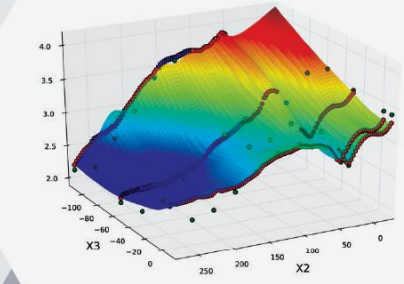
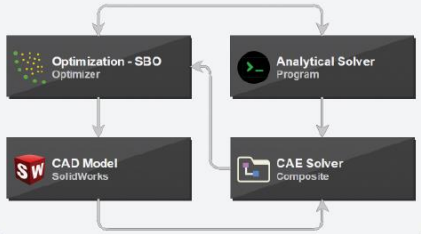
EXPLORE AND OPTIMIZE YOUR DESIGNS

pSeven





pSeven platform

From research in algorithms to large scale industrial applications

DATADVANCE

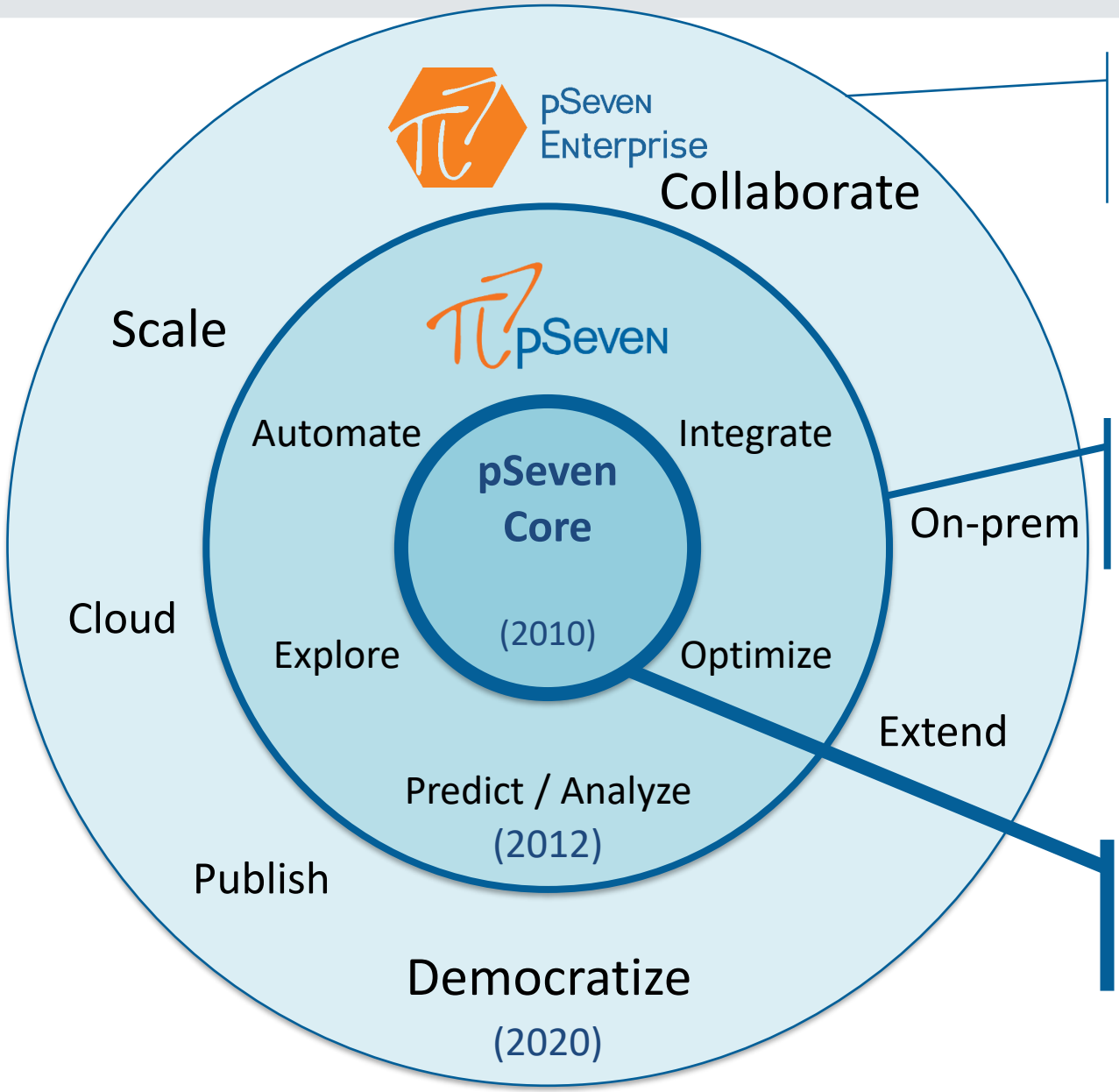
April 2021

DATADVANCE

About DATADVANCE

- We develop a low-code web-based software platform for predictive modeling and optimization.
- We serve customers from industries like aerospace, automotive, energy, marine and offshore and related industries.
- Our roots go to French aviation and Russian mathematics. We evolved out of a joint research program between
  - Airbus – 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
- We were incorporated in 2010.
- We are located at
  - Toulouse, France (HQ and Operations)
  - Moscow, Russia (R&D)
- R&D team of 40+ highly skilled researchers, data scientists, software developers and application engineers, with 8 PhDs among them.
- World-wide sales through a network of Value Added Resellers.

pSeven – 10 years of Innovation



For large corporate deployments, engineers, data scientists, analysts

For every engineer
For every data analyst

For software developers
For advanced engineers
For data scientists

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pSeven Core, pSeven and pSeven Enterprise users

Aerospace

Automotive & Heavy Machinery

Energy & Turbomachinery

Shipbuilding & Offshore

Life Sciences & Other

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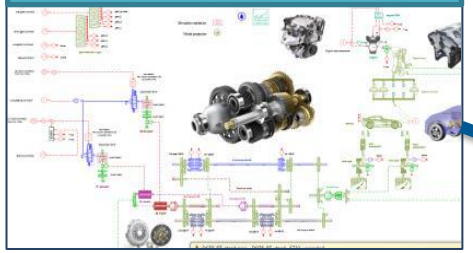
Digital Twin: Set of Simulation and ML Models Associated with Real Equipment

As Design Models in Operation

1D Simulations



Simulate to Predict

Digital Twin

ML to Predict Online

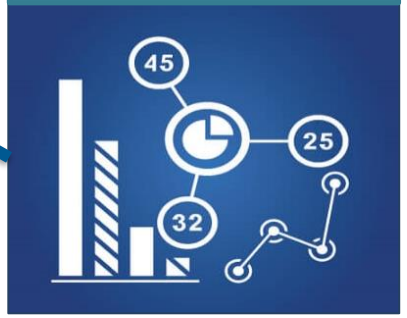
In-Operation Historical Data

Simulate to Enrich Dataset

3D Simulations

ML to get Insights

Online Data



Manufacturing Models

Test Data

As Built/Operated Models In Design

Design

Manufacturing

Operation

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Predictive Model is the Cornerstone of Digital Twin

CAE

Machine Learning

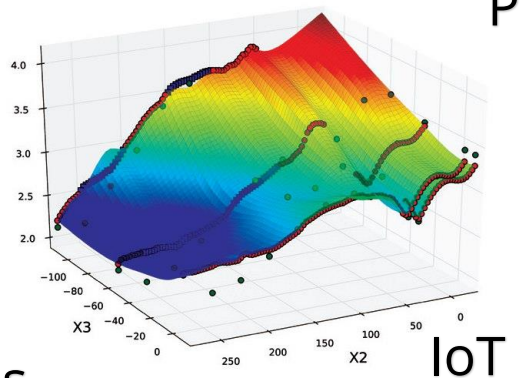
Artificial Intelligence

Predictive Model

Big Data

Predictive Analytics

Industrial AI



Digital Twin

Sensors data

Simulations

IoT

MBSE

We need a powerful yet easy to use low-code web-based platform to **build**, **explore** and **operate** physics-based or data-driven predictive models, to **automate** and **orchestrate** processes, data and models, and to **deploy** models and applications.

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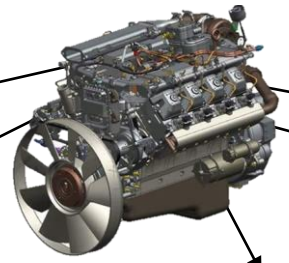
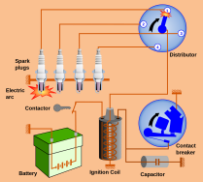
Building Digital Twin: Illustration - Engine

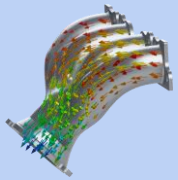
Physical Object →



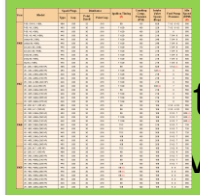
Combustion



Mechanics
Hydraulics
Electrics



Gas flow



Telemetry: temperatures, vibrations, etc.

...

Analytics Models

1D Simulation Models

3D CFD Models

In-Operations (Historical) Data

Integration of Existing Models and Development of new Analytical Models

Direct Integration with CAE software tools

Characterization and construction of Predictive Models, e.g. using ML

Construction of Predictive Models using Machine Learning

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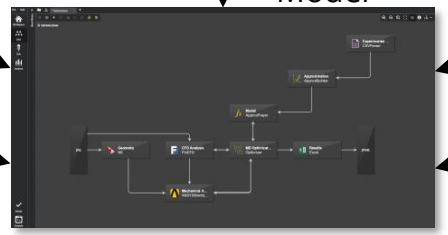
Model

Model

Model

Model

Model



Predictive Model(s) →

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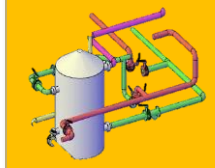
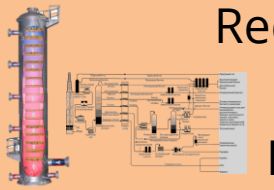
Building Digital Twin: Illustration – Refinery

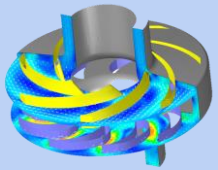
Physical Object →



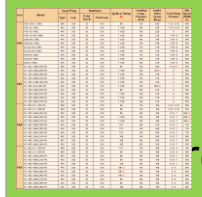
Pipelines



Rectification Columns Processes



Pumps



Telemetry: temperature, pressure, Q, etc.

...

Analytics Models

1D Simulation Models

3D CFD Models

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Construction of Predictive Models using Machine Learning

pSeven

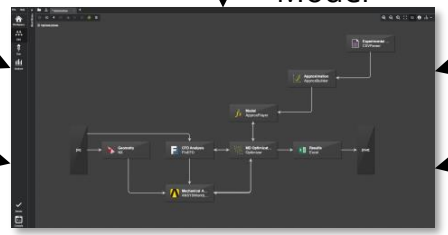
Model

Model

Model

Model

Model

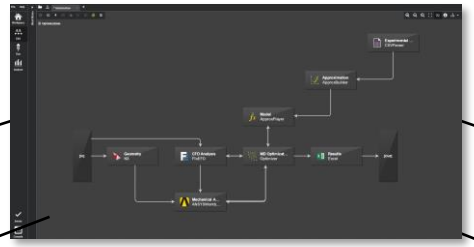


Predictive Model(s) →

DATADVANCE

Design Space Exploration* with Digital Twin: Illustration

Predictive Model(s) →



Design or Process Parameters

Design of Experiments

Multidisciplinary Design Optimization

Sensitivity Analysis

Uncertainty Quantification

Product technical and performance indicators

Optimal Design Decisions

* **Design Space Exploration** is a way to *systematically and automatically* explore very large numbers of design alternatives to find *optimal* performance parameters.

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Usage of Digital Twin in Operations: Illustration - Engine

- Telemetry
- Raw Data
- Extracted Features

- Virtual sensors
- Detected anomalies
- Failure indicators
- Prognostics

Combustion

Gas Flow

Telemetry: temperatures, vibrations, etc.

...

Mechanics Hydraulics Electrics

«Sensor» 1

«Sensor» 2

«Sensor» 3

«Sensor» ...

«Sensor» n

pSeven Model Execution Engine

Digital Twin

Operator
(Decision Maker)

Asset Management System

- Action, e.g. predictive maintenance
- Change management
- Business processes optimization

DATADVANCE

Usage of Digital Twin in Operations: Illustration - Refinery

- Telemetry
- Raw Data
- Extracted Features

- Virtual sensors
- Detected anomalies
- Failure indicators
- Prognostics

Pipelines

Pumps

Telemetry: temperature, Pressure, Q, etc.

...

Rectification Columns

«Sensor» 1

«Sensor» 2

«Sensor» 3

«Sensor» ...

«Sensor» n

pSeven Model Execution Engine

Digital Twin

Operator

(Decision Maker)

Asset Management System

- Action, e.g. predictive maintenance
- Change management
- Business processes optimization

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Digital Twins: New opportunities for business transformation

- Significant **reduction of design time and cost** while improving the technical and operational characteristics of products (quality, reliability, safety, etc.)
  - New aircraft design lead time reduction by up to 10% with pSeven, - Airbus in 2013

- **Increase of product reliability and reduction of maintenance costs** through online monitoring, diagnostics and **predictive maintenance** (as a value added service for consumers).
  - Digital Twins allow to reduce the time to the first production by 1-3 years. At the same time, capital costs in the development of deposits are reduced by 20-30%, - Leading provider of products and services to the energy industry

FROM THE ASSET BASED … TO A SERVICE DRIVEN

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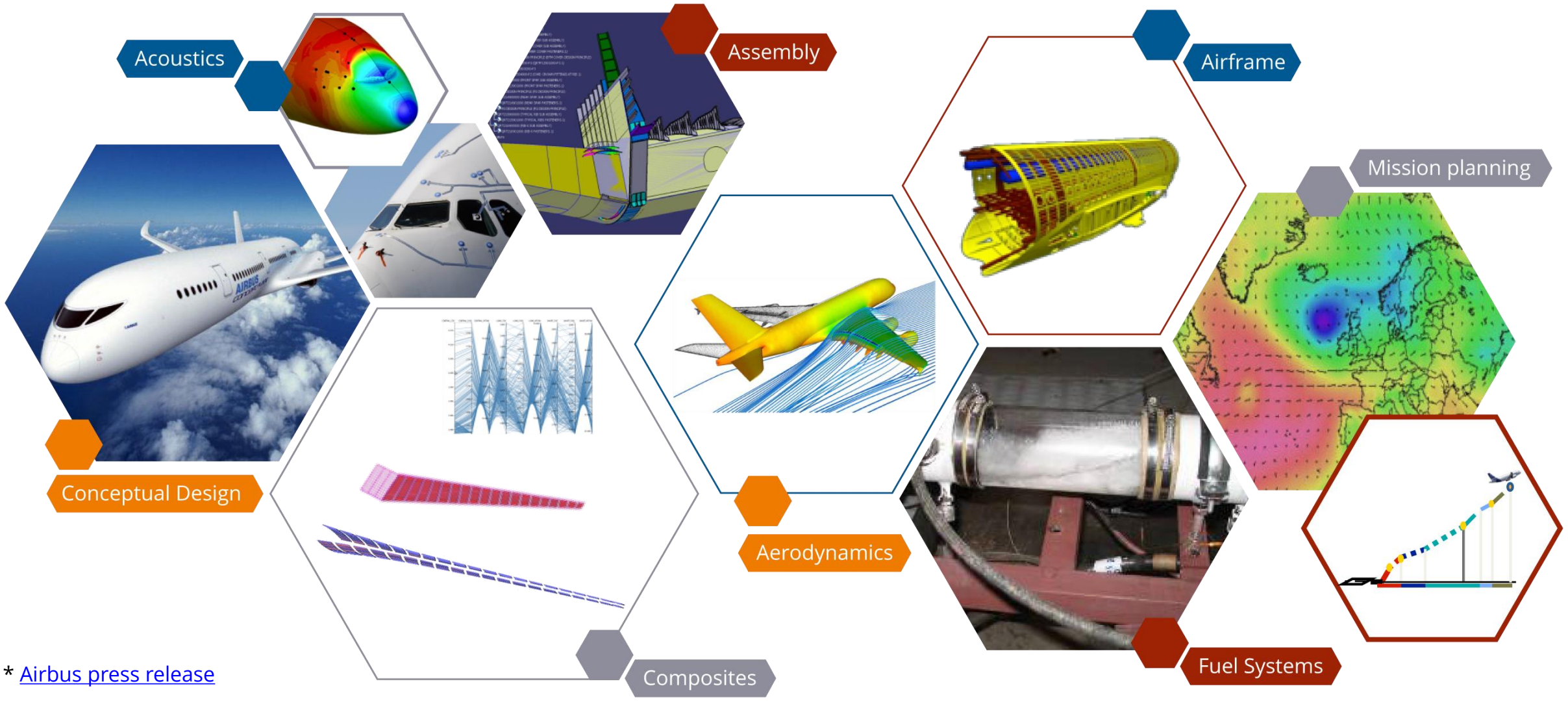
AIRBUS Lead time reduction by up to 10%*



