Partnership for Advanced Computing in Europe

Understand your design

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PRACE Autumn School 2013 - Industry Oriented HPC Simulations, September 21-27, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

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University of Ljubljana
Faculty of Mechanical Engineering

CAPACITIES

e-infrastructure

Agenda

- Introduction
- Motivation for parametric variations
- Parametric workflow in ANSYS
- Manual variation
- Systematic variation using optiSLang for ANSYS
- Typical Questions
- Efficient performance of extensive design variation

Understand your Design

Motivation for parametric variation

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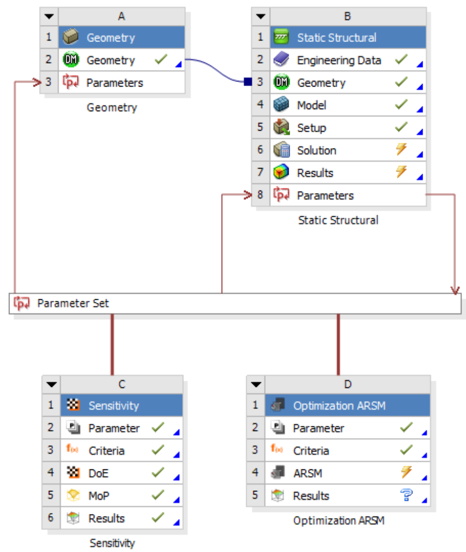
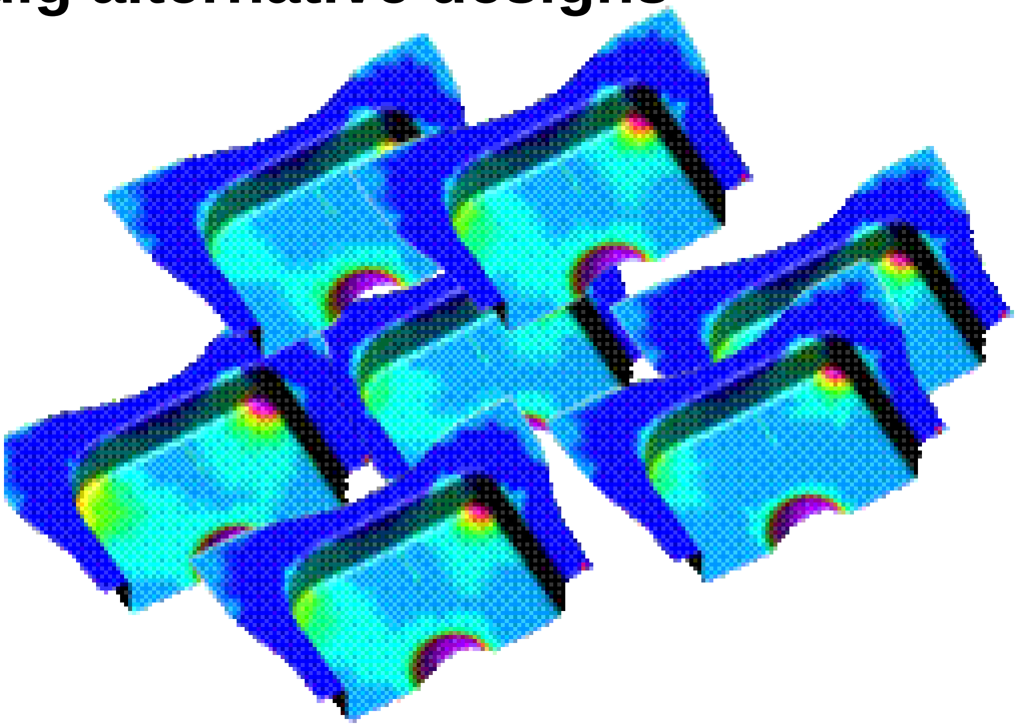
Motivation

- Understand a Design
- Match Tests and Simulation
- System Behavior
- Design Improvement
- Safe Designs

optiSLang



Understandig alternative designs



- Which designs will appear?
- What is the performance of each design?
- What causes the differencies?
- Which is the best one?

Understand a Design

Design
Part Assembly
Brake Pressure
Friction
Material
Manufacturing

Which one is most important?
Is a larger value better or a smaller value?

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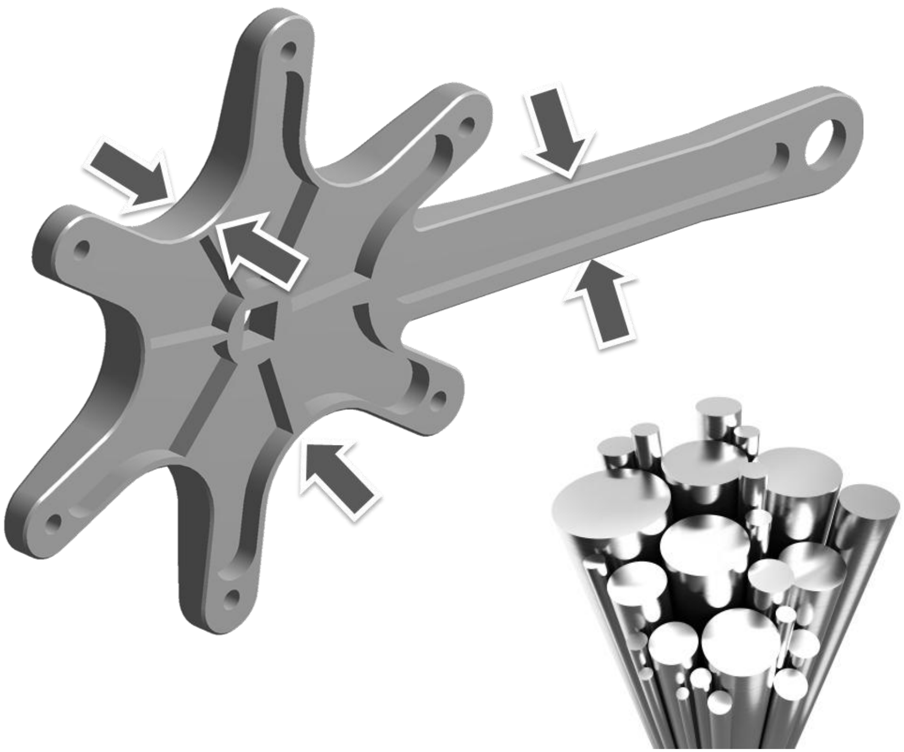
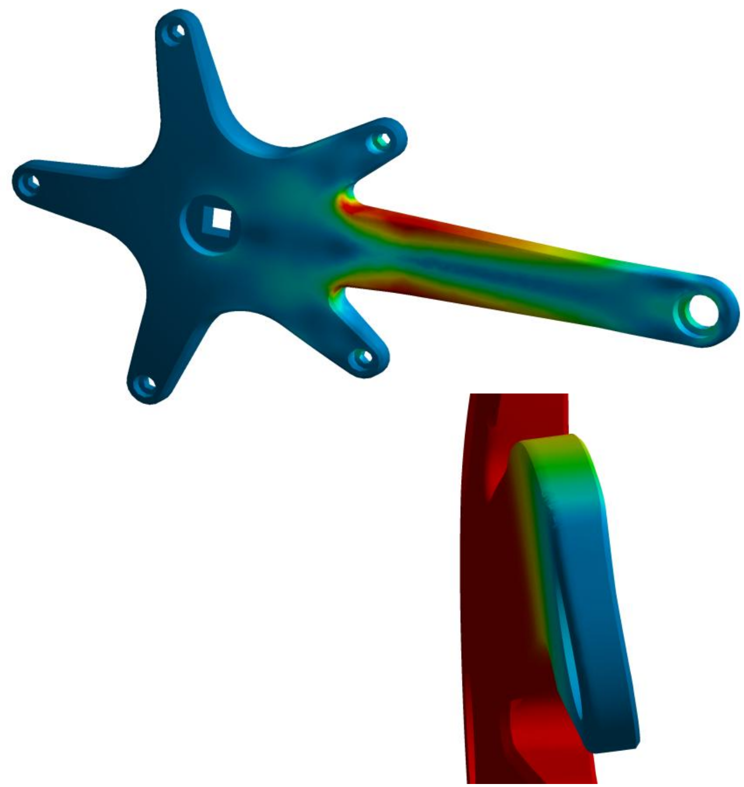
Engineering a Design





Input of engineers
defines a final design

Input is based on design
evaluations and results

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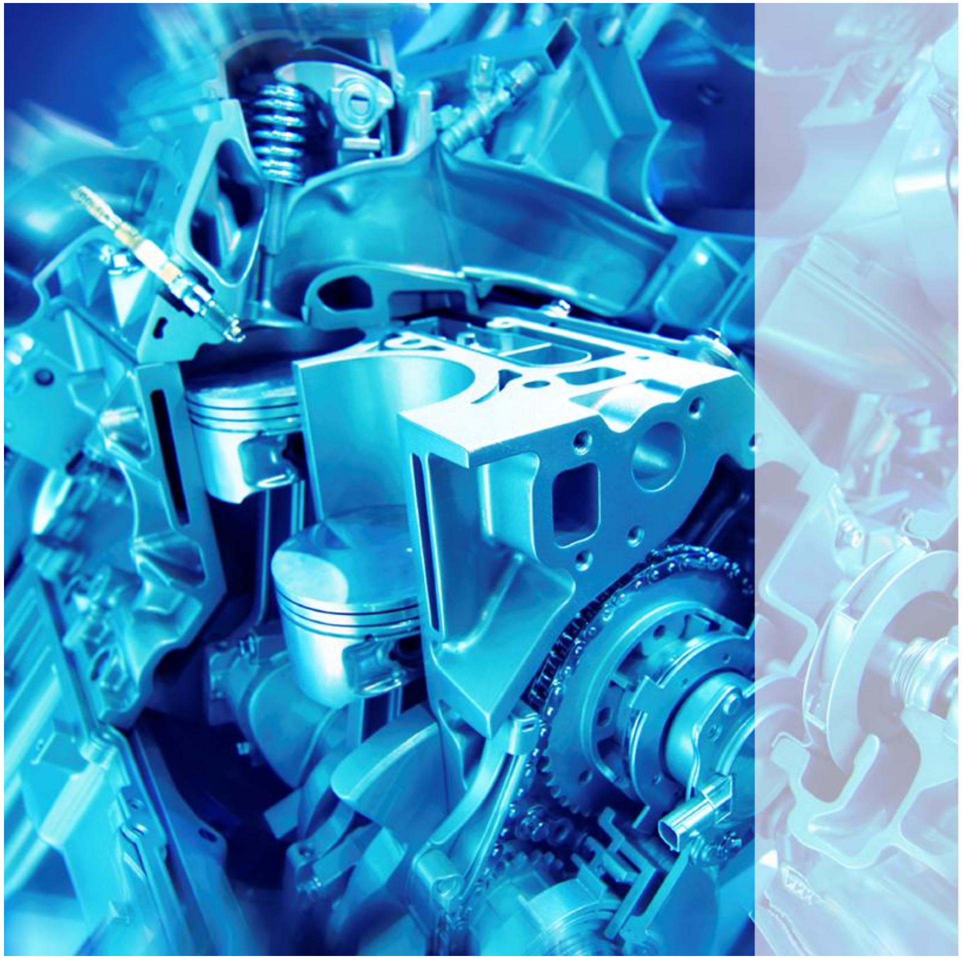
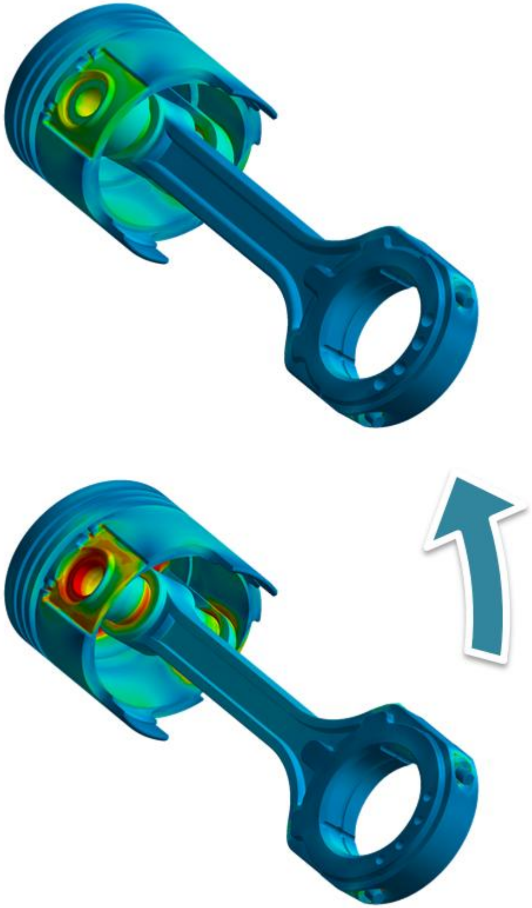
Benefits of a parametric design variation

- Get the most significant parameters.
- Check correlations.
- Estimate numerical noise.
- Determine difficulties in extracting results.
- Estimate numerical stability.
- Check your geometrical validity.
- Check potential design improvement.

Design Improvement



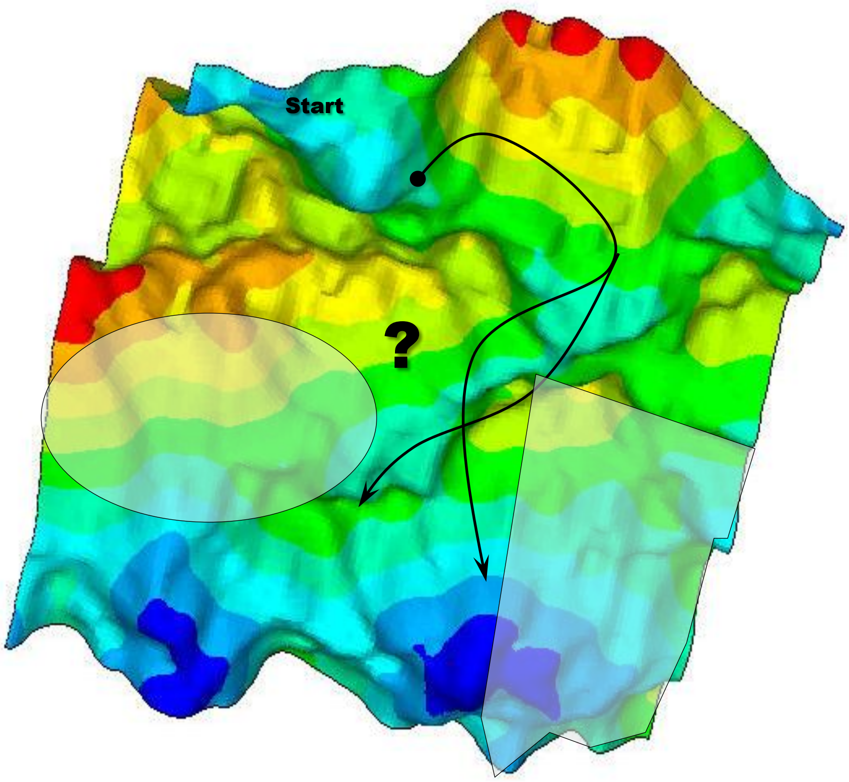


Reduce
Stress

Design Improvement

- Define improvement goals

- Insert constraints to fulfill additional conditions



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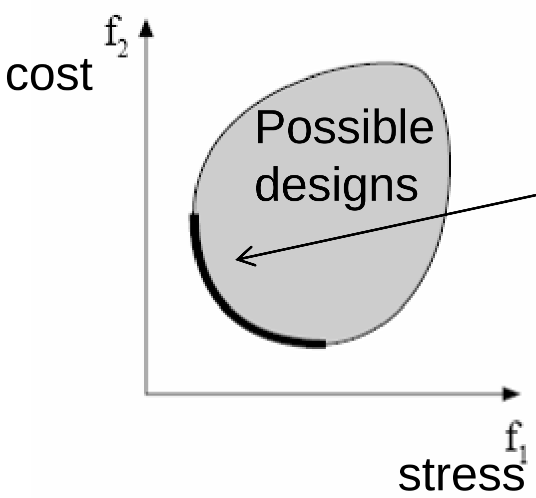
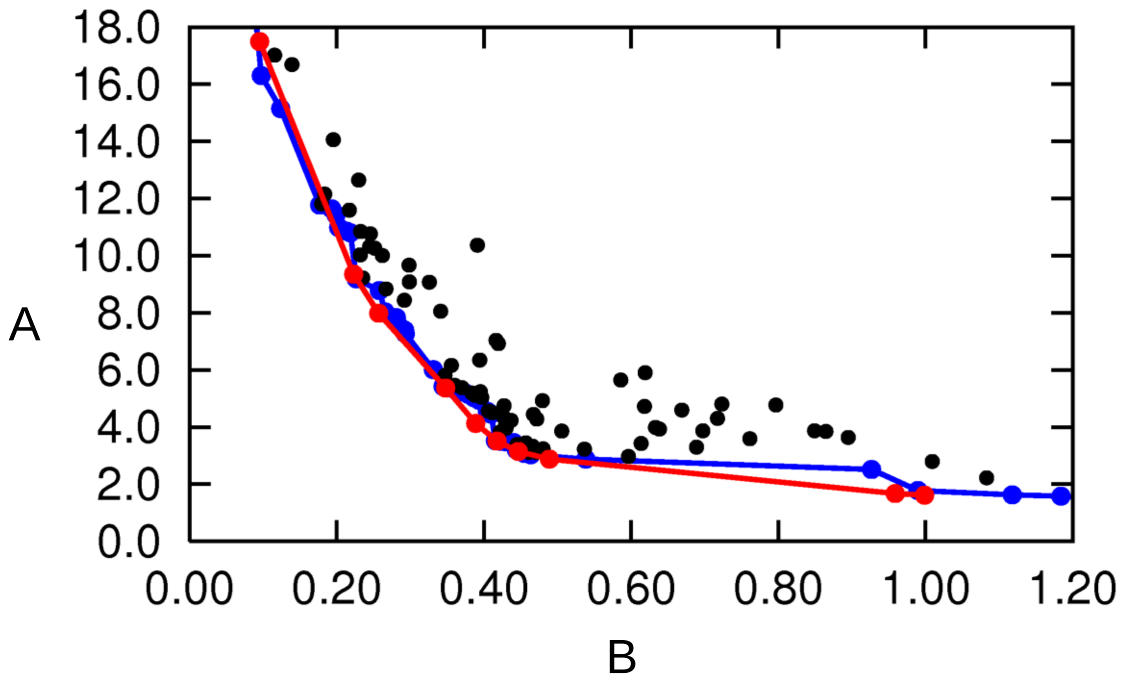
Improve conflicting properties

- Somehow conflicting requirements occur.
- Find a compromise for two (or even more) different requirements.
- „Classical“ example: minimize the volume (costs) and stress ensuring the performance.



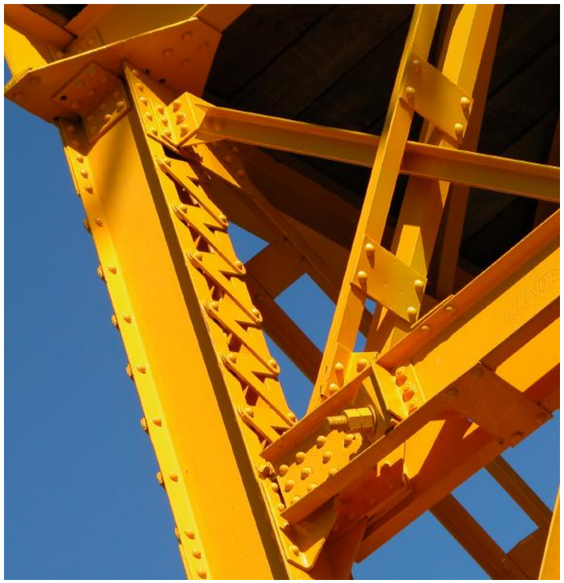
Where is my best
compromise ?

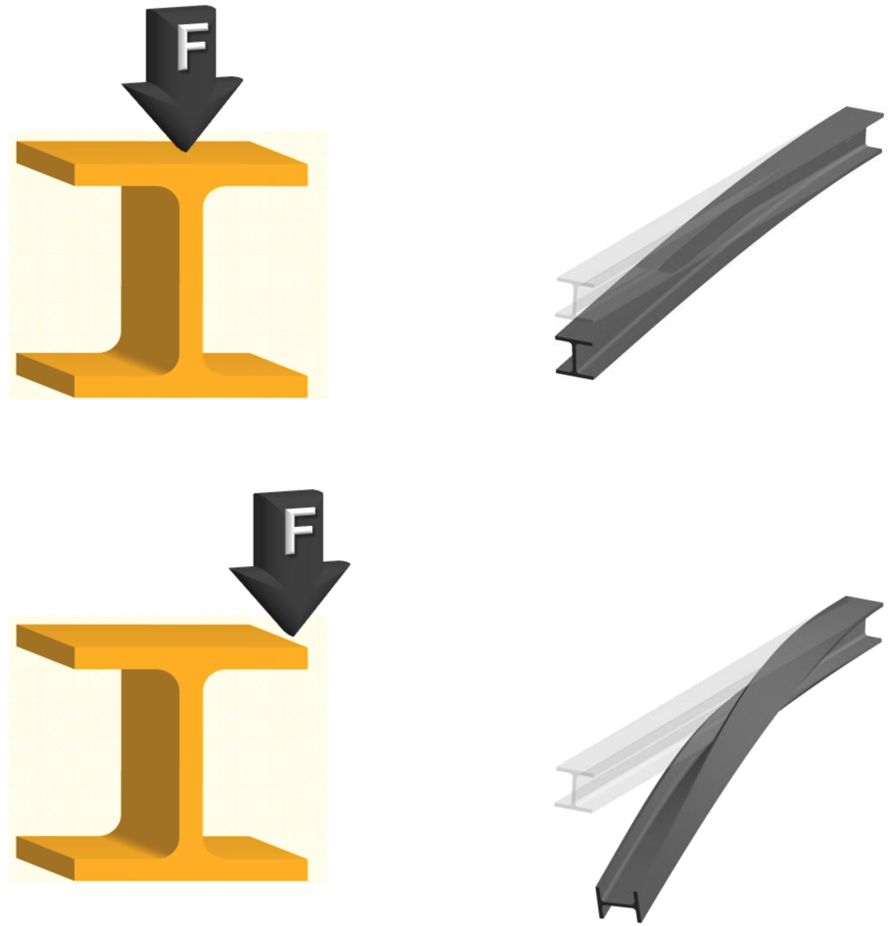
Improve conflicting properties



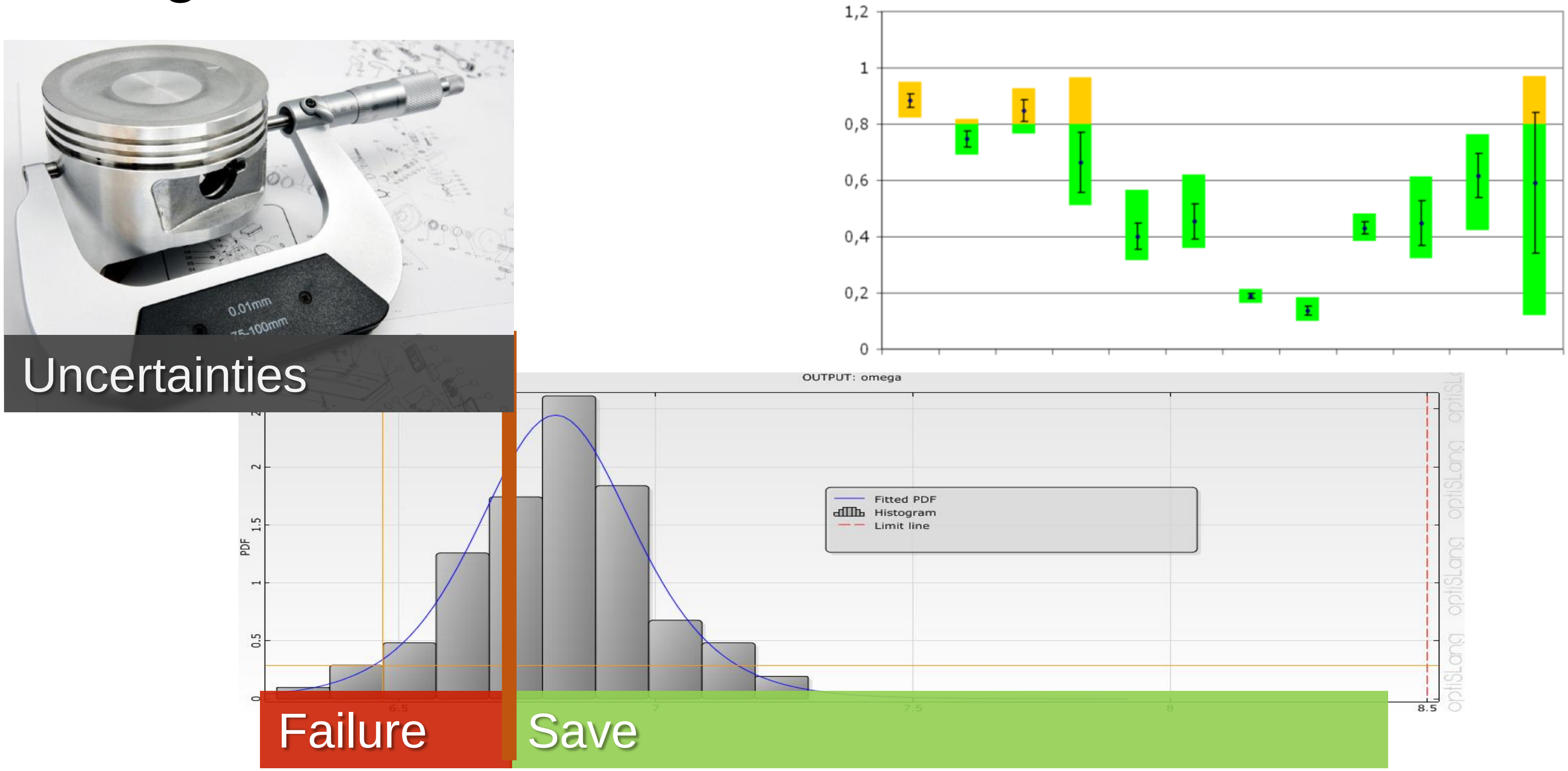
- Taking the design out of a set, that fits the demands best.
- Chose yourself, which suits more:
  - Can I improve A with no setback of B?
- How do I find the best compromise for all properties?

