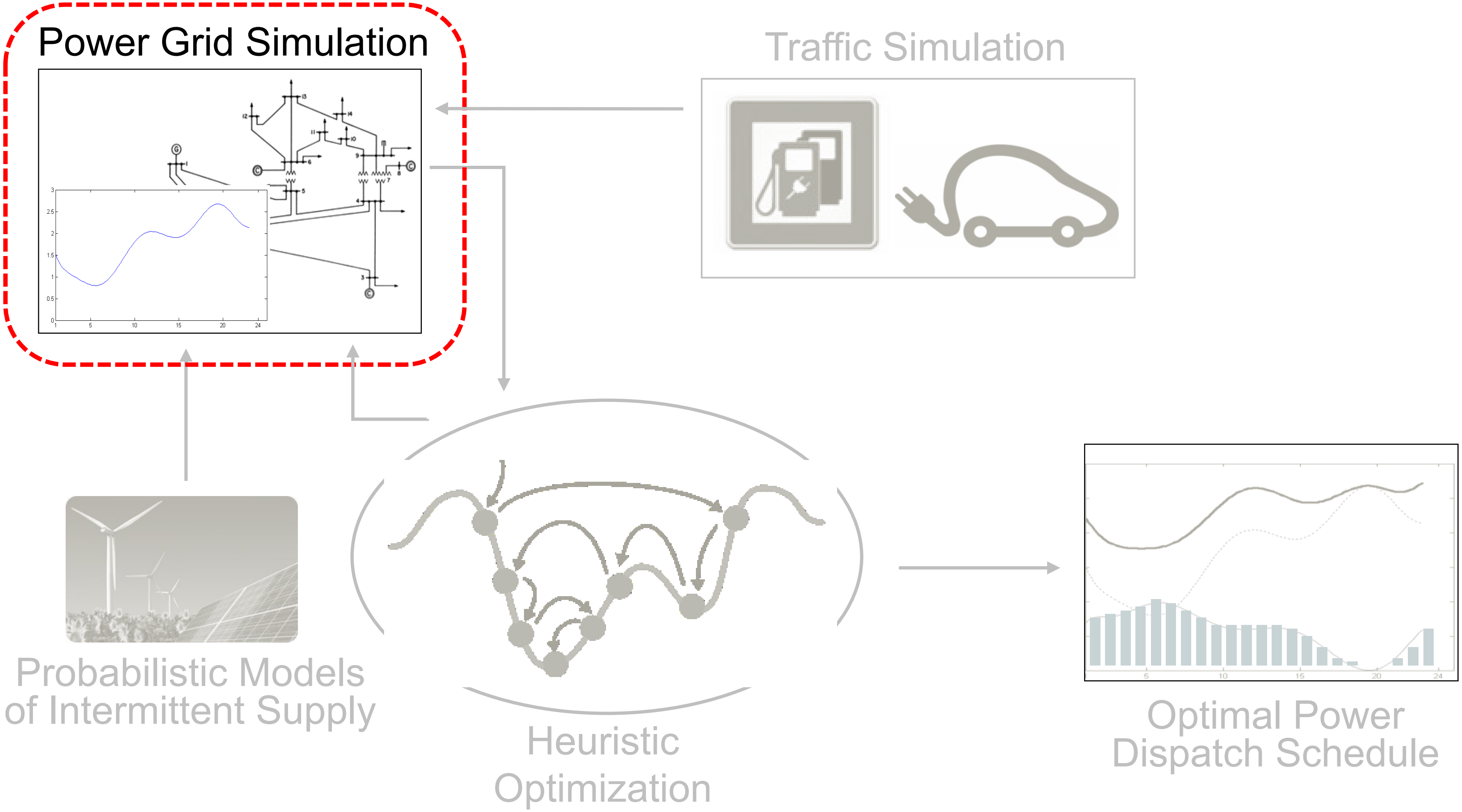


Heuristic Optimization



Optimal Power Dispatch Schedule

A Powerful Use- Case:
The Role of Power Grid Simulation



A Powerful Use- Case:
The Role of Power Grid Simulation

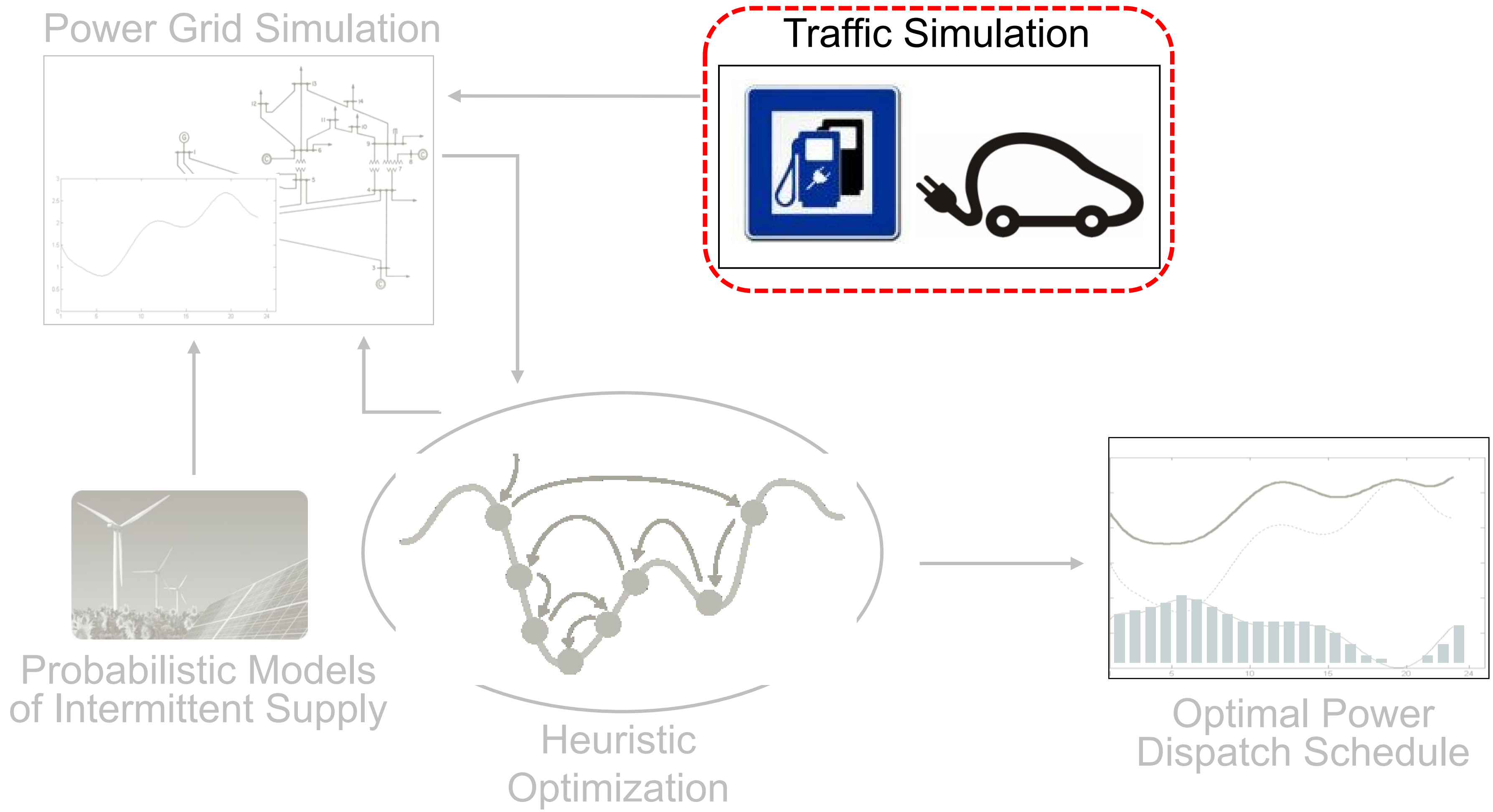
Consideration of Power Grid Constraints through Simulation

- Generation Capacities: Real and Reactive Power Generation
- Transmission Capacities: Real and Reactive Power Flows
- Lower and Upper Bounds for Bus Voltages

Target Variables can be stated, like for instance:

- Financial Fuel Cost Minimization
- Maximization of Power Quality
- Minimization of Greenhouse Gas Emission