* Airbus press release

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ISS Optimal Propellant Maneuver Algorithm

Objective

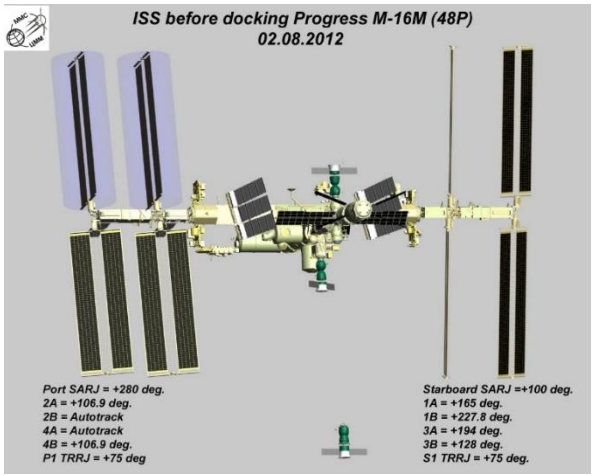
- Find optimal control parameters of ISS large angle maneuvers under the influence of external forces and with constraints on flexible modes

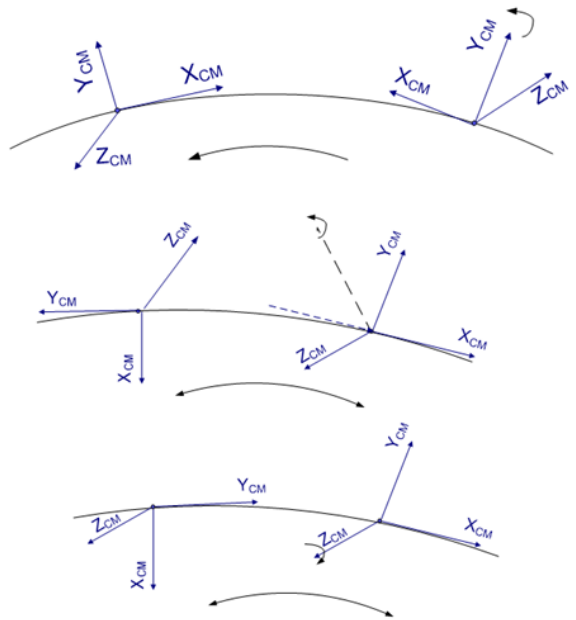
Solution

- A set of program modules were developed in pSeven aimed to:
  - Model arbitrary ISS maneuvers
  - Exhaustively parameterize control signals in each channel
  - Determine fuel-optimal control cyclograms, type and number of thrusters

Result – Proven by the a set real ISS maneuvers in Dec 2019

- Fuel efficiency of developed approach is about **x40** more effective than the existing method:
  - 180° turn on Ycm axis - from 80 to 4 kg of fuel
  - 180° turn on Euler axis - from 58 to 9.7 kg of fuel
  - 90° turn on Zcm (pitch) axis - from 17 to 1 kg of fuel
- Developed approach is **x5** more effective than upcoming NASA methodology





: Multistage Aerodynamic Steam Turbine Gas Path Optimization

Objective:

- Maximize efficiency of High Pressure Cylinder (HPC), Intermediate Pressure Cylinder - 1 (IPC-1) and Intermediate Pressure Cylinder - 2 (IPC-2) subject to geometry and mechanical stress constraints

Problem:

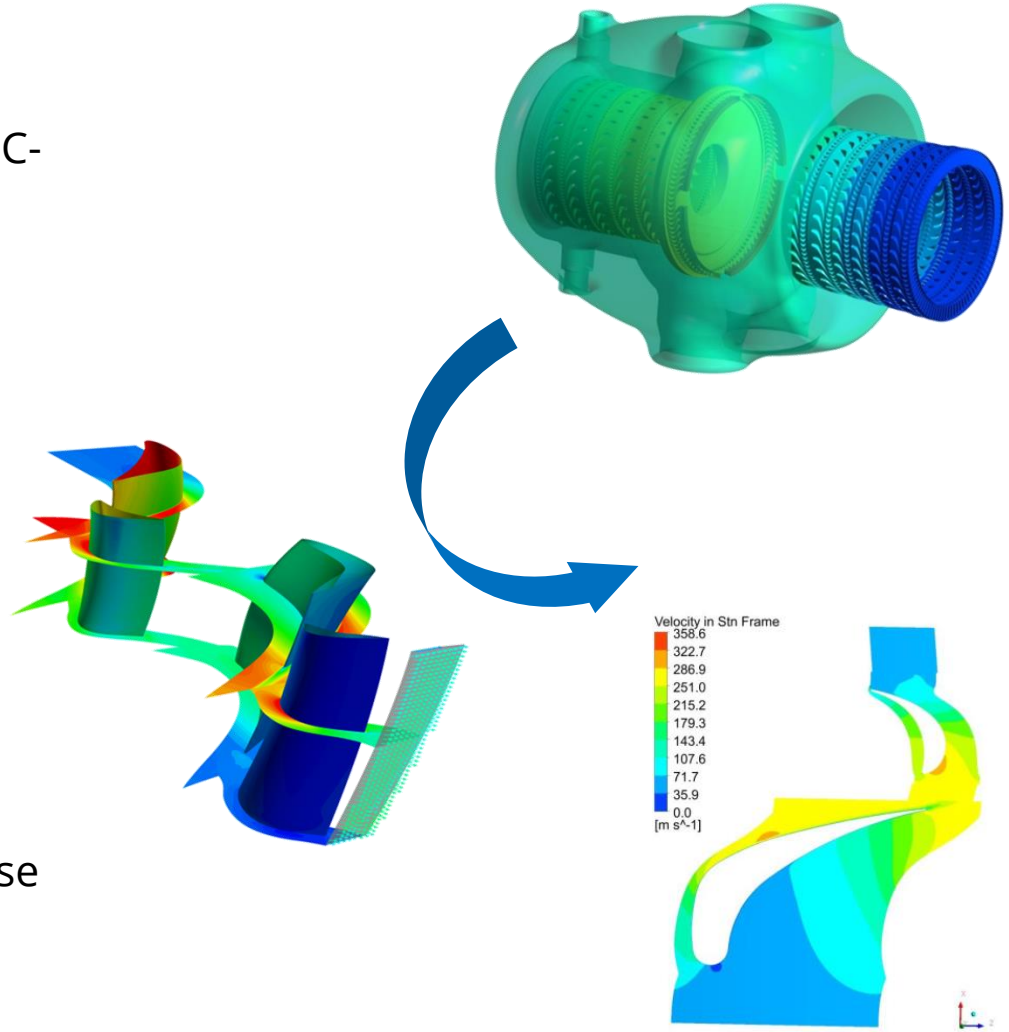
- HPC – 9 stages (69 parameters)
- IPC-1 – 10 stages (90 parameters)
- IPC-2 – 6 stages (72 parameters)
- 3D simulation in ANSYS CFX using HPC cluster

Solution:

- Local gradient optimization method implemented in pSeven

Results:

- **Efficiency boosted by 2%-4%** with capacity increase by 3%-6% because of geometry optimization (rotor and stator blades) and changing of operating mode



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Adaptive DoE for Simulation Based Testing of Automated Driving Systems

Intro

Simulation Based Testing of Automated Driving Systems, provided by FDTech GMBH, has several advantages compared to the real world testing. The objective of this use case is to help FDTech ensure the benefits of virtual testing like large scalability and variability, automated generation of driving scenarios, traceability and reuse of the testing data

Objective

- Enable scalable test beds by:
  - Controllable Test bed automation layer (TAL)
  - Traceable and reusable testing scenarios data
  - Automation of test preparation, run and analysis
- Ensure full coverage of important driving scenarios with lowest possible number of test points

Challenges

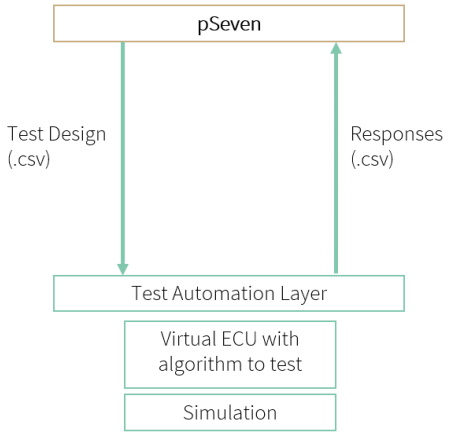
- Number of scenarios increases exponentially with number of parameters
- Different scenarios have different importance

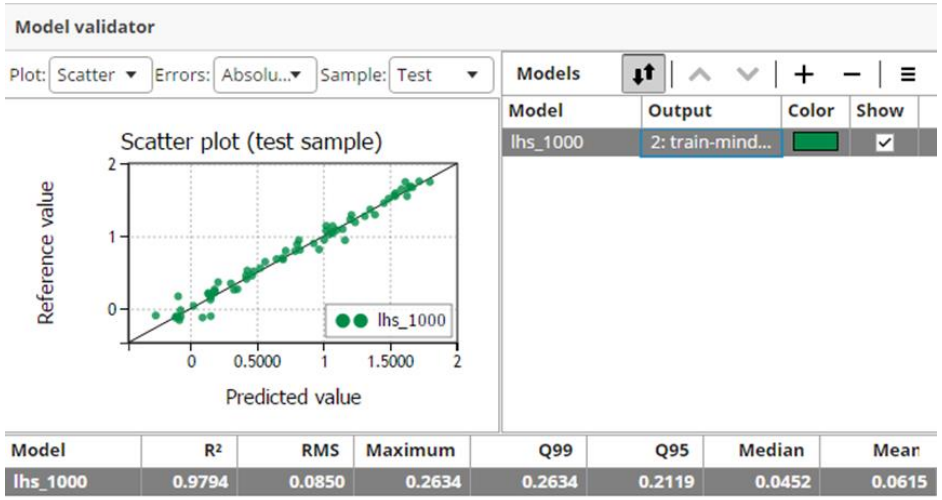
Solution

- Workflow automation in pSeven
- Adaptive Design of Experiments technique to drastically reduce number of simulations
- Predictive modelling and Machine Learning to cover the whole test space

Result

- Fully automated and scalable workflow for virtual test execution
- Adaptive exploration of the driving scenarios to reveal most important with minimum test runs

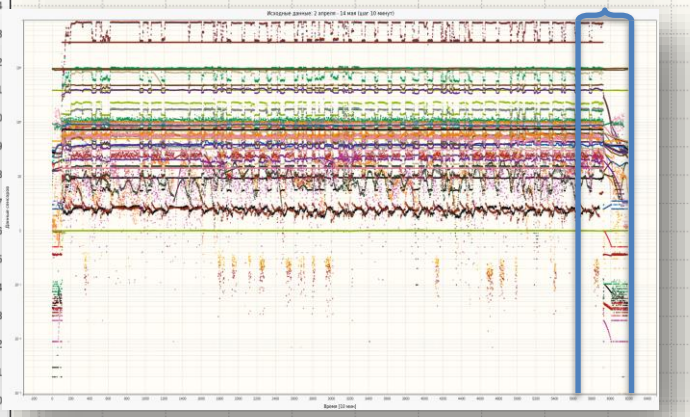




Model	R^2	RMS	Maximum	Q99	Q95	Median	Mean
lhs_1000	0.9794	0.0850	0.2634	0.2634	0.2119	0.0452	0.0615

POTEK : Post-mortem analysis of accident on power plant gas turbine

Location: Somewhere in Russia
Object: Gas Turbine
Sensors: 100+, 54 monitored



The turbine can be stopped 2 weeks prior to the failure!

Potential cost savings: ~10 mln. Euro!

Failure

Systematic deviation from the normal state

Failure early precursor

No domain specific knowledge was used. Just pure data analysis!

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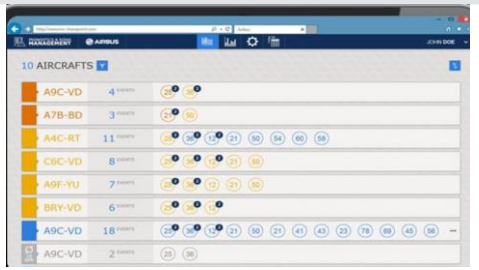
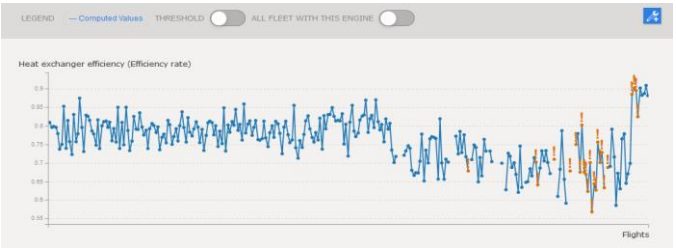
AIRBUS Predictive Modelling for Airbus Customer Service





ATA49
✔ APU core engine

Goal
- Predict failures of APU to improve maintenance procedure

Result
- Detection of failures with an accuracy of ~**90%** (9 correctly predicted failures account for 1 false alarm)
- **Cost reduction** associated with downtime of plane due to unexpected failures **by ~30%**

ATA79
✔ Oil filter clogging

Goal
- Optimize maintenance of an aircraft engine oil filter (minimize the number of checks and the costs of consumables)

