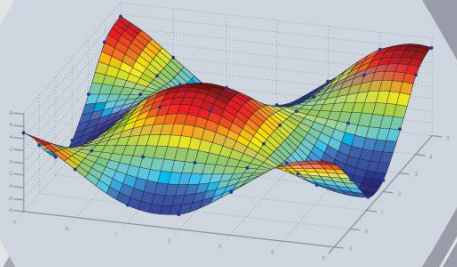
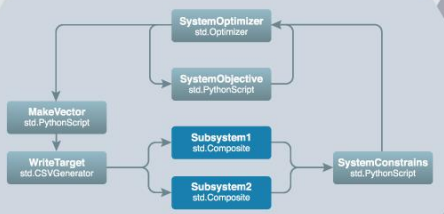
DESIGN SPACE EXPLORATION FOR EVERY EXPERTISE

pSeven





Confused with algorithm selection during Design Space Exploration?

Laurent Chec,
General Director
DATADVANCE SAS

June, 2017

NAFEMS World Congress 2017 | 11-14 June | Stockholm

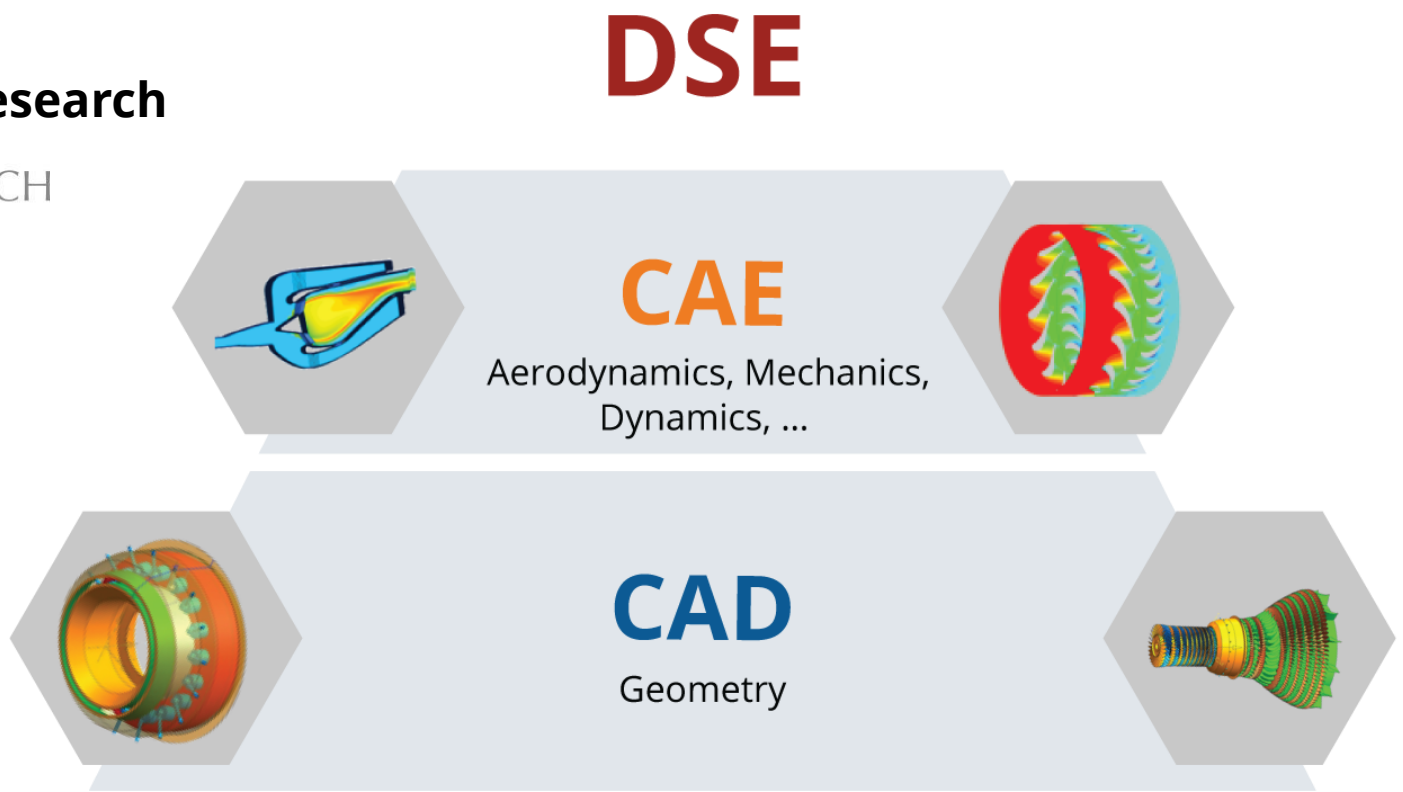
DATADVANCE

What is Design Space Exploration?

“Design Space Exploration is both a class of quantitative methods and a category of software tools for **systematically and automatically** exploring very large numbers of design alternatives and identifying **optimal** performance parameters. »

B. Jenkins, Ora Research

Ora RESEARCH



pSeven - Complete Toolkit for DSE

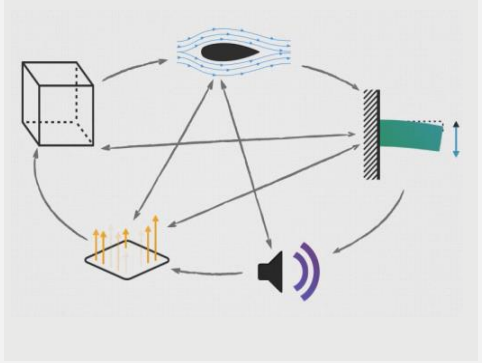
pSeven contains 7 tools for Design Space Exploration:

- **Optimization** (multidisciplinary, robust)
- Design of Experiments
- **Approximation** (a.k.a. surrogate modeling, metamodels, RSM models etc.)
- Data Fusion (for surrogate modeling)
- Sensitivity & Dependency Analysis
- Dimension Reduction
- Uncertainty Quantification (OpenTURNS library)