A Powerful Use- Case:
Modelling of Individual Traffic

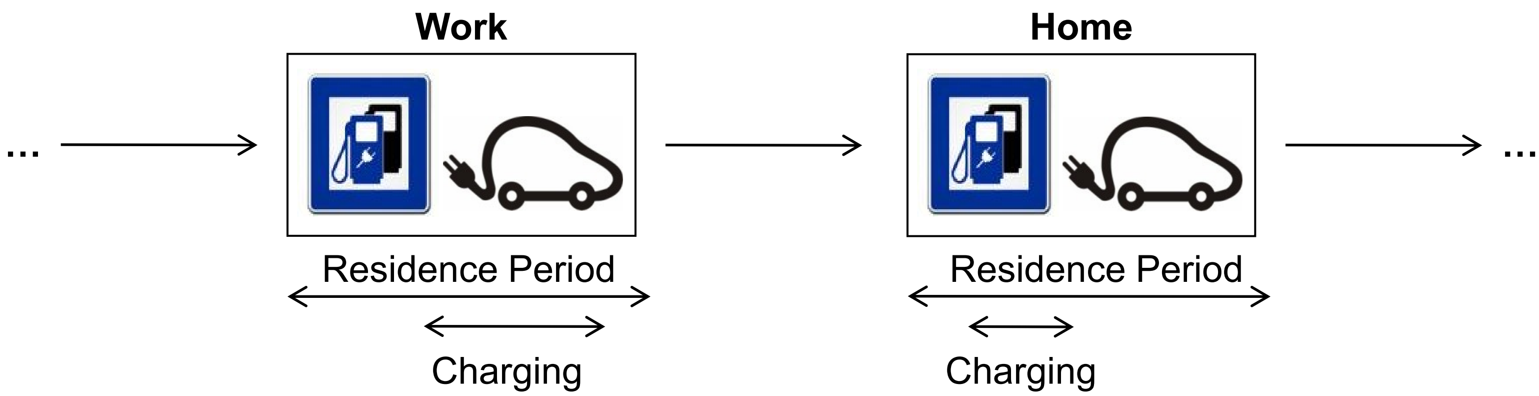


A Powerful Use- Case:
Modelling of Individual Traffic

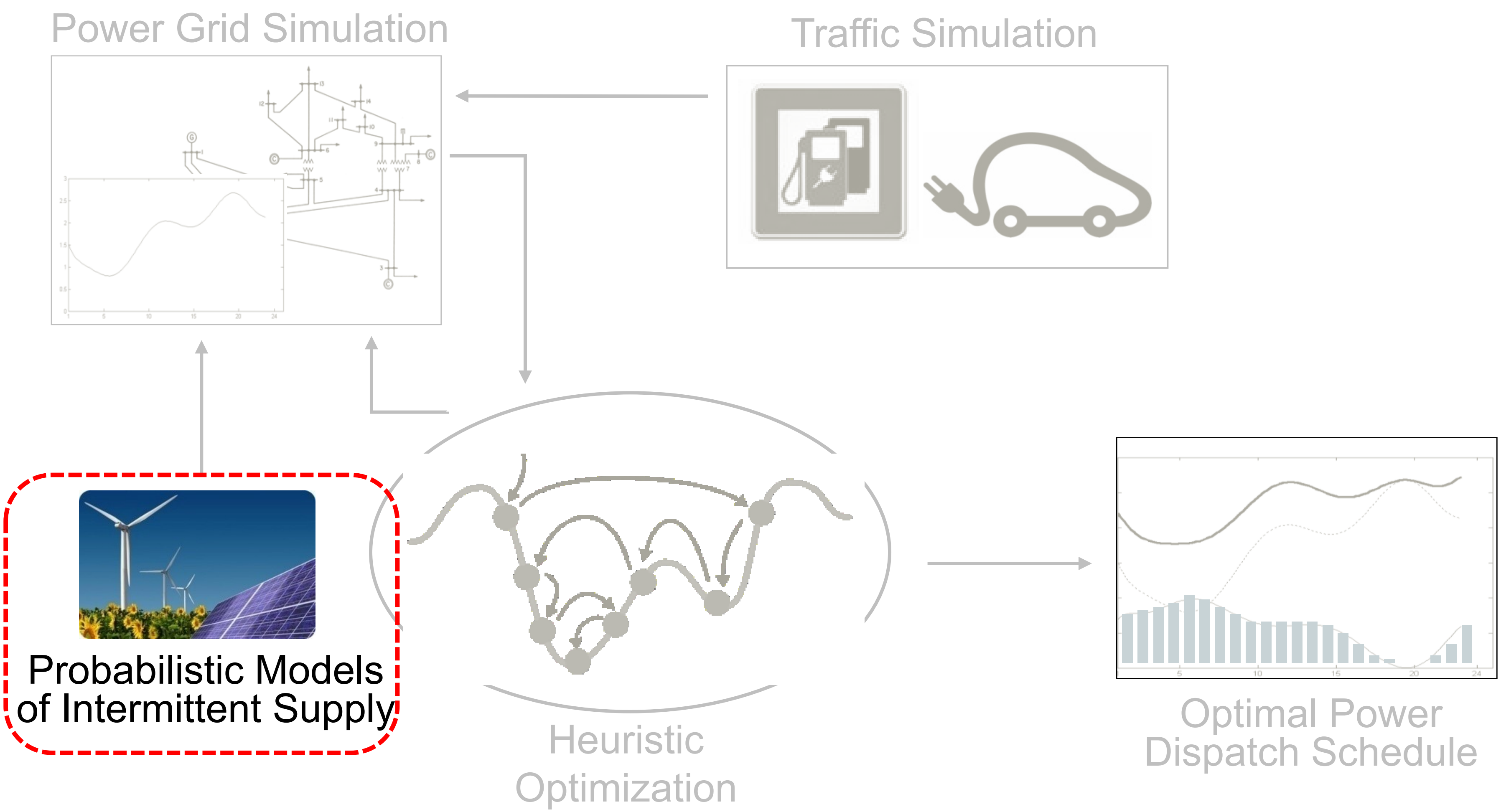
Electric load caused by vehicle battery charging
→Uncertainty through individual behaviour

Discrete- Event Simulation is able to consider probabilistic behaviour!

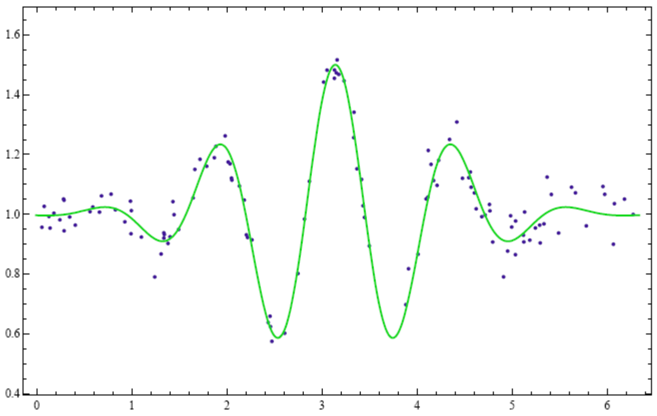
Given an arbitrary power dispatch schedule: satisfaction of consumer‘s energy demand under uncertain conditions can be computed



A Powerful Use- Case:
Probabilistic Supply Models



A Powerful Use- Case:
Probabilistic Supply Models



Statistical Data (for example time series) available

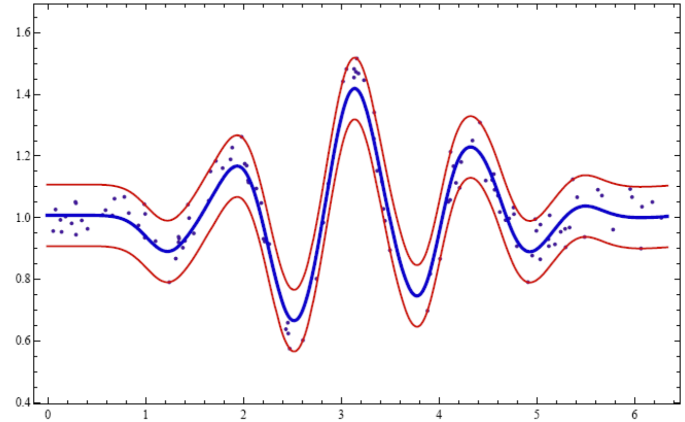
(Regression-) Models can be found, that are able to forecast supply from renewables

But: forecasts are inaccurate due to intermittent nature of wind or solar irradiation