Dealing with tolerances





Dealing with tolerances



- How does my product react when tolerances occur?
- How safe is my product?

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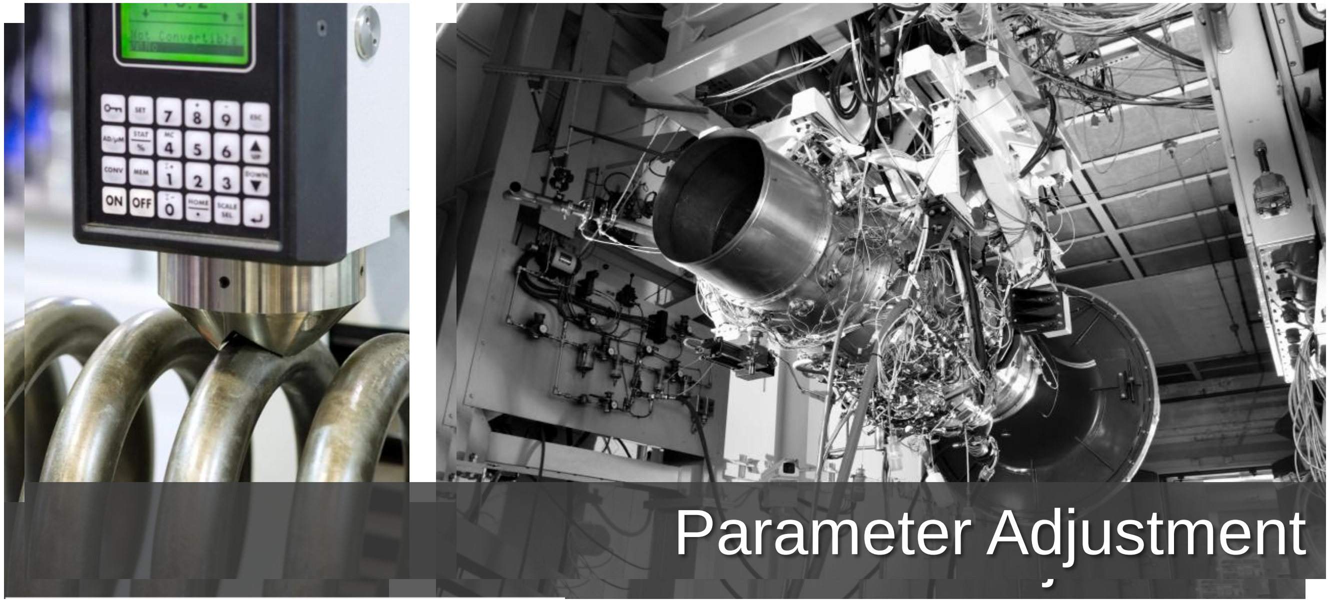
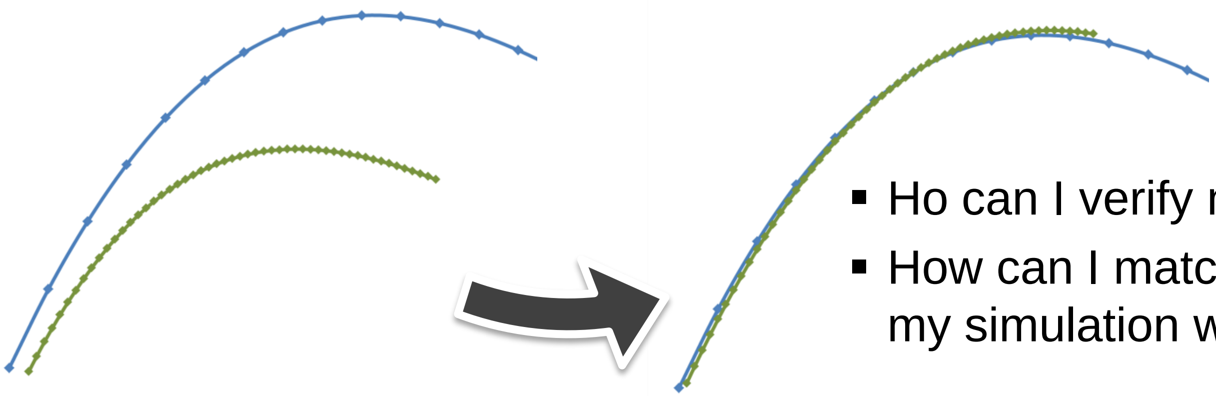
Matching simulation and test





- Ho can I verify my simulation with tests?
- How can I match the result of my simulation with tests?

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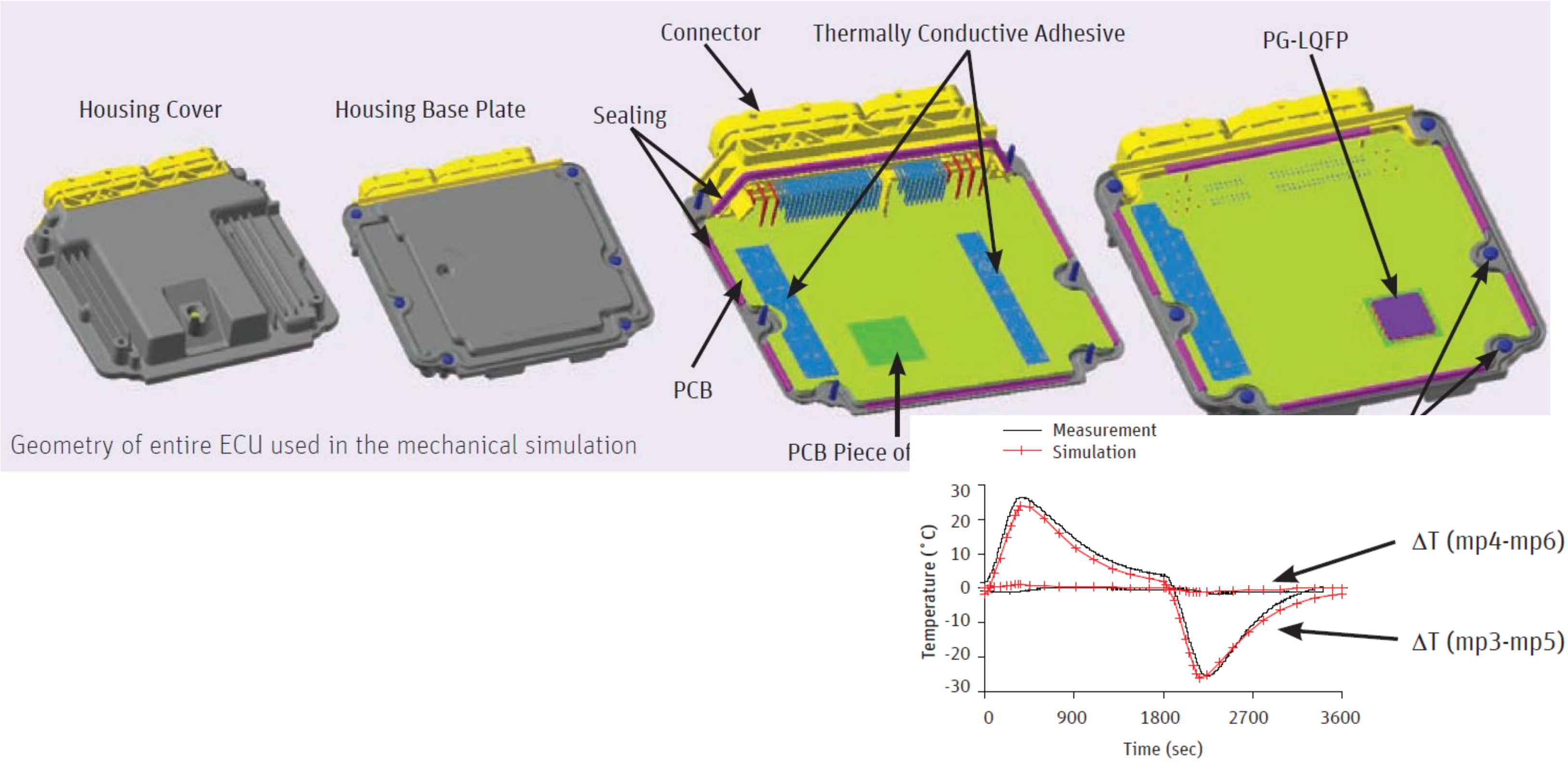
Matching simulation and test



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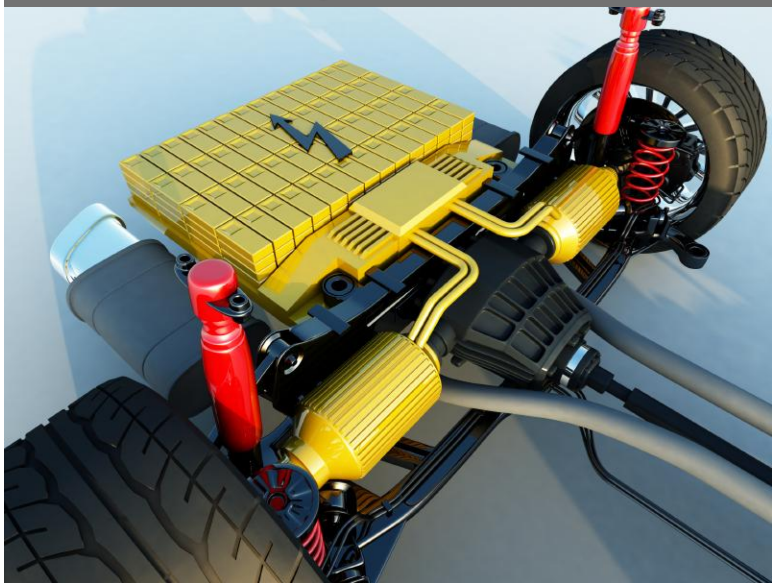
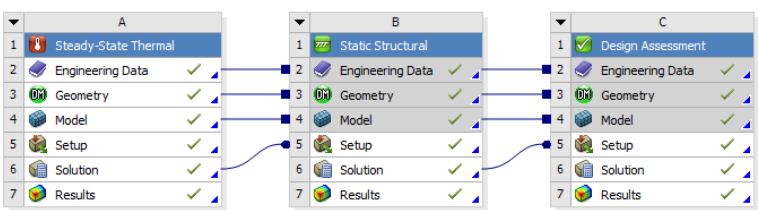
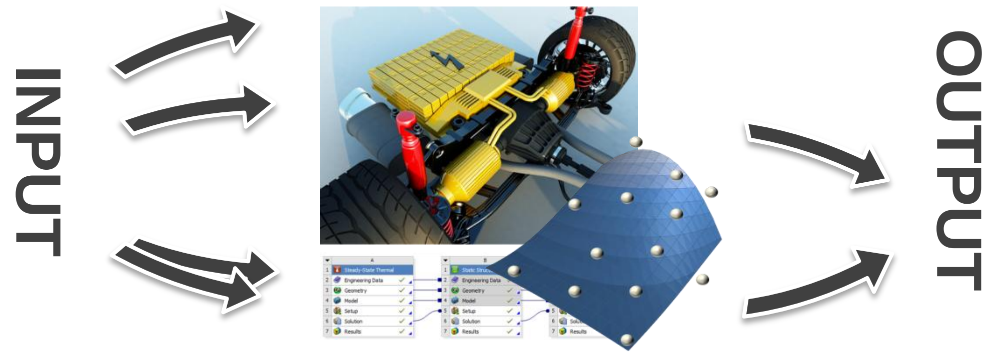
System Simulation

System Behavior



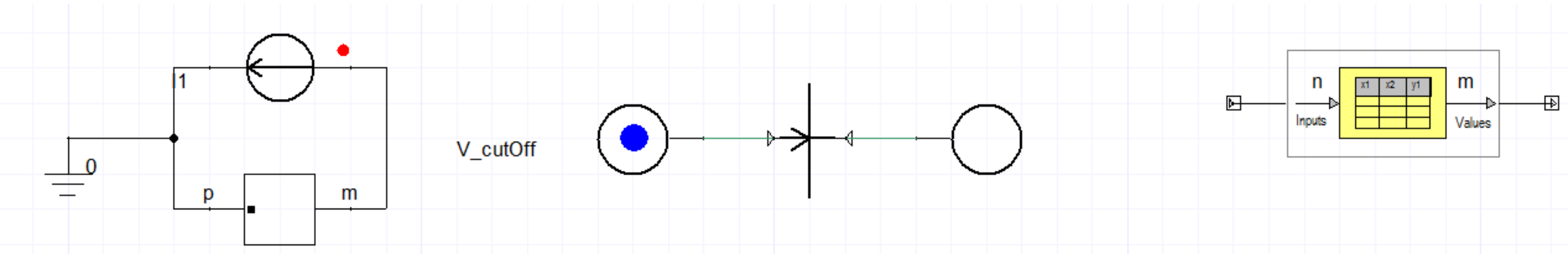


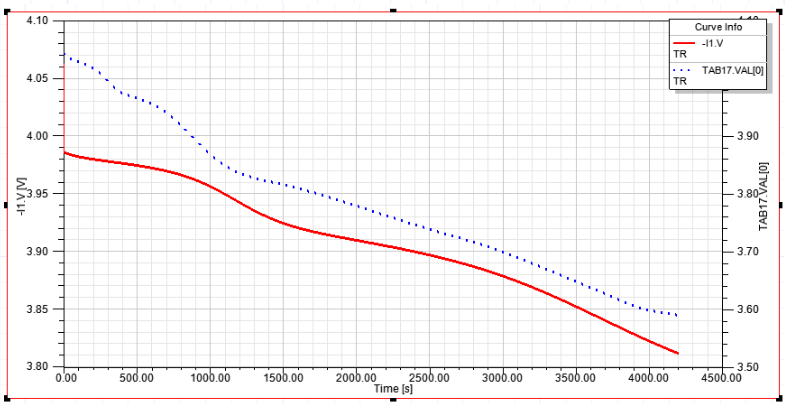


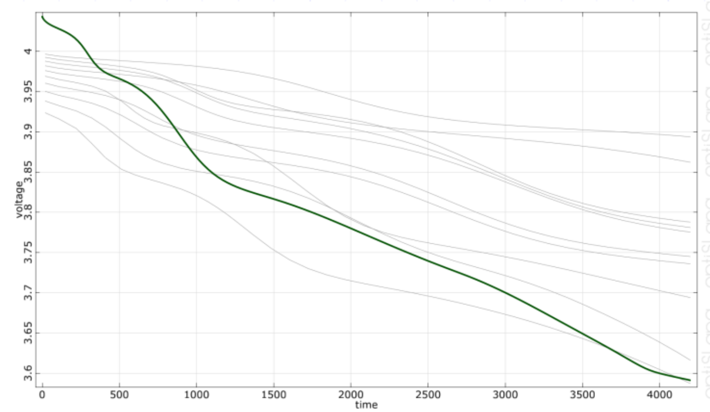
Behavior Model

Multiphysics simulation based on system coupling

- Dynamic interaction of multiple components in a system
  - Nonlinear components → Nonlinear Characteristics







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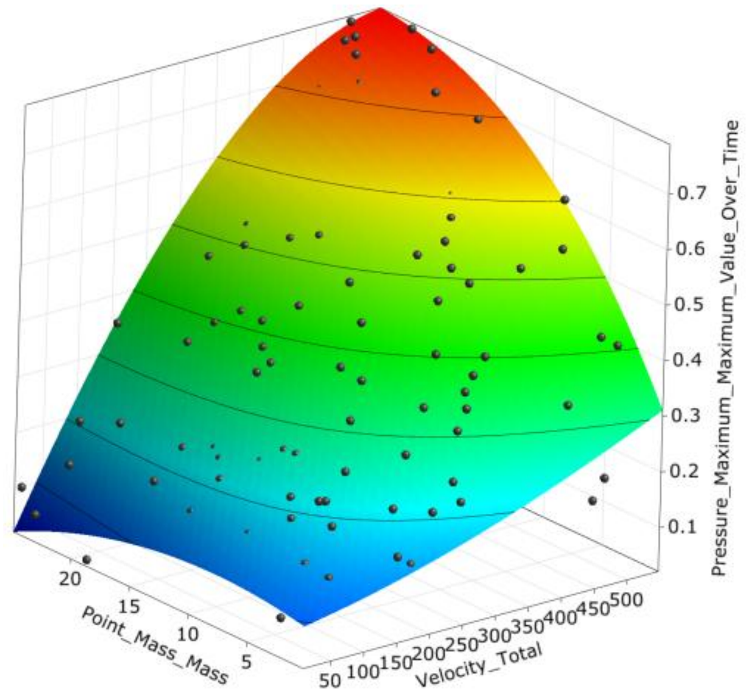
Model Reduction for Nonlinear Components

- Transfer function as characterization
  - n simulatios (DoE)
  - Extract the relation from design variables to results as behavior model
- optiSLang
  - Automatic verification and adjustment of the behavior model
    for high comfort and safety
  - High efficiency and accuracy by optimal design samples
- Implementation in system simulation (Simplorer, Matlab)
  as table or C-Code



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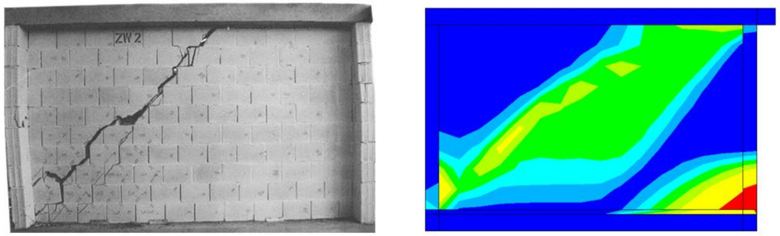
Behind optiSLang – dynardo

- Software
  - optiSLang
  - mutiPlas
  - Statistics on Structures



multiPlas: material models for masonry, soil, rock, sand, concrete, reinforced concrete, steel, wood, mortar and stone

- Consulting
  - Sensitivity, Optimization, Robust Design
  - Classroom and individual Trainings

- WOSD – Weimar Optimization and Stochastic Days
  - >70 attendees
  - >20 talks

Understand Your Design

Parametric Workflow in ANSYS

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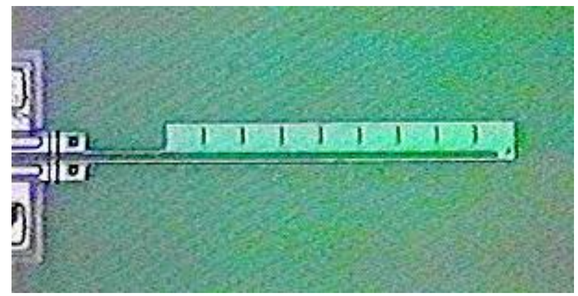
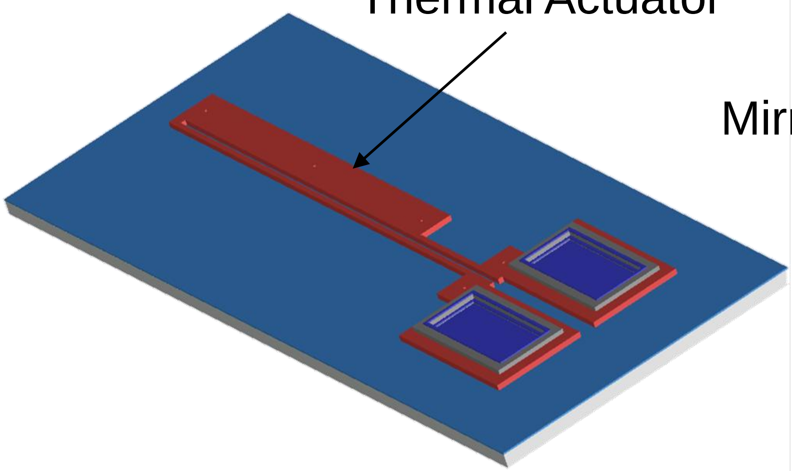
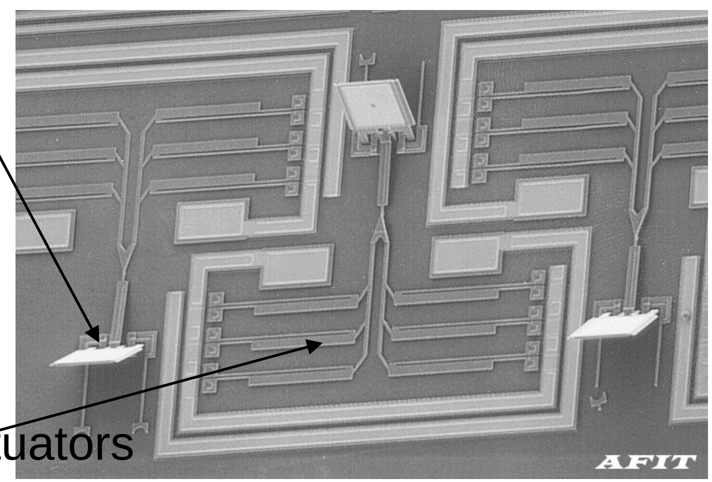
Multiphysics Analysis of an Electric-Thermal Actuator