Result
- **~50% reduction of the oil filter maintenance costs**

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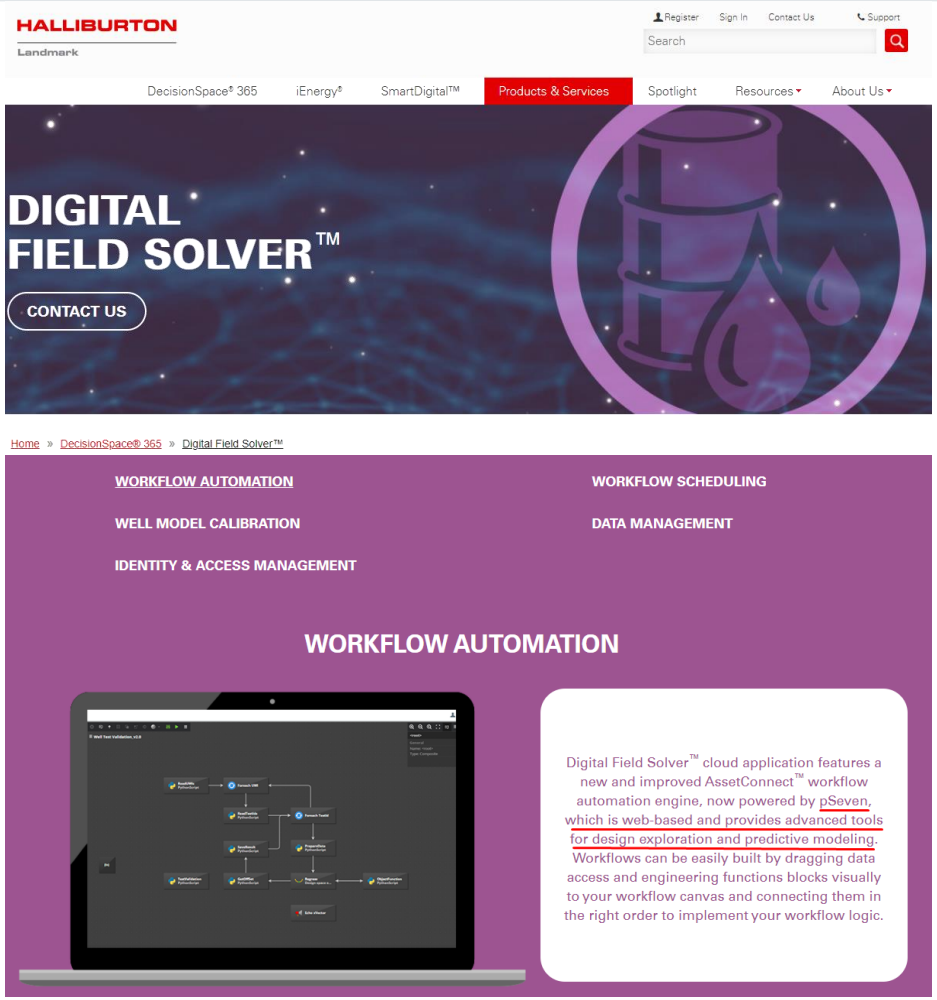
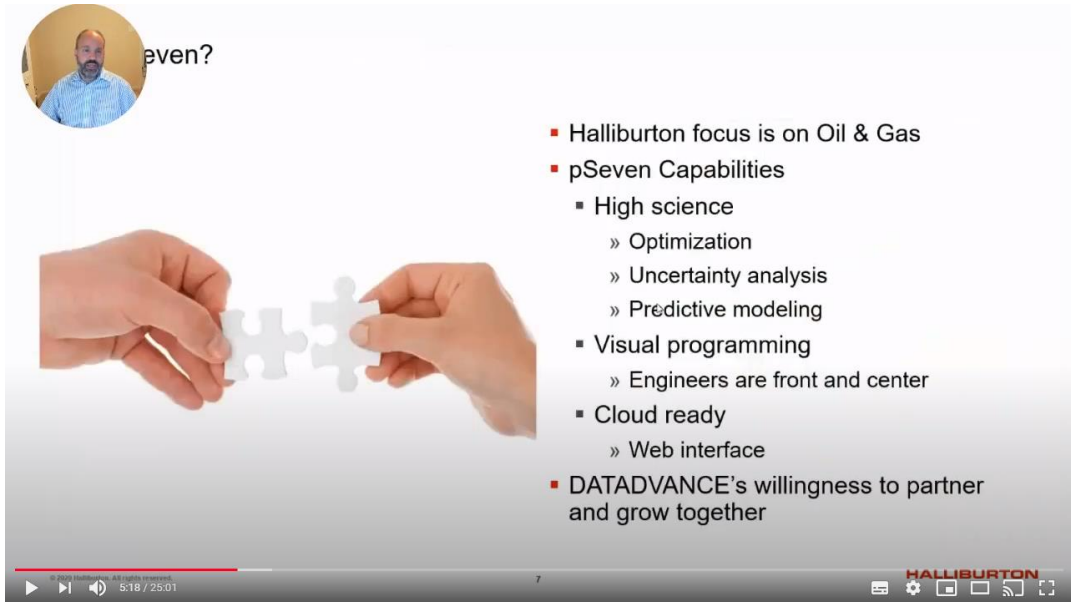
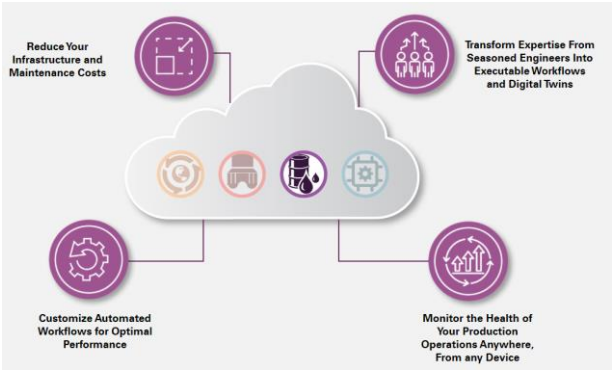
Digital Oil Field with Halliburton Landmark*





https://youtu.be/RS14qrwp-HQ?t=318



* Information is publicly available at Halliburton website

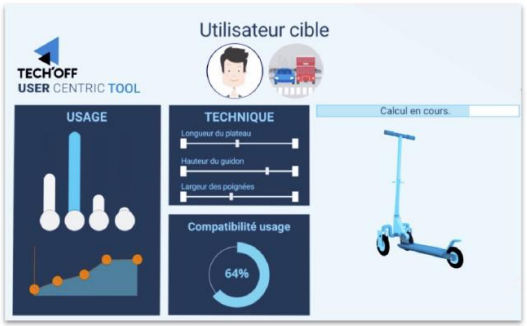
** https://www.datadvance.net/solutions/industry-solutions/resource-request/

Key driver: Process automation, Openness, Cloud-readiness, Algorithms

DECATHLON

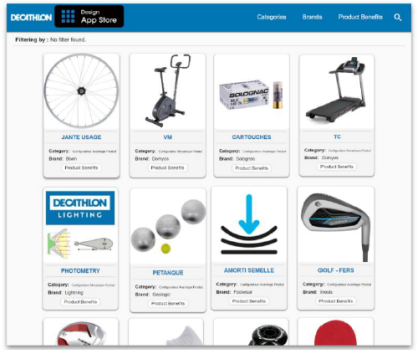
Purpose

CREATE** SMART-ENGINEERING **TOOLS** DEDICATED TO **PRODUCT DESIGN



 # Configurator

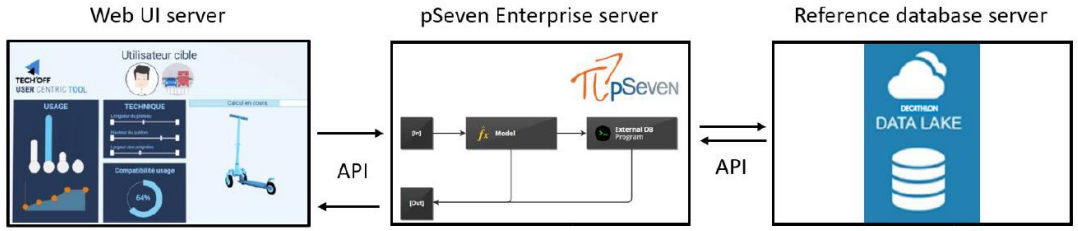
DESIGN APPLICATION STORE

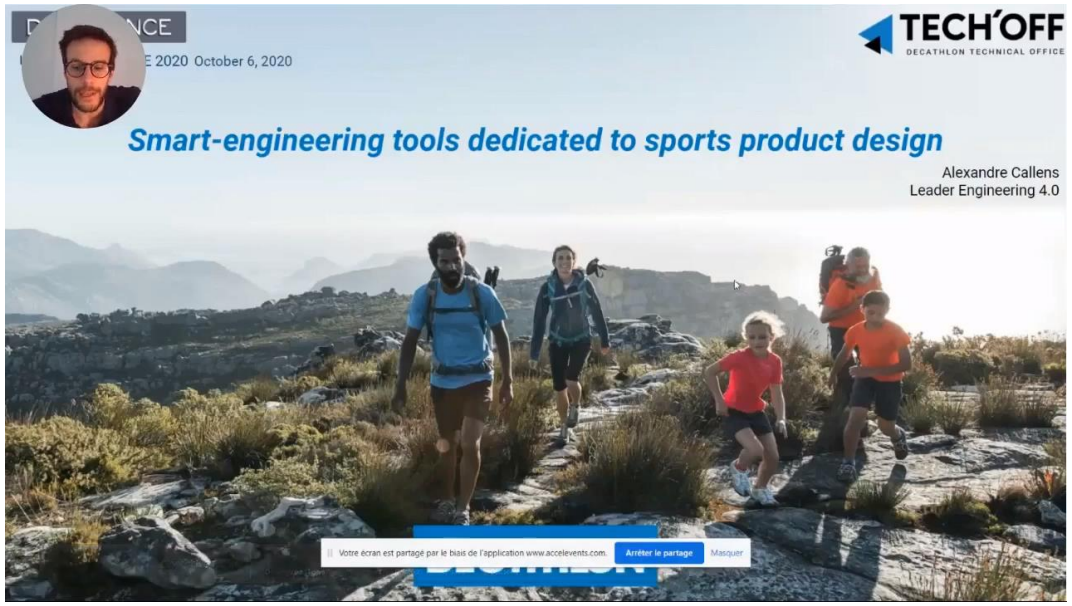


***PLATFORM** TO HOST AND SHARE ENGINEERING KNOWLEDGE AND DESIGN INTERFACE*

/ Accessibility
/ Interoperability
/ User-Friendly

Server-based solution for predictions and optimization with approximation models.





https://youtu.be/kbaUR_4wZqI

Key drivers: Open cloud Platform, Complete set of Integrated Capabilities

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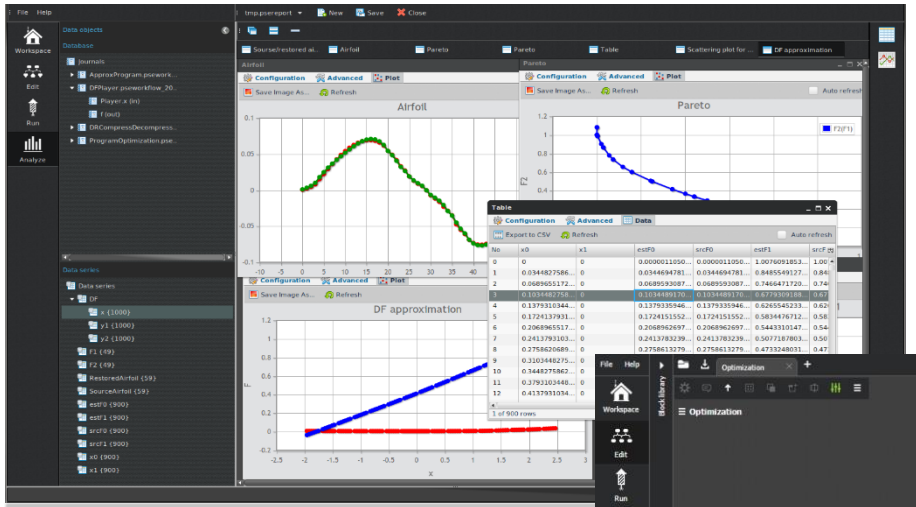
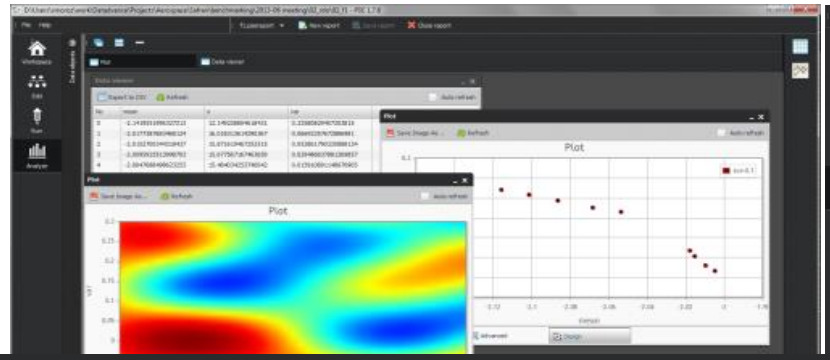
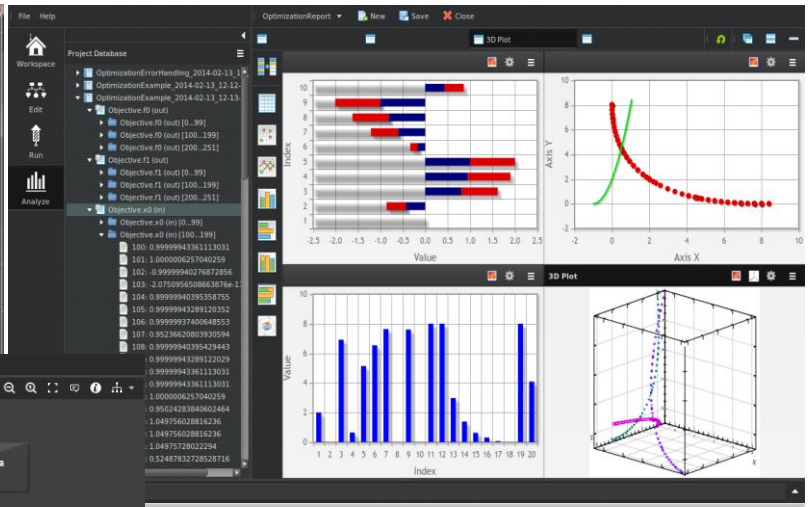
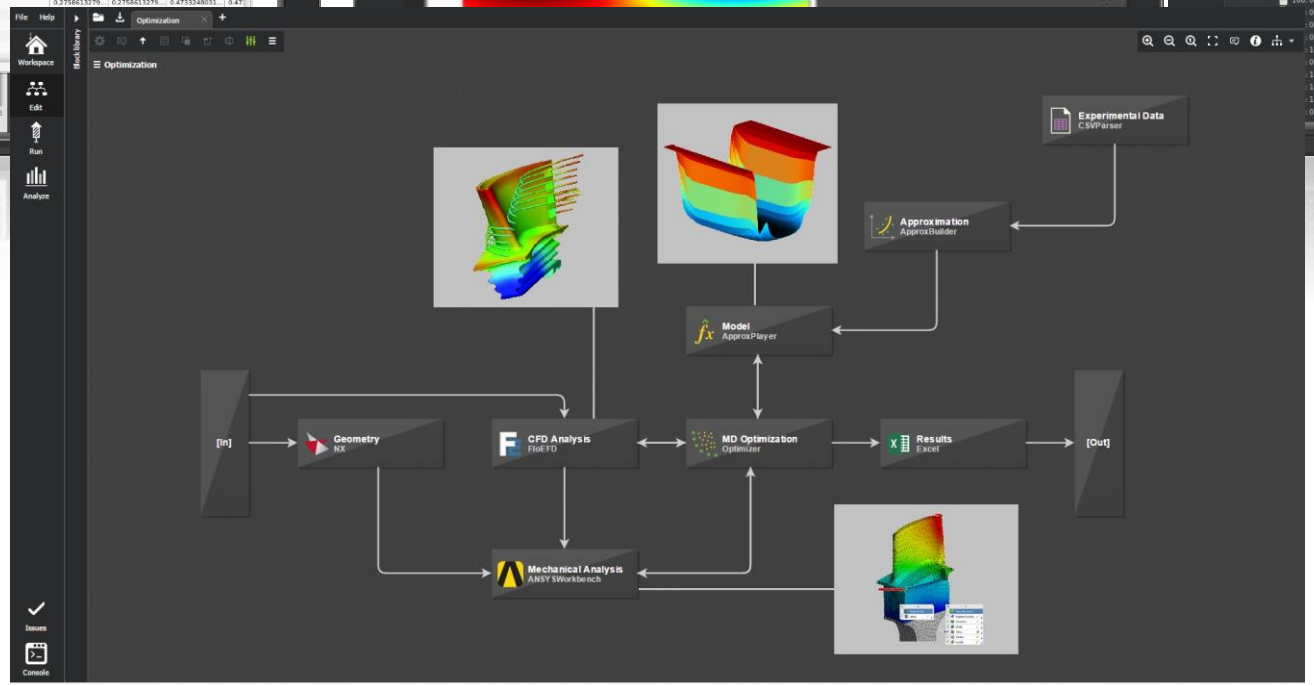
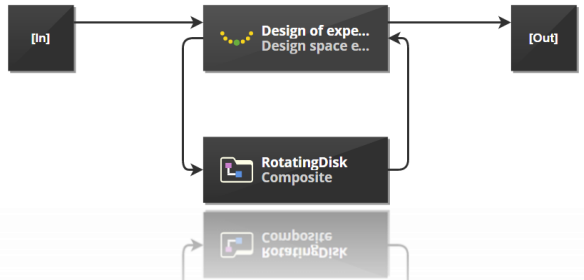
Look and Feel