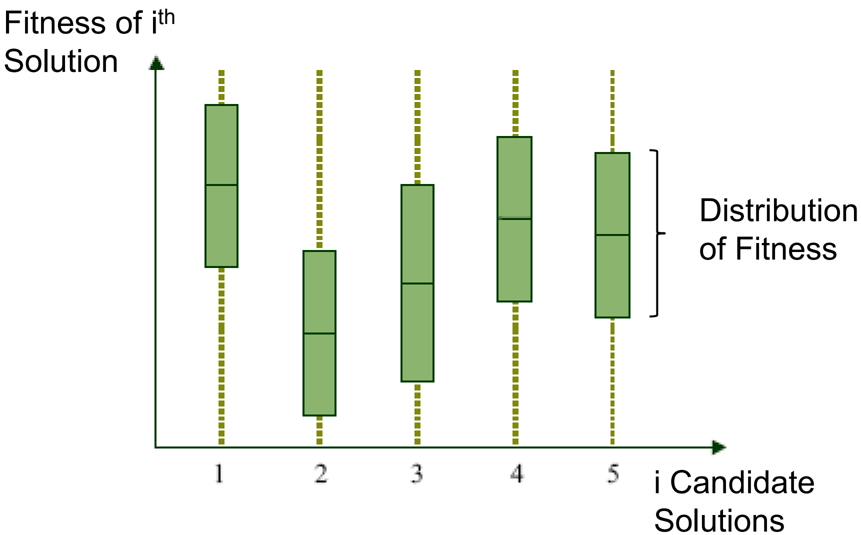
Uncertainty can be handled by defining a confidence interval around the regression- model

Forecasted value represents the mean of a probability distribution

Standard deviation can be estimated by applying model to test data



A Powerful Use- Case:
Simulation- Based Sampling

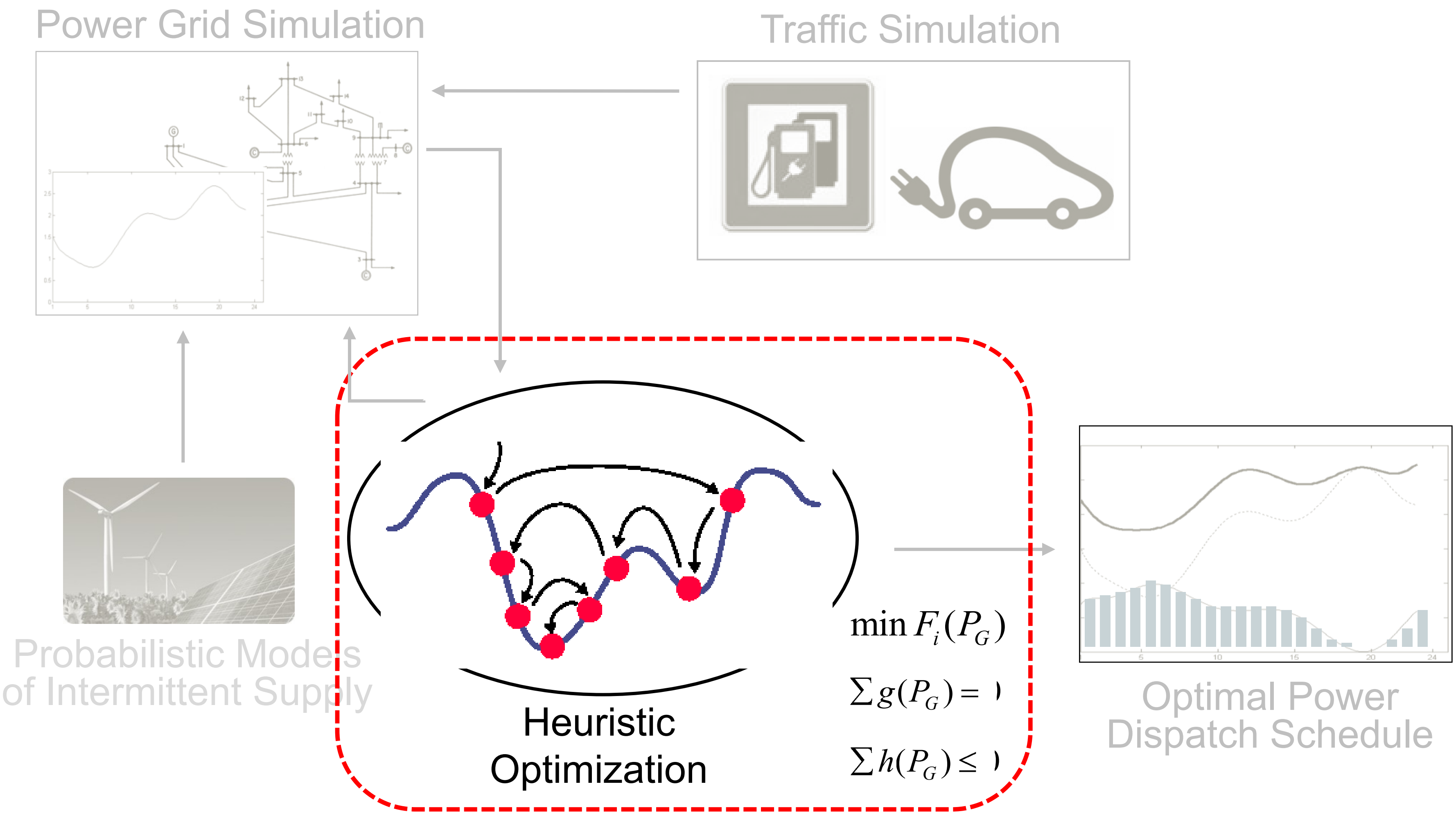


Fitness of a candidate solution has to be averaged over N random samples:

$$F_i = \frac{1}{N}\sum_{n=}^{N}$$

- Samples are drawn from both traffic simulation as well as probabilistic supply model
- For each sample:
  - satisfaction of constraints is evaluated through power grid simulation
  - resulting Fitness is computed

A Powerful Use- Case:
Planning With Uncertainty



A Powerful Use- Case:
Heuristic Optimization

Control Variables: Power that can be spent for battery charging in discrete time- steps j=1…24 (over the day), forming a schedule

Objective: Maximize consumer satisfaction → minimize # uncharged vehicles after simulation period (day)

$$\min \sum_{j=}^{24}$$

Eavg… Average Energy/EV
nEVU… # uncharged EVs

Constraints: Violation of system constraints for candidate solution c_i is measured through simulation and added as penalty term

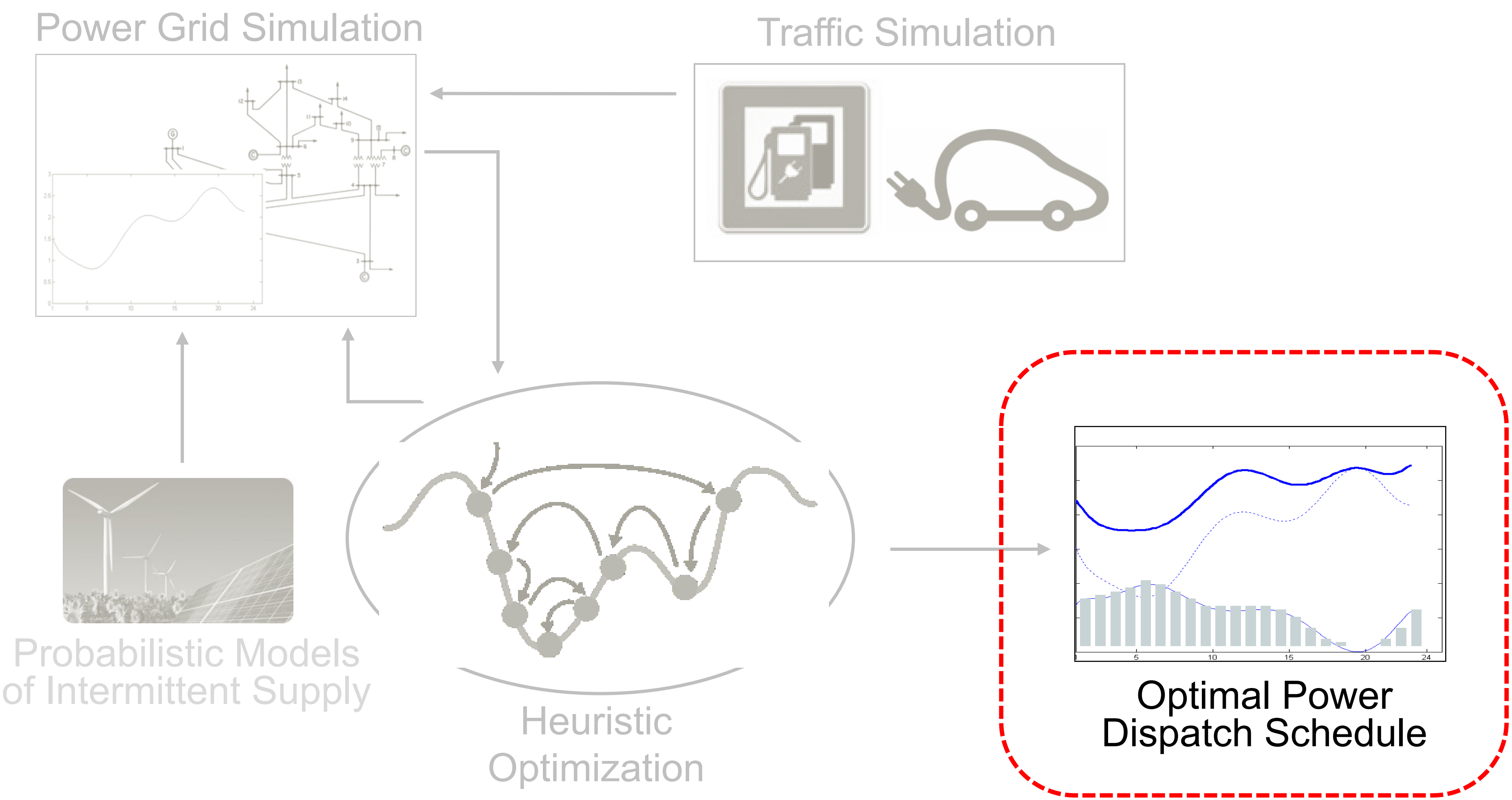
Resulting Fitness of i^th candidate is averaged over random n samples