All of the tools (except UQ) were developed **in-house** at the same time that makes them **homogeneous** and **highly interconnected**

pSeven Components

Process Automation and Integration

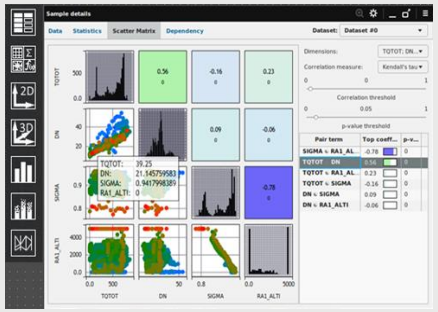


Powerful Workflow Execution Engine

pSeven Core

Efficient Data Analysis and Optimization

Data Analysis and Visualization



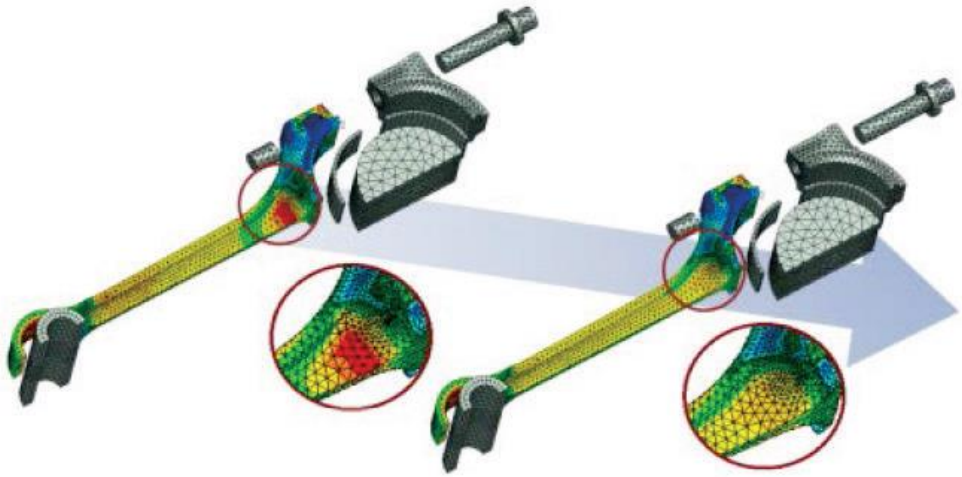
pSeven Platform

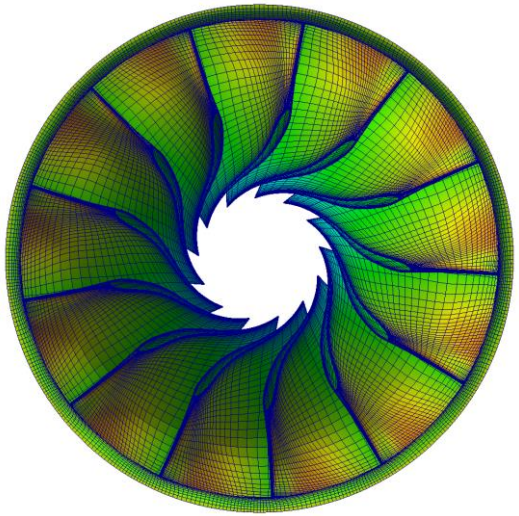
Design Optimization

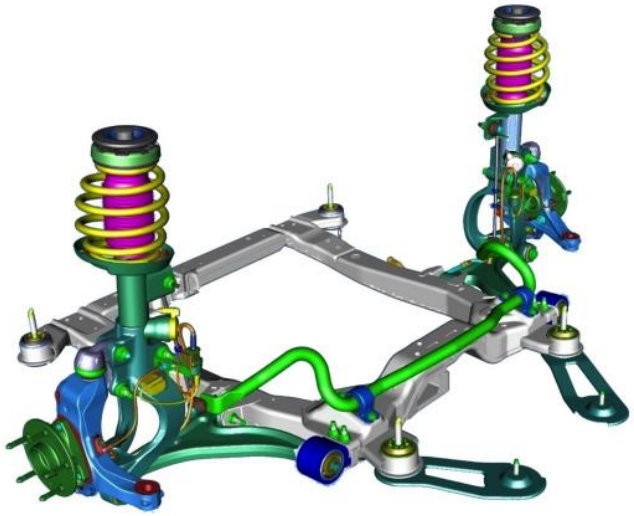
Which product design parameters are the **best**?

How to **improve** product characteristics?

How to decrease effect of parameters **variability** on overall product **behavior**?

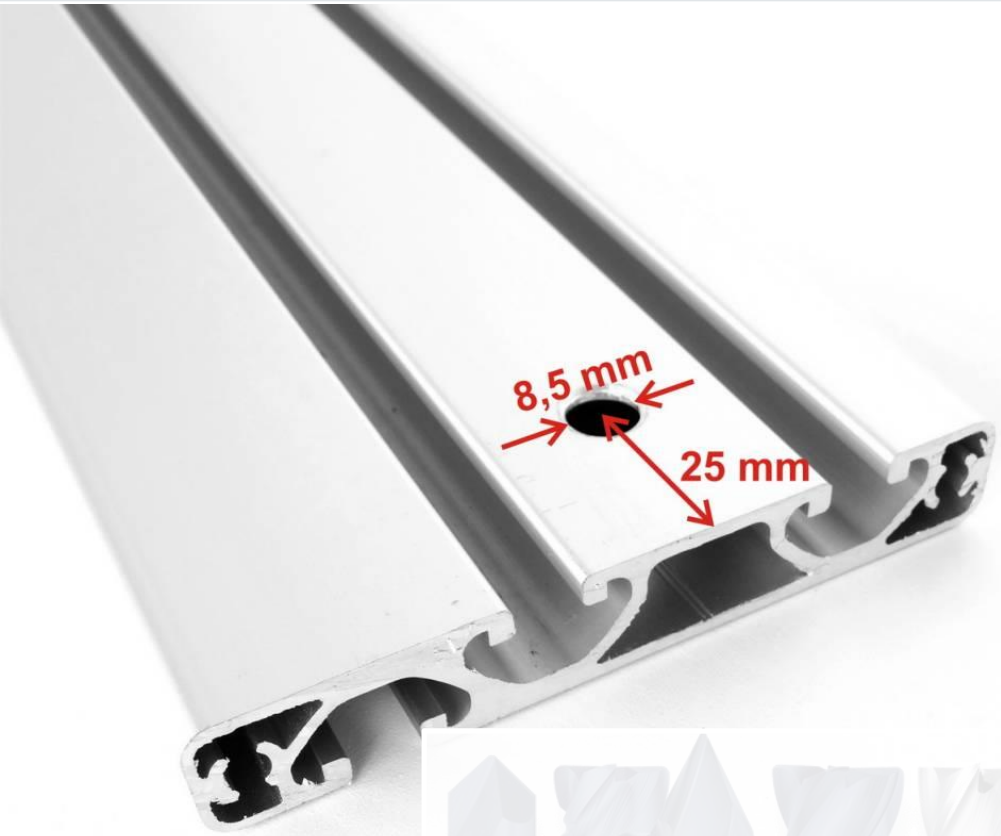






Design optimization helps engineers to answer these questions.

Challenge : Choice of best optimization strategy



?