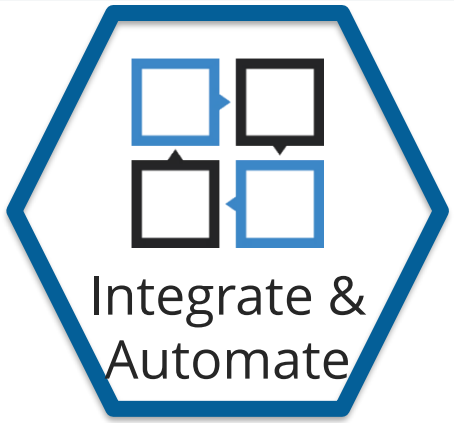






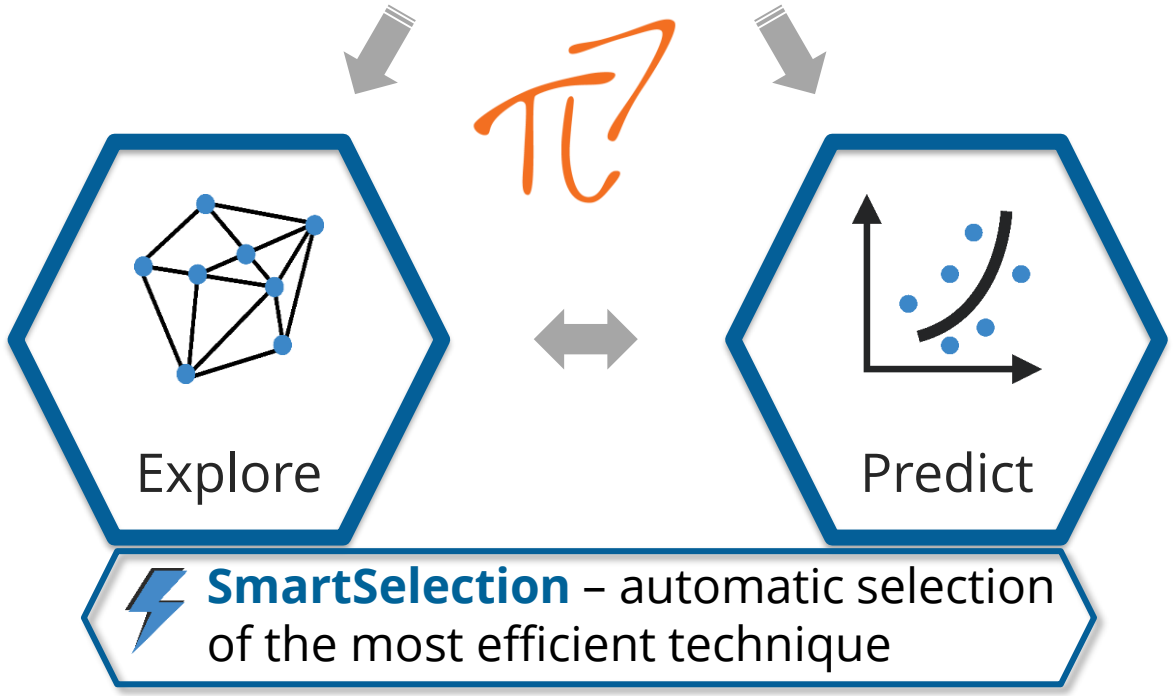
Key Features

- Integrate CAD/CAE tools
  - Seamless fit with existing PLM environment
  - Build multidisciplinary models
  - Master multi-scale models



- Automate workflow execution
  - Enable multi-run strategies
  - Increase productivity
  - Use your Python-scripts

- Select the best design alternative
  - Perform trade-off studies
  - Identify dominant design parameters
  - Find optimal design based on best in class algorithms
- Make smart design and operation decisions
  - Unique Adaptive Design of Experiments analysis
- Calibrate numerical models with test data



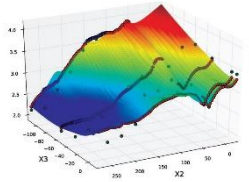
- Create predictive models
  - From Simulation, Test and Operation data
  - Data fusion from various high and low fidelity sources
  - Unique Mixture of Approximators models

SmartSelection: Predictive Modelling & Design Space Exploration for Every Engineer

Problem description

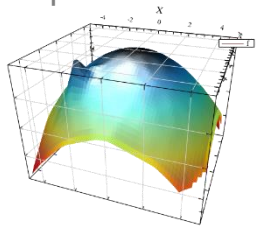
SmartSelection

Predictive Modeling



15 Techniques

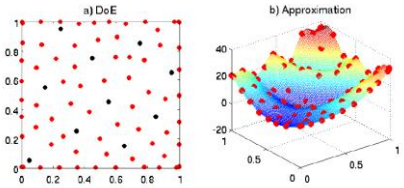
Optimization



NEW!

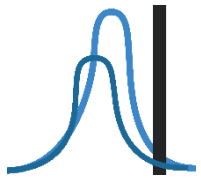
17+2 Algorithms

Design Of Experiment



16 Techniques

Uncertainty Quantification



5 Techniques

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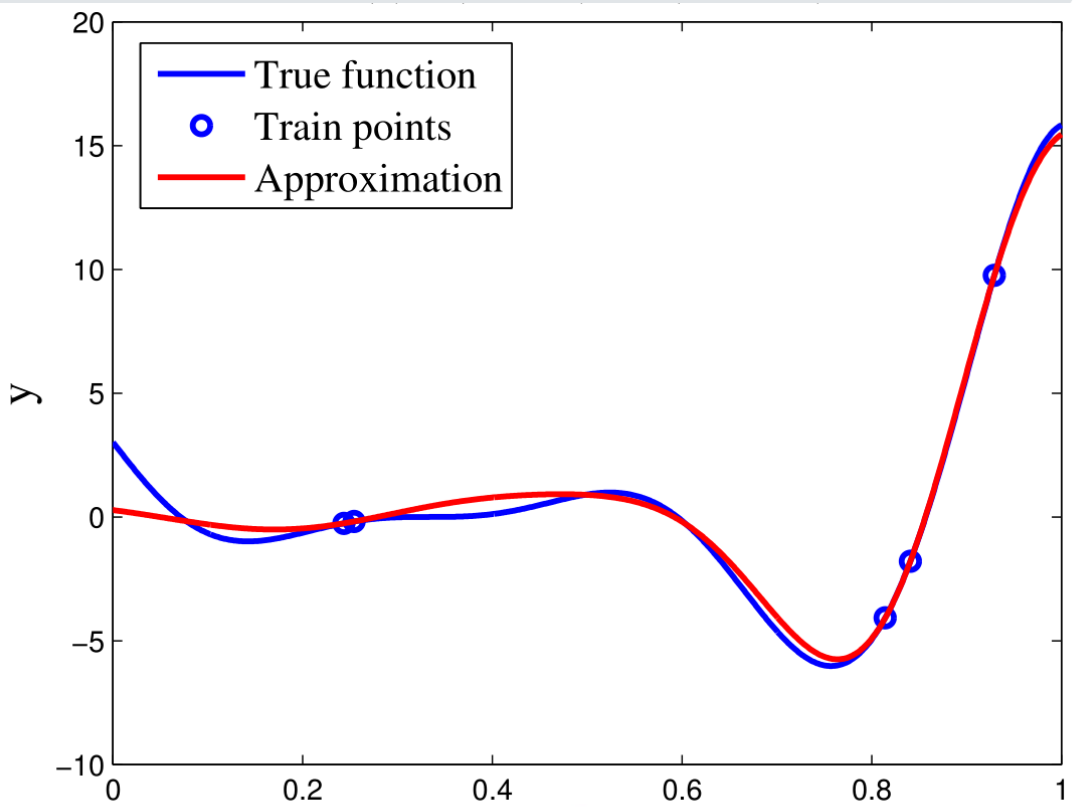
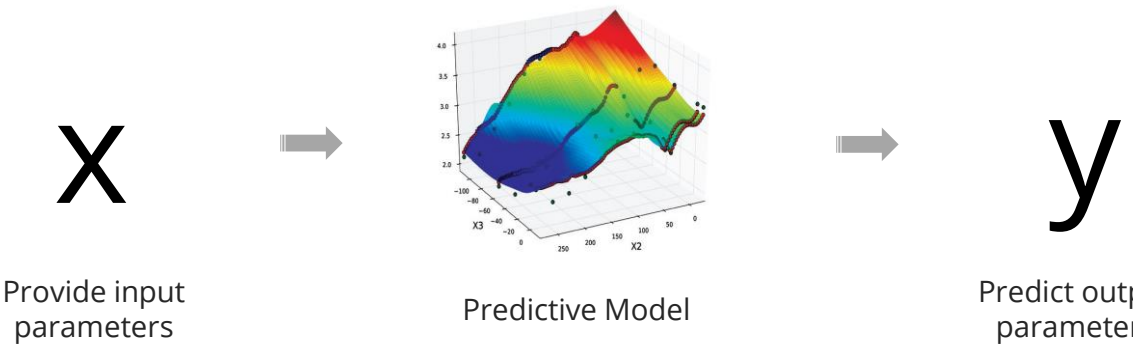
Predictive Model - Supervised Learning Problem Formulation

- On defined set of objects X and set of known features Y, target function $y: X \to Y$ assumed to exist
- By given training sample $X^l = (x_i, y_i)_{i=1}^l$, build decision function $\hat{y}: X \to Y$ to approximate y all over X

Regression estimation consider $Y \in \mathbb{R}$

Classification consider $Y = \{1, \dots, M\}$ or $Y = \{0,1\}^M$





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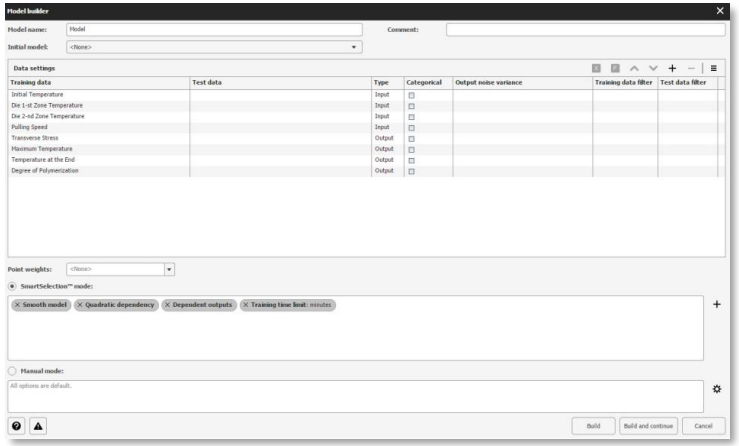
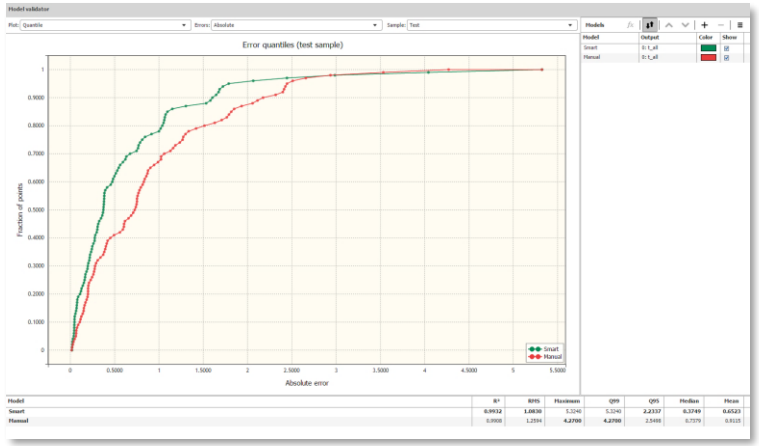
Tools for Predictive Modeling

pSeven includes a dedicated set of tools for building and managing predictive models that allows to:

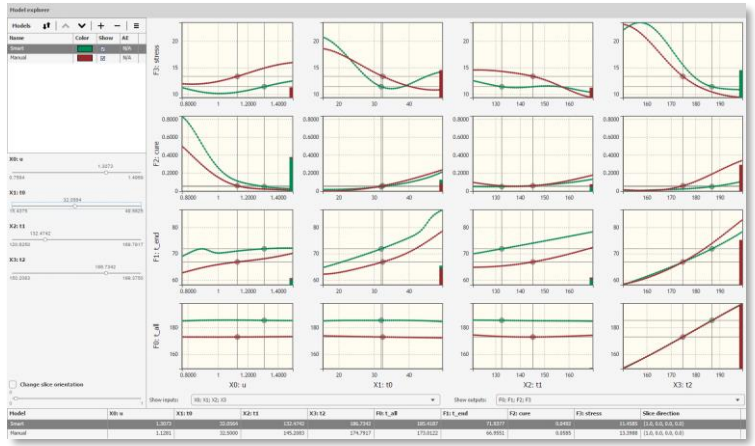
- Build fast and robust predictive models with automatic selection of technique
- Validate, test against reference data and compare models to find the best approximation quality
- Explore behavior of multidimensional models with studying input-output dependencies
- Export models to external file, including C source code, executable, Matlab/Octave, Excel and FMI



Model Builder



Model Validator



Model Explorer

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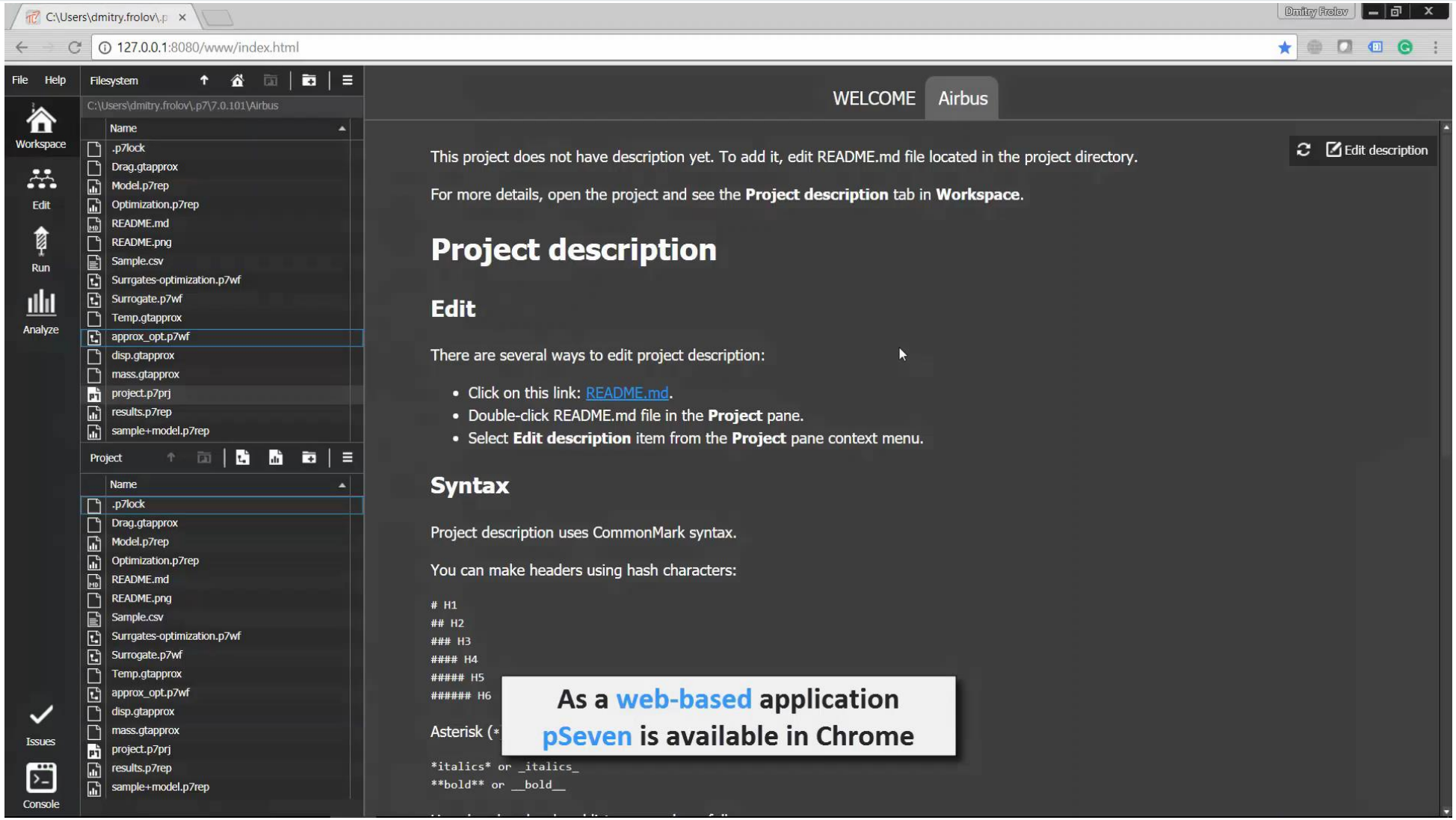
How to build Predictive Model in a few clicks