For each sample, the resulting Fitness is computed:

$$\min[\sum_{j=}^{24}$$

P… penalty: degree of constraint violation (squared error)

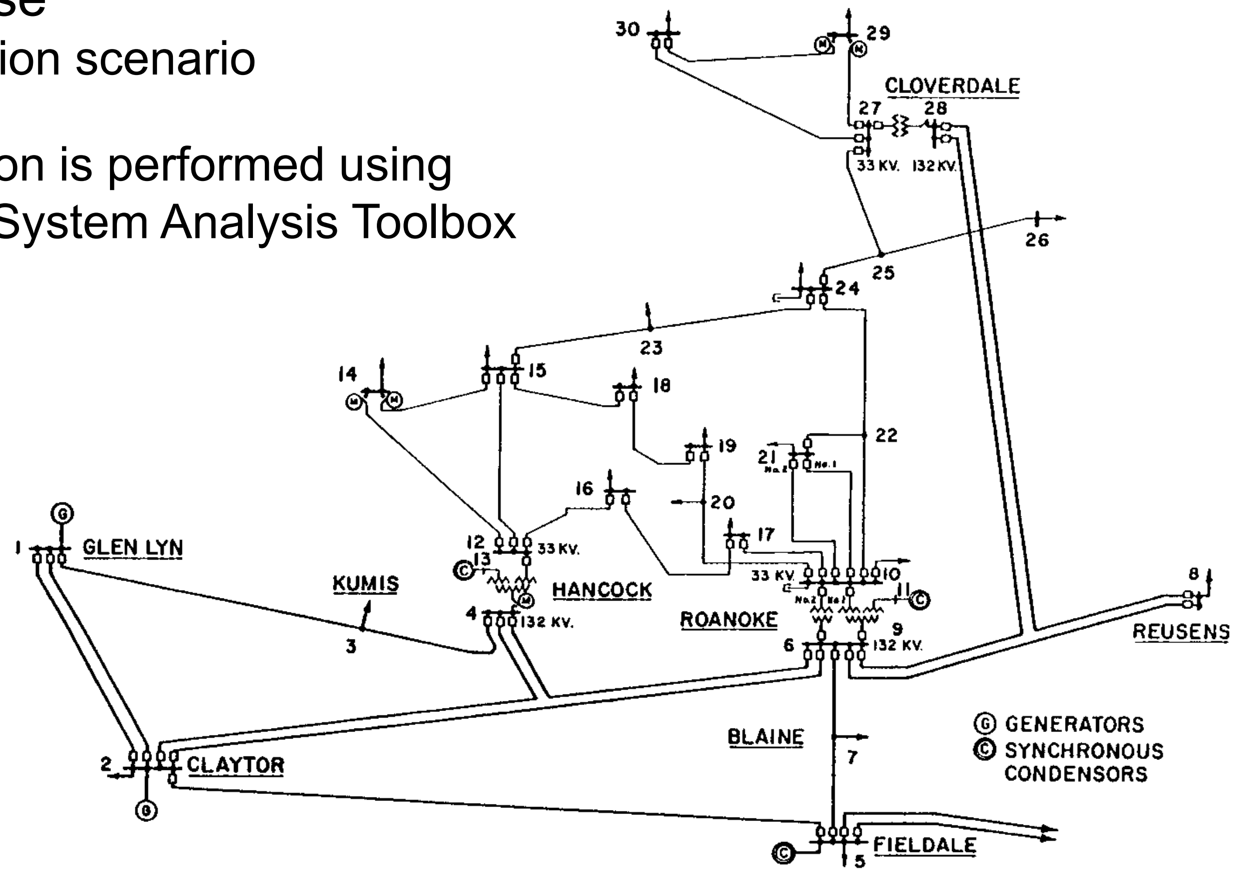
A Powerful Use- Case:
Experimental Results



A Powerful Use- Case
Experiments: The Model

IEEE 30 Bus
Power Flow Testcase
As practical optimization scenario

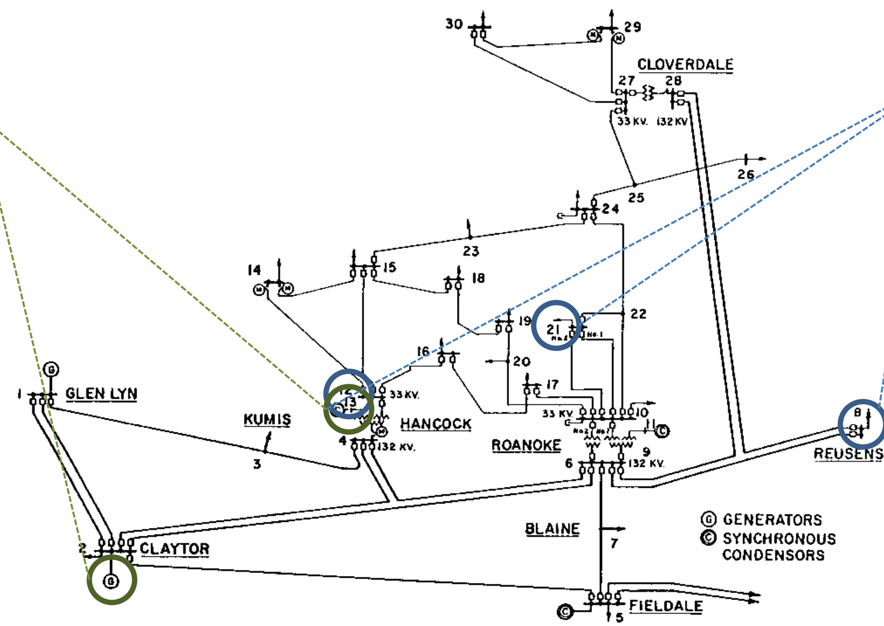
Power Flow Calculation is performed using Open Source Power System Analysis Toolbox (**PSAT**)



A Powerful Use- Case
Experiments: The Model

IEEE 30 Bus Test Case

Renewable Energy
probabilistic
model of
intermittent supply



E-Mobility
underlying
stochastic
simulation of
individual traffic

Simulation based sampling: each model- configuration is simulated multiple times!