←SmartSelection

Optimization in pSeven

Optimization problem statement → **Hints setup** → **SmartSelection chooses algorithm** → **Solution**

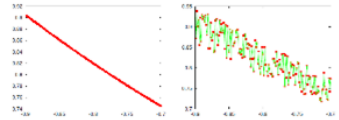
- Single-objective
- Multi-objective
- Multidisciplinary
- Robust-based
- Reliability-based

$$\min_{\vec{x}} \vec{F}(\vec{x})$$

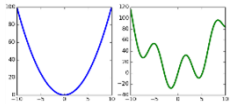
$$\vec{x}_0 \le \vec{x} \le \vec{x}_1$$

$$\vec{C}_0 \le \vec{C}(\vec{x}) \le \vec{C}_1$$

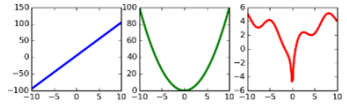
- Noisy



- Multi-extremal



- Linearity type



- Computational time

- **pSeven includes full set of optimization algorithms:**
  - QN – Single or Multi-Objective Quasi-Newton
  - QP – Quadratic Programming
  - SQP – Sequential QP with Filter
  - SQCQP – Quadratically Constrained SQP
  - RDO - Robust Design Optimization
  - SBO – Surrogate-Based Optimization
  - …and other local, governing and global algorithms

16 Algorithms

Single- and Multi-Objective Optimization

Single-objective algorithms:

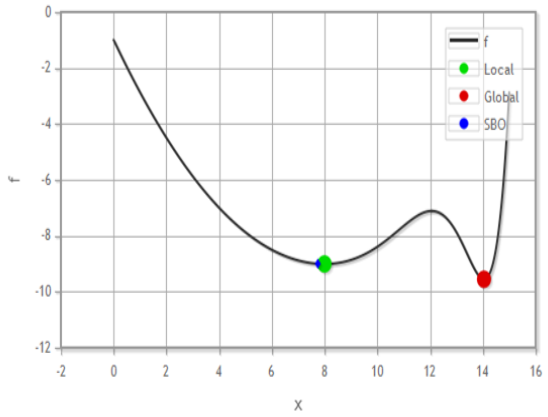
- Most of them originally implemented and specifically tuned for engineering problems

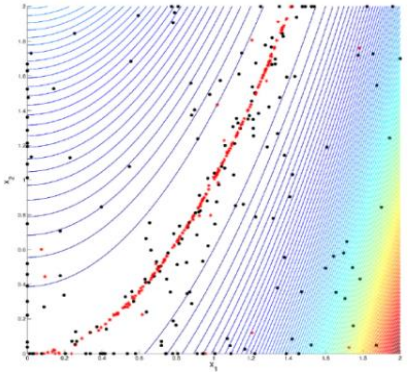
Multi-objective algorithms:

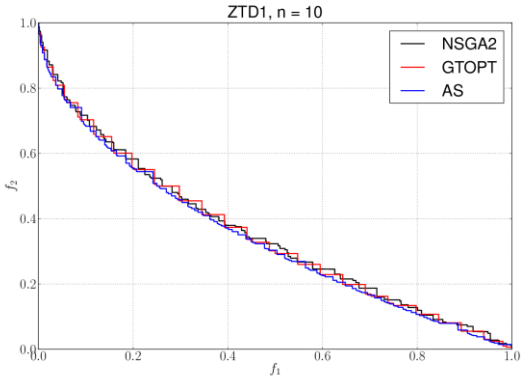
- Avoids evaluations far from Pareto frontier
- Beat genetic algorithms and scalarization techniques on most of the problems

Algorithms features:

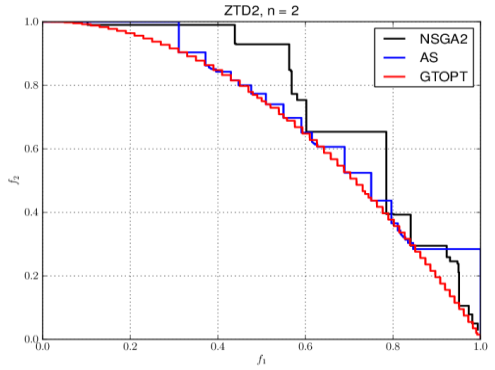
- Run evaluations in parallel
- Unique technology for handling problems with noise
- NaN support: functions have incomputable areas







NSGA-II – 2368 iterations
Adaptive Scalarization – 3765 iterations
GTOpt – 488 iterations



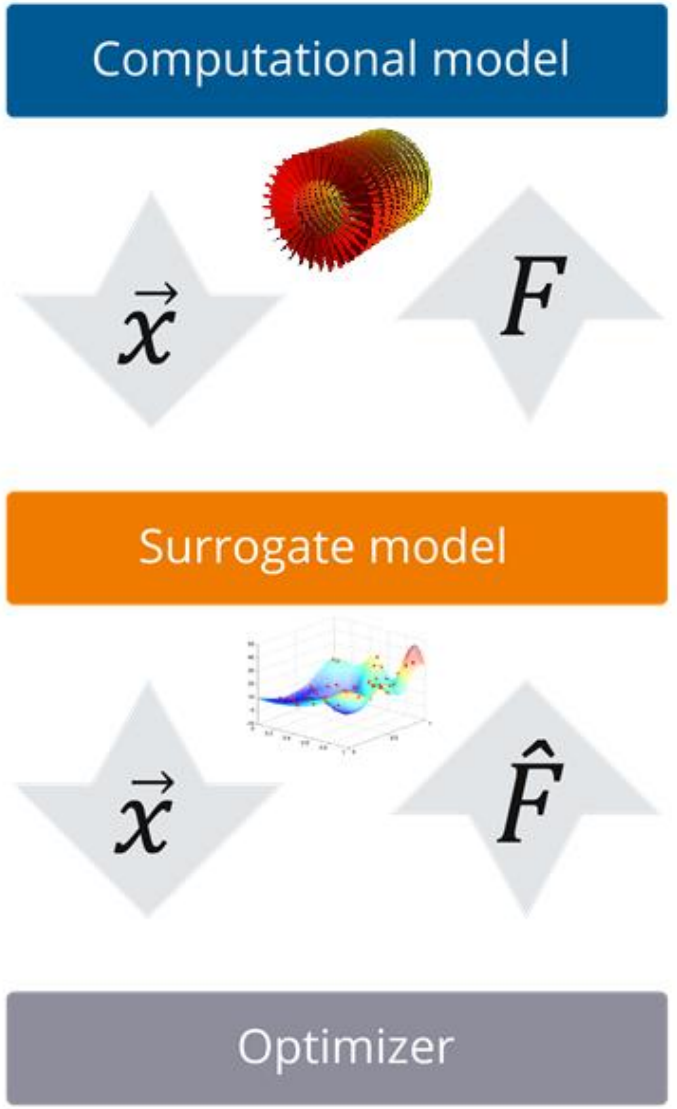
NSGA-II, Adaptive Scalarization,
GTOpt – 280 iterations each

Surrogate-Based Optimization (SBO)

Surrogate-Based Optimization (SBO) is a class of optimization algorithms involving constructing and optimizing surrogate models as auxiliary steps.