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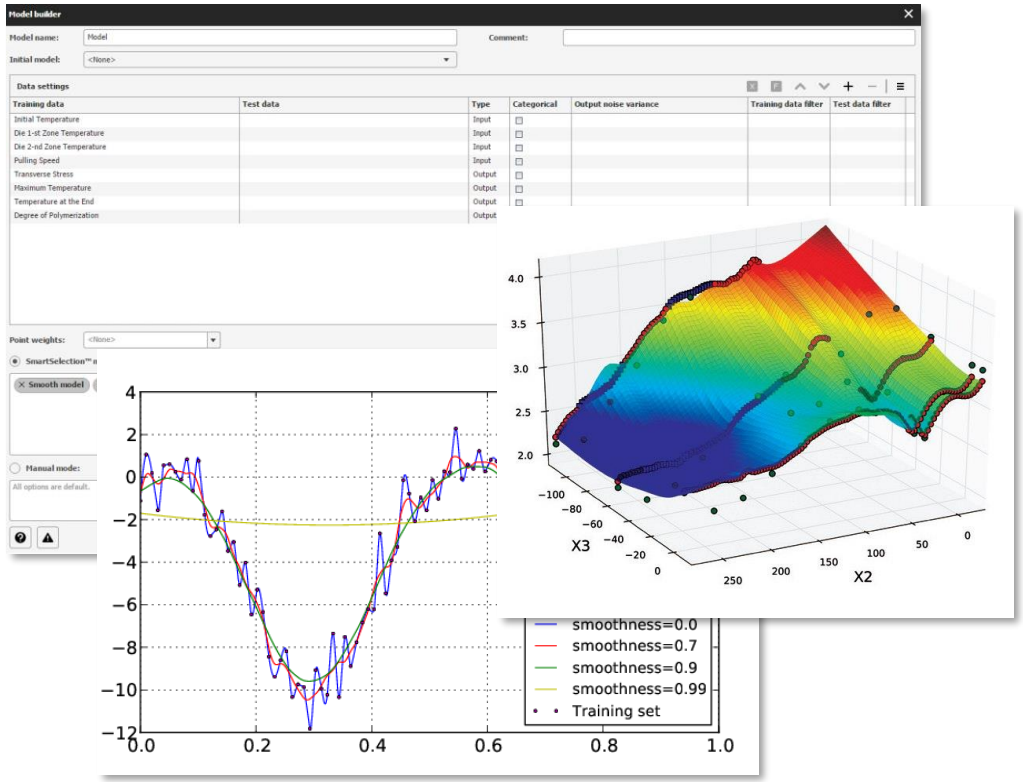
Building Predictive Models

pSeven provides capabilities and flexibility for building predictive models:

- Variety of industry-proven approximation techniques
- Full control of the model building time
- Accuracy and error estimation
- Dealing with oscillations and model smoothing
- Logarithm of outputs and exact fit
- Handling anisotropic data, discontinuities and inhomogeneous data, multi-fidelity data
- Updating existing models with new data & combining of the models



SmartSelection selects the most efficient technique for a given problem and data automatically!

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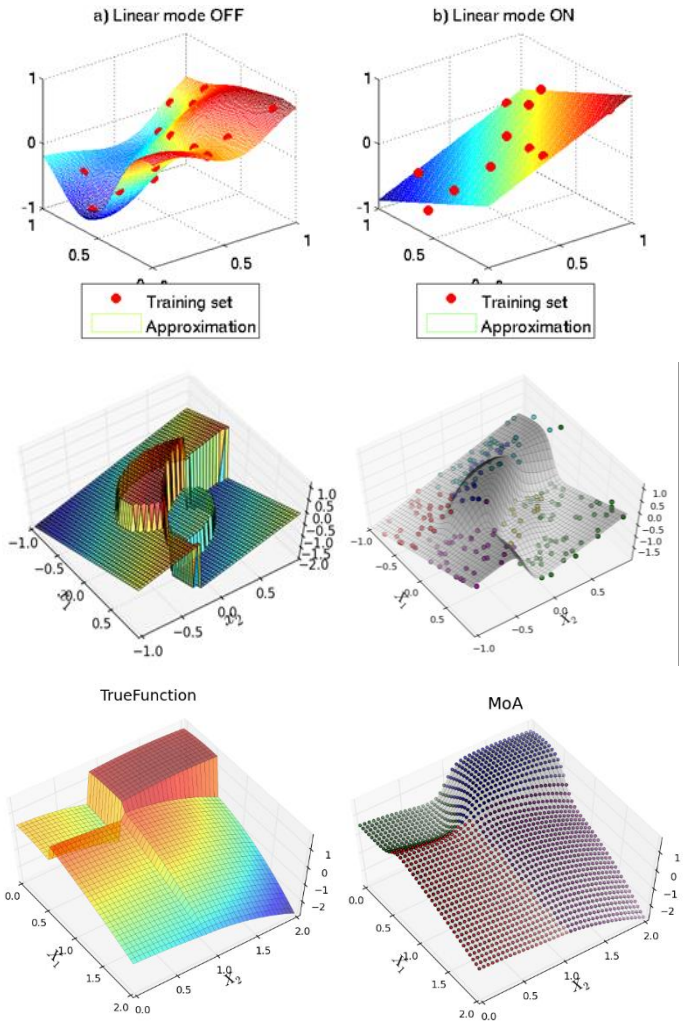
Predictive Modeling Techniques

pSeven provides industry proven techniques for any type of approximation and data:

- Piecewise Linear Approximation (PLA)
- 1D Splines with Tension (SPLT)
- Response Surface Model (RSM)
- Tensor Approximation (TA)
- Incomplete Tensor Approximation (iTA)
- Gaussian Processes (GP)
- Sparse Gaussian Process (SGP)
- Tensored Gaussian Processes (TGP)
- Gradient Boosted Regression Trees (GBRT)
- High-Dimensional Approximation (HDA)
  - 2 Layer Artificial Neural Network
- High-Dimensional Approximation Combined with Gaussian Processes (HDAGP)
- Mixture of Approximators (MoA)
- Table Function (TBL)



SmartSelection selects the most efficient technique for a given problem and data automatically!

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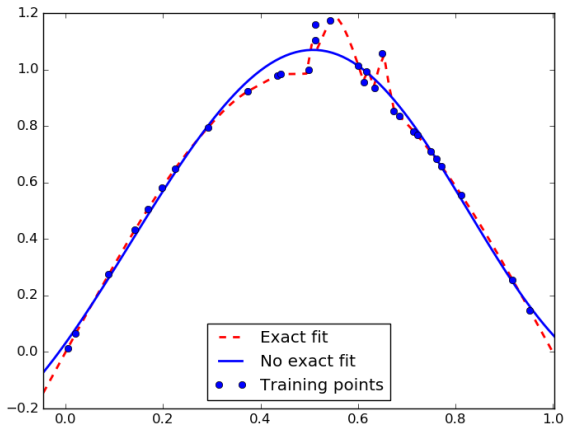
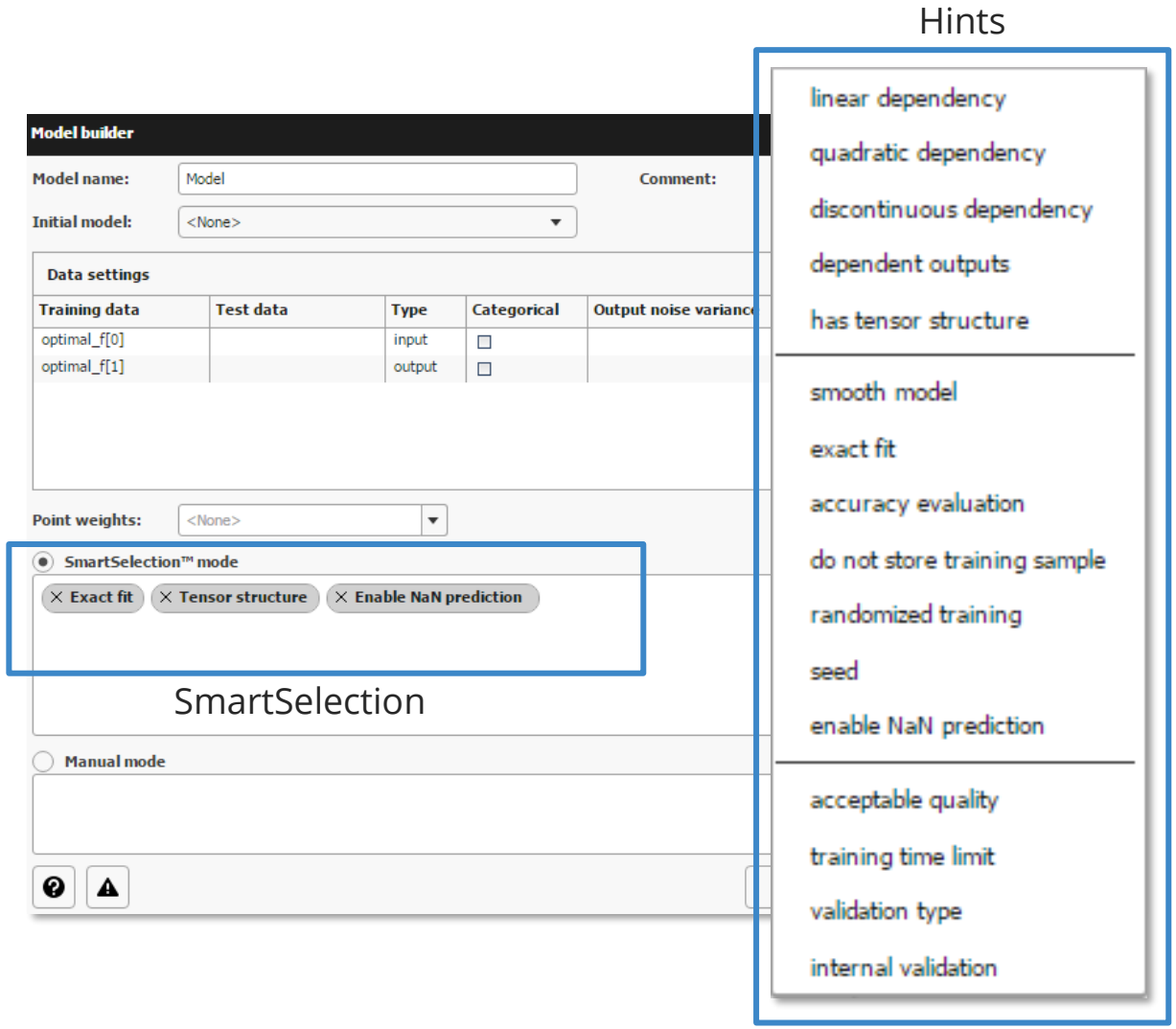
SmartSelection for Predictive Modeling ~ AutoML

SmartSelection grants automatic and adaptive choosing of approximation technique(s):

- Set of hints helps the user to describe problem and desired solution:
  - Hints about the data: dependencies, structure, etc.
  - Desired model properties: exact fit, smooth, etc.
  - Building properties: time, quality, etc.
- For better approximation quality, different parts of the model can be built using different techniques
- Meta-learning inside
- Hyper-Parameter Optimization inside





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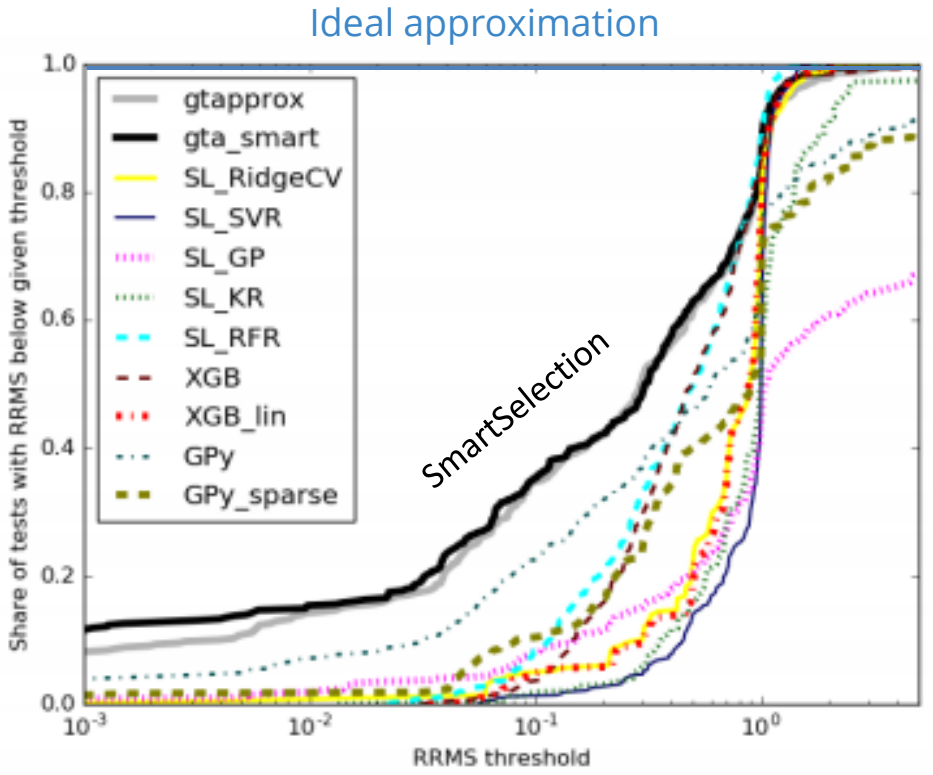
Benchmark: SmartSelection for Predictive Modeling

Quality of predictive model built with SmartSelection:

- Even with default settings SmartSelection builds predictive models of better approximation quality than famous open algorithms, like Scikit-learn, XGBoost and GPy.