A Powerful Use- Case
Experiments: Optimization Algorithm

Evolution Strategies

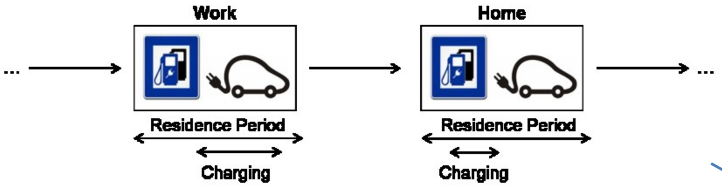
- Well suited for real- valued parameter optimization
- Proven to work well with relatively low population sizes (simulation runtime!)
- Dynamical adaption of mutation step-with (and direction)

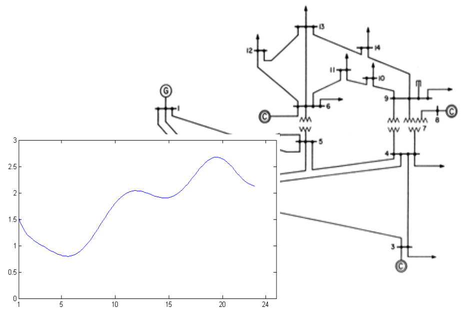
<table>
<tr><th>Experiment 1</th><th>Experiment 2</th><th>Experiment 3</th></tr>
<tr><td>(1+1) ES</td><td>(2+4) ES</td><td>(4+4) ES</td></tr>
<tr><td>Parents per Child: 1</td><td>Parents per Child: 2</td><td>Parents per Child: 2</td></tr>
<tr><td colspan="3">Normal All Positions Mutation</td></tr>
<tr><td></td><td colspan="2">Average Crossover</td></tr>
<tr><td colspan="3">Evaluated Solutions: 1000</td></tr>
</table>

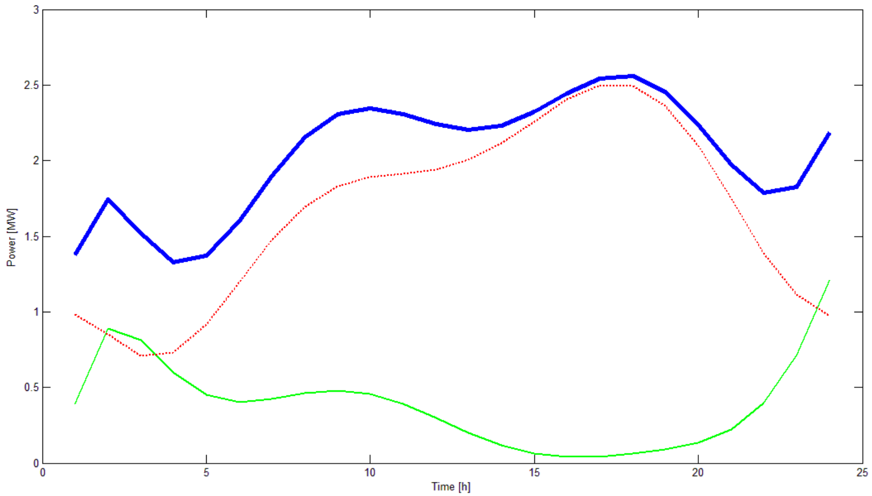
Any arbitrary settings possible!

A Powerful Use- Case:
Experimental Results

Best results (so far) with (2+4) ES:



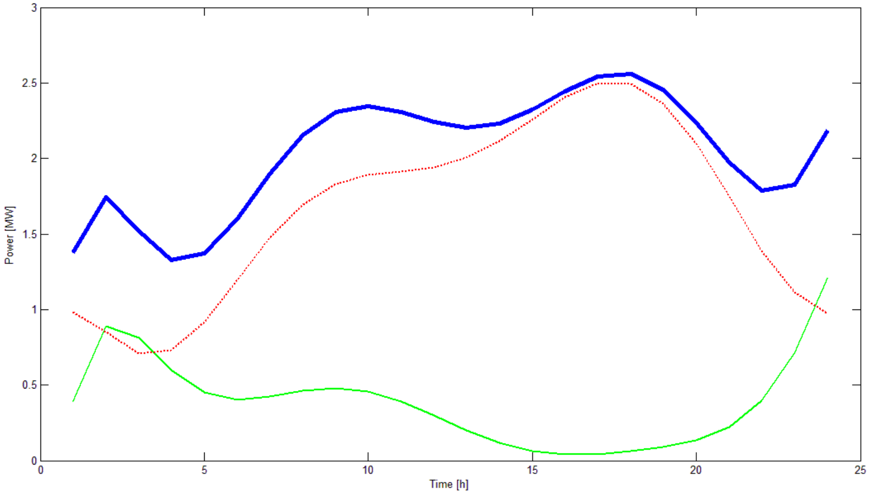




A Powerful Use- Case:
Experimental Results

Best results (so far) with (2+4) ES:

- Probabilistic Influences can be considered using simulation based sampling
- Power- schedules for load- control can be found that consider behaviour of individual traffic
- Satisfaction of power grid constraints is evaluated in PSAT
- Metaheuristics are capable of optimizing highly complex systems



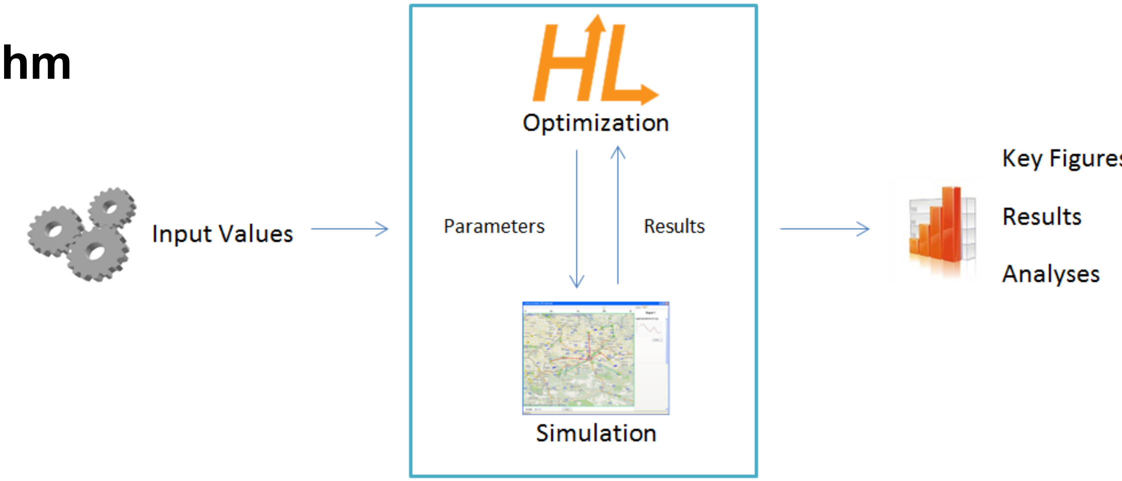
Simulation- Based Optimizaion with HeuristicLab

Parameterized Simulation Model

Metaheuristic Algorithm

Intelligent search in parameter space

Ability of massive parallelization!



Applications:

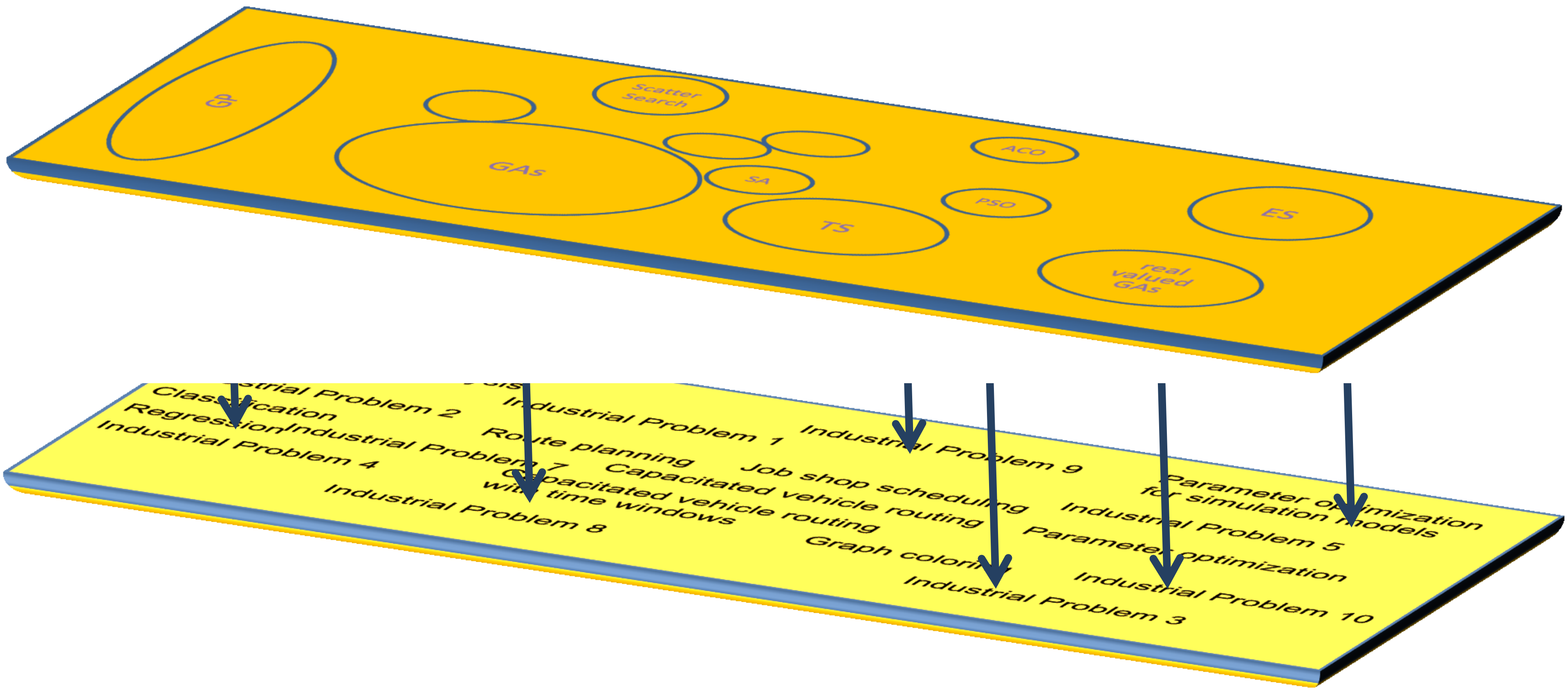
- Objectives (key figures) cannot be calculated directly
- Analysis of different scenarios
- Verification & Visualization

Combinatorial Complexity

Meta-heuristics

- 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
  - Parameterization
  - Hybridization

Metaheuristics: No-Free-Lunch Theorem



Introduction

Motivation and Goals

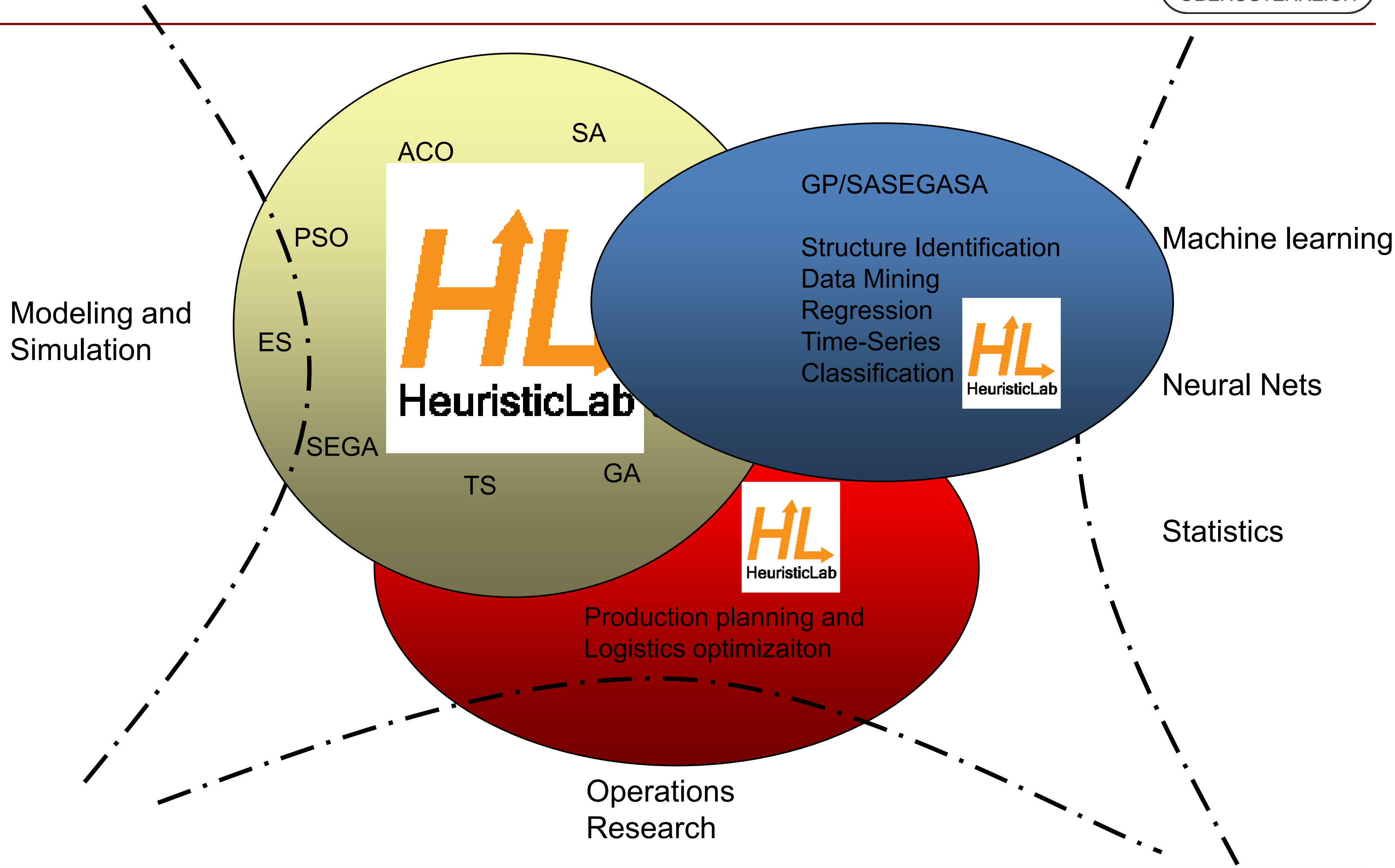
- graphical user interface
- paradigm independence
- multiple algorithms and problems
- large scale experiments and analyses
- Parallelization (core & computer)
- extensibility, flexibility and reusability
- visual and interactive algorithm development
- multiple layers of abstraction

HeuristicLab

Facts

- development of HeuristicLab started in 2002
- based on Microsoft .NET and C#
- used in research and education
- second place at the Microsoft Innovation Award 2009
- open source (GNU General Public License)
- version 3.3.0 released on May 18th, 2010
- latest version 3.3.5 released in June 2011

Metaheuristics



Available Algorithms & Problems

Algorithms

- Genetic Algorithm
- Island Genetic Algorithm
- Offspring Selection Genetic Algorithm
- Island Offspring Selection Genetic Algorithm
- SASEGASA
- Evolution Strategy
- NSGA-II
- Particle Swarm Optimization
- Local Search
- Simulated Annealing
- Tabu Search
- Variable Neighborhood Search
- Linear Regression
- Linear Discriminant Analysis
- Support Vector Machine
- k-Means
- User-defined Algorithm

Problems

- Single-Objective Test Function
- Traveling Salesman Problem
- Quadratic Assignment Problem
- Vehicle Routing Problem
- Scheduling
- Knapsack
- OneMax
- Data Analysis
- Regression
- Symbolic Regression
- Classification
- Symbolic Classification
- Clustering
- Artificial Ant
- External Evaluation Problem
- User-defined Problem