Features:

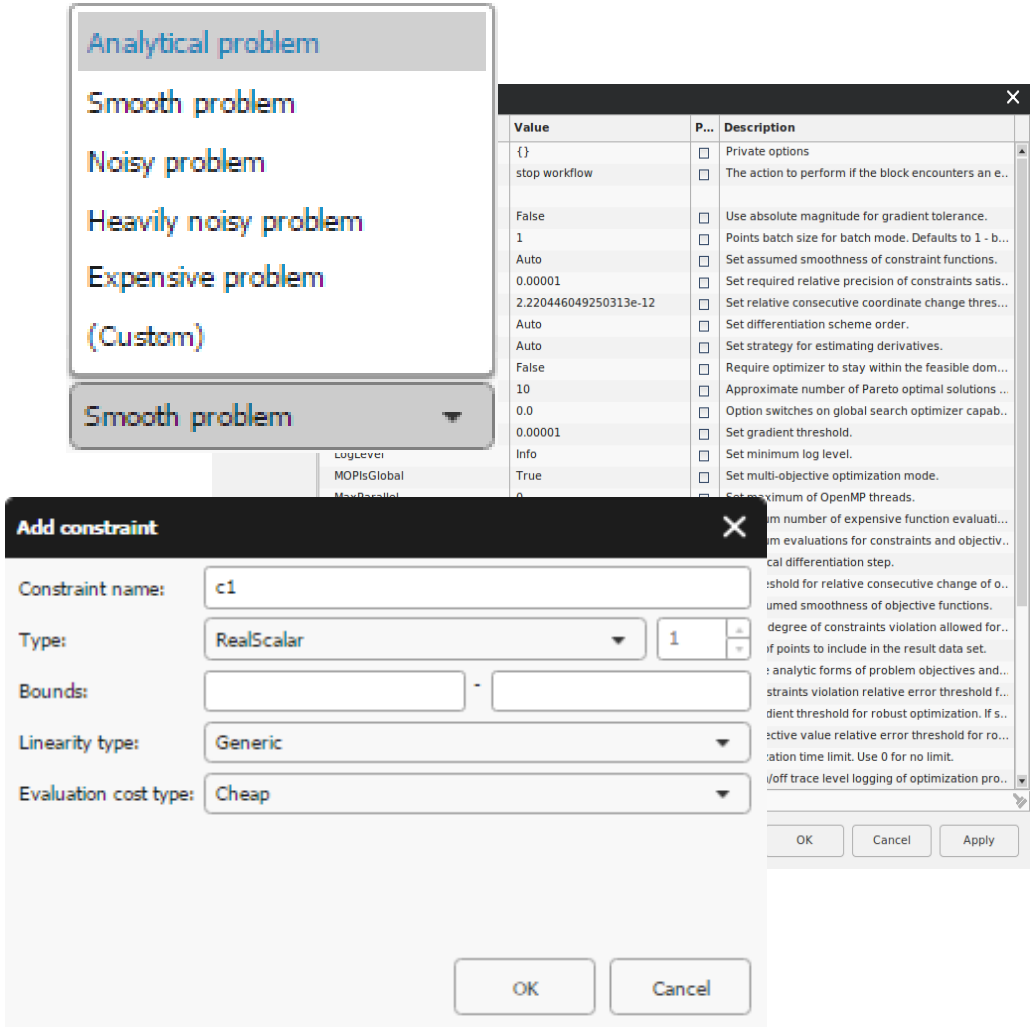
- Intelligently spends evaluations budget
- Allows to effectively solve large scale problems (up to 100 design variables) based on unique implementation of multi-resolution GP.
- In-house developed DoE strategy, which respects as much feasibility domain of the problem as possible
- Single slider regulates the complexity of applied global methods



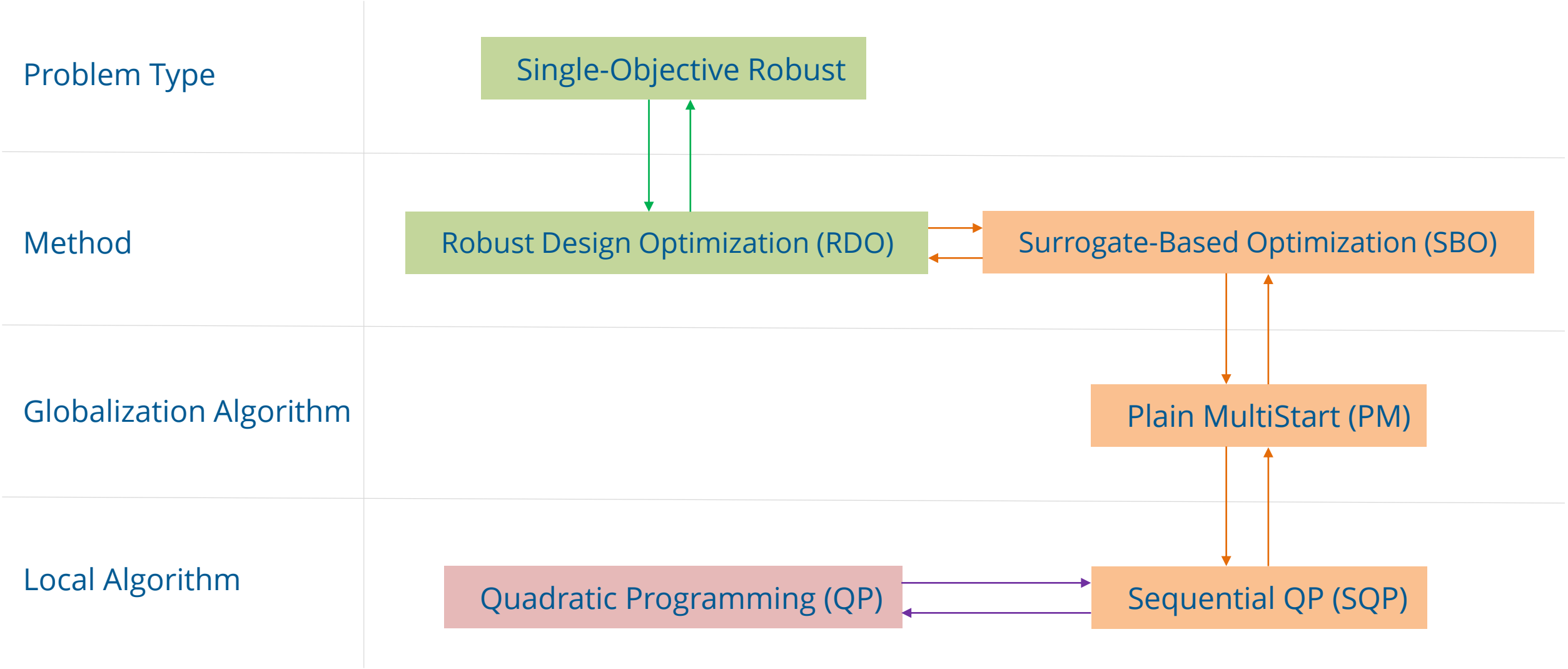
Optimization Configuration in pSeven

pSeven doesn't require knowledge of a specific optimization algorithm and its settings from user:

- **Set of options and hints** helps user to describe problem and desired solution from his point of view, not from the algorithmic point of view:
  - Hints for variables and responses: expensive/cheap, linear/quadratic/generic.
  - Options presets: analytical problem, smooth problem, noisy problem, heavily noisy problem, expensive problem.
  - High-level options: optimization stop criteria, globalization intensity, number of Pareto points.
- **SmartSelection** technology chooses the optimal algorithm automatically based on hints, options and optimization behavior.