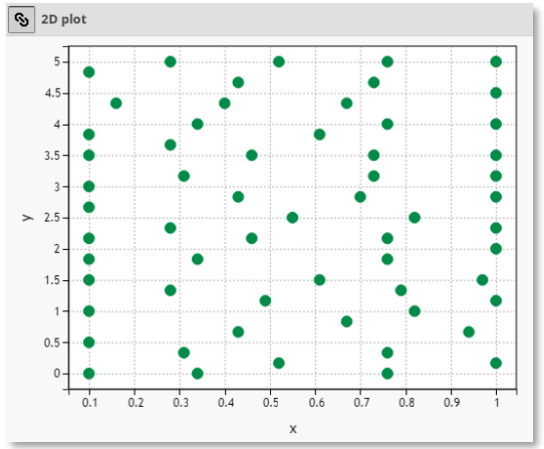


pSeven vs. open algorithms

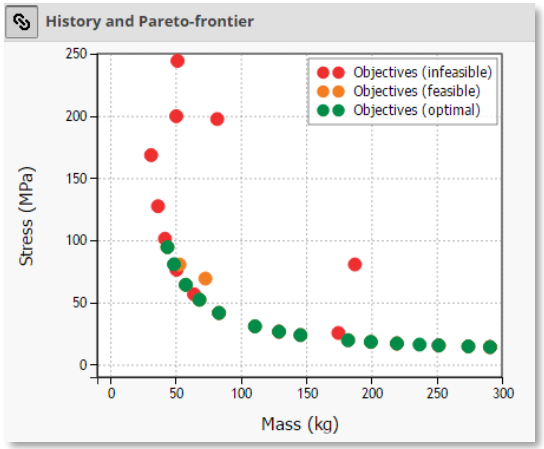
Full benchmark can be found here: https://arxiv.org/abs/1609.01088

Design Exploration Tools in pSeven

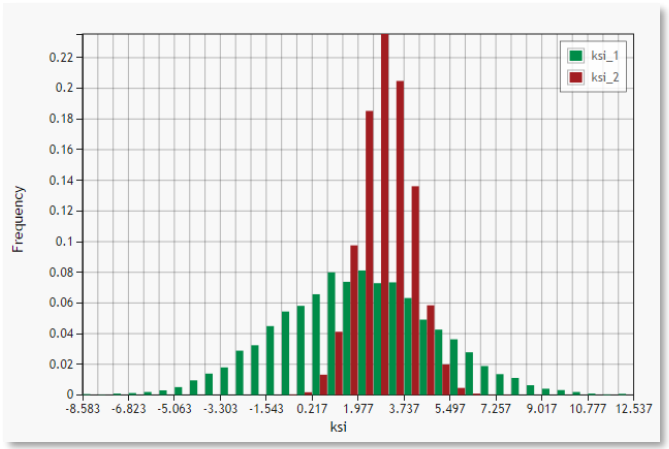
- Design of Experiments



- Design Optimization



- Uncertainty Quantification



Design space exploration

UQ

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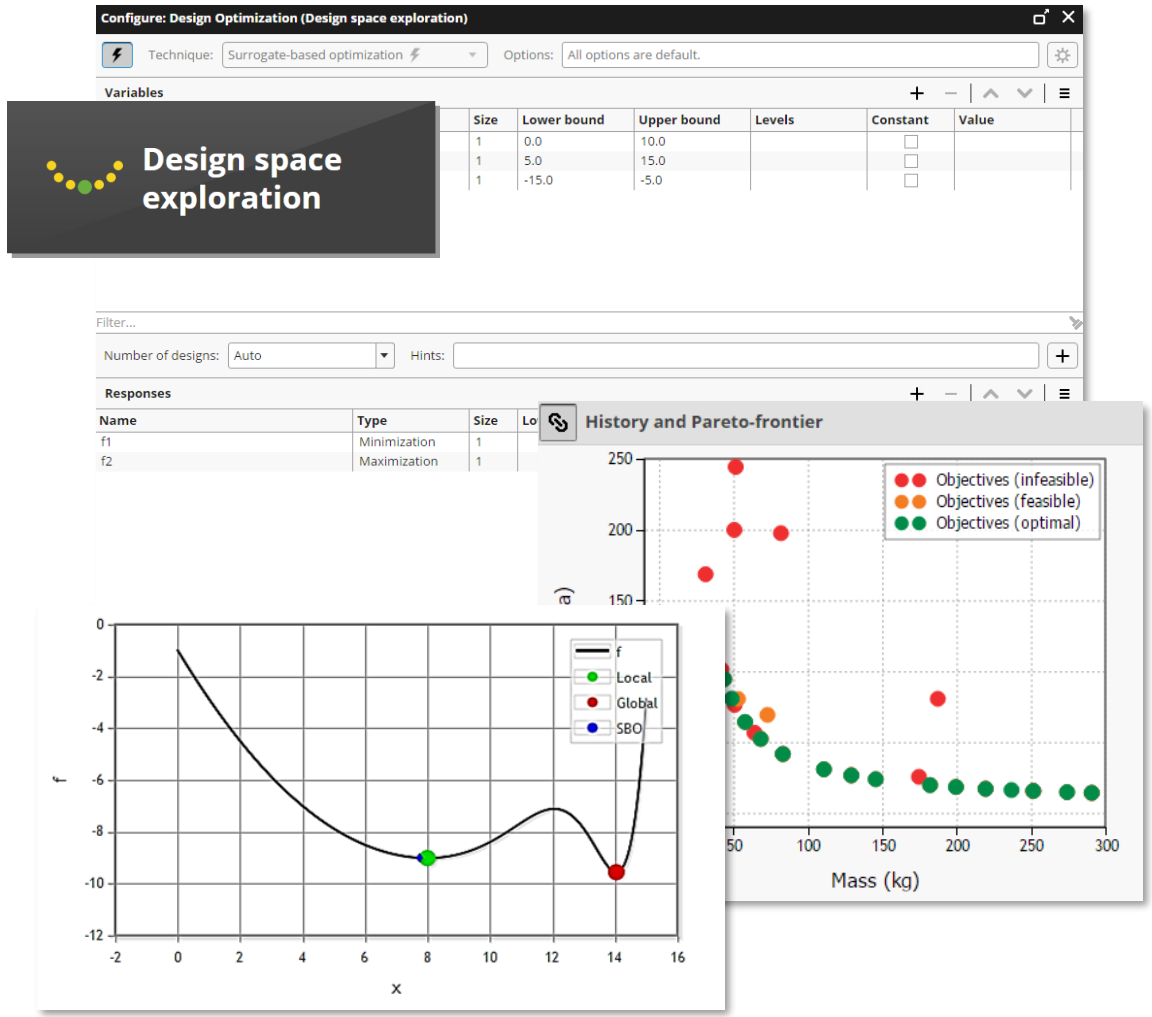
Design Optimization in pSeven

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

- Single- or multi-objective, robust optimization
- Large dimensionality*
- Long model evaluation time**
- Continuous and discrete input variables
- Nonlinear, multimodal or noisy objective functions and constraints
- Presence of implicit constraints and domains of undefined behavior
- Presence of uncertainties

SmartSelection chooses the optimization algorithms automatically and adaptively!



* - Up to 100 design variables for nonlinear time-consuming models

** - For example, any CAE model

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Optimization Algorithms in pSeven

pSeven includes full set of algorithms for solving single- and multi-objective design optimization problems:

- Method classes*:
  - Multi-Objective
  - Derivative-Free Optimization
  - Gradient-Based Optimization
  - Surrogate-Based Optimization (SBO)
- Globalization algorithms:
  - Random Linkage (RL)
  - Plain MultiStart (PM)
  - MultiStart Pi (MS)
- Local algorithms:
  - Quadratic Programming (QP)
  - Sequential QP (SQP)
  - Sequential Quadratic SQP (SQ2P)
  - Feasible Direction (FD)
  - Mixed-Integer Linear Programming (MILP)
  - Method of Multipliers (MoM)
  - Non-Linear Conjugated Gradients (NCG)
  - Non-Linear Simplex (NLS)
  - Powell's Conjugate Direction Method (Powell)

SmartSelection chooses the optimization algorithms automatically and adaptively!

* - Multiple method classes are also supported, for example: Multi-Objective Gradient-Based Optimization

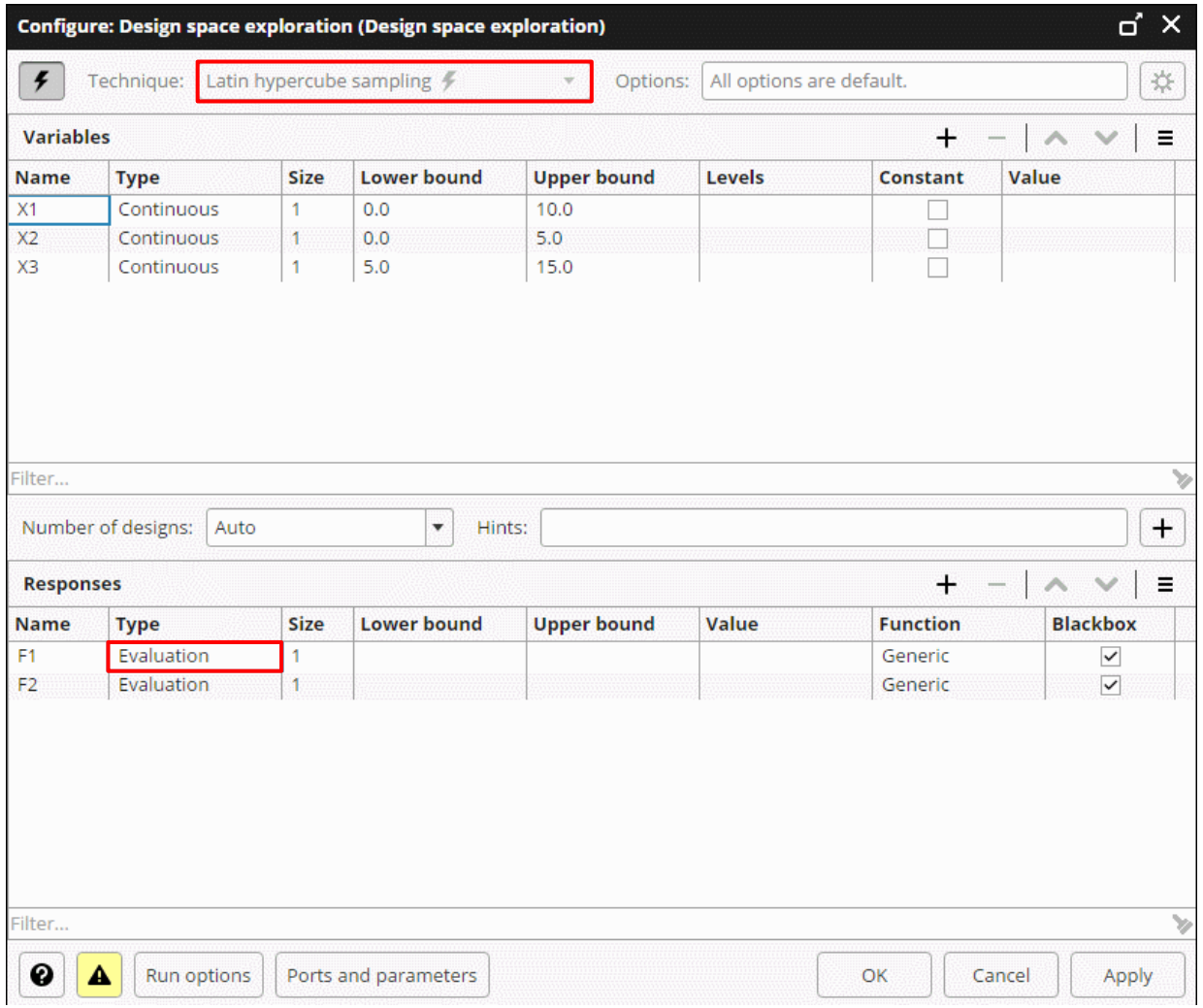
SmartSelection for Design Exploration

Design Exploration technique is chosen automatically with SmartSelection:

- Set of options and hints helps the user to describe a problem and desired solution:
  - Types of variables: continuous, discrete, categorical
  - Types of responses: evaluation, minimization, constraint etc.
  - Function of responses: generic, linear, quadratic etc.
  - Problem hints: noisy, expensive

Design Optimization algorithms' parameters are adaptively tuned during the solution:

- In the case of performance degradation solution process interrupts and restarts with the next suitable algorithm



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Benchmark: Multi-Objective Gradient-Based Optimization

- Test problem: Well-known TP7
- Objective functions evaluations:
  - pSeven - 187
  - NSGA2 - 200

$$\min_{\vec{x}} \left(x_0, \frac{1+x_1}{x_0}\right),$$

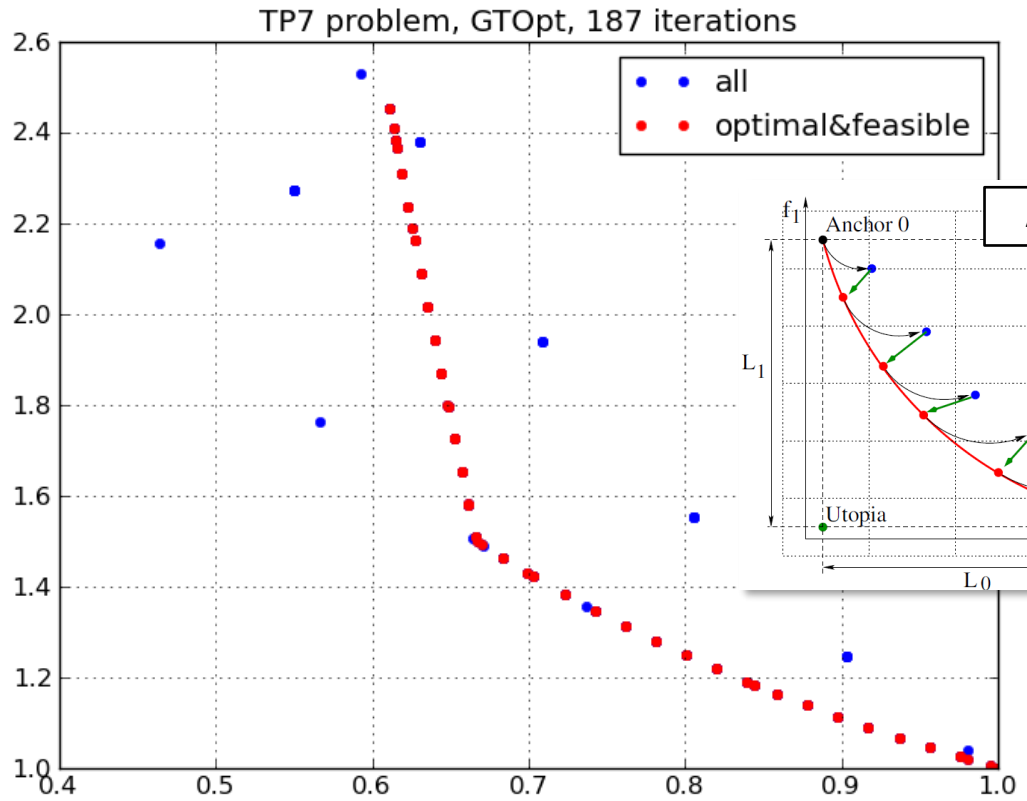
where

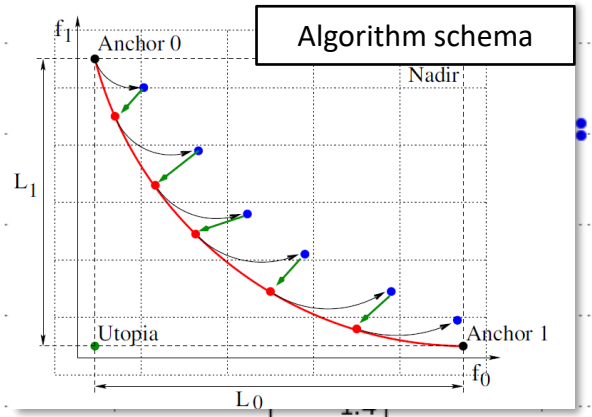
$$0.1 \leq x_0 \leq 1$$
$$0 \leq x_1 \leq 0.5$$