- Mirror actuator in a DLP projector
- Electric field & Joule heating
- Thermal strain and deformation

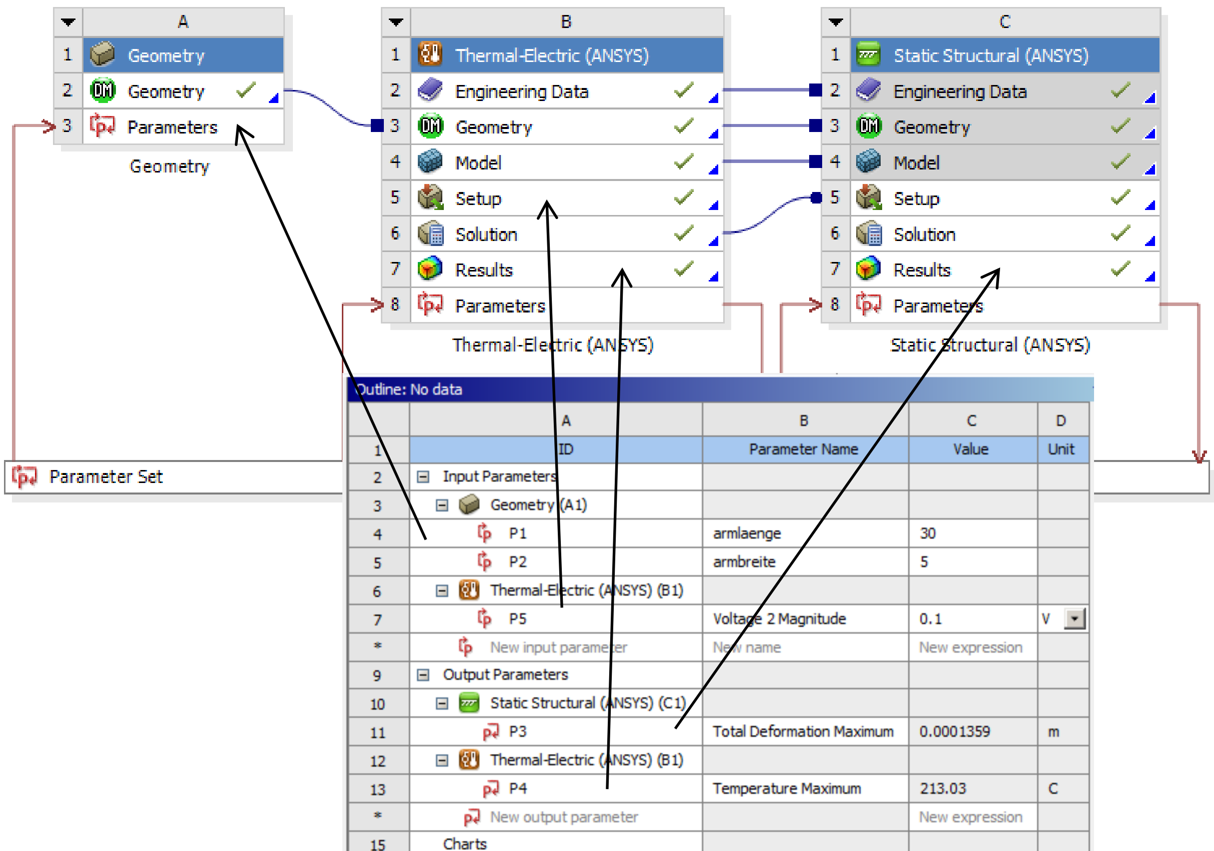






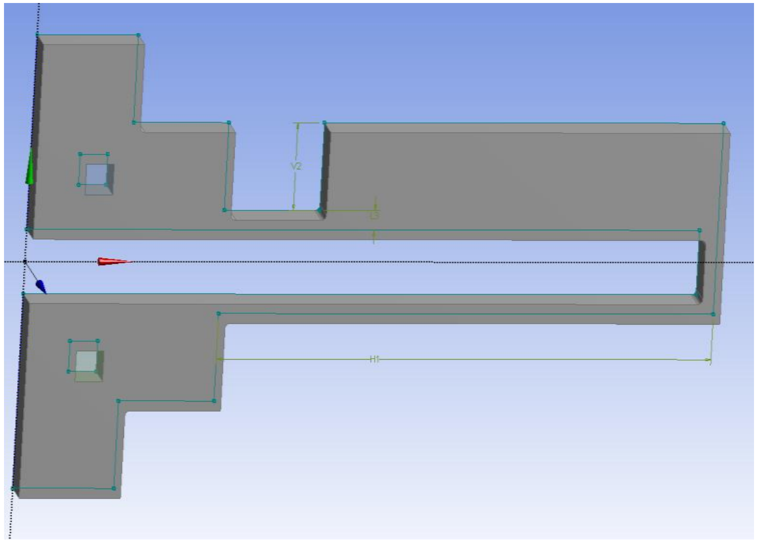
The ANSYS Workbench philosophy:

- Multiphysics in one environment by coupling of simulation systems
- Parametric persitency for all included simulations

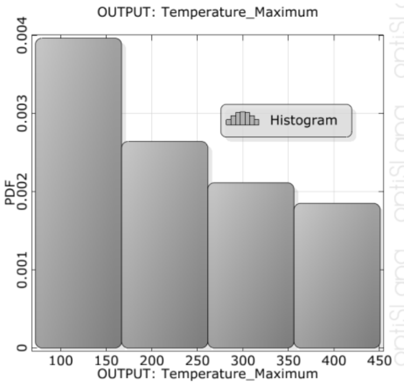


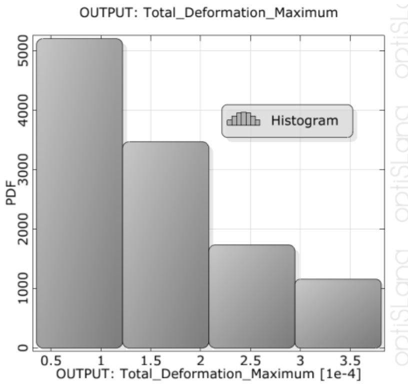
Thermal-electric Actuator

- Silizium
- Thermal-electric analysis for joule heating
  - 0.1 V on Pins
  - Convection 11W/m²K on actuator
  - 22° on Pins



- Parametric persistency
  - From electric-thermal to structural FEA
  - Understand variation
    - of Voltage, Length, Thickness
    - on Temperature, Deformation





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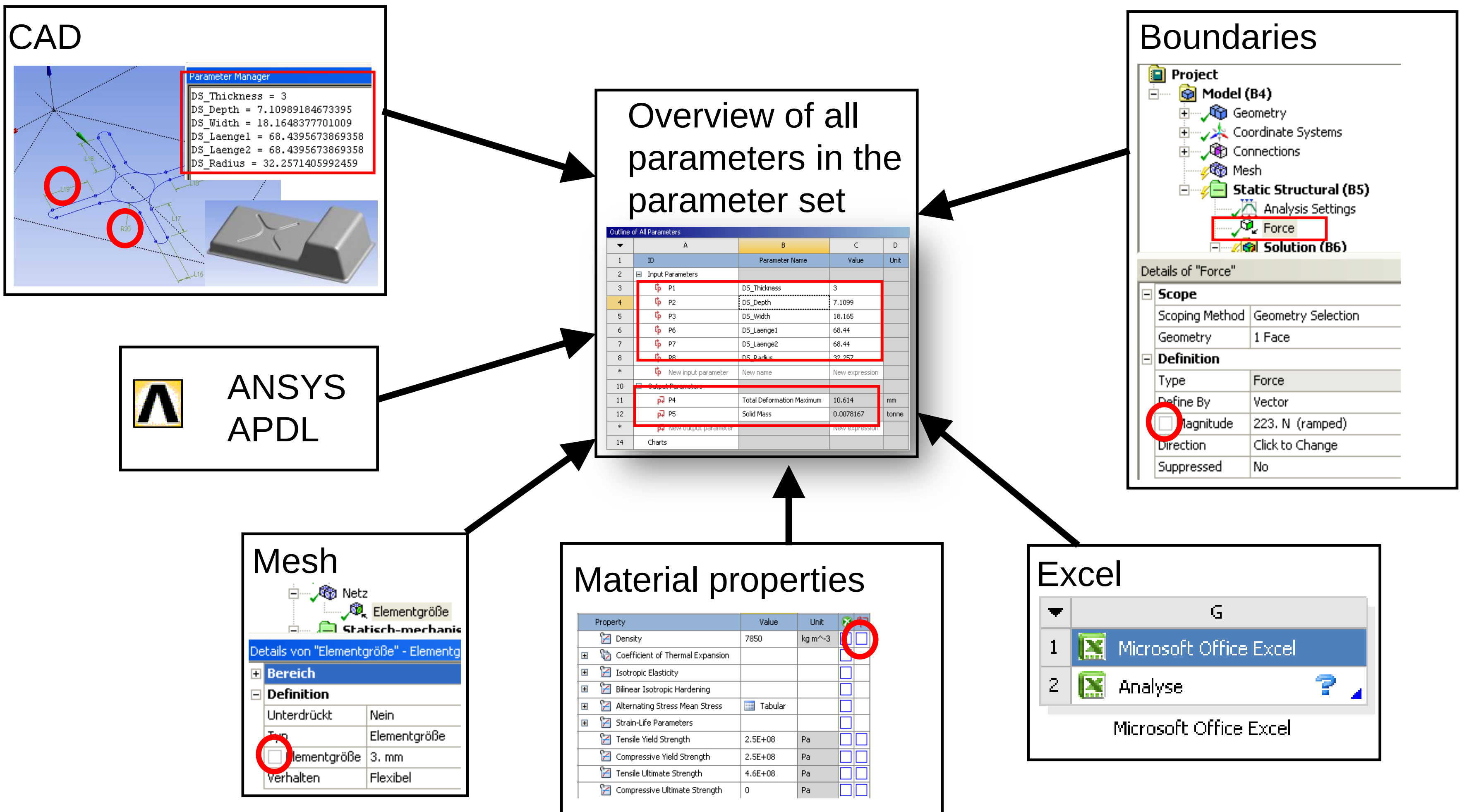
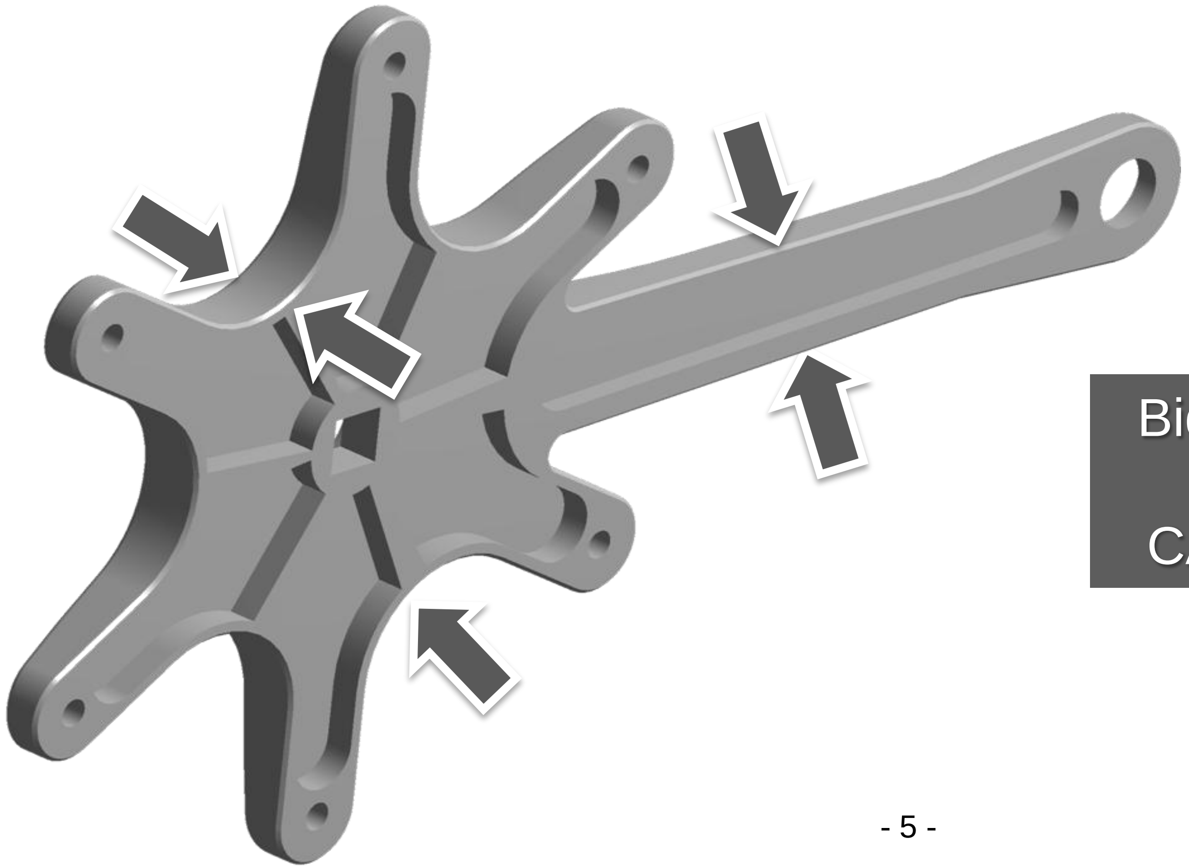
Where to get the parameters



CAD-Model Variation

- Judge design alternatives in shape and sizing



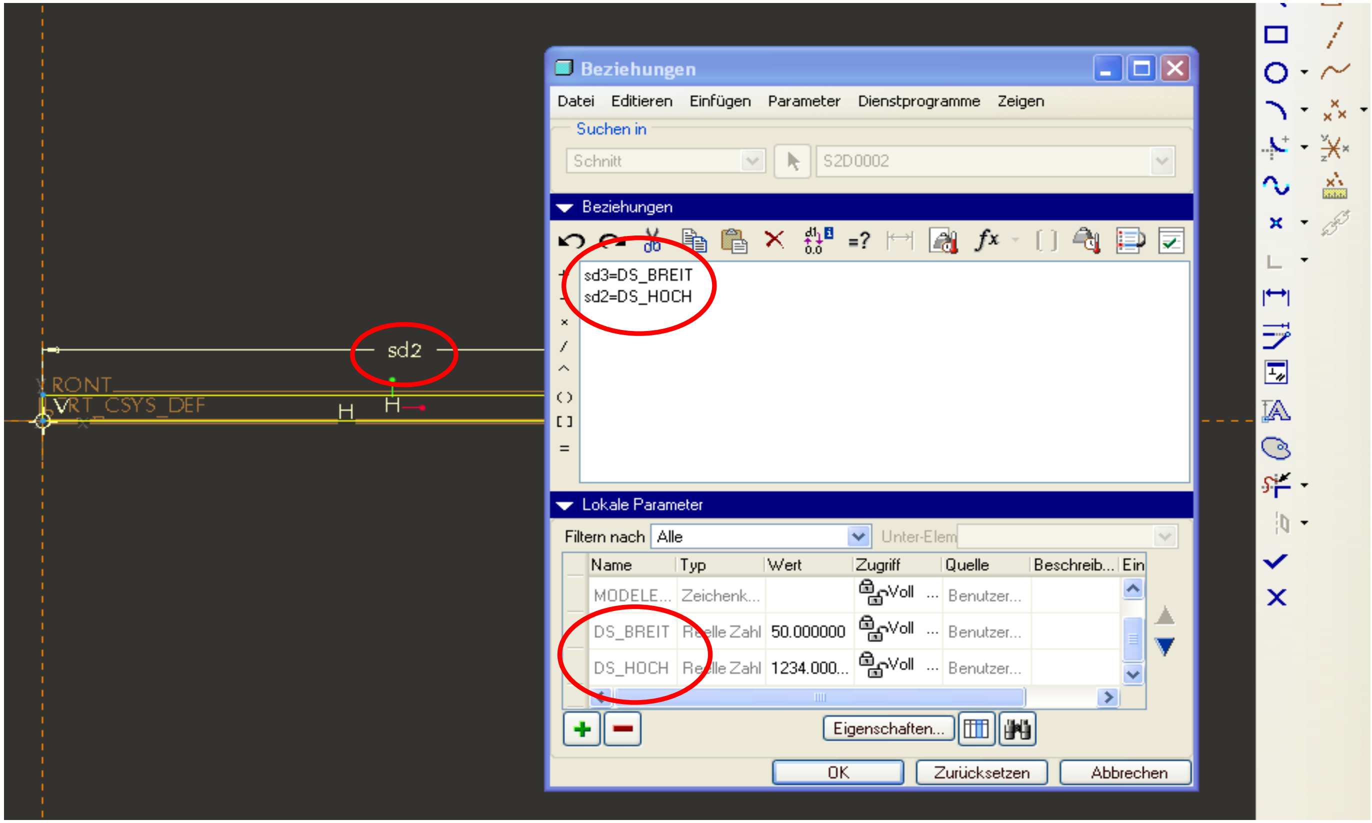
Bidirectional CAD interfaces working with parametric CAD models build the basis

Which CAD system provides parametric interfaces?

ANSYS DesignModeler	CATIA V5
ANSYS SpaceClaim Direct Modeler	NX
Autodesk Inventor	Solid Edge
Creo Parametric (früher ProE)	Solid Works

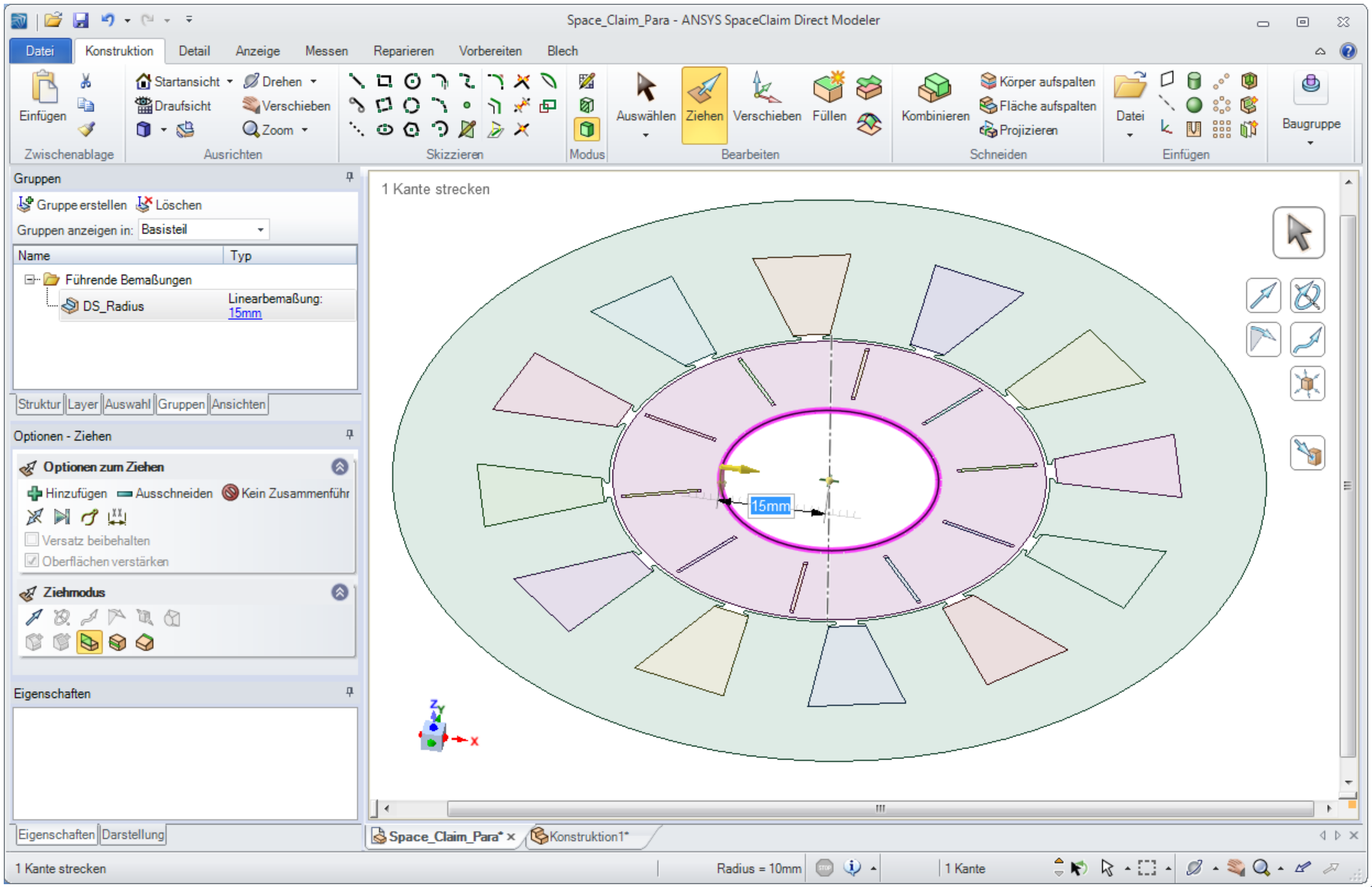
CAD Parameters

- Create some parameters in your CAD System (Here: Pro/E)



Use the SpaceClaim Direct Modeler

- Easy parametrization of „static“ geometry files (STEP, Parasolid) in SCDM



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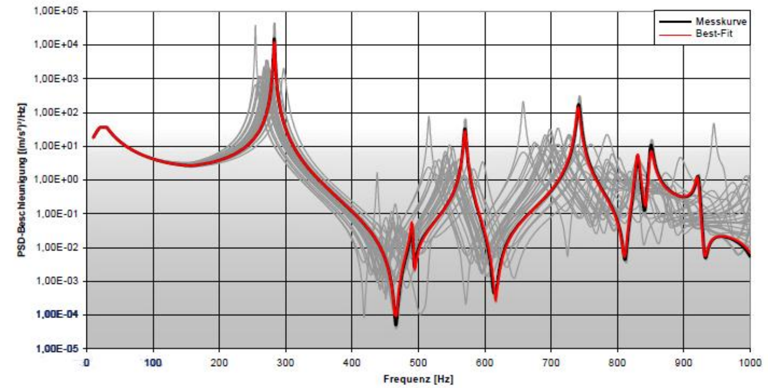
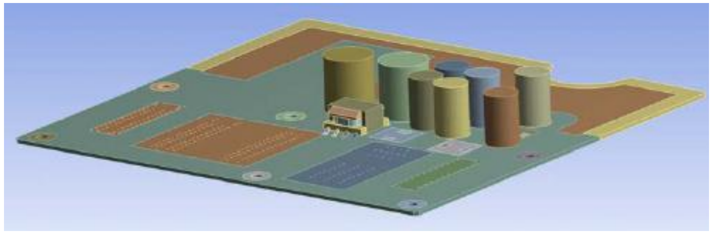
Parametric Material Modeling

- Material Parameters often application specific
  - Damping
  - Friction
  - Stiffness
  - Yield point
  - Failure
  - …
- Identification of relevant parameters by systematic variation





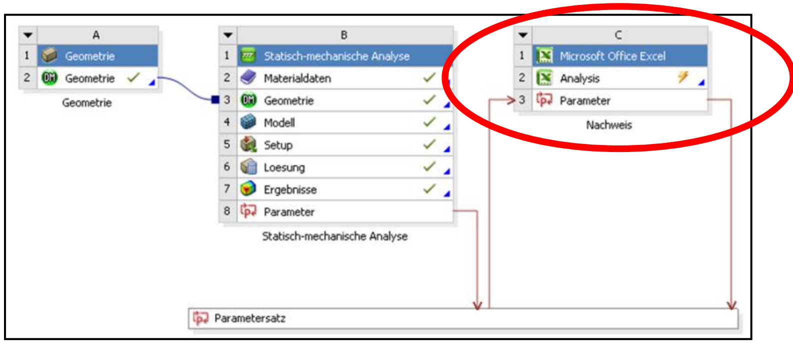
Source: Microconsult Engineering

MS Excel

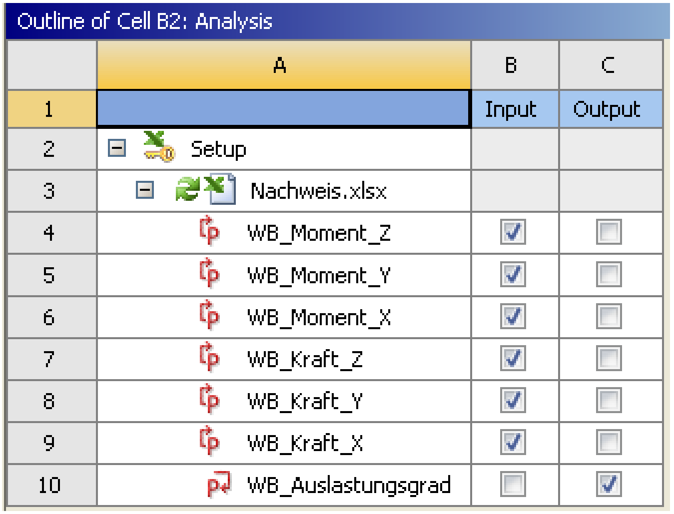
You have geometric conditions
that have to be pre-calculated?