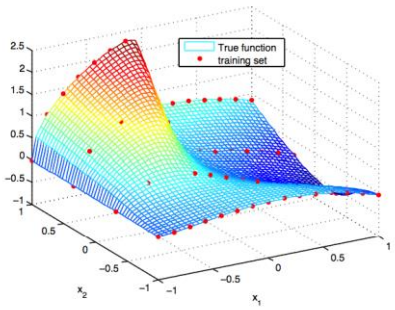
pSeven Adaptive Optimization Example

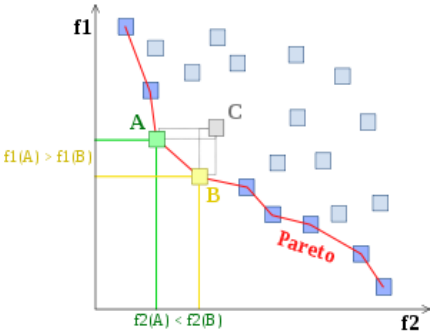


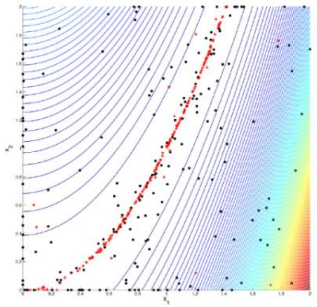
Design Optimization Made Easy

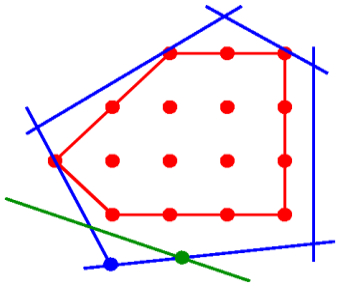
pSeven provides easy and effective solution for most of industry optimization problems:

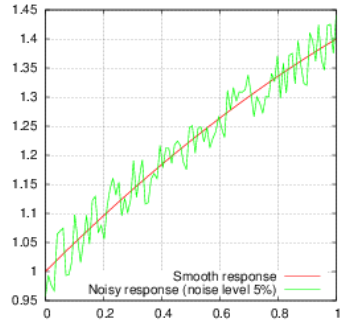
- Problem statement: single- or multi-objective, multidisciplinary, robust- or reliability-based
- Large dimensionality
- Continuous and/or discrete input parameters
- Nonlinear, multimodal or noisy objective functions and constraints
- Presence of implicit constraints (domains of undefined behavior)
- Presence of uncertainties
- Long calculation time











Approximation Models

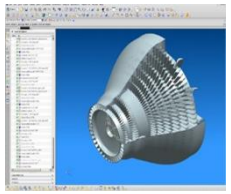
Approximation models are the **substitution** ("blackbox") of existing **data** and **simulation** models.

- **Predict** response function values for new designs
- **Accelerate** computation of complex simulation models by many orders of magnitude
- Use fast surrogate models in **parametric and optimization** studies
- **Capture** essential knowledge from vast amounts of data
- Easily and safely **exchange** surrogate models between partners preserving IP rights

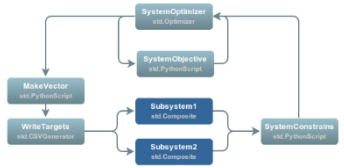
Mach number
Reynolds
The angles of attack slip
x, p, f, h ….

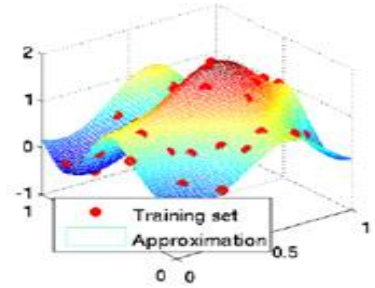
$$\text{minimize: } \begin{cases} -\sqrt{\eta_{HPT}(\mathbf{p}_{HPT}) \cdot \eta_{LPT}(\mathbf{p}_{LPT}, r(\mathbf{p}_{HPT}))}, \\ m_{LPT}(\mathbf{p}_{LPT}, r(\mathbf{p}_{HPT})), \end{cases}$$

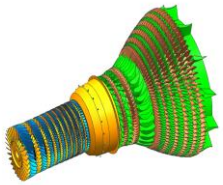
$$\text{w.r.t.: } \mathbf{p}_{HPT}, \mathbf{p}_{LPT},$$
$$\text{s.t.: } \mathbf{p}^L_{HPT} \le \mathbf{p}_{HPT} \le \mathbf{p}^U_{HPT},$$
$$\mathbf{p}^L_{LPT} \le \mathbf{p}_{LPT} \le \mathbf{p}^U_{LPT}.$$



Inputs X → Mathematical model (differential equations) → Output Y







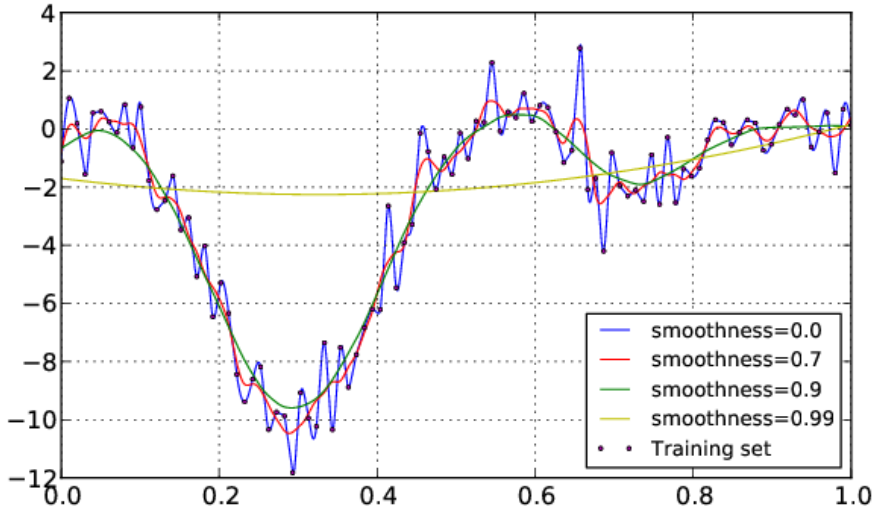
Inputs → Approximation model → Output prediction

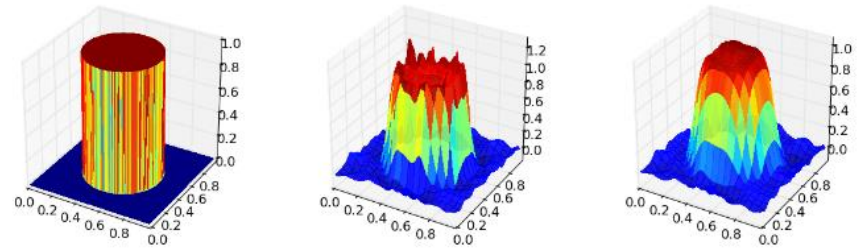
Approximation in pSeven

Data can be very different in dimensionality, size and noisiness. Modeling may also require additional pre-and post-processing to collect data and assess the results.

pSeven is a **«Swiss army knife»** for creating approximation models:

- **Data fusion** – construction of models from multi-fidelity data sources
- **Accuracy** and **error** assessment of constructed models
- **Exact fit** and **smoothing**
- Full control of the model construction **time**
- Handling of **missing data** and **discontinuities**
- **Updating** existing models with new data
- **Combining** of models
- **Neutral Export** to C, Octave, FMI, Excel



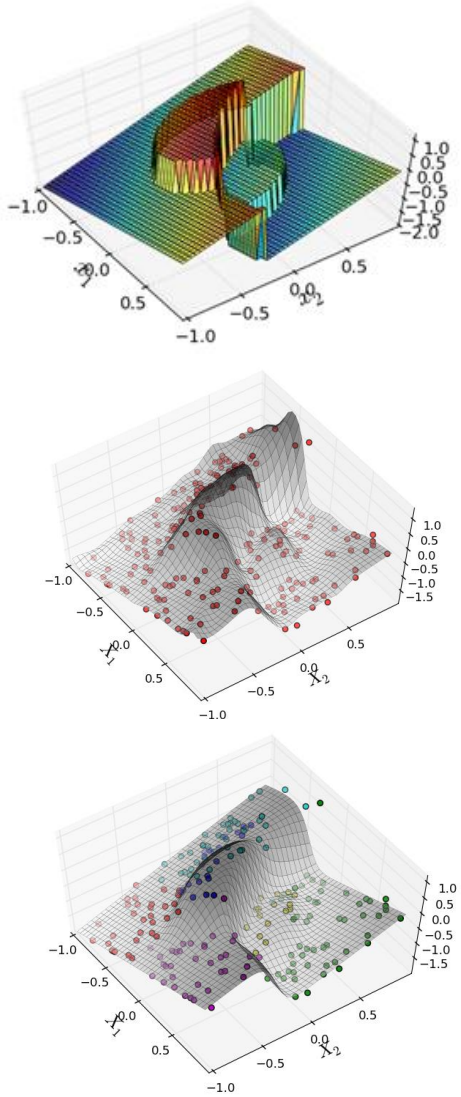


Approximation Techniques in pSeven

pSeven provides industry proven techniques for approximation:

- Piecewise Linear Approximation (PLA)
- 1D Splines with tension (SPLT)
- Response Surface Model (RSM)
- Gaussian Processes (GP)
- Gradient Boosted Regression Trees (GBRT)
- High Dimensional Approximation (HDA)
- Tensor Approximation and Incomplete Tensor Approximation (TA, iTA)
- …and other in-house techniques

13
Techniques



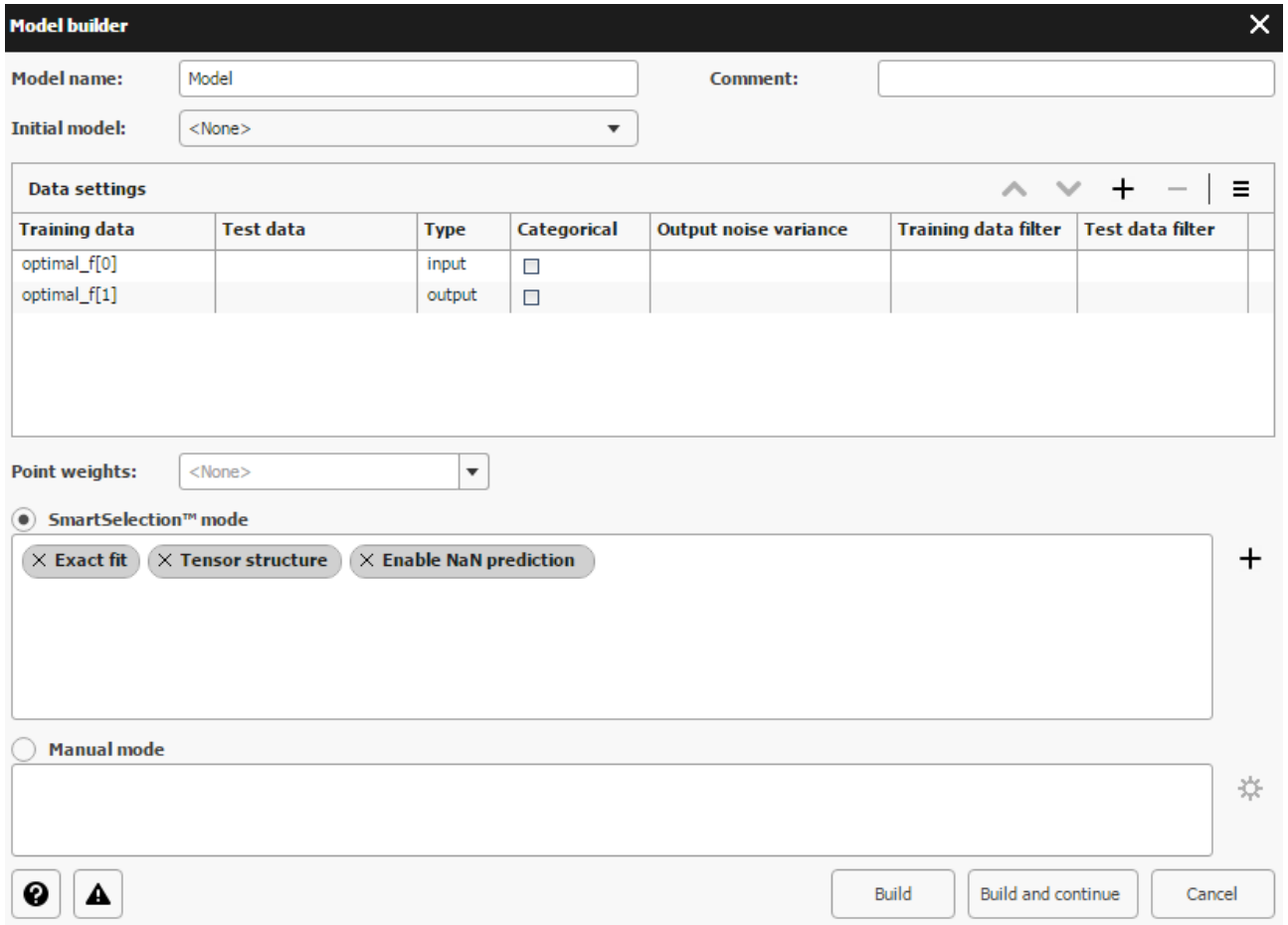
User-Friendly GUI for Creating Approximation Models

pSeven **Model Builder** allows to easily set up approximation model creation**:**

- Select **input** and **output** data series
- Choose **SmartSelection** or **Manual** mode
- Add **hints** about the model (linear, exact fit, etc.)
- **Build** approximation model

After building model **export** it to:

- Excel
- FMI
- C
- DLL
- Executable file



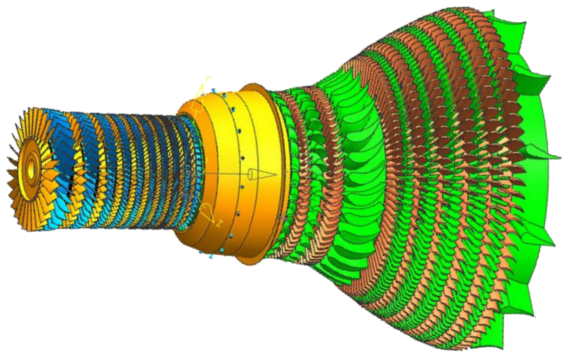
Model Builder in pSeven

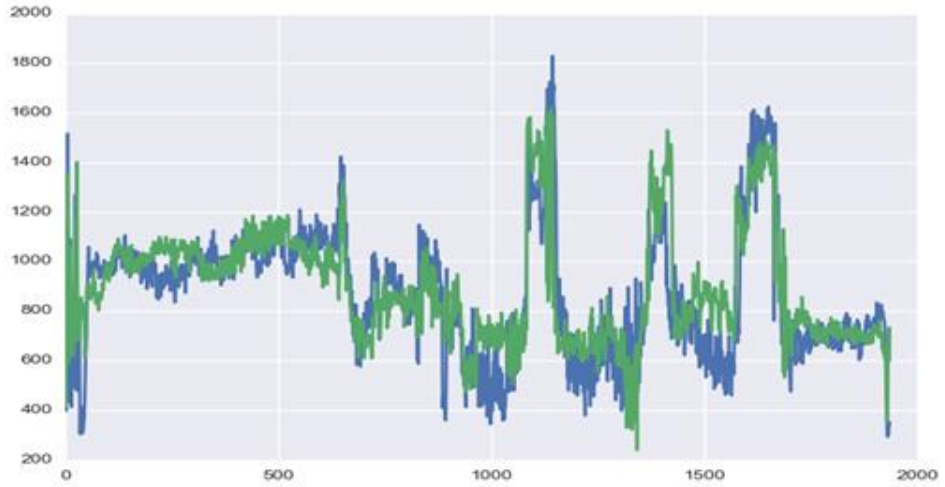
Predictive Modeling

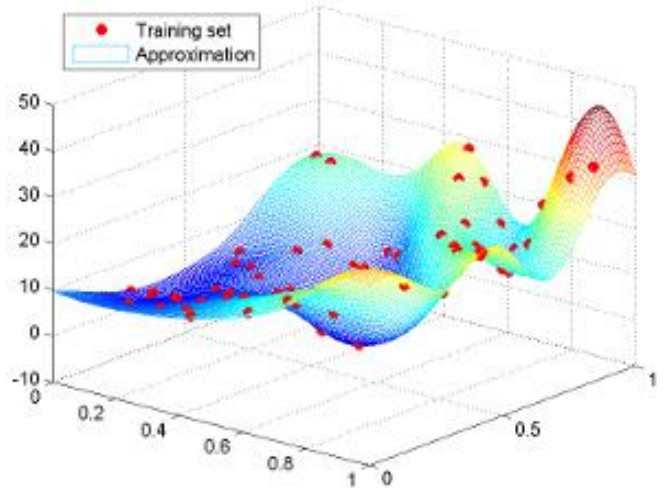
How to **predict** product behavior in various conditions?

How to process **data** from **experiments** and **simulations** together?

How to use huge data samples and simulations **faster**?





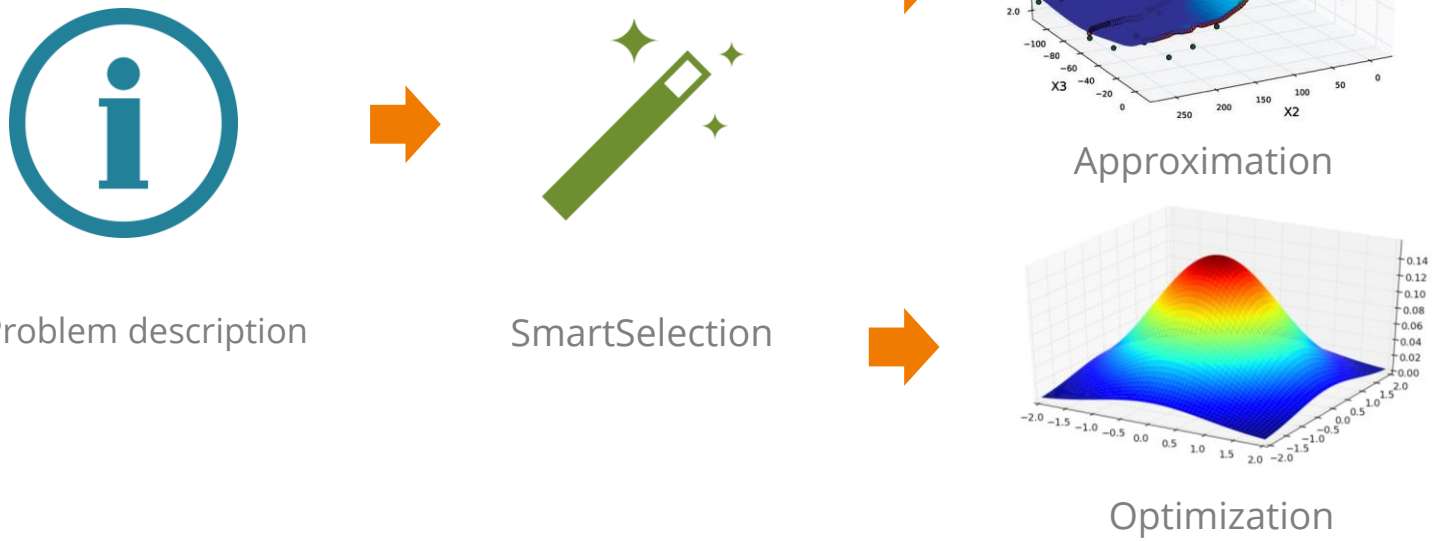


Predictive modeling is based on using approximation models created from available data or simulation.

SmartSelection for Automatic Choosing of Algorithms

pSeven doesn't require knowledge of a specific algorithm or technique and its settings from user:

- **SmartSelection** is available for **optimization** and **approximation**
- **Set of options and hints** helps user to describe problem and desired solution from his point of view, not from the algorithmic point of view
- **SmartSelection** automatically selects the most efficient technique or combination of techniques for a given problem and data, so users can concentrate on the engineering problem itself



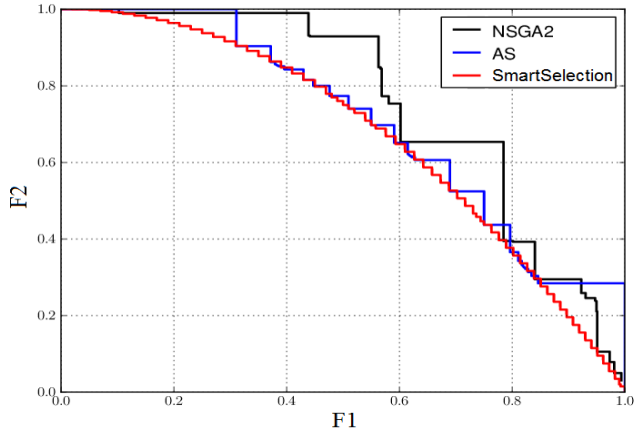
Automatic Choosing of Best-in-Class Algorithms for Optimization and Approximation