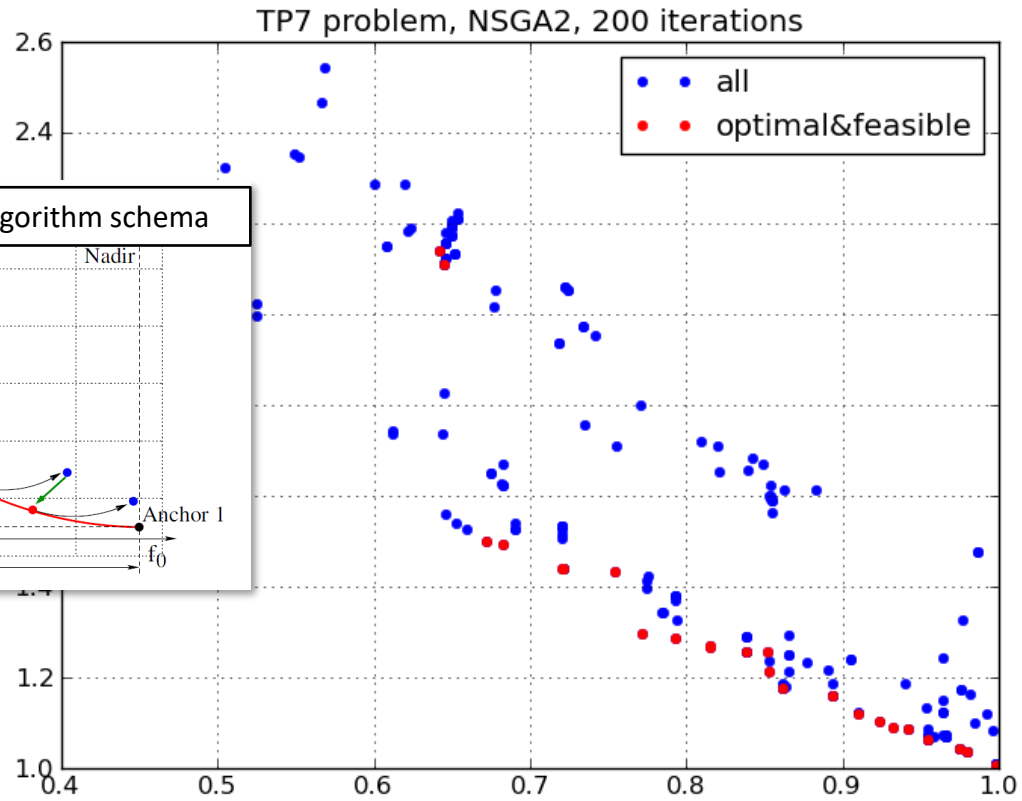
subject to

$$x_1 + 9\,x_0 \geq 6$$
$$-x_1 + 9\,x_0 \geq 1$$

- NSGA2 can't reconstruct Pareto frontier using the same number of evaluations







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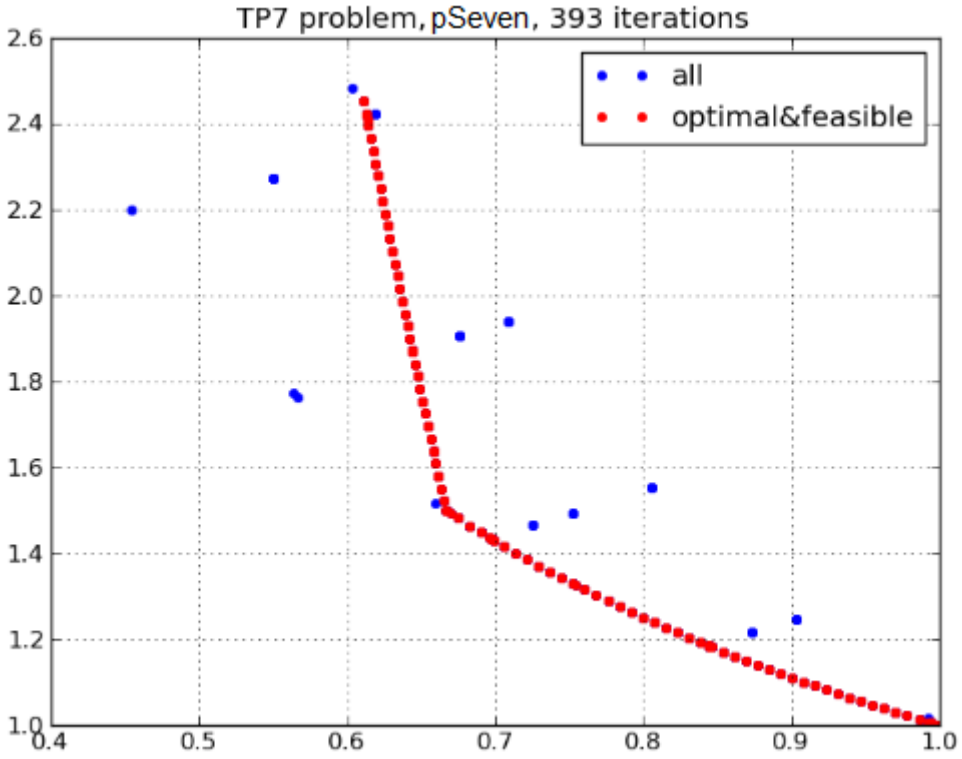
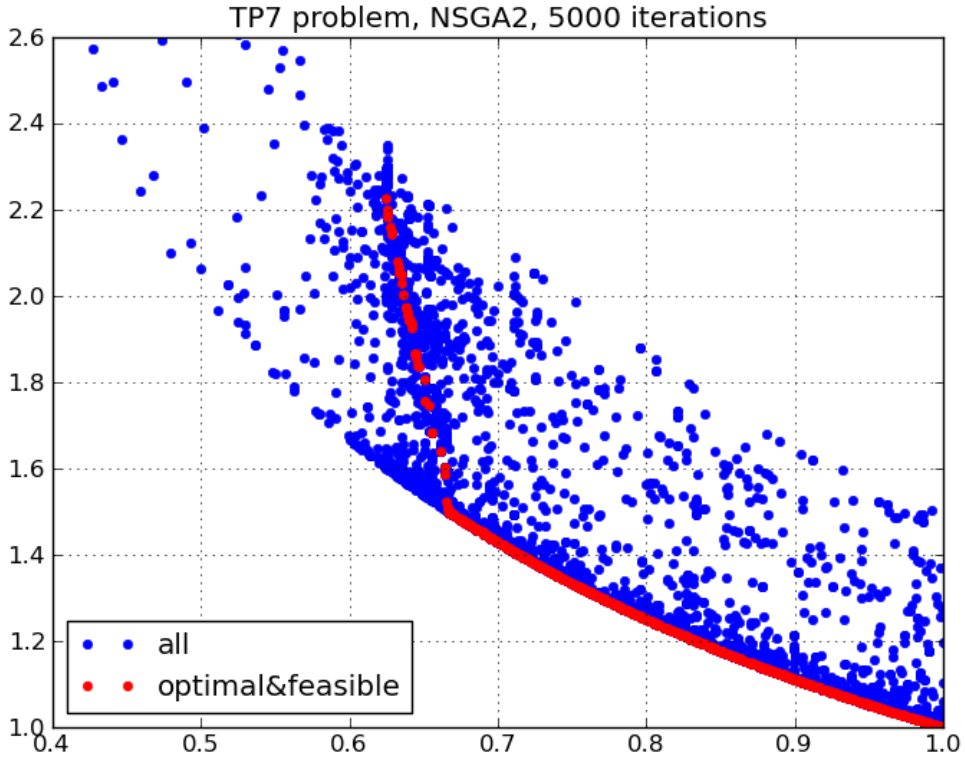
Benchmark: Multi-Objective Gradient-Based Optimization

- Test problem: Well-known TP7
- Objective functions evaluations:
  - pSeven - 393
  - NSGA2 - 5000



- NSGA2 needs 13x times more evaluations to have the same Pareto Frontier density



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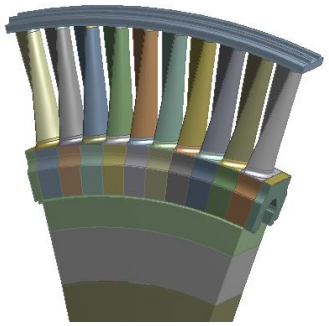
Surrogate-Based Optimization in pSeven

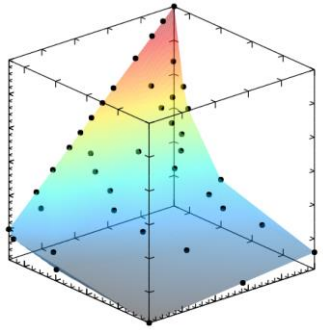
Surrogate-Based Optimization (SBO) is a class of optimization methods that involves building and optimizing surrogate models as an intermediate step.

SBO in pSeven:

- Implements in-house developed DoE strategy, which respects as much feasibility domain of the problem as possible
- Intelligently spends model evaluations budget and speeds up the solution multiple times
- Allows solving large scale problems (up to 1000 design variables) effectively using in-house implementation of **multi-resolution GP**



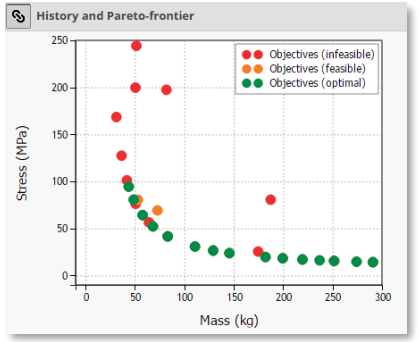
Create model



SBO runs a DoE to build an initial surrogate

SBO predicts next design point

Surrogate is rebuilt



Optimization step

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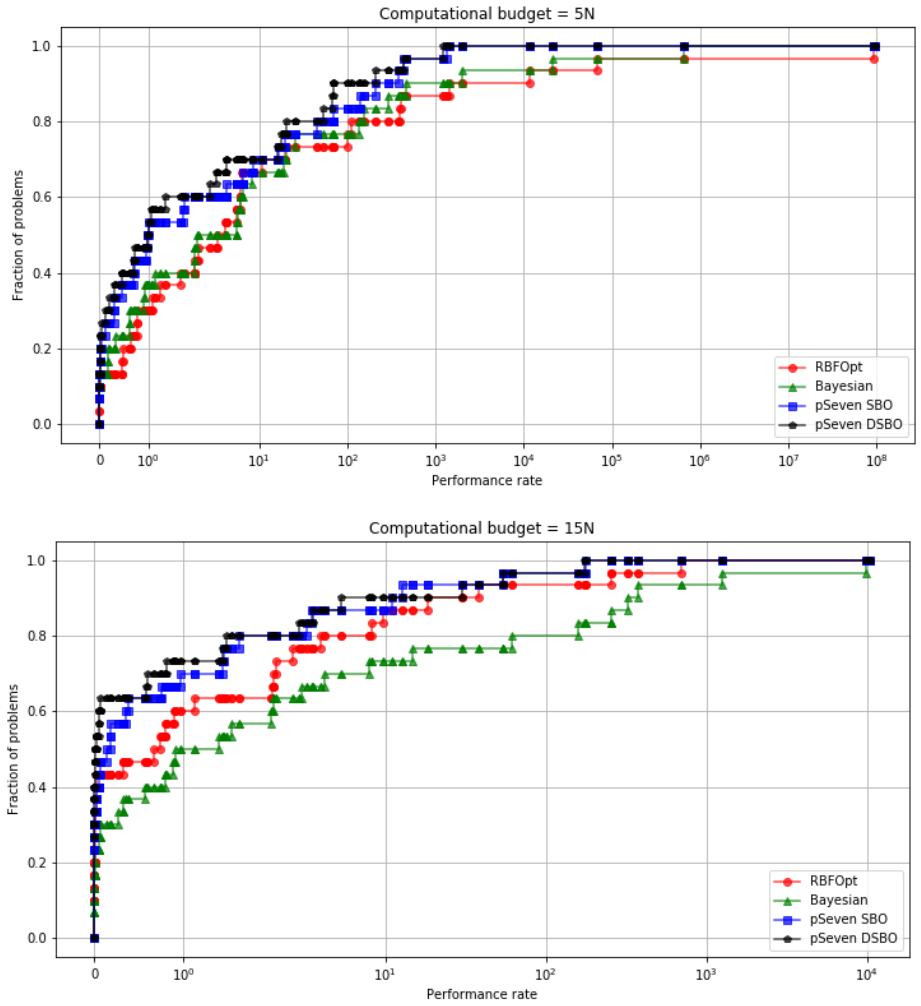
Benchmark: Surrogate-Based Optimization Algorithms for Expensive Problems

- Test problem: combination of 30 different benchmark functions
- pSeven, RBFOpt and Bayesian surrogate-based optimization algorithm were used
- pSeven is well-suited for expensive optimization problems in cases of the restricted computational resources
  - Especially the Direct SBO (DSBO) algorithm that fundamentally relies only on the exploitation meaning that it takes into account only the values of a surrogate model

Learn more →



Performance profiles of algorithms at the given number of evaluations

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Simulation Process and Data Processing Automation in pSeven

All Simulation, Data Analytics and Optimization tasks can be routinely automated!

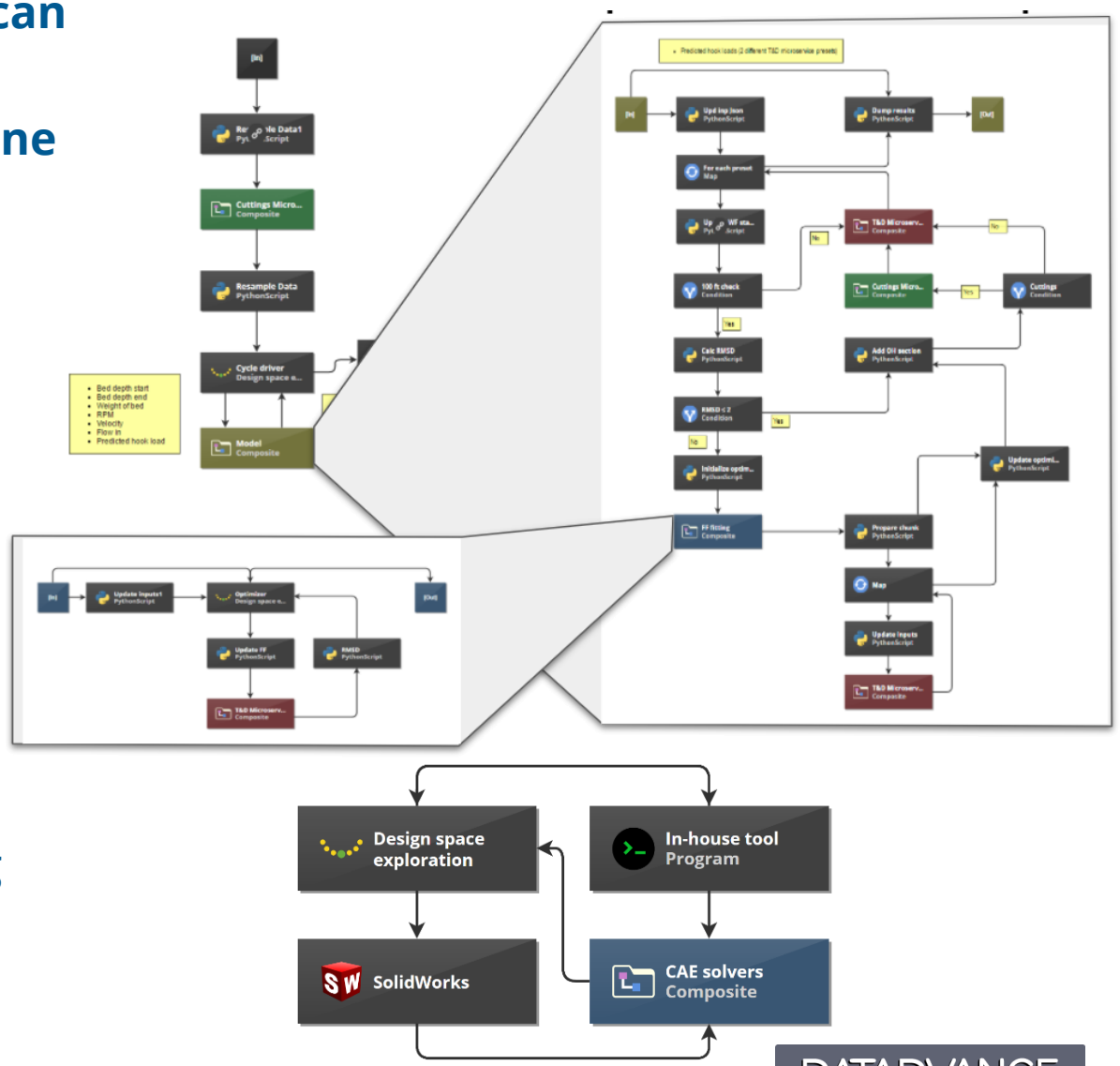
Powerful workflow automation and orchestration engine

Full-fledge visual programming:

- Intuitive and visual definition of complex processes
- Implementation of logic operations and nested loops
- Parallel and remote execution
- Data reuse and caching