You have your own result evaluation
routines?

You want to do additional postprocessing
regarding external criteria?



Use and link MS Excel for additional pre- and postprocessing!



Outline of Cell B2: Analysis

	A	B	C
1		Input	Output
2	Setup		
3	Nachweis.xlsx		
4	WB_Moment_Z	☑	☐
5	WB_Moment_Y	☑	☐
6	WB_Moment_X	☑	☐
7	WB_Kraft_Z	☑	☐
8	WB_Kraft_Y	☑	☐
9	WB_Kraft_X	☑	☐
10	WB_Auslastungsgrad	☐	☑

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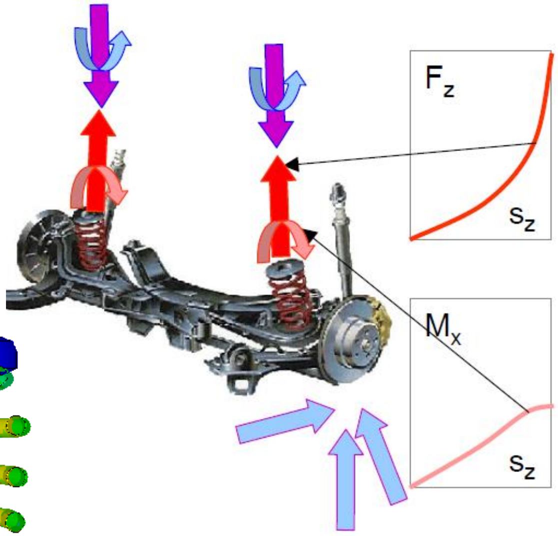
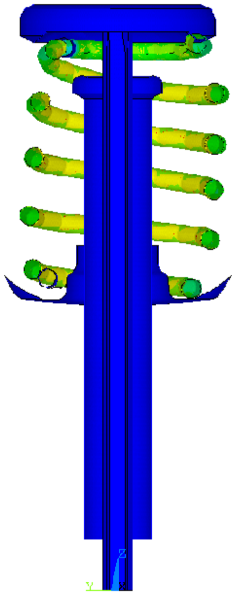
Fully Automated Simulation Workflows in APDL

- Example: Spring simulation at Muhr und Bender
  - Complete workflow
    - Geometry modeling
    - Loads
    - Simulation
    - Result calculation
- Classic model setup by ANSYS Parametric Design Language APDL
  - Text file drives workflow
  - Numbers in text files can be set as parameters





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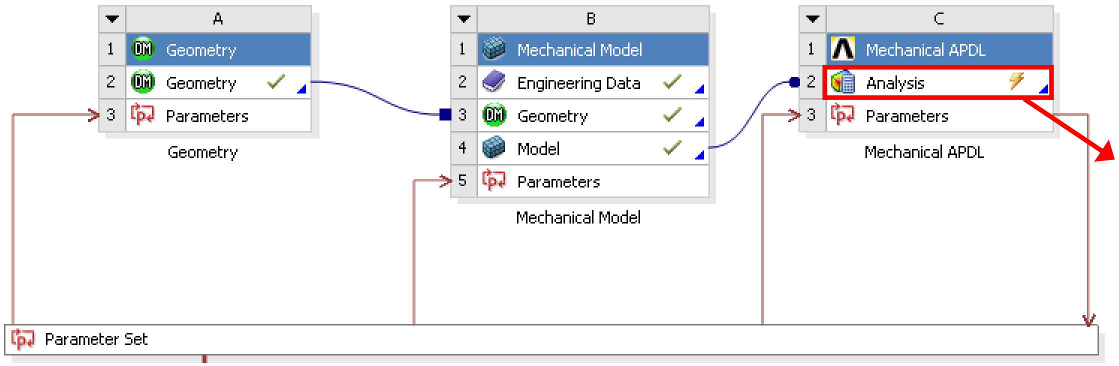
Fully Automated Simulation Workflows in APDL

- Each parameter that is created by *name=..*, **get,..* or **set,..* in an APDL Makro can be transfered to the parameter set.




```
nspin=10
maxspin=50000
*DIM,SPIN,,nspin
*do,i,1,nspin
SPIN(i) = (i-1)*50000/(nspin-1)
*enddo

! Change element type to 272 axisymm

esel,s,enam,,200
et,1,272,,3
SECT,1,AXIS
SECDATA,1,0,0,0,1,0,0

emodif,all,type,1
emodif,all,sect,1
emodif,all,mat,1

!NAXIS
ALLSEL,ALL

/COM, create springs and fix ends
et,100,combi214,,1
r,100,bestif
type,100
real,100
*get,nmax,node,0,count
cmsel,s,spring1
```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Understand your Design

Manual Variation

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Example: Notch

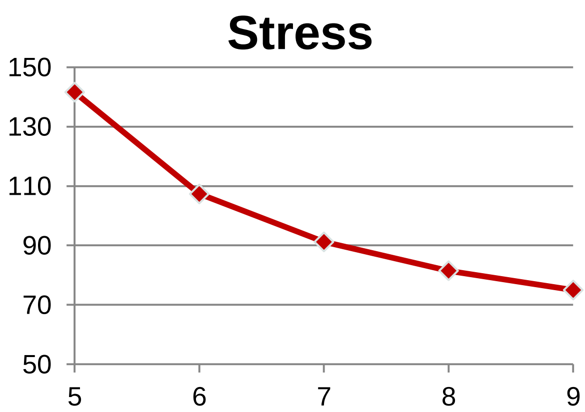
cRad = 7
thck_l = 5
cthck = 3
thck = 8
nthck = 0.42
nRad = 1
blend = 10

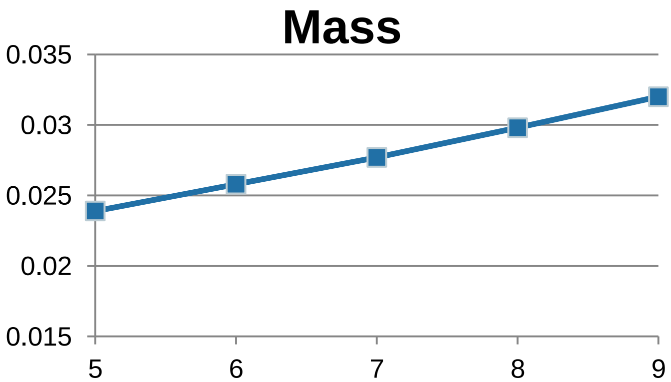
Which parameter shall be taken for a manual variation?

Example: Notch

- Take 1 Parameter: Thickness (thck) and vary it between 5 and 9
- The evaluation of the results is quite simple.
- Just use two graphs in Excel.

Thck	Stress	Mass
5	141.6	0.0239
6	107.34	0.0258
7	91.2	0.0277
8	81.5	0.0298
9	75	0.032





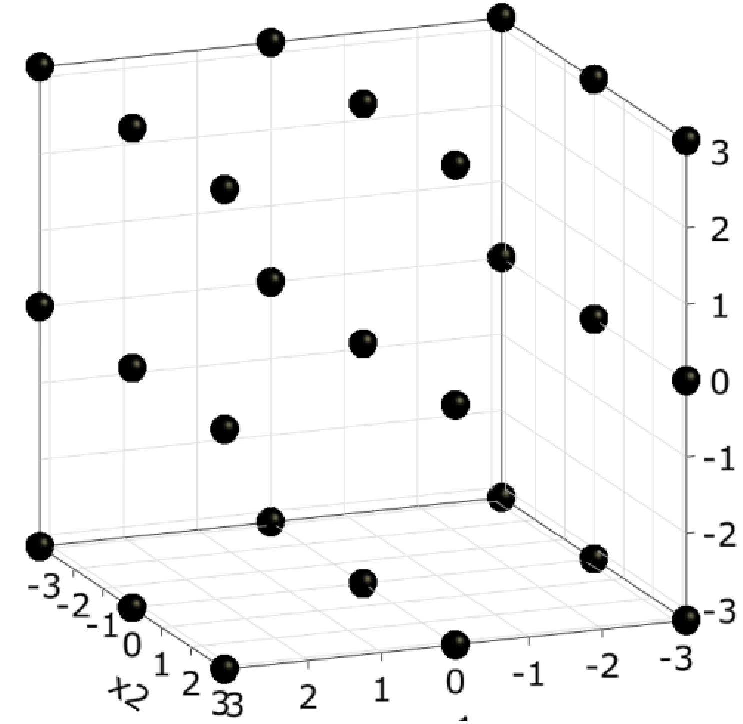
Example: Notch

- 2nd parameter: cThck, variation: 2 … 3.5
- Which combination to create?
- 3 Designs per Parameter (low-mid-high): 2^3 = 8 designs.
- Check the effect.
- Taken the right parameter?

cThck	Thck	Stress	Mass
2	5	127.9	0.0176
2	7	95.1	0.0213
2	9	82.1	0.0255
2.75	5	135.4	0.0223
2.75	7	91.9	0.0260
2.75	9	76.9	0.0303
3.5	5	181.4	0.0274
3.5	7	96.5	0.0311
3.5	9	74.5	0.0354

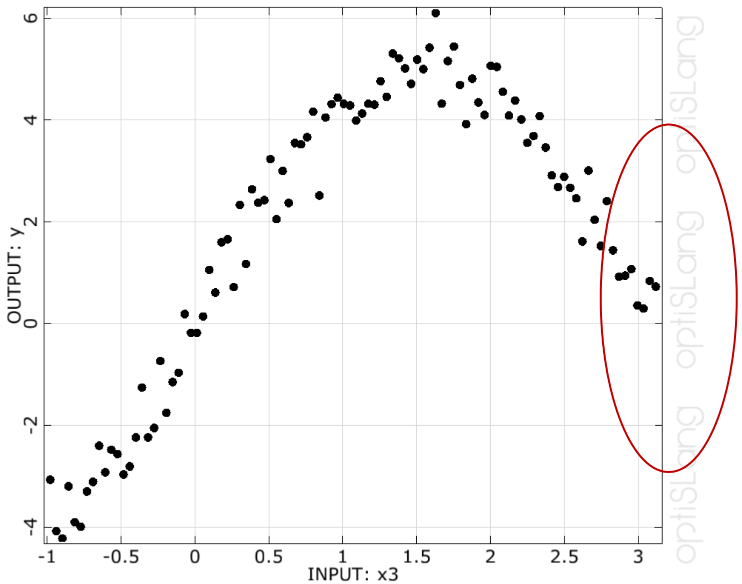
Manual variations

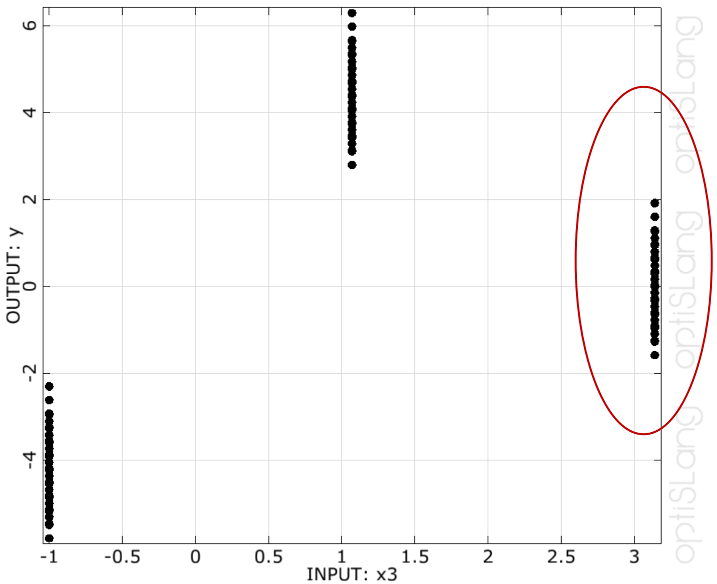
- All 7 parameters: 3^7 = **2187** designs!
- Do you want to set this up manually?
- Can you ensure that all designs can be regenerated?
- Information useful?



Understand your Design

- Manual variation: normally 3 designs (low-mid-high)
- Failed design: loss of large amount of information
- Stochastic sampling:
  - No loss of information, best representation of variation space!





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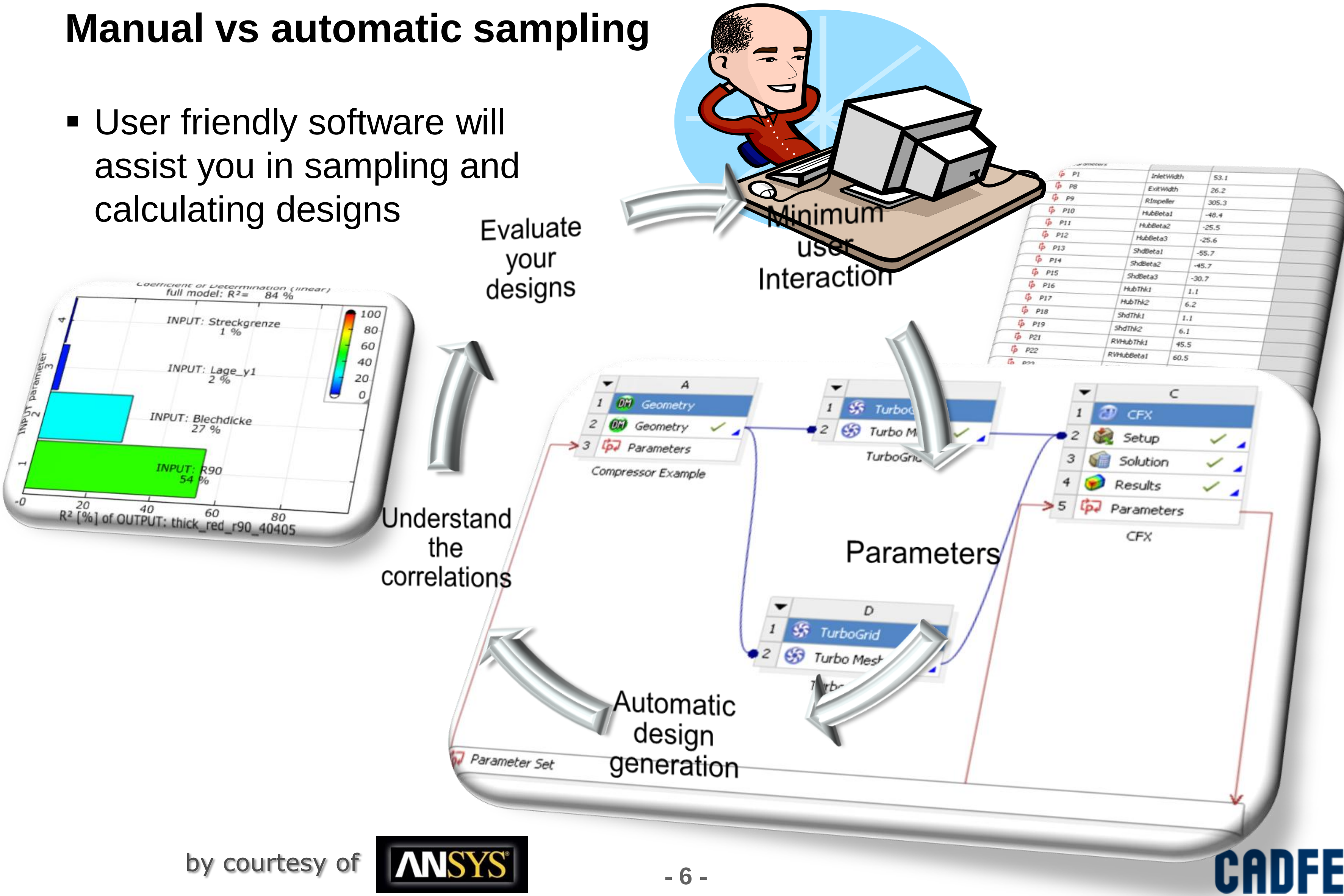
Manual vs automatic sampling

- User friendly software will assist you in sampling and calculating designs



by courtesy of ANSYS

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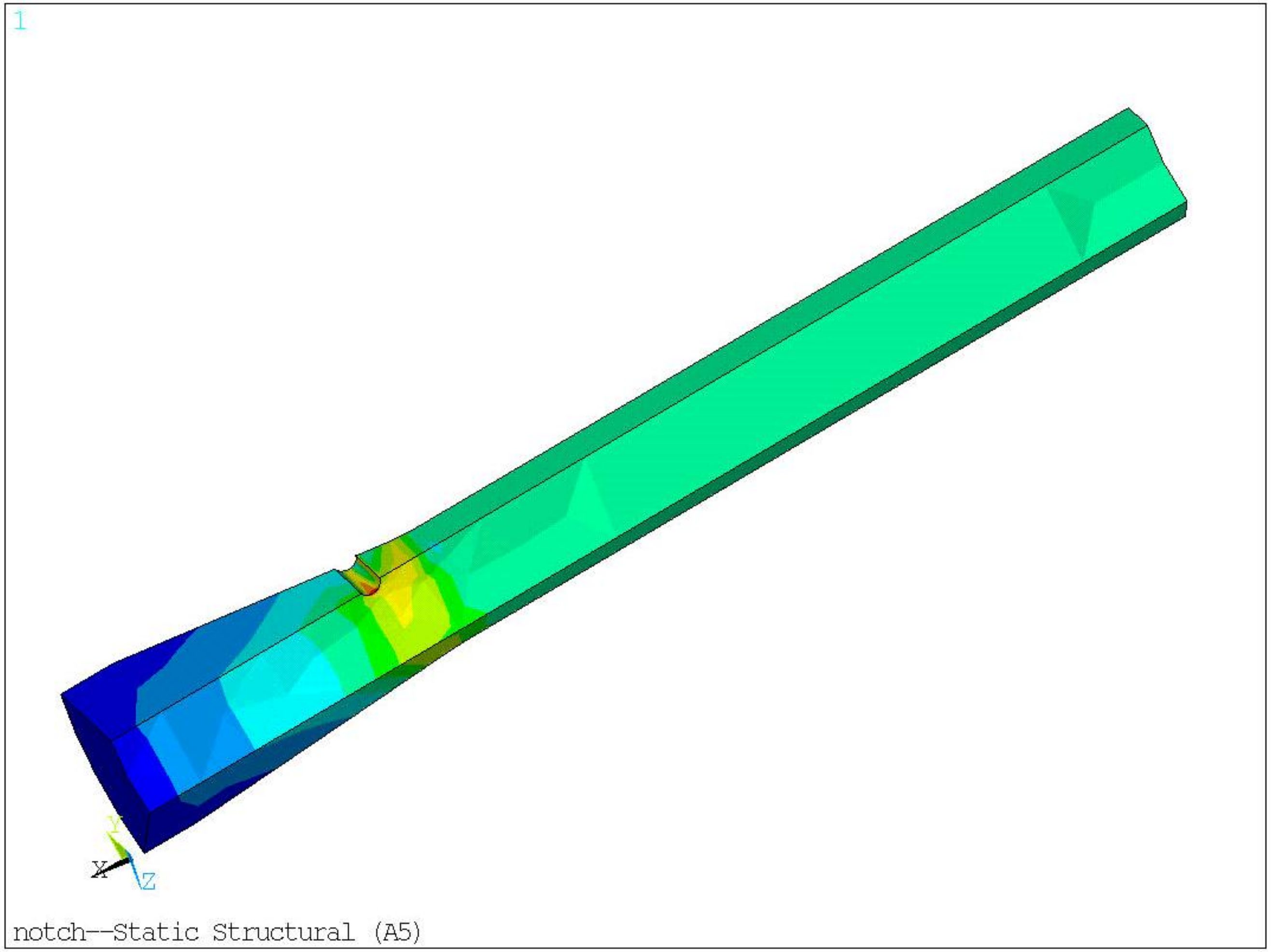
The automatic sampling



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Understand your Design

Systematic variation using optiSLang inside Workbench

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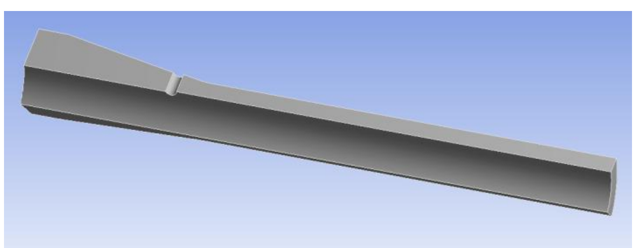
Example: Notch

Parametrization

force= const. 1000N
cylinder_radius = 7 (5-8)
thickening_length = 5 (2-6)
cylinder_thickness = 3 (2-3.5)
thickening_thickness = 8 (5-9)
notch_thickness = 0.42 (0.3-0.5)
notch_radius = 1 (0.6-1.2)
ausrundung = 10 (4-12)



Design Improvement goal:

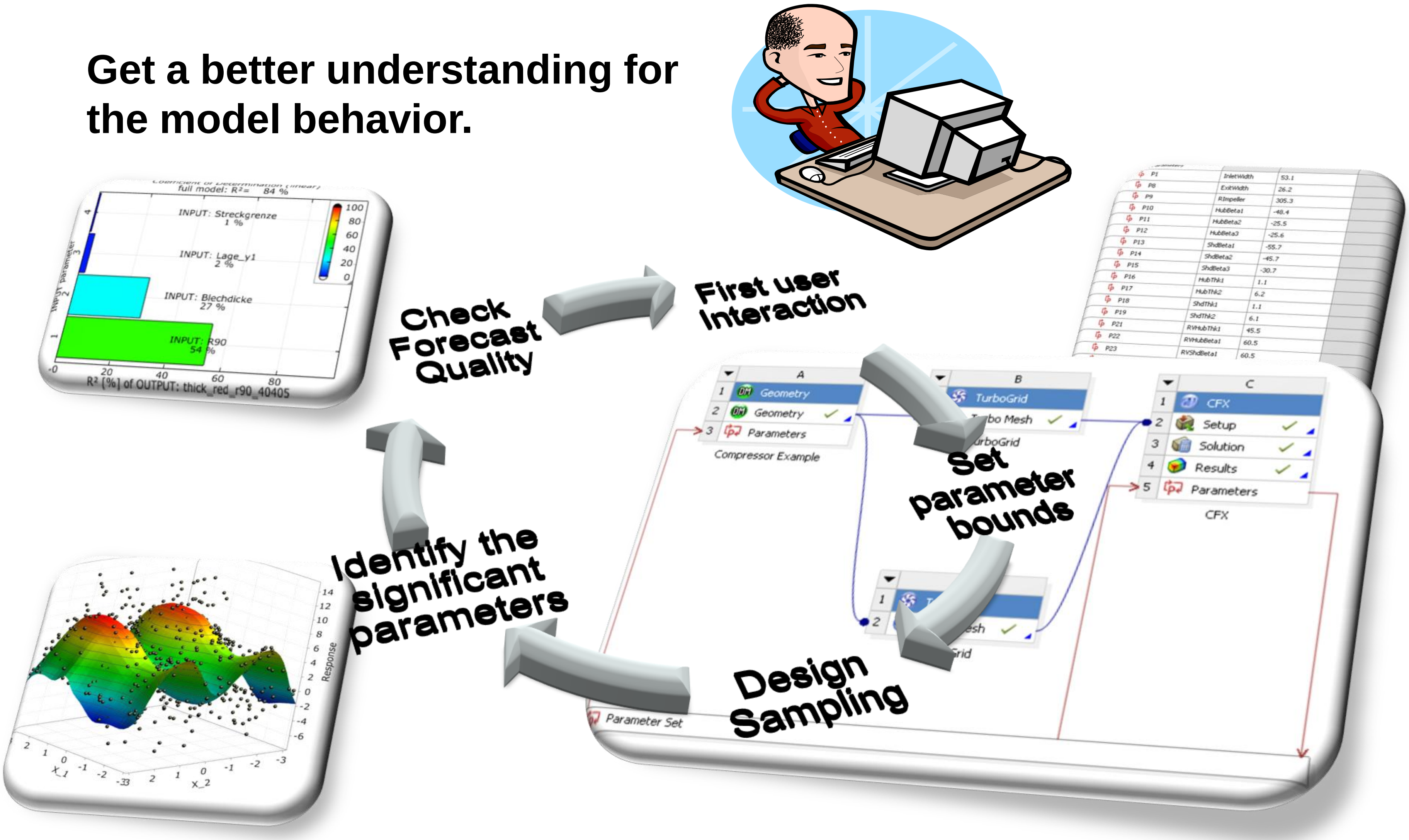
- Minimize the deformation and the mass.
- The stress should not exceed 140 MPa.

Content

- Systematic variation using optiSLang inside Workbench
  - Get a better understanding for the model behaviour
  - Improve your design
  - Dealing with tolerances
- Examples
  - Sensitivity Analysis and Design Improvement of a notch

Understand your Design

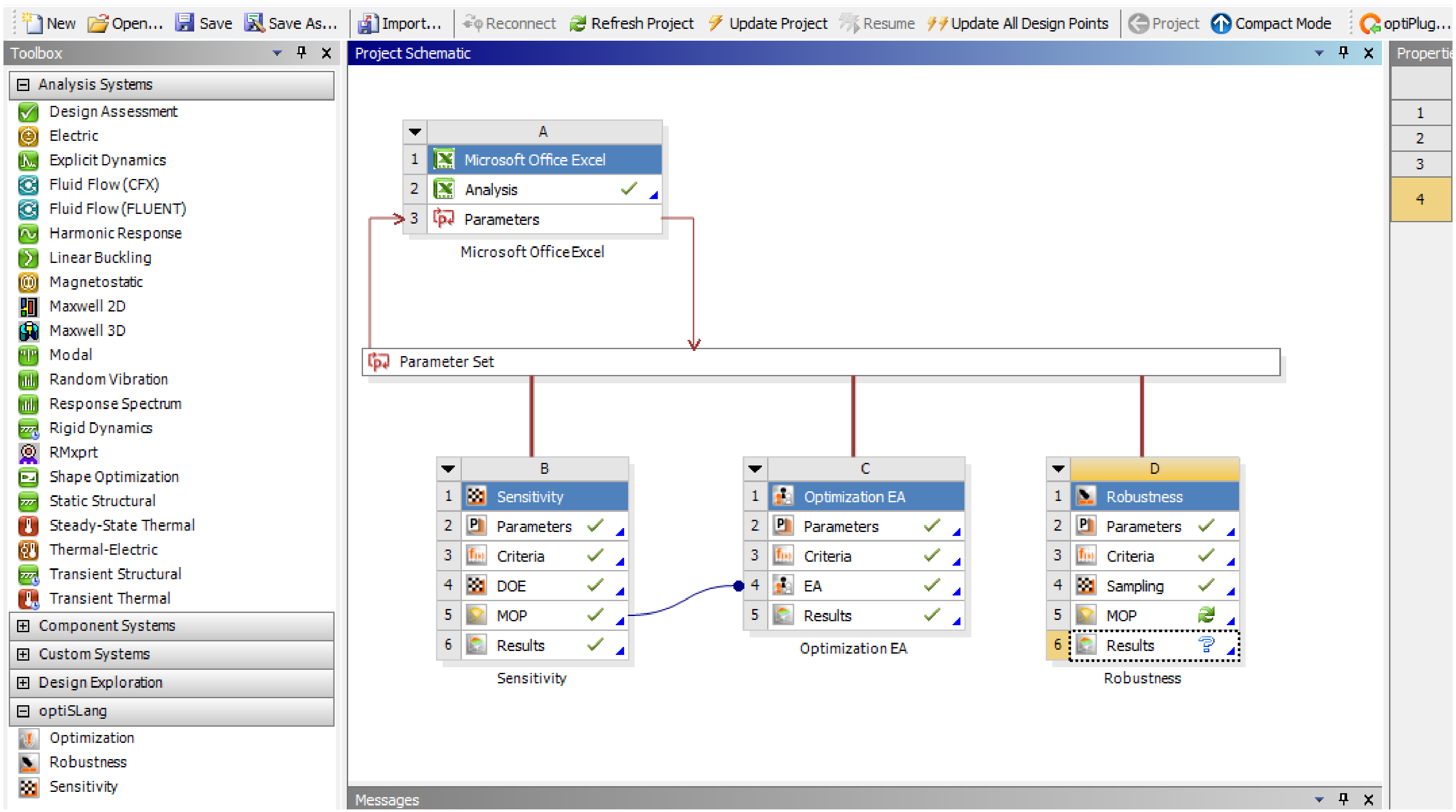
Get a better understanding for the model behavior.



CADFEM

Understand your Design

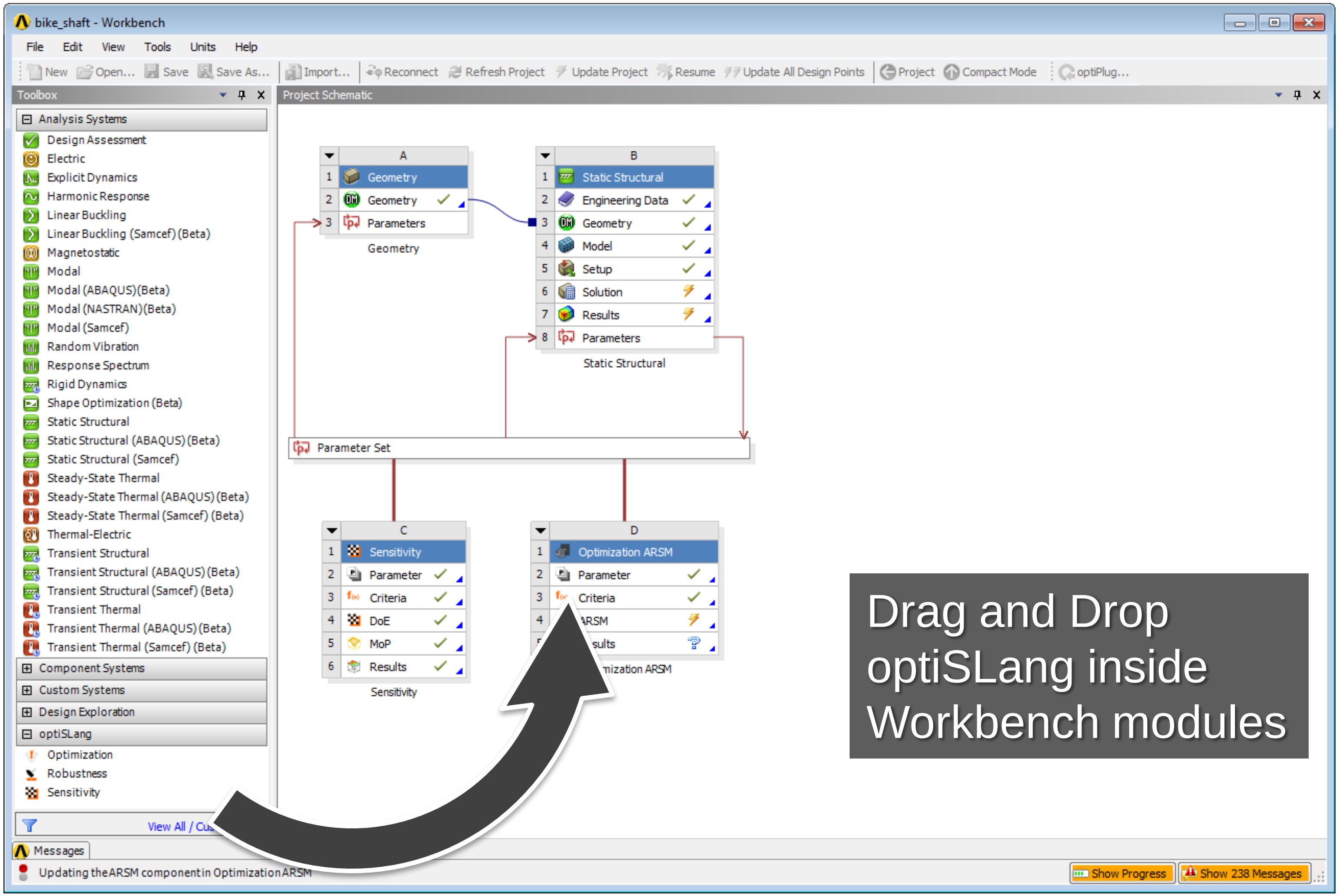
The developed modules Sensitivity, Optimization and Robustness provide user friendly wizards for each task



CADFEM

Understand your Design

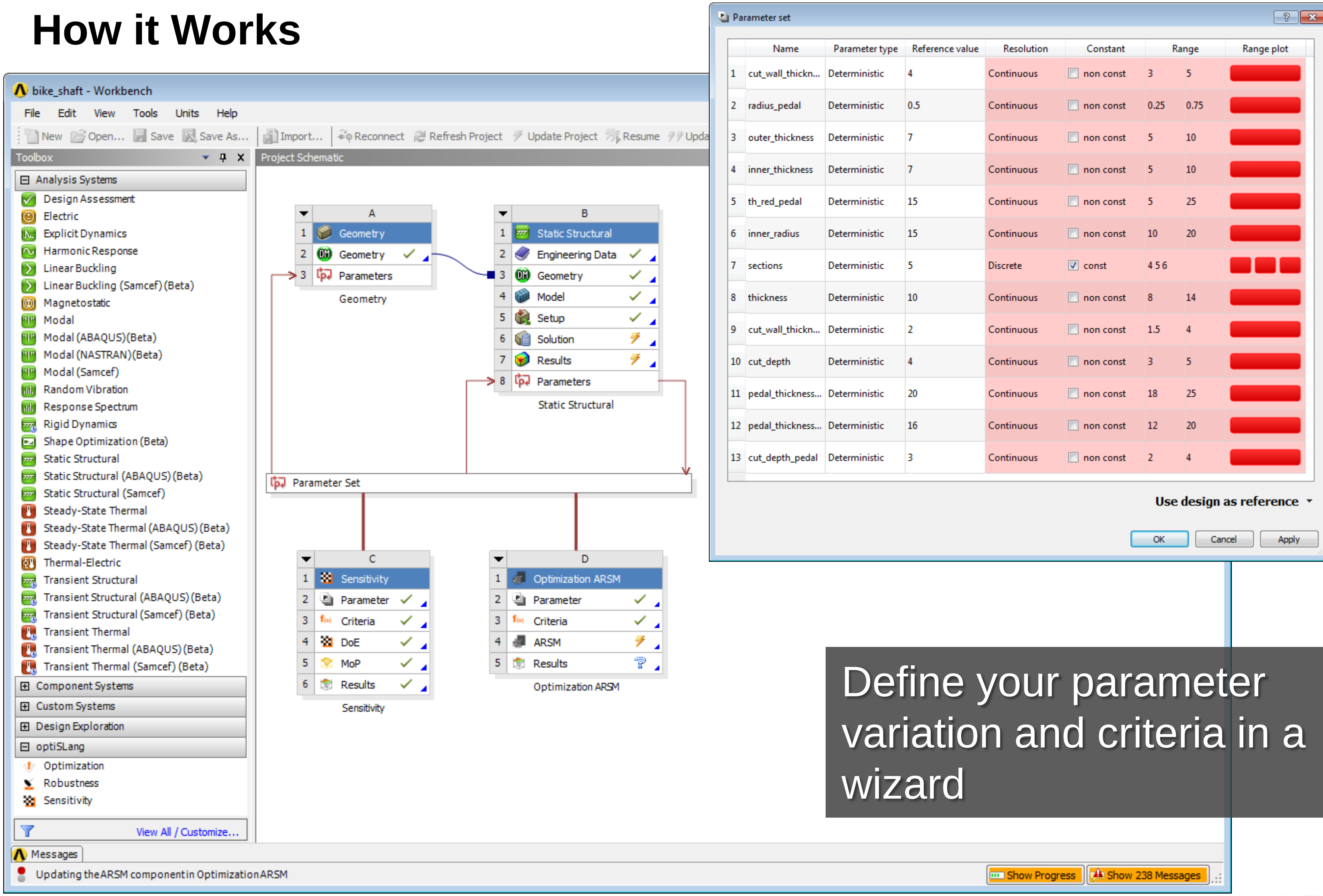
How it Works



CADFEM

Understand your Design

How it Works

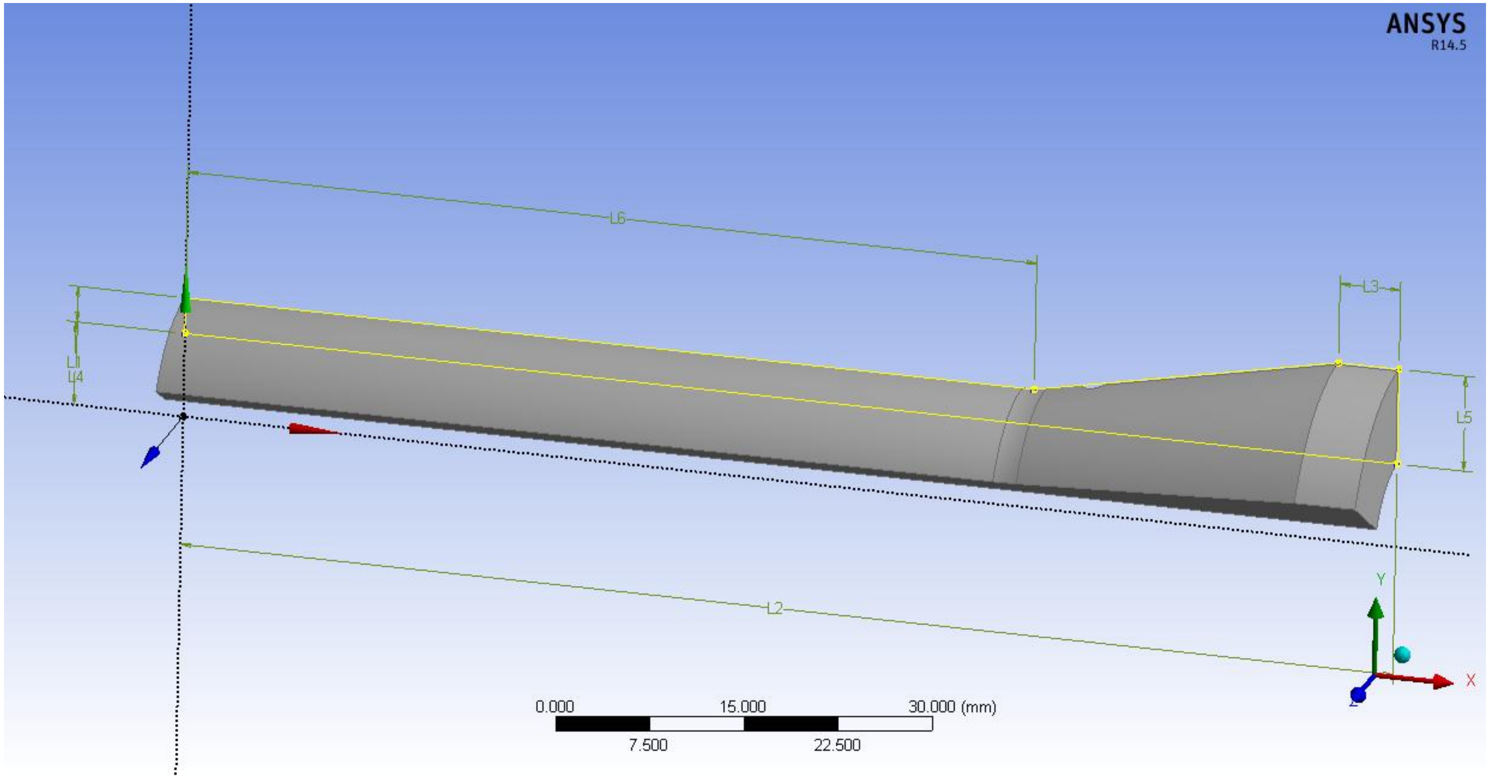


Define your parameter variation and criteria in a wizard

CADFEM

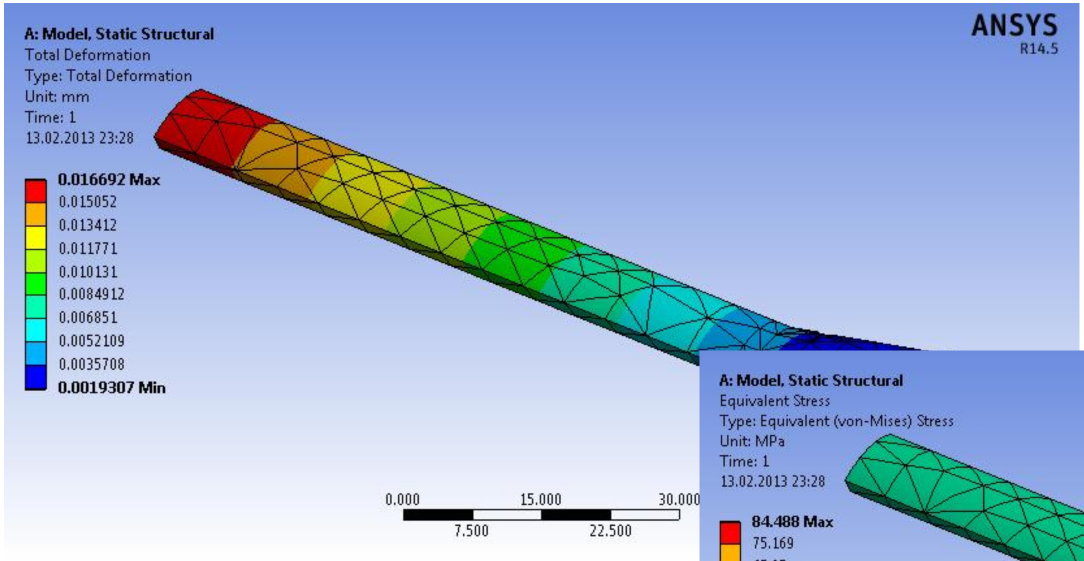
Example: Notch

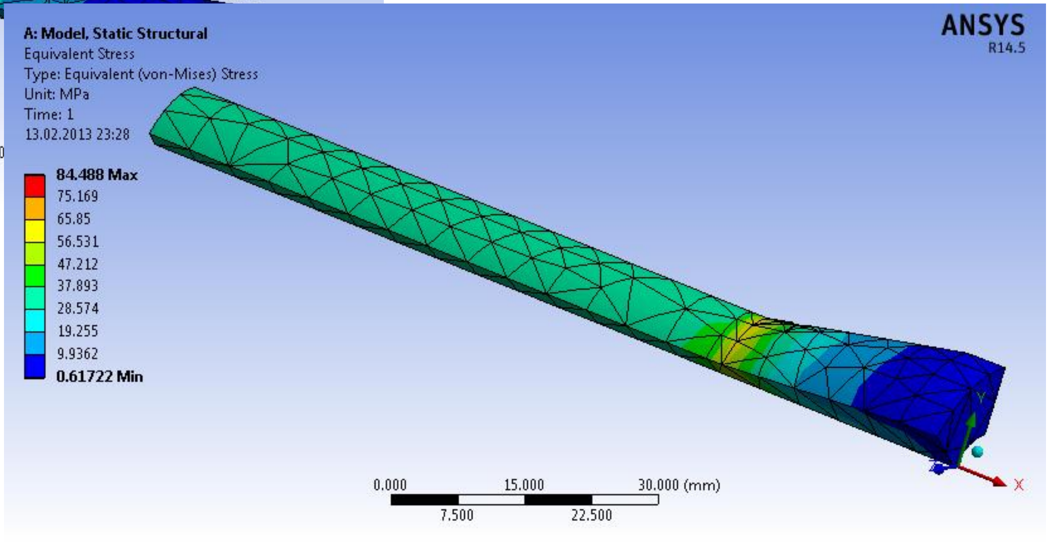
CAD Parametrization in ANSYS DesignModeler



Example: Notch

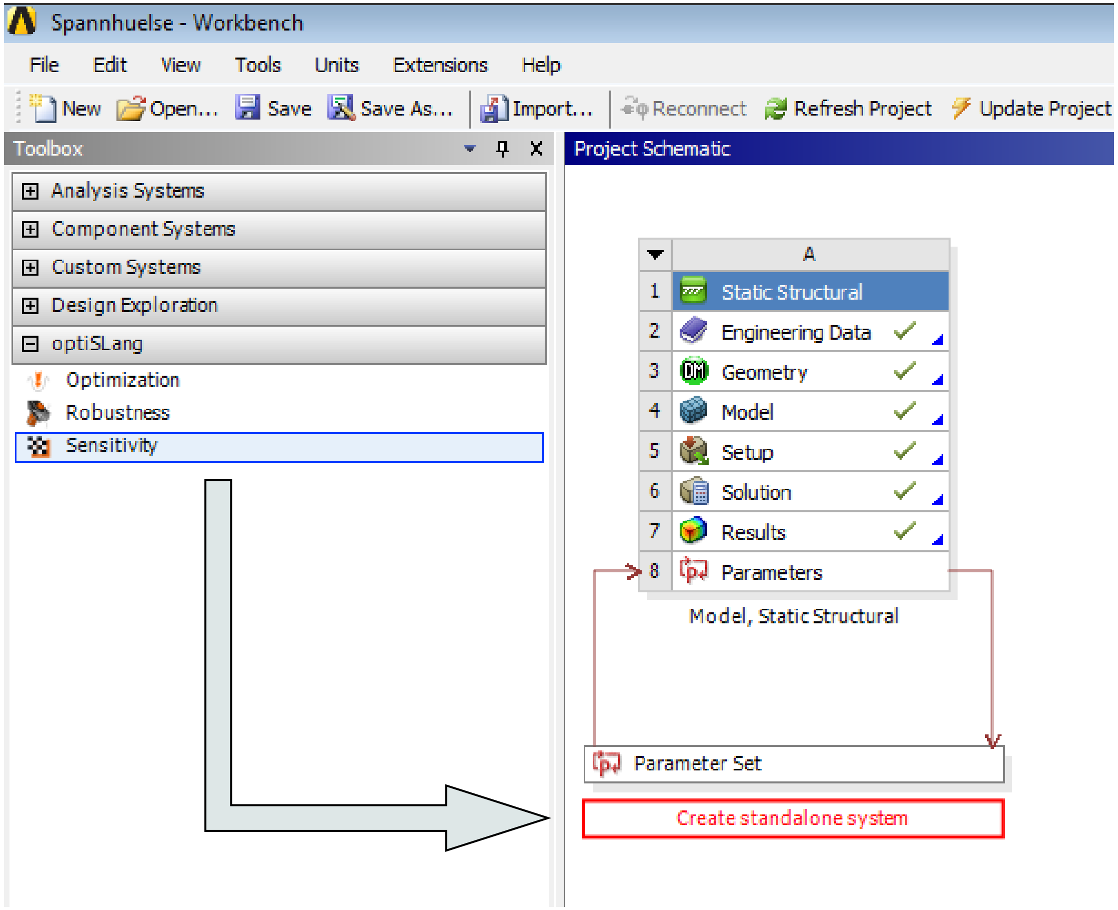
Reference Results





Example: Notch

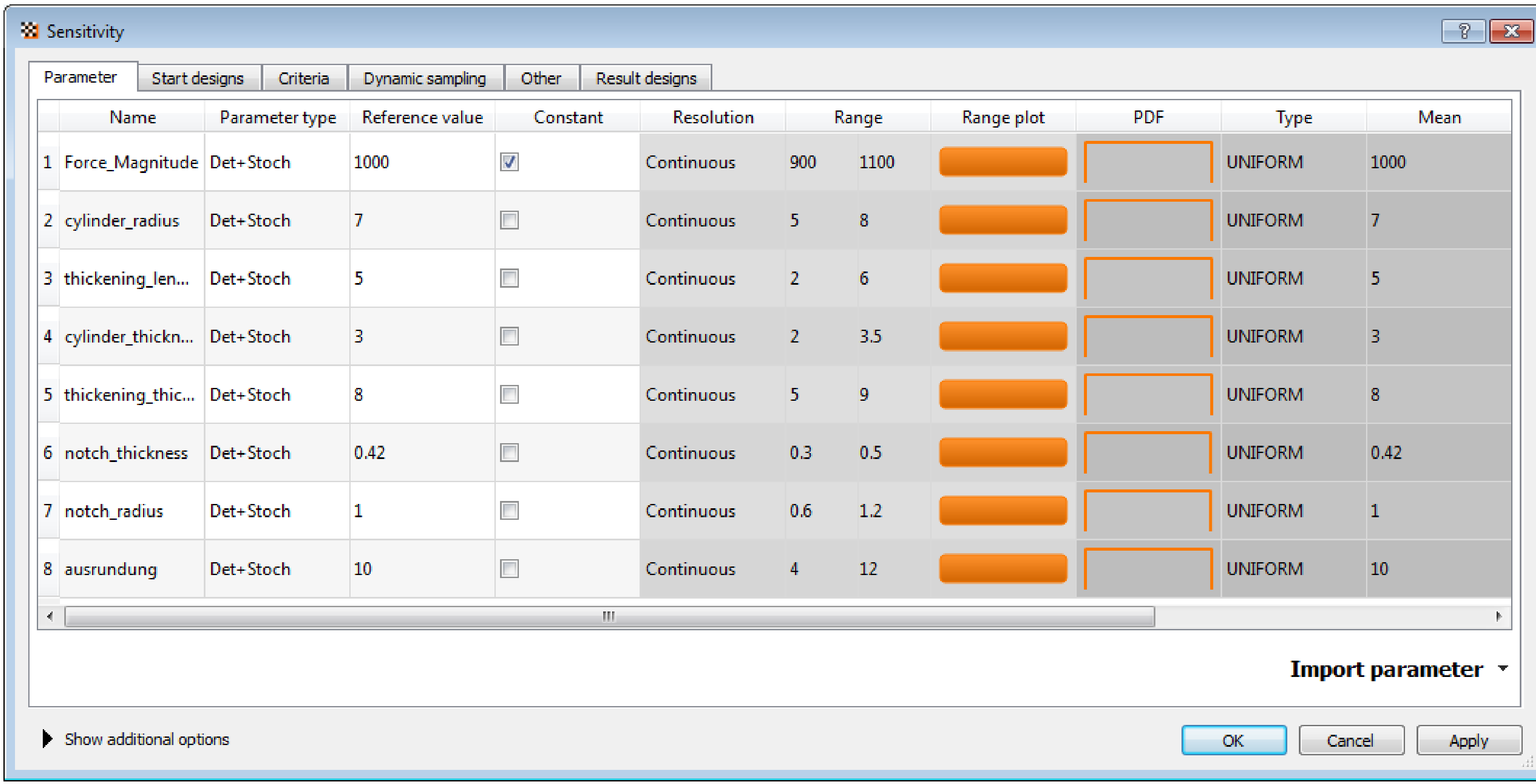
Drag & Drop a new sensitivity analysis in ANSYS



CADFEM

Example: Notch

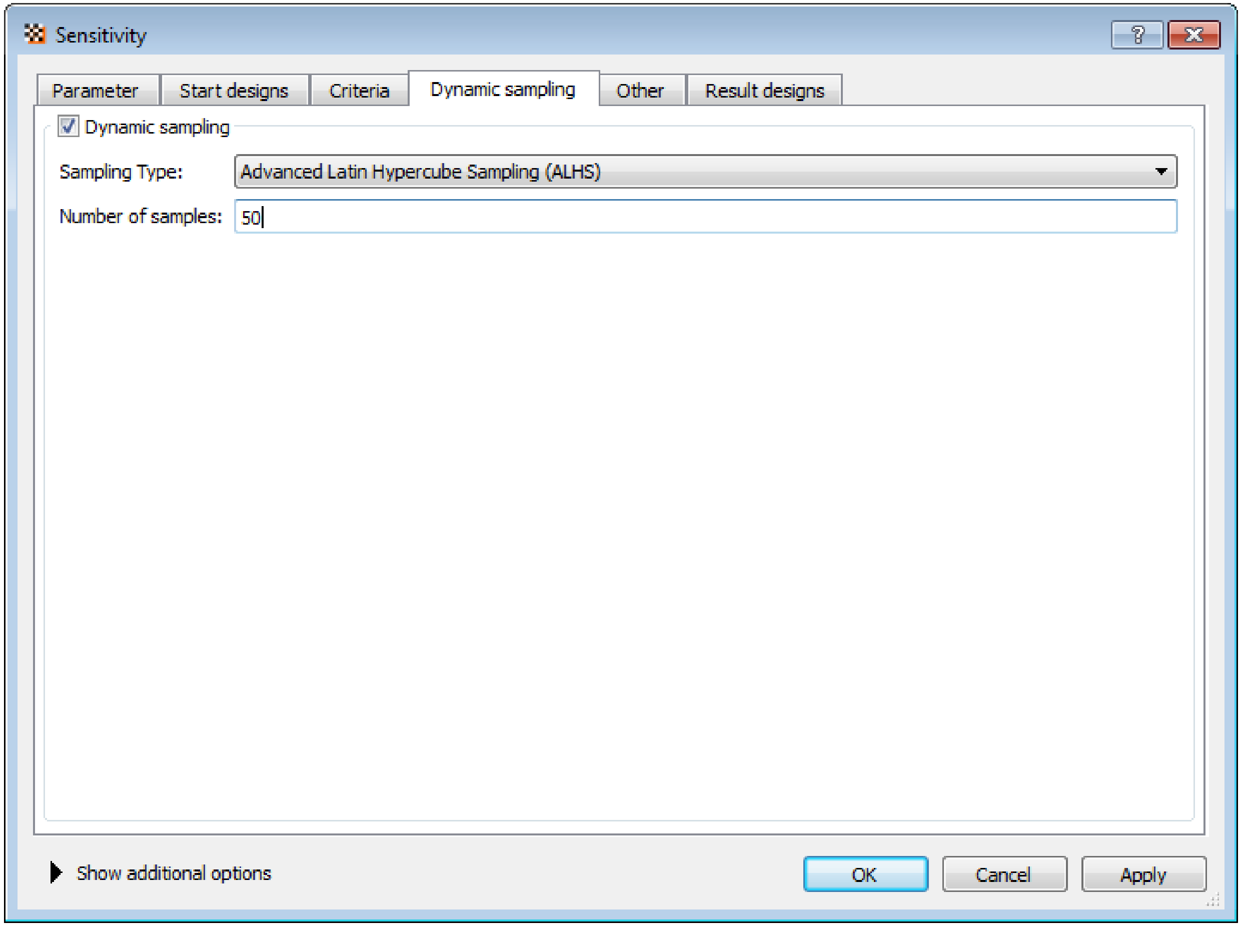
The Wizard opens to insert the given parameter variations.



	Name	Parameter type	Reference value	Constant	Resolution	Range		Range plot	PDF	Type	Mean
1	Force_Magnitude	Det+Stoch	1000	☑	Continuous	900	1100			UNIFORM	1000
2	cylinder_radius	Det+Stoch	7	☐	Continuous	5	8			UNIFORM	7
3	thickening_len...	Det+Stoch	5	☐	Continuous	2	6			UNIFORM	5
4	cylinder_thickn...	Det+Stoch	3	☐	Continuous	2	3.5			UNIFORM	3
5	thickening_thic...	Det+Stoch	8	☐	Continuous	5	9			UNIFORM	8
6	notch_thickness	Det+Stoch	0.42	☐	Continuous	0.3	0.5			UNIFORM	0.42
7	notch_radius	Det+Stoch	1	☐	Continuous	0.6	1.2			UNIFORM	1
8	ausrundung	Det+Stoch	10	☐	Continuous	4	12			UNIFORM	10

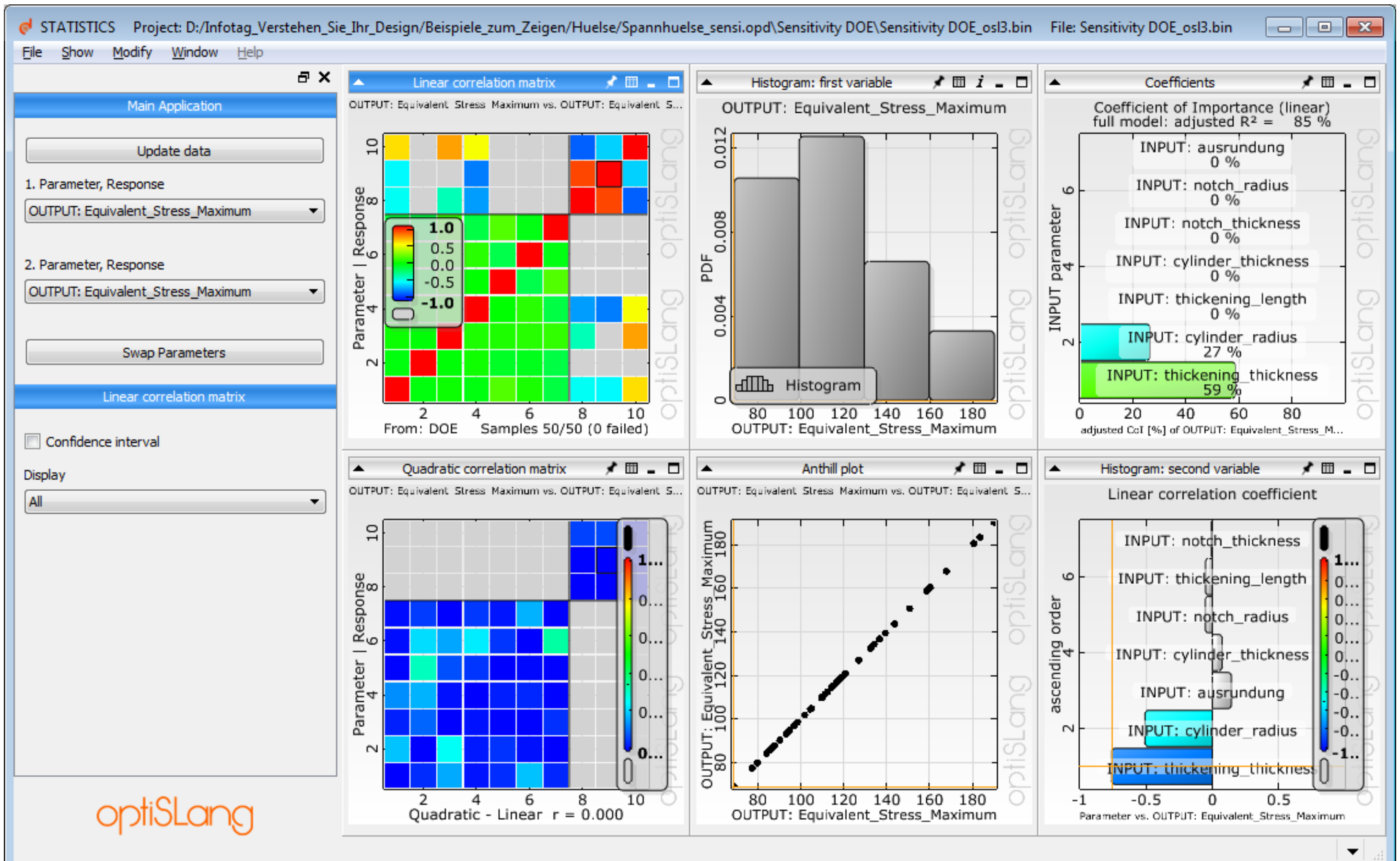
Example: Notch

A number of samples to calculate of 50 should be enough!



Example: Notch

The post-processing gives you an overview over all sensitivity results

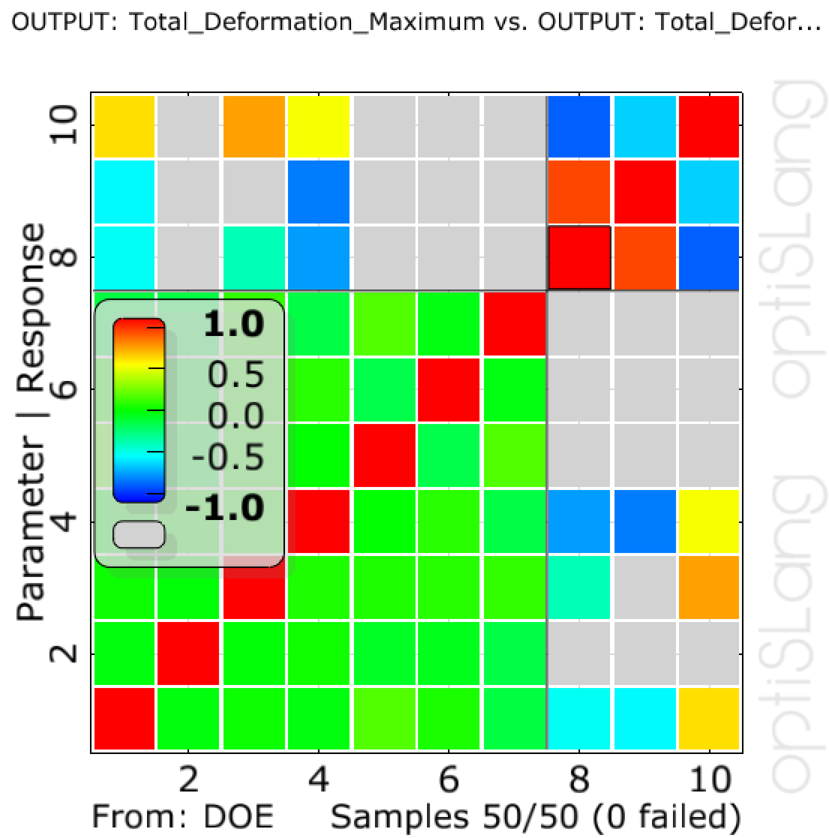


CADFEM

Understand your Design

Example: Notch

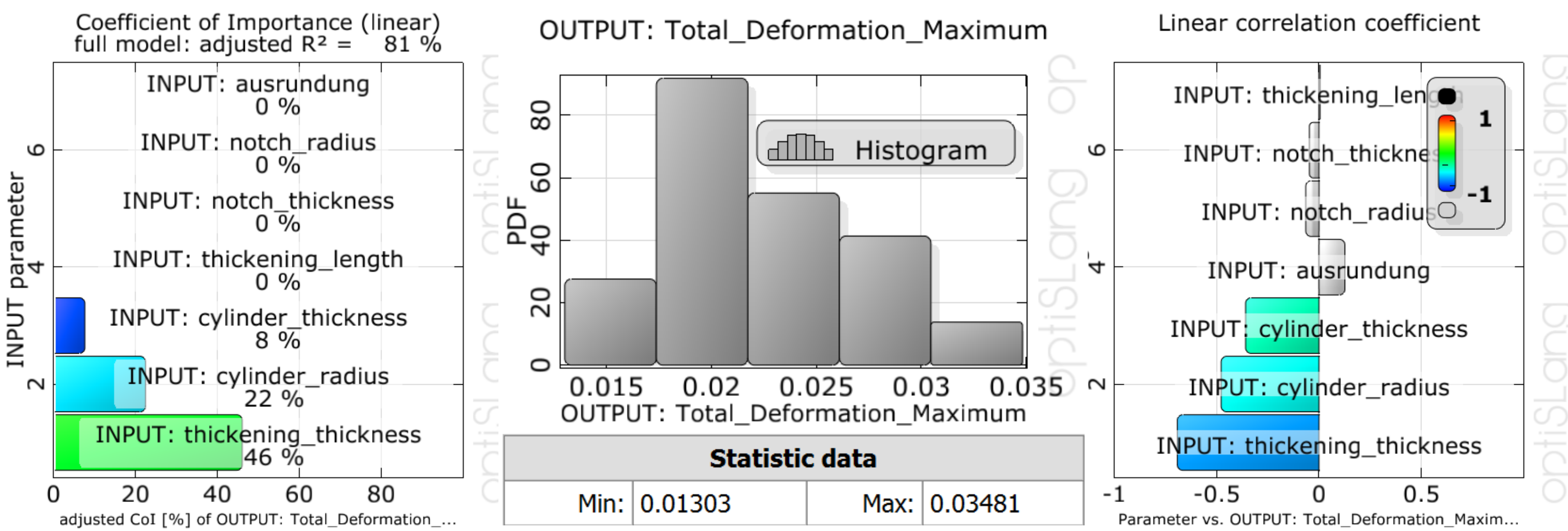
4 of the 7 Parameters seem to have no recognizable Influence on the results.
Two Paramers are more significant. One is minor significant.



CADFEM

Example: Notch

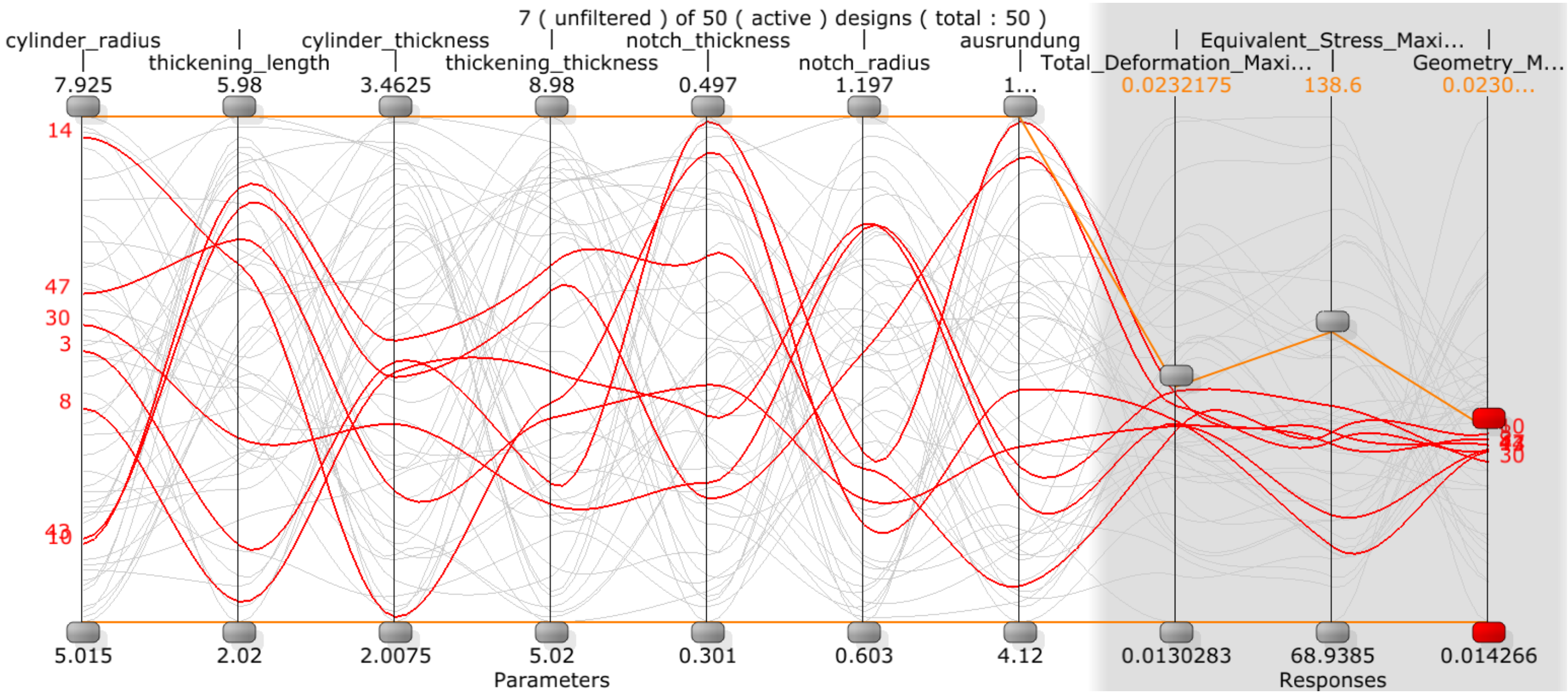
Take a look at the different result modes:
- See which parameters have an influence
- Check the result variation. Does the variation reach critical stages?
- How do I have to modify my parameters to get a desired value for the deformation.



Statistic data			
Min:	0.01303	Max:	0.03481

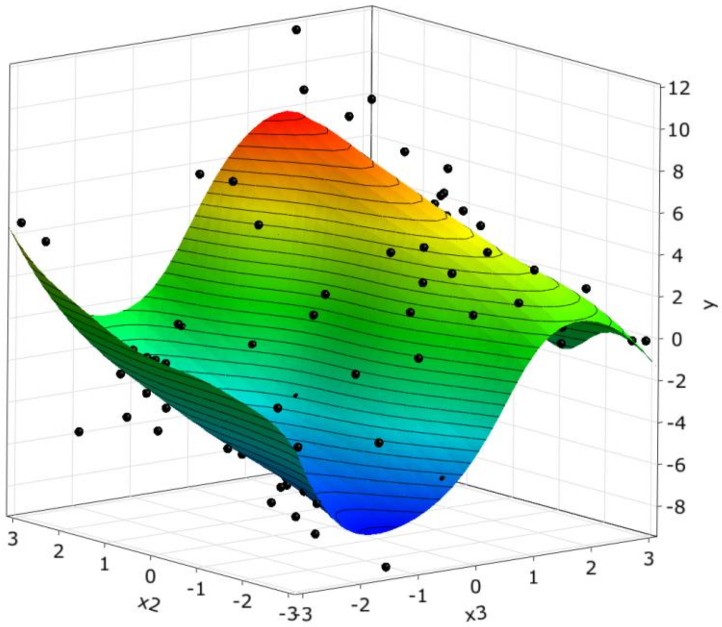
Example: Notch

Remember the optimization goal of minimizing mass and deformation by considering a maximum stress of 140 Mpa?
Open the parallel coordinates plot to check your optimization possibilities!



Example: Notch

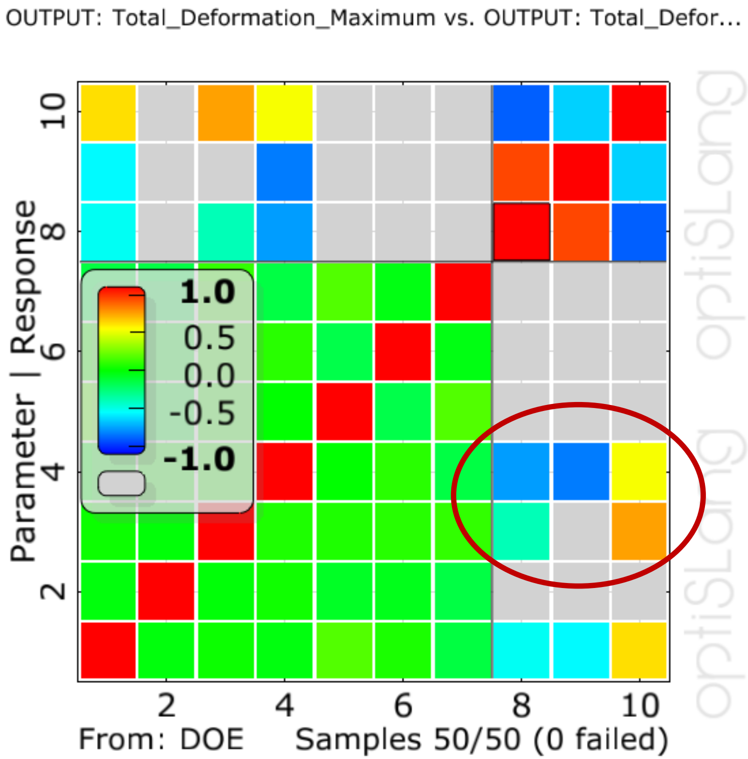
Now check your forecast quality and deeper correlations by starting the optiSLang meta model of optimal prognosis!

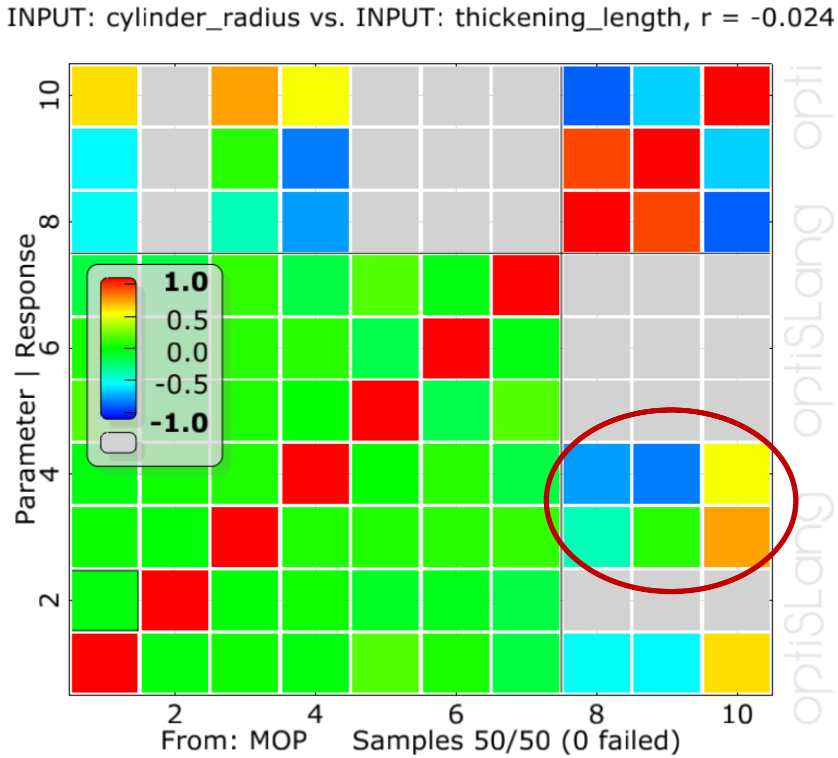


The model will be automatically reduced to the significant inputs.
All noticable correlations will be determined.
The forecast quality is estimated.

Example: Notch

The correlations are determined more detailly

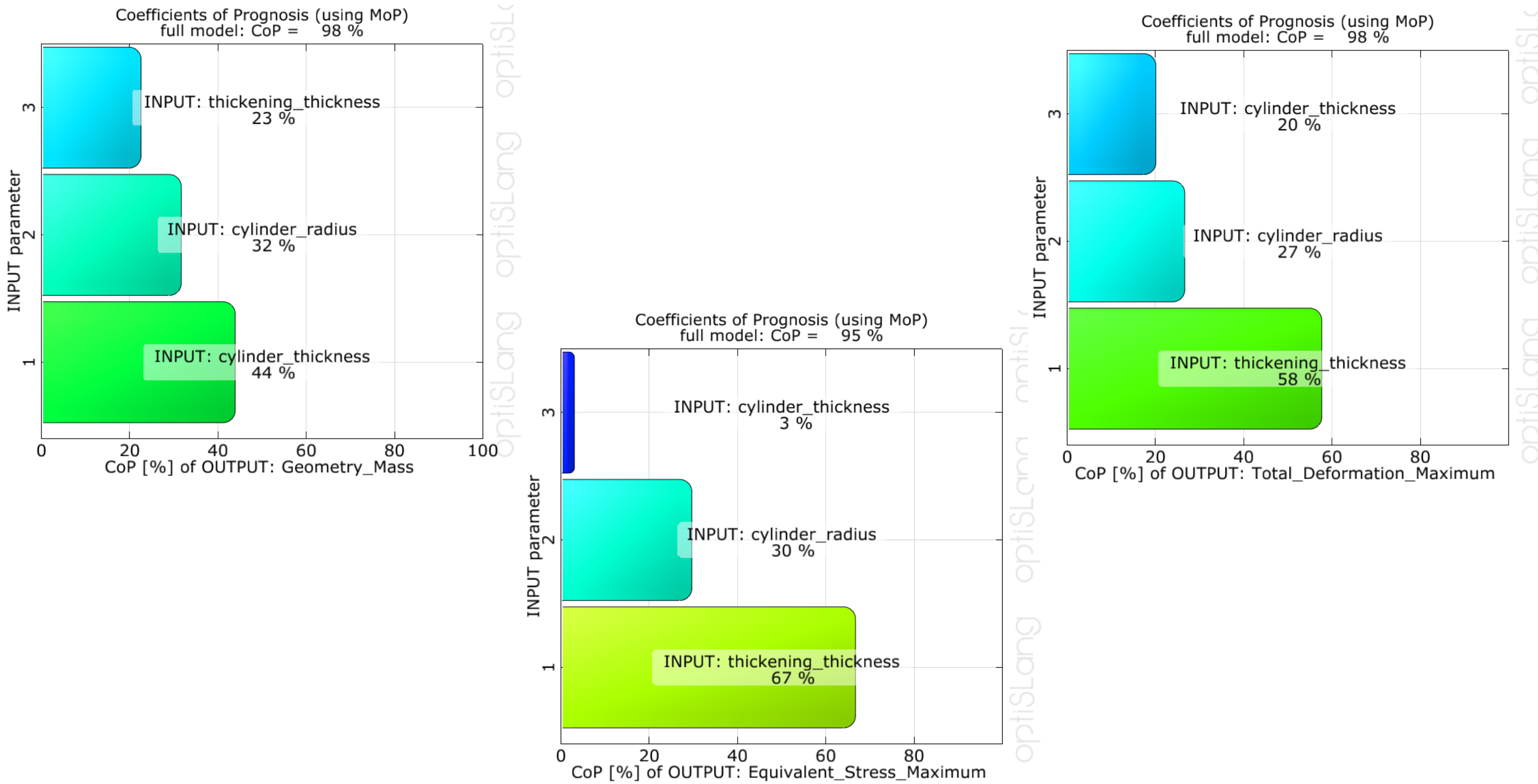




Understand your Design

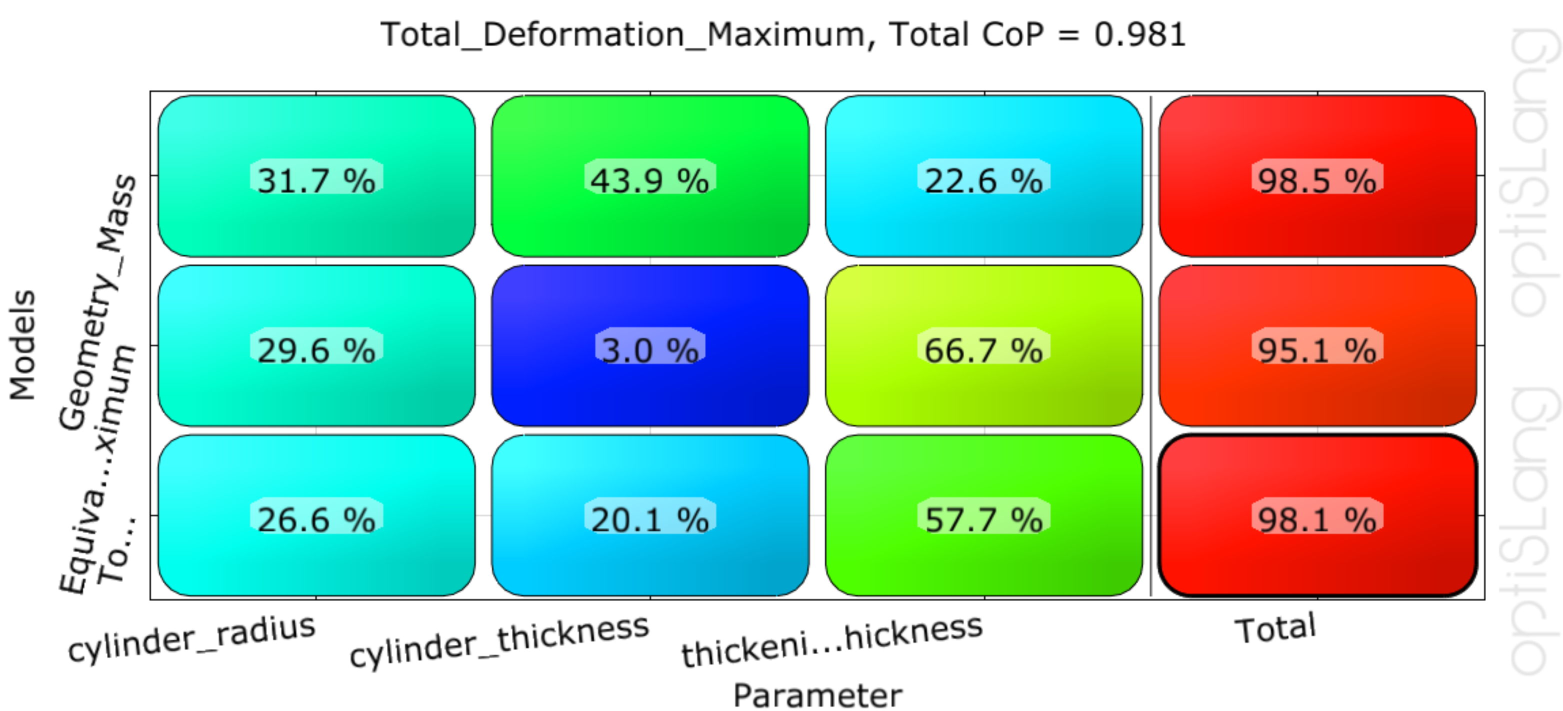
COPs

- Check the single CoPs to extract the significance of each input



Example: Notch

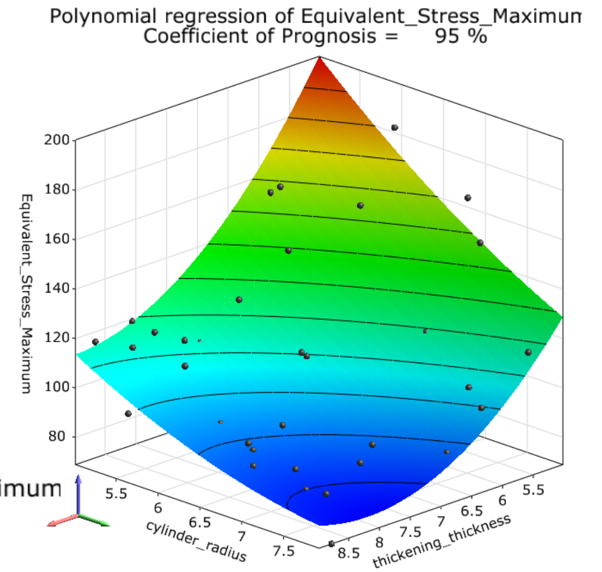
As a summary, check the CoP Matrix:
You can explain all of the variations perfectly just with 3 of 7 parameters!
Any other parameter variation is not necessary – this saves time.

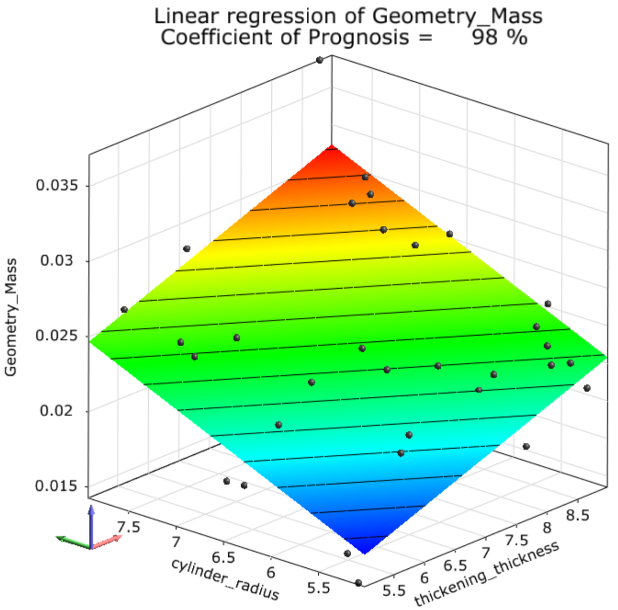


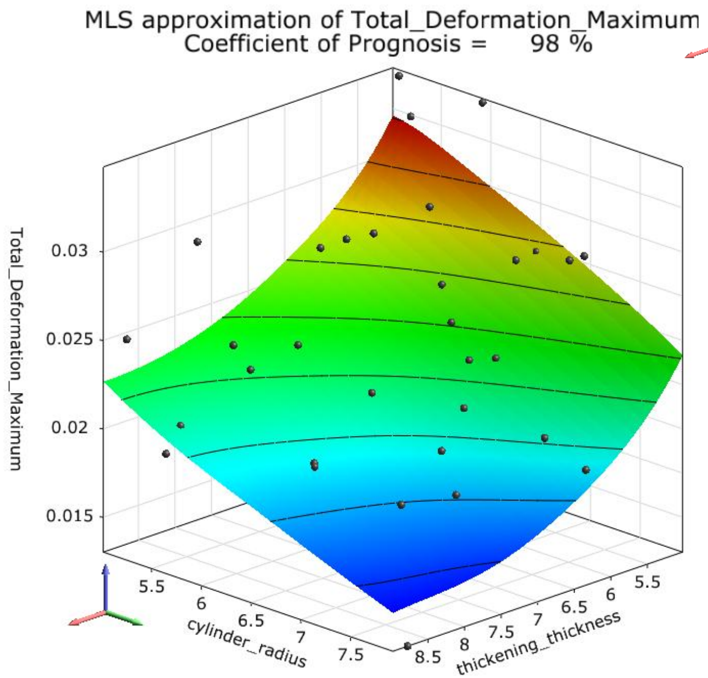
Understand your Design

Example: Notch

The deformation and the stress has nonlinear correlations to the input parameters.
The mass is linear as is common.



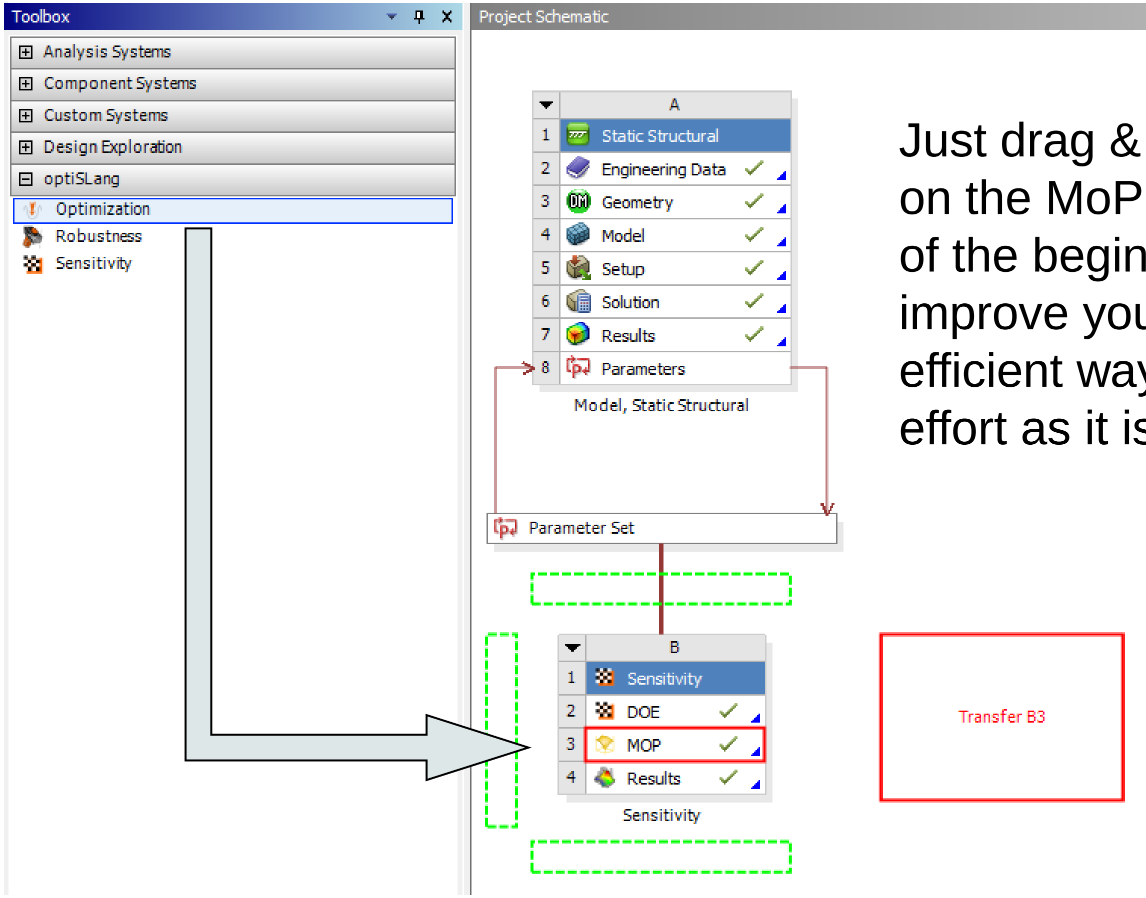




CADFEM

Example: Notch

Now let‘s improve our design!

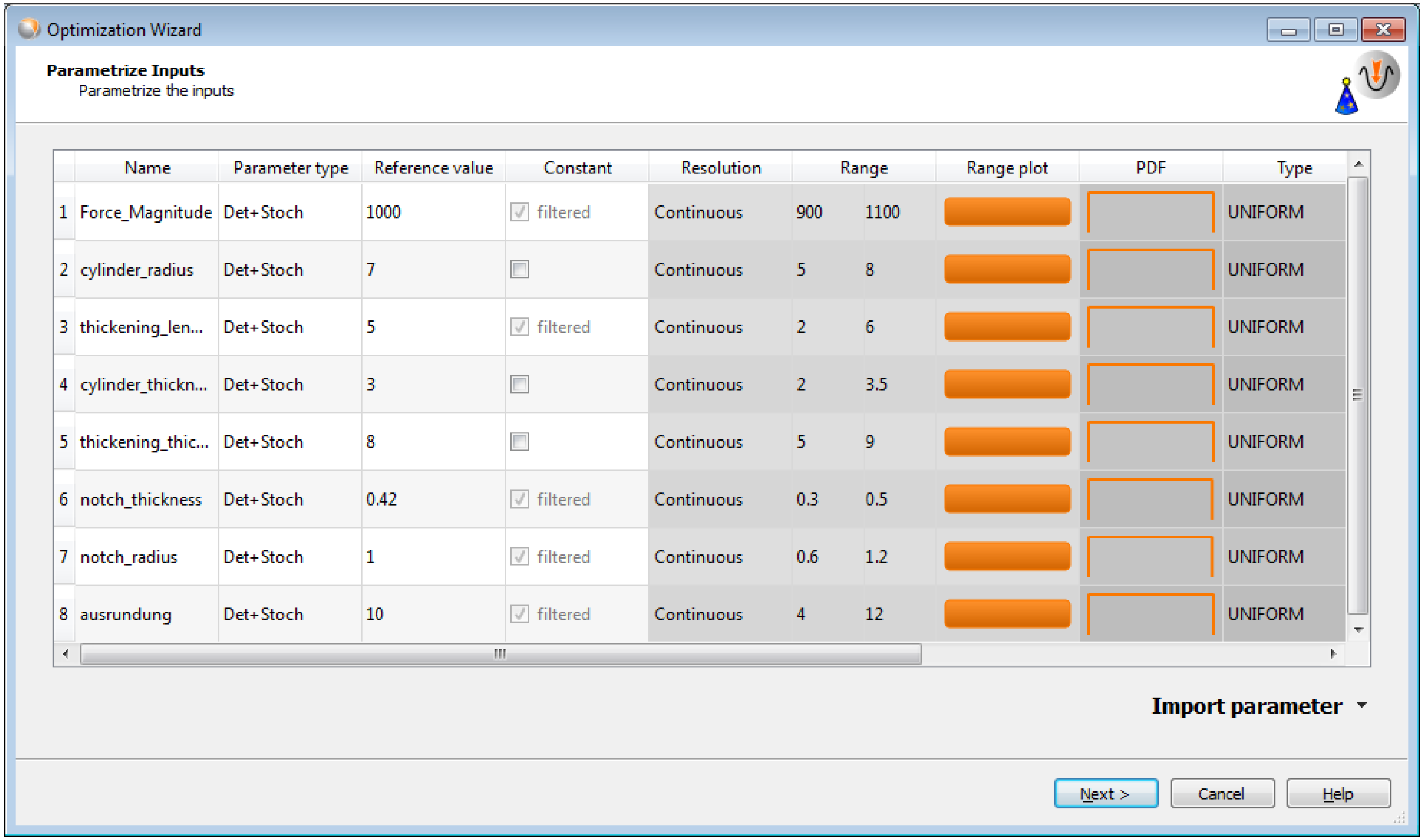


Just drag & drop the optimization on the MoP – use the information of the beginning analysis to improve your design in the most efficient way with as less calculation effort as it is possible.

Understand your Design

Example: Notch

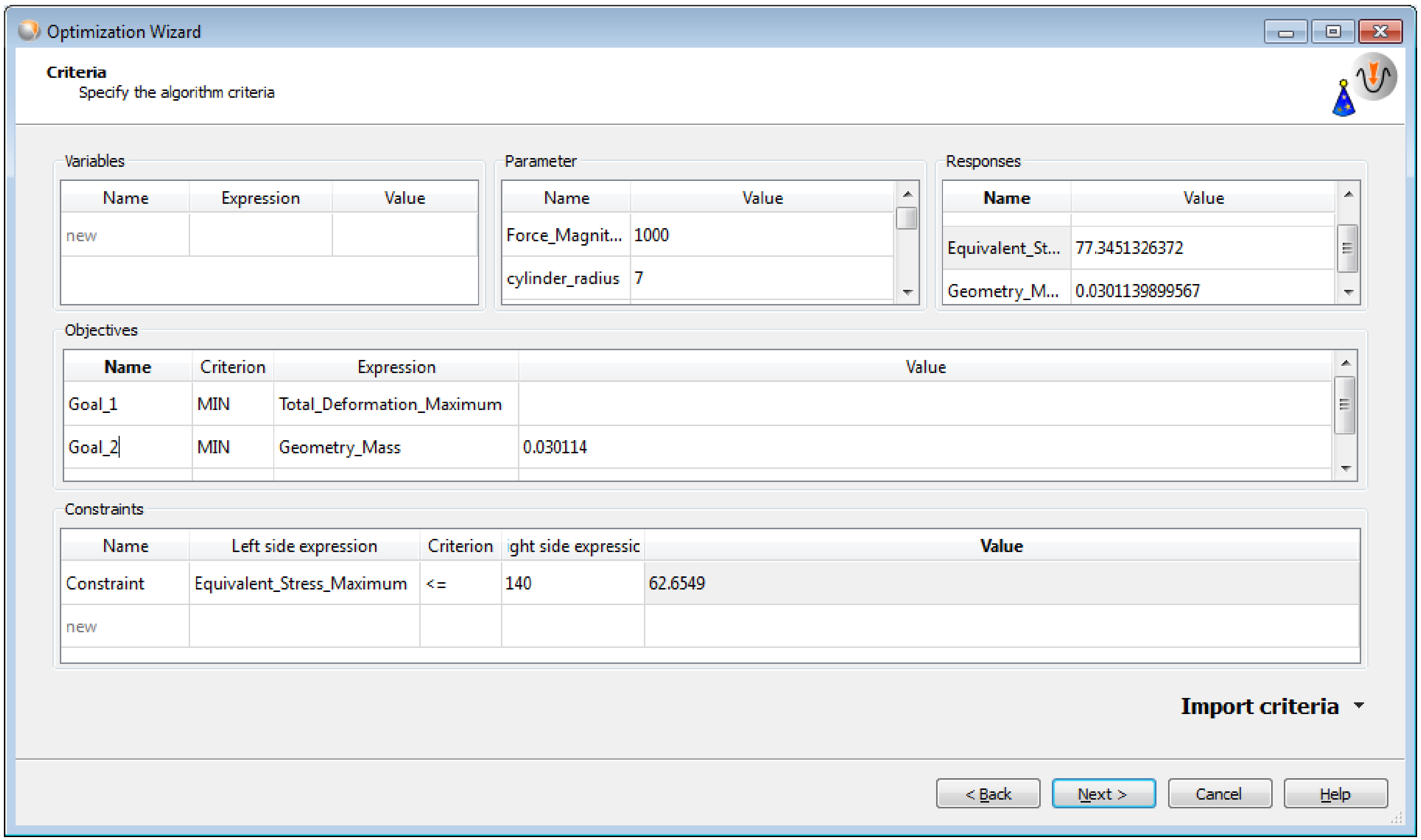
The unimportant parameters are automatically filtered!



	Name	Parameter type	Reference value	Constant	Resolution	Range		Range plot	PDF	Type
1	Force_Magnitude	Det+Stoch	1000	filtered	Continuous	900	1100			UNIFORM
2	cylinder_radius	Det+Stoch	7		Continuous	5	8			UNIFORM
3	thickening_len...	Det+Stoch	5	filtered	Continuous	2	6			UNIFORM
4	cylinder_thickn...	Det+Stoch	3		Continuous	2	3.5			UNIFORM
5	thickening_thic...	Det+Stoch	8		Continuous	5	9			UNIFORM
6	notch_thickness	Det+Stoch	0.42	filtered	Continuous	0.3	0.5			UNIFORM
7	notch_radius	Det+Stoch	1	filtered	Continuous	0.6	1.2			UNIFORM
8	ausrundung	Det+Stoch	10	filtered	Continuous	4	12			UNIFORM

Example: Notch

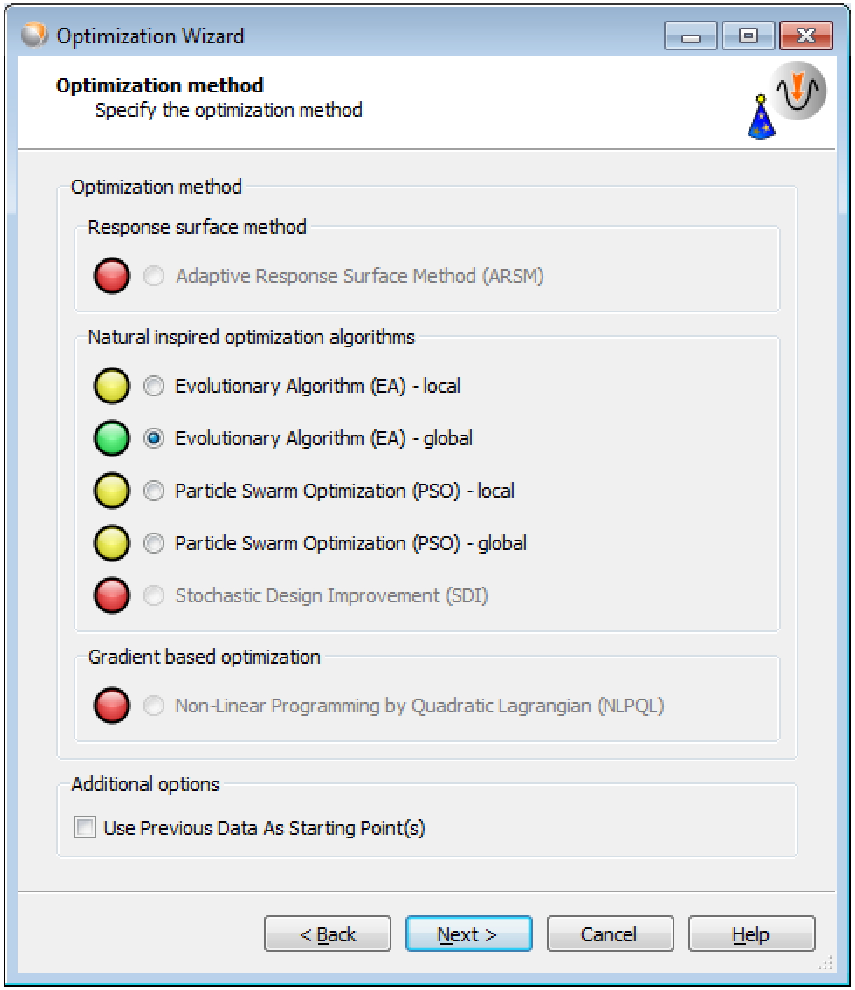
Let‘s insert our goals using the wizard



Example: Notch

optiSLang suggests automatically the best suiting method!

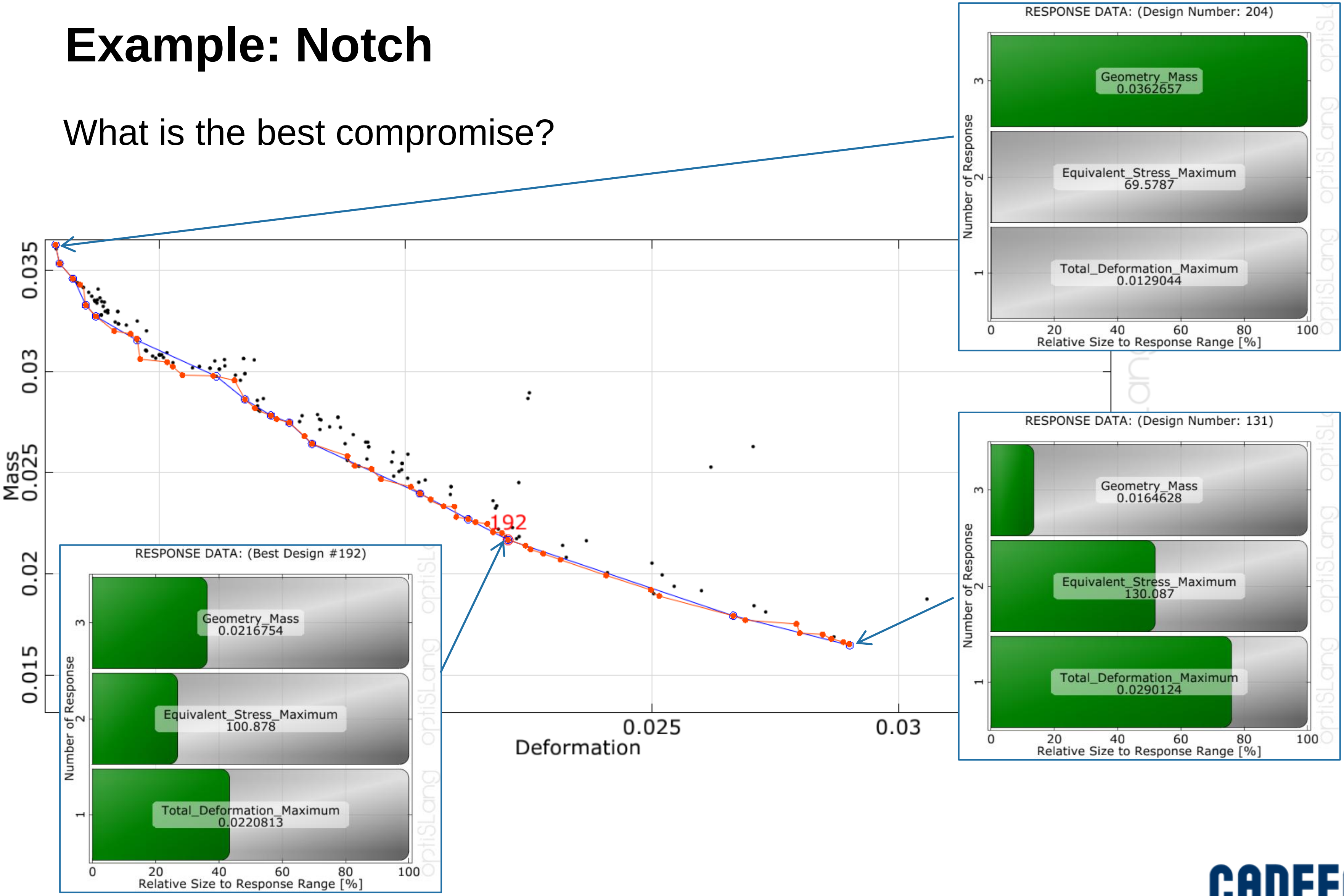
Therefore you do not have to care about different algorithms or sophisticated settings. This is done by the software!



Understand your Design

Example: Notch

What is the best compromise?

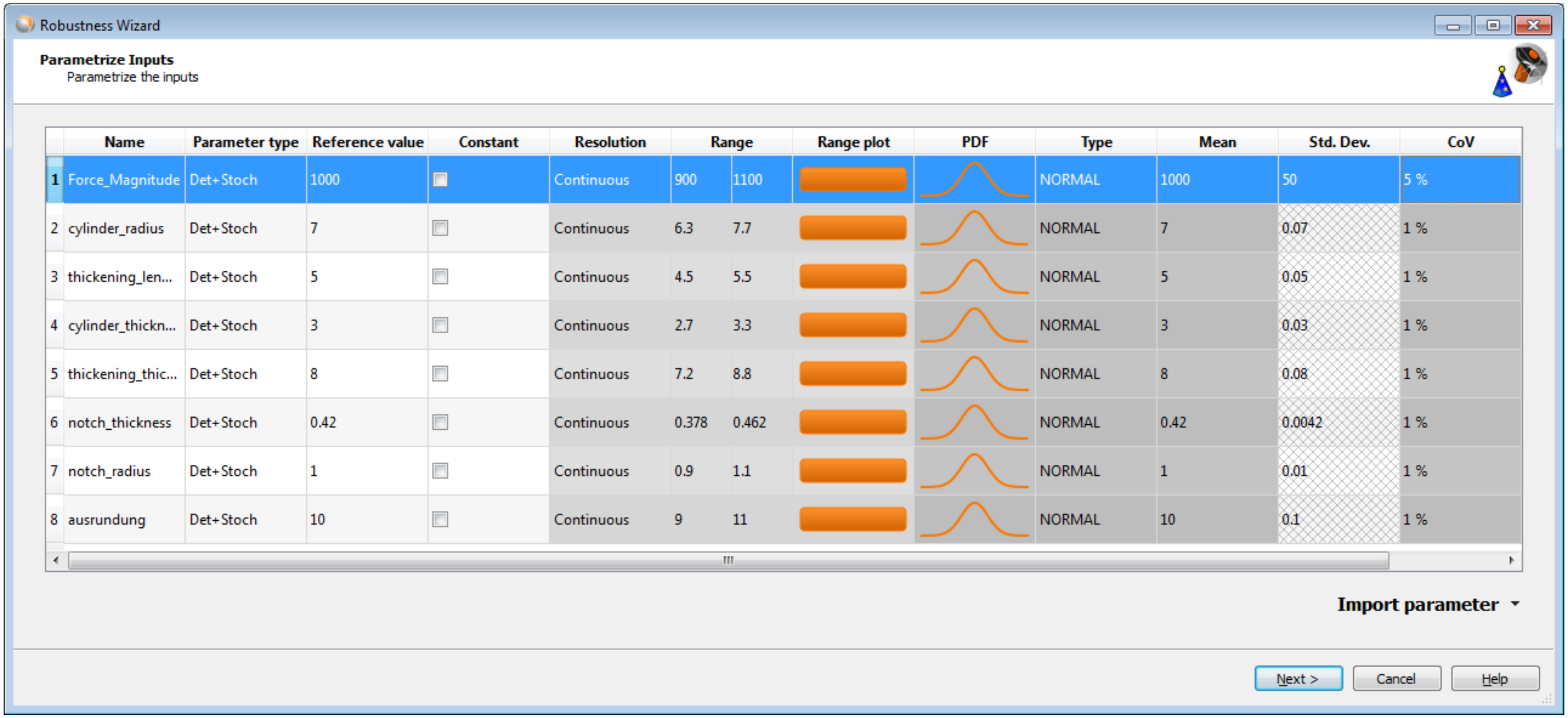


CADFEM

Understand your Design

Example: Notch

Check the effect of manufacturing tolerances!
Vary the geometry by 1% and the Force by 5%

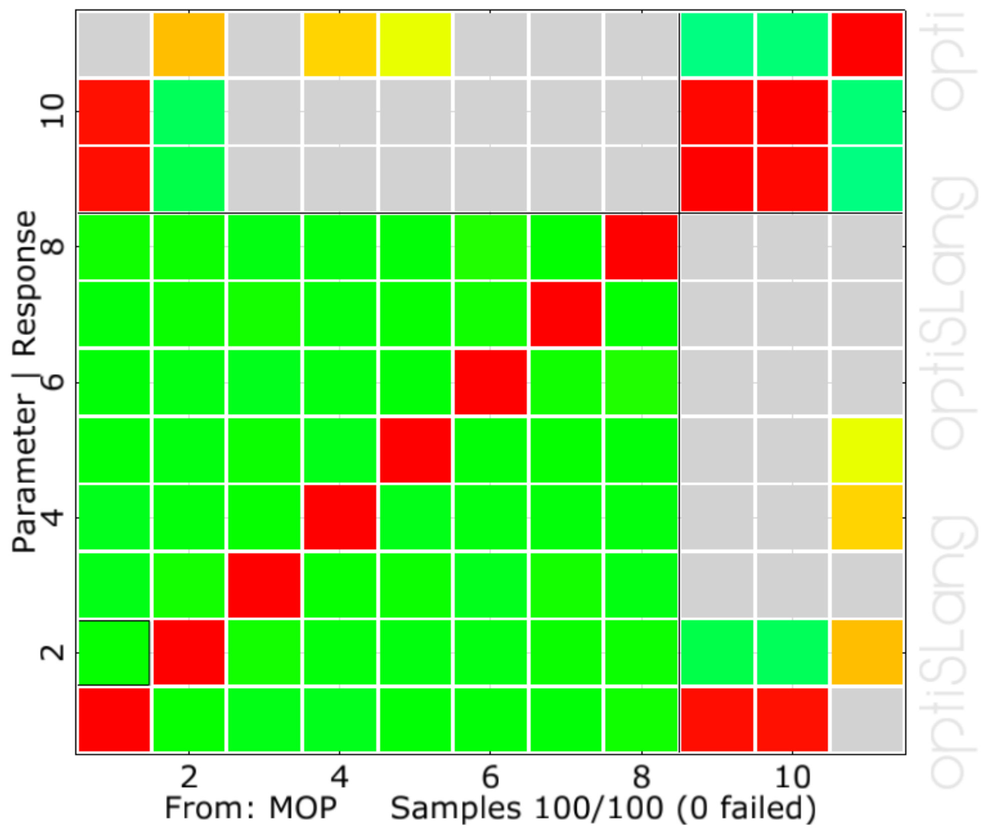


	Name	Parameter type	Reference value	Constant	Resolution	Range		Range plot	PDF	Type	Mean	Std. Dev.	CoV
1	Force_Magnitude	Det+Stoch	1000		Continuous	900	1100			NORMAL	1000	50	5 %
2	cylinder_radius	Det+Stoch	7		Continuous	6.3	7.7			NORMAL	7	0.07	1 %
3	thickening_len...	Det+Stoch	5		Continuous	4.5	5.5			NORMAL	5	0.05	1 %
4	cylinder_thickn...	Det+Stoch	3		Continuous	2.7	3.3			NORMAL	3	0.03	1 %
5	thickening_thic...	Det+Stoch	8		Continuous	7.2	8.8			NORMAL	8	0.08	1 %
6	notch_thickness	Det+Stoch	0.42		Continuous	0.378	0.462			NORMAL	0.42	0.0042	1 %
7	notch_radius	Det+Stoch	1		Continuous	0.9	1.1			NORMAL	1	0.01	1 %
8	ausrundung	Det+Stoch	10		Continuous	9	11			NORMAL	10	0.1	1 %

Example: Notch

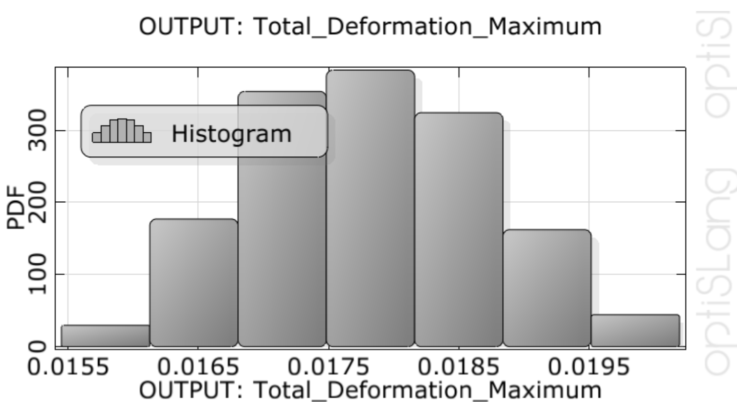
The correlation matrix indicates that the 5% variation of the force is dominant.

INPUT: Force_Magnitude vs. INPUT: cylinder_radius, r = 0.010

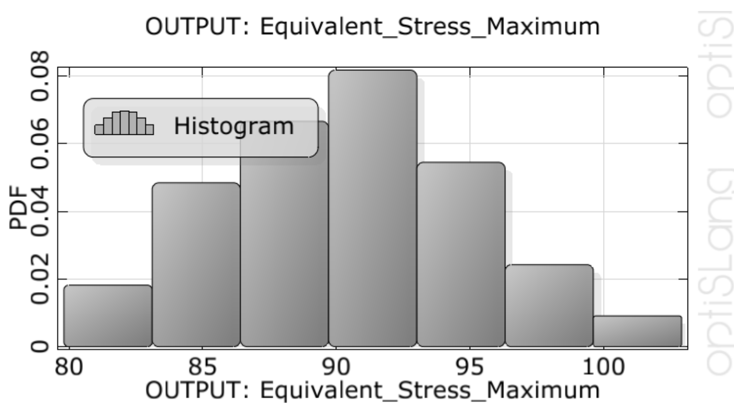


Example: Notch

The variation is of the same magnitude as the input variation of the force



Statistic data			
Min:	0.01545	Max:	0.0202
Mean:	0.01782	Sigma:	0.0009201
CV:	0.05164		
Skewness:	0.1116	Kurtosis:	2.825



Statistic data			
Min:	79.81	Max:	102.9
Mean:	90.22	Sigma:	4.649
CV:	0.05152		
Skewness:	0.1469	Kurtosis:	2.71

Understand your Design

Typical Questions