Scalable and effective **optimization:**

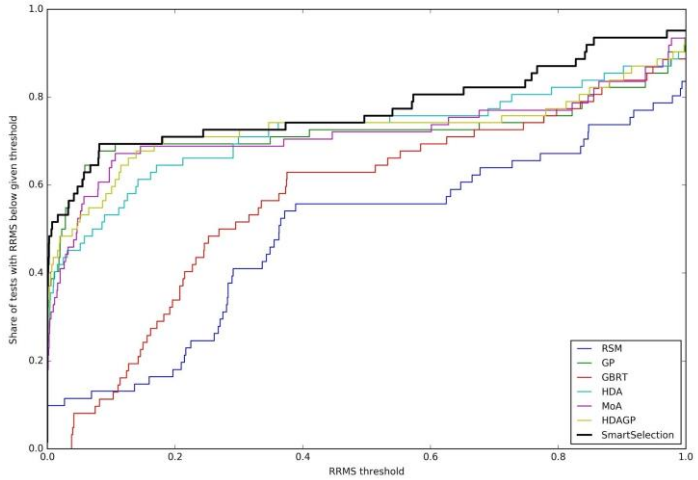
- **Full set** of gradient-based algorithms for any type of problem
- **Multi-objective** surrogate-based optimization (SBO)
- Up to **100 input** parameters for SBO

Flexible and accurate **approximation:**

- **Data Fusion** for building models from **multi-fidelity data**
- Full control over **time**, **accuracy** and **missing data**
- Calculation of **error** and **gradient** for predicted value
- **Re-training** and **combining** of models



pSeven vs. open optimization algorithms accuracy



pSeven vs. open approximation algorithms accuracy

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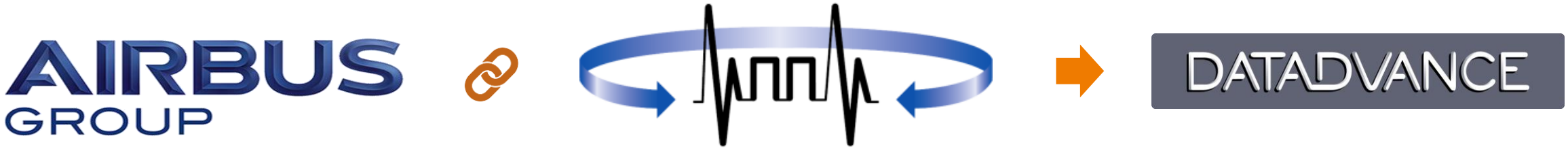
Roots of the Company

Company roots goes to European aviation and Russian mathematics:

- DATADVANCE has been incorporated in 2010 as a result of a collaborative research program by:
  - Airbus Group (formerly EADS) – a global leader in aerospace and defense industry
  - Institute for Information Transmission Problems – one of the leading mathematical centers in Russia with three Fields prize winners on the staff
- More than 200 engineers have been trained at Airbus



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Finance

Life Sciences

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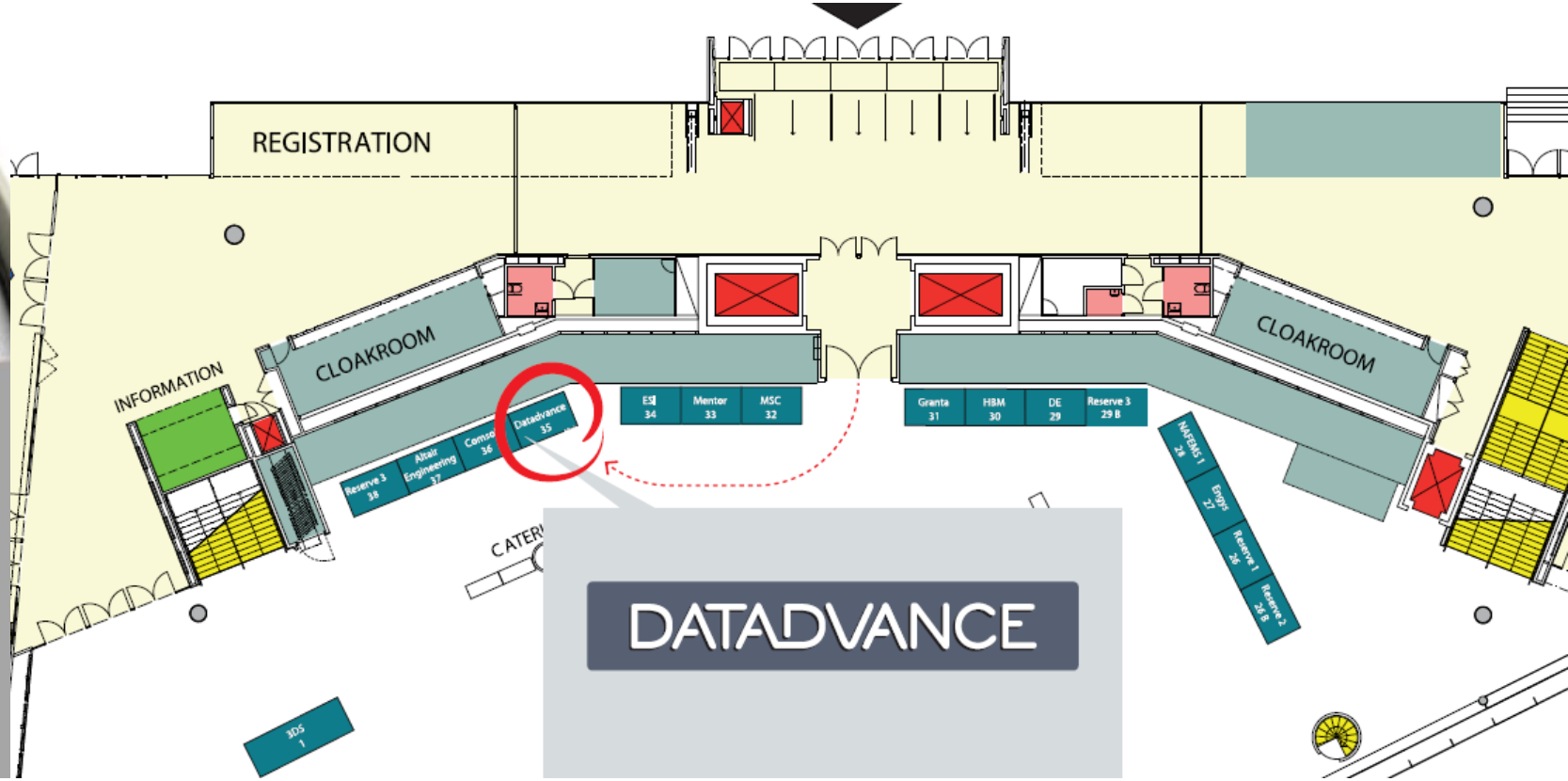

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