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

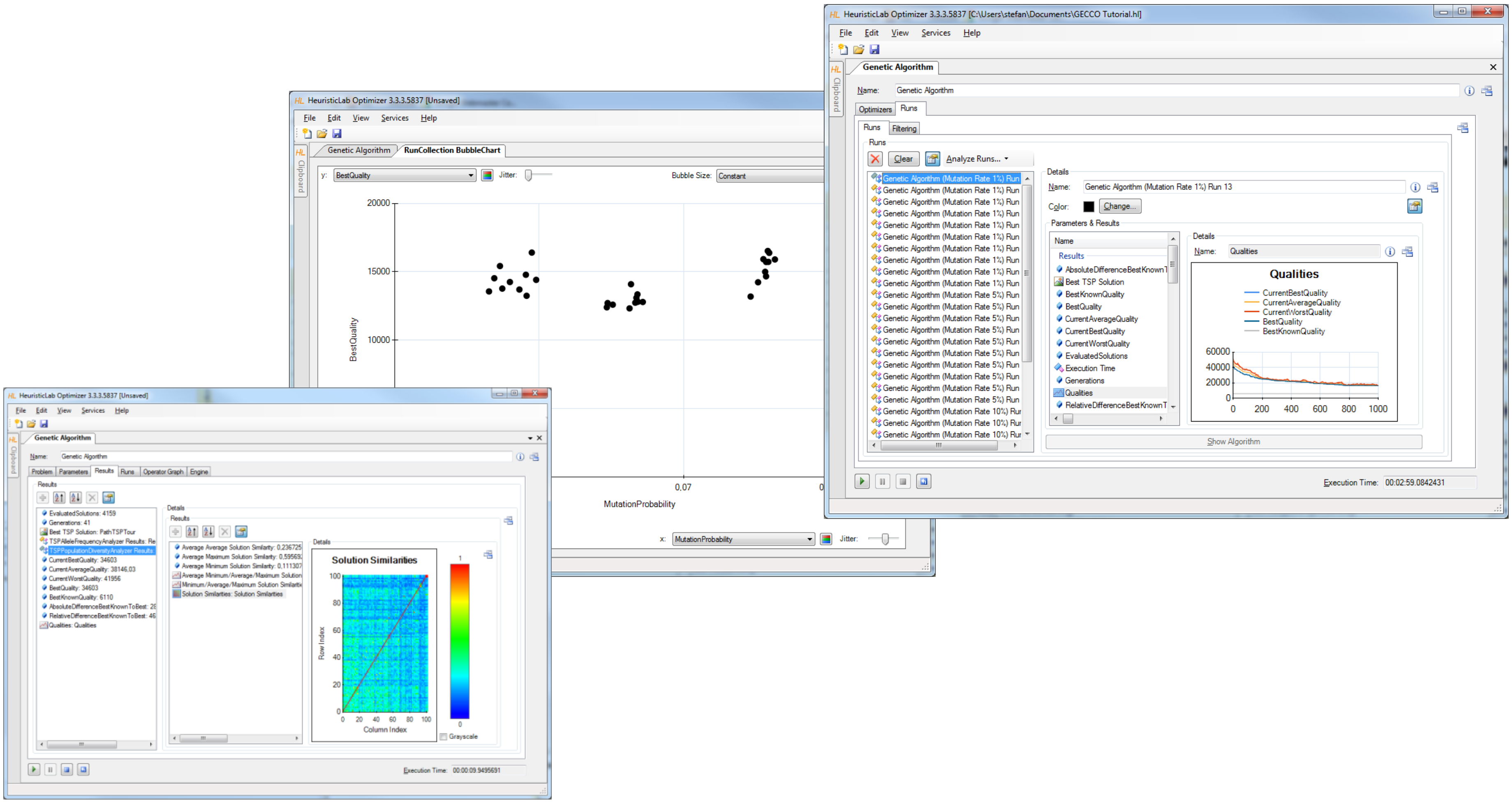
External solution evaluation and simulation-based optimization

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

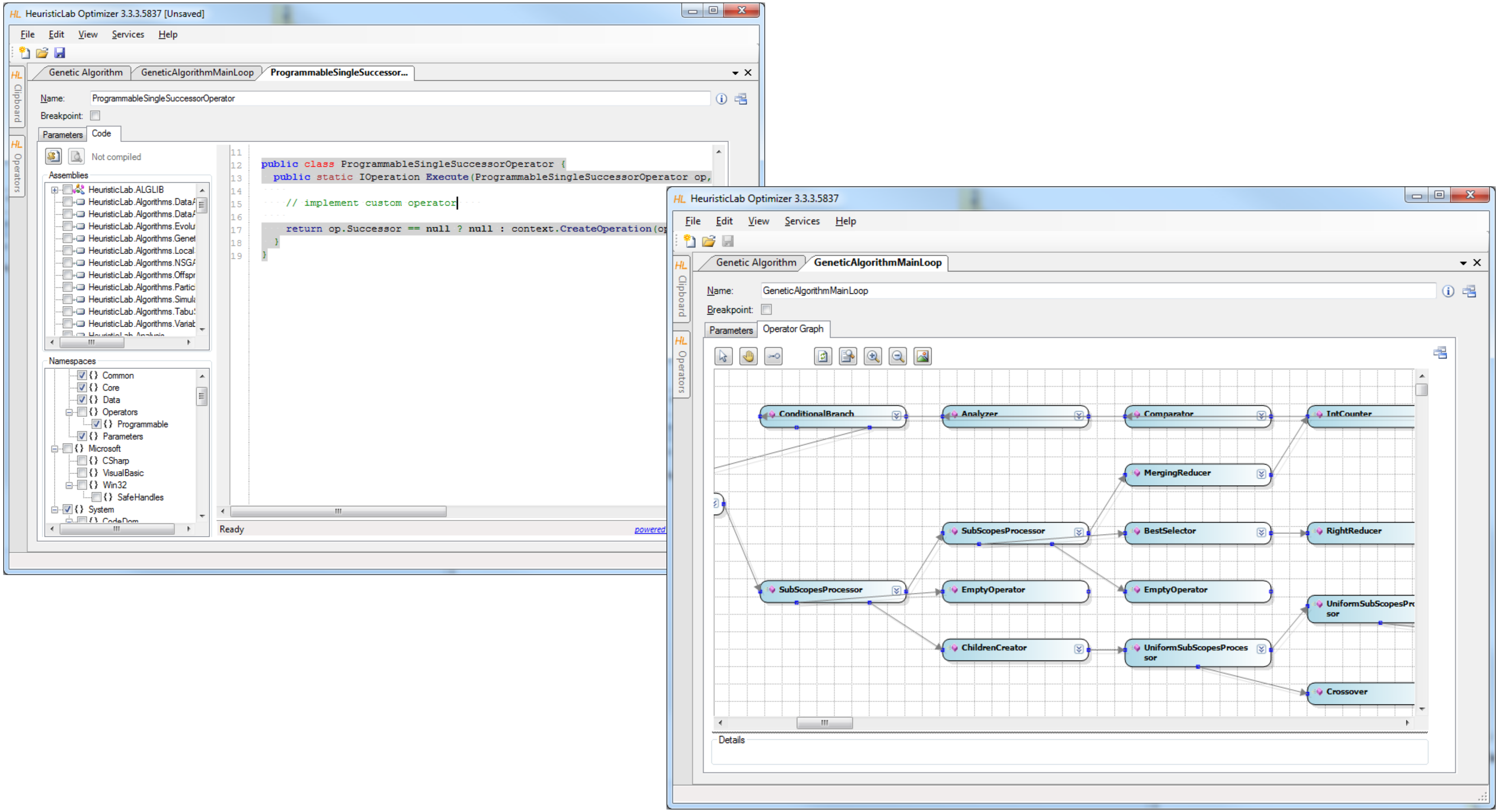
Parameter grid tests and meta-optimization

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

HeuristicLab Experiments: Extensive Analyzation Abilities



HeuristicLab Extendability: Create User- Defined Algorithms



Dataset: Matrix $(x_{i,j})_{i=1..N,\ j=1..K}$

- N observations of K input variables
- $x_{i,j}$ = i-th observation of j-th variable
- Additionally: Vector of labels $(y_1 \ldots y_N)^T$

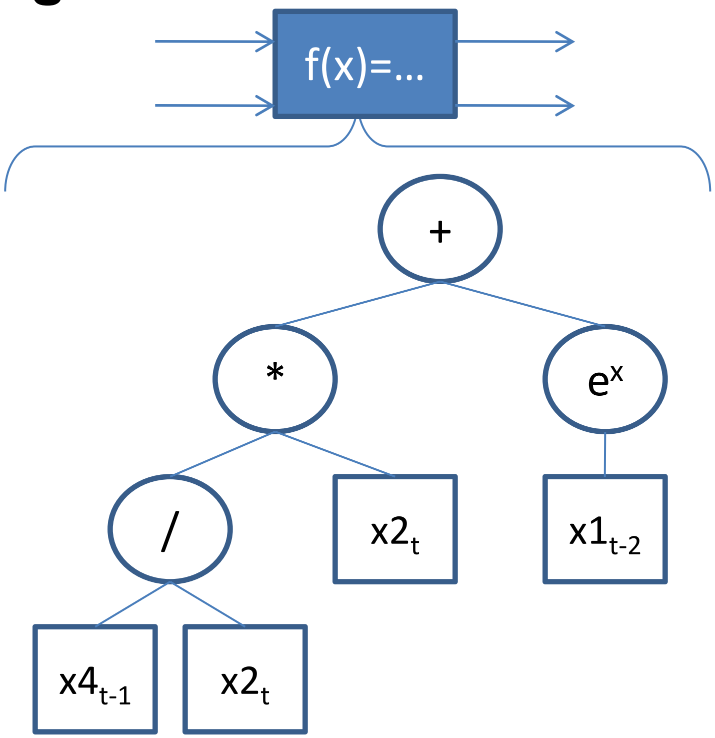
Goal: learn association of input variable values to labels