Rich library of building blocks

Missing blocks and tools can be easily embedded using Python, a first class citizen in pSeven



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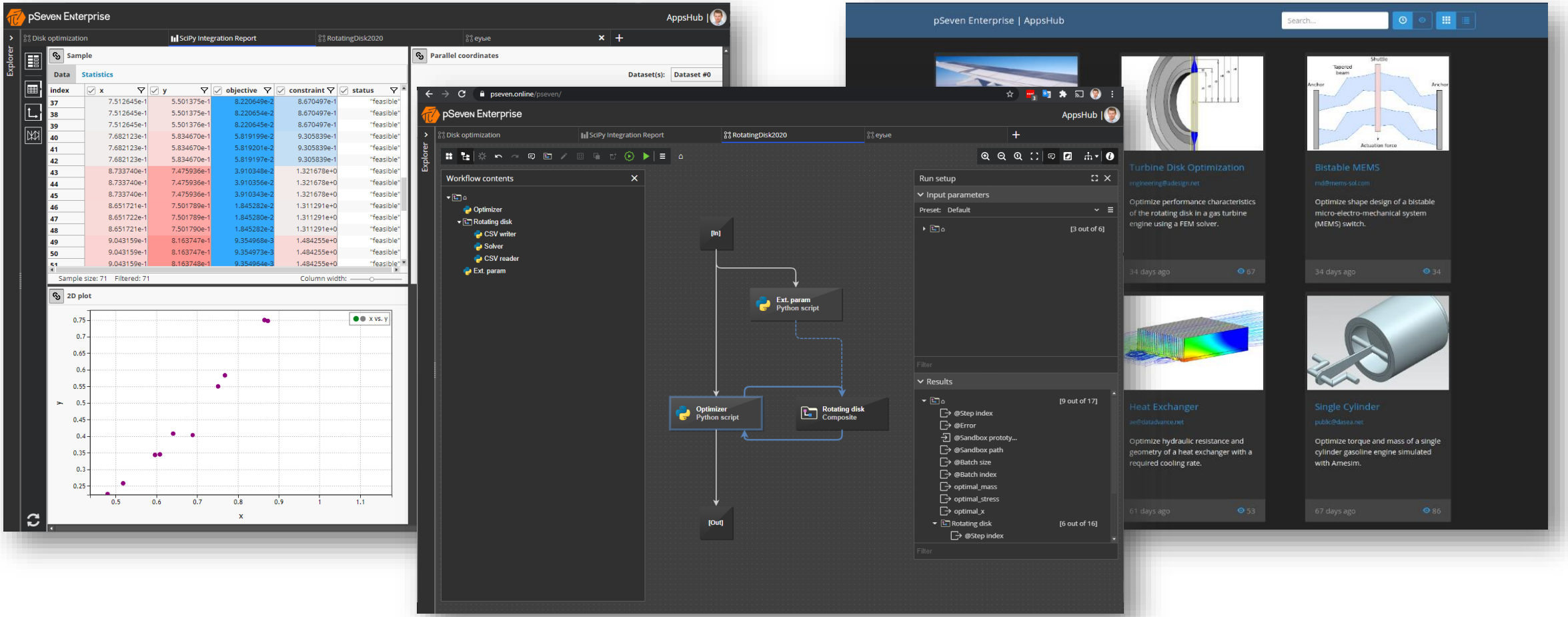
pSeven Enterprise

Same Look and Feel, But …



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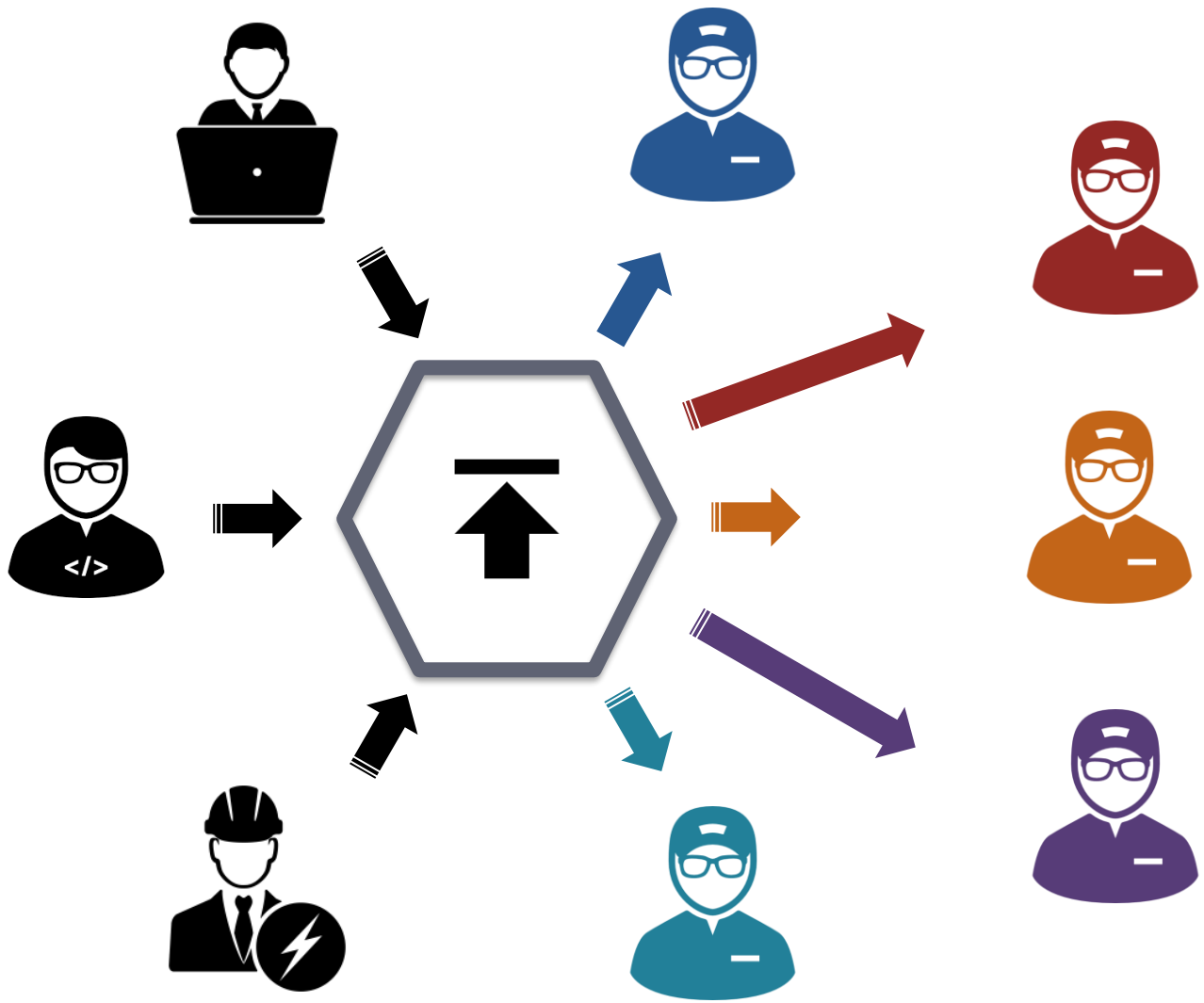
Key Features

- Facilitate collaboration between engineering teams worldwide thanks to cloud-native solution
- Improve accessibility of pSeven, external software and computational resources thanks to modern scalable architecture

- Democratization through publishing of workflow-powered web applications and services
- Easy extension of platform capabilities and integration within existing ecosystem through open APIs

Create, Publish and Run Apps and Services, and Democratize



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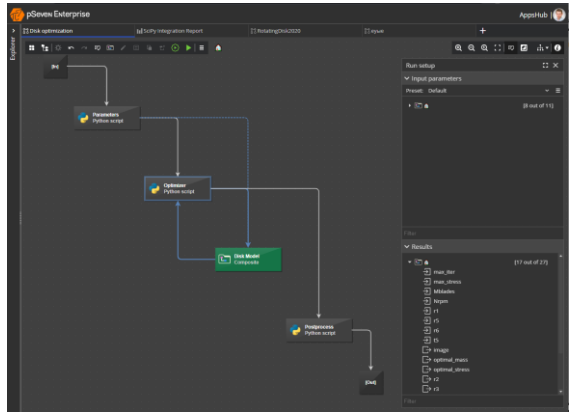
Create and Publish Workflow-powered Web Applications using AppsHub

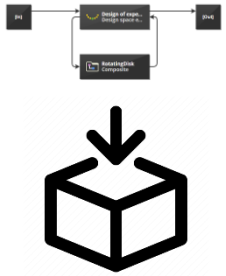
M&T EXPERTS (sim experts or data scientists)

DOMAIN EXPERTS



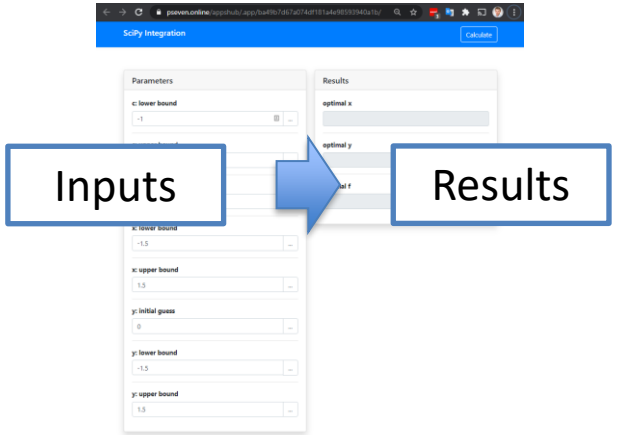
Create automated workflows

Setup simulations, load data, tune algorithms, ...



Package and Publish fully automated workflows to **AppsHub**

Experts can build Custom UI themselves, using any web UI framework



Run Workflow-Powered Apps using auto generated UI

Specify inputs, run and analyze results, ...

Run Workflow-powered Apps using Customer User Interface (via REST API)

pSeven Enterprise

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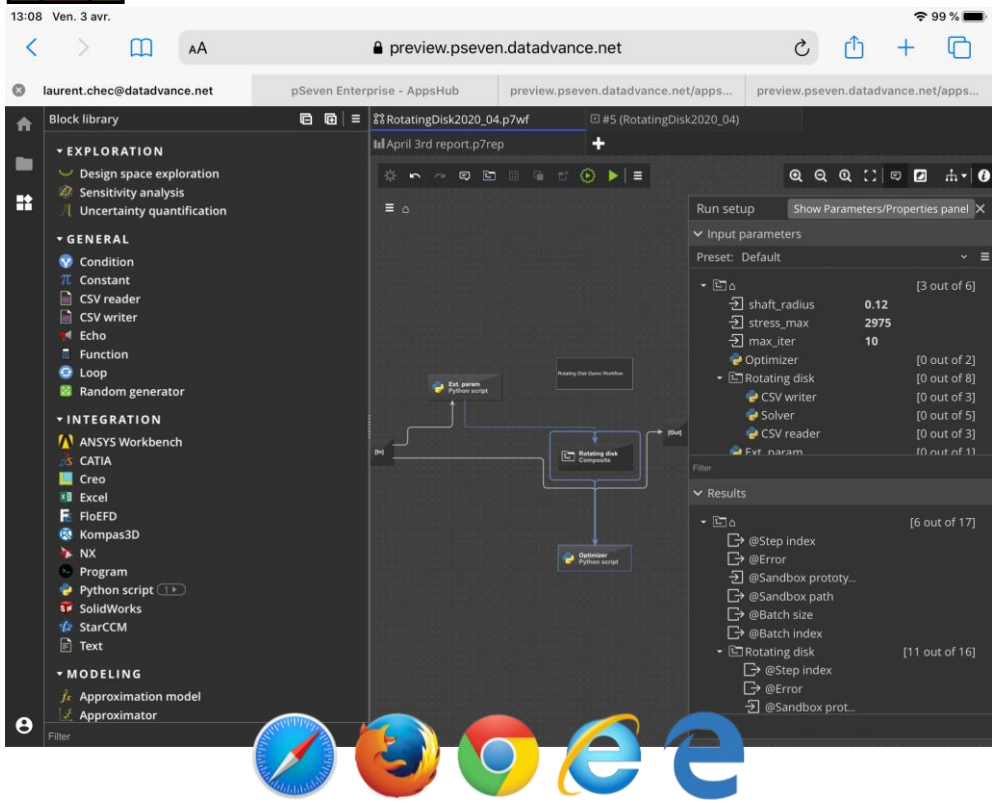
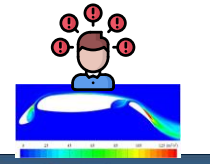
Run Apps – AppsHub Examples

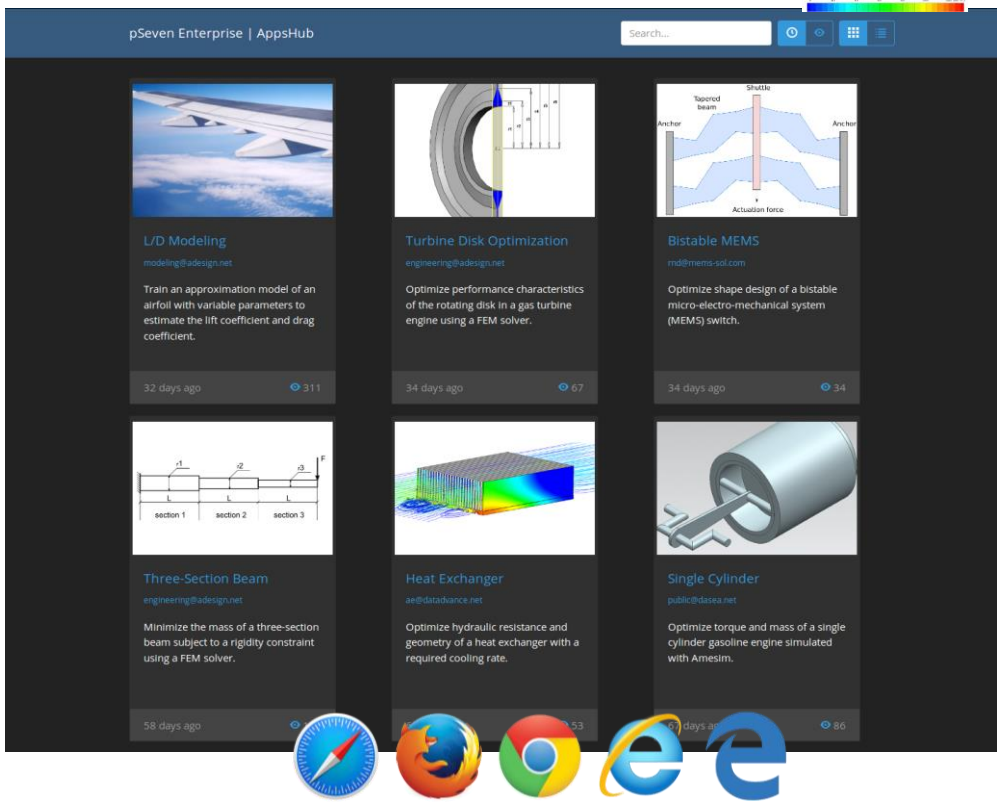
Co-authoring UI



Publish

AppsHub UI





What's next?

- You are encouraged to use pSeven in your Skoltech design and data analytics projects
- You are also encouraged to use pSeven in any other projects you just plan and already do
  - We will provide you and your team with the student licenses for free!
  - Key URLs
    - www.datadvance.net
    - https://www.datadvance.net/download/
    - https://www.datadvance.net/user/protected/license-request/
- Welcome to contribute!
  - Prototype and develop new algorithms right within the platform
  - Embed software tools
  - Build vertical apps with low-code platform – they will become part of our publicly available AppsHub
  - Join https://pseven.online/pseven/ to play/test/contribute.

pSeven Tutorials on YouTube

1 - Workflow Basics

2 - Integration capabilities basics

3 - Design Exploration. Design of Experiments

4 - Design Exploration. Optimization

5 - Analyze Basics

6 - Predictive Modeling. Model Builder

7 - Predictive modeling. Model Validator and Model Explorer

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