Common tasks

- Regression (real-valued labels)
- Classification (discrete labels)
- Clustering (no labels, group similar observations)

Data-based Modeling Algorithms in HeuristicLab

Symbolic regression and classification based on genetic programming



External Libraries:

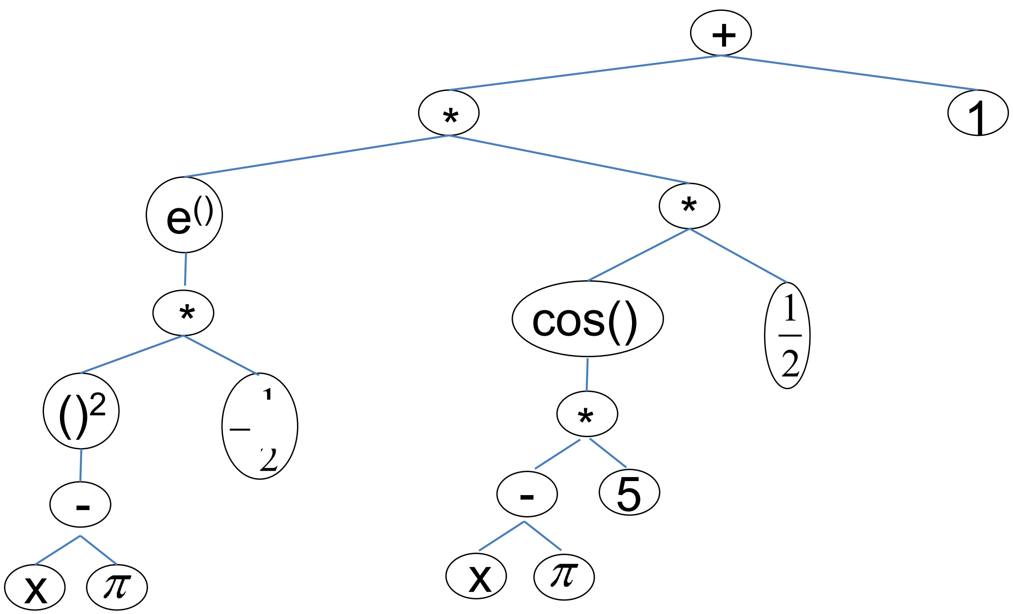
- Support Vector Machines for Regression and Classification
- Linear Regression
- Linear Discriminate Analysis
- K-Means clustering

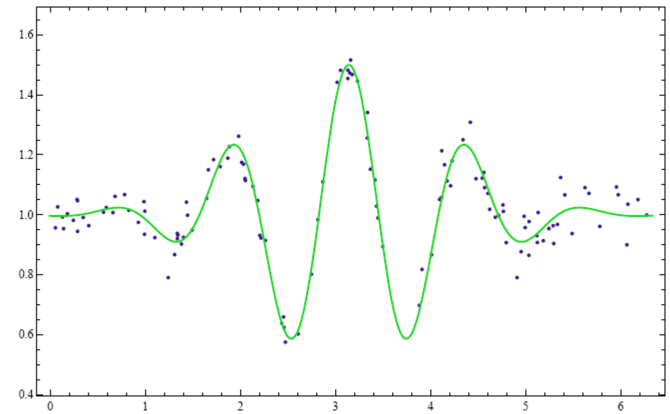
Data-based Modeling

Referring To Short- Term Wind Forecast

Model can be identified by symbolic regression using Genetic Programming

$$f(x) = \quad + \frac{1}{2} \qquad - \qquad -\frac{1}{2} \quad -$$

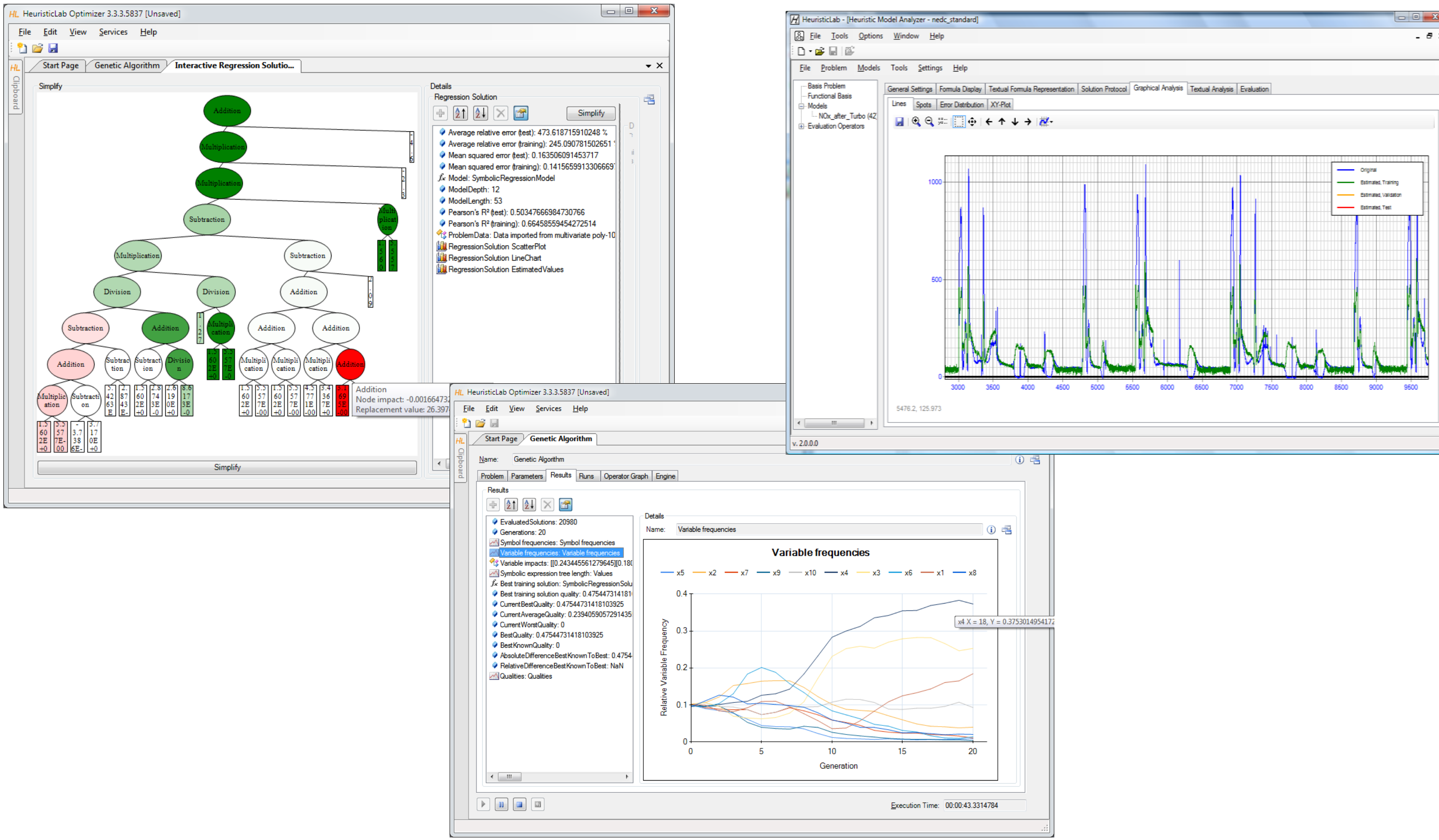




White- Box model is obtained based on historical data

Standard deviation is computed by applying model to test-data

Data-based Modeling
Model Analyzation in HeuristicLab



Contact Information

Stephan Hutterer
Department of Electrical Engineering
School of Engineering/Environmental Sciences
Upper Austria University of Applied Sciences

stephan.hutterer@fh-wels.at

Heuristic and Evolutionary Algorithms Laboratory (HEAL)
School of Informatics, Communications and Media
Upper Austria University of Applied Sciences

support@heuristiclab.com
http://heal.heuristiclab.com & http://dev.heuristiclab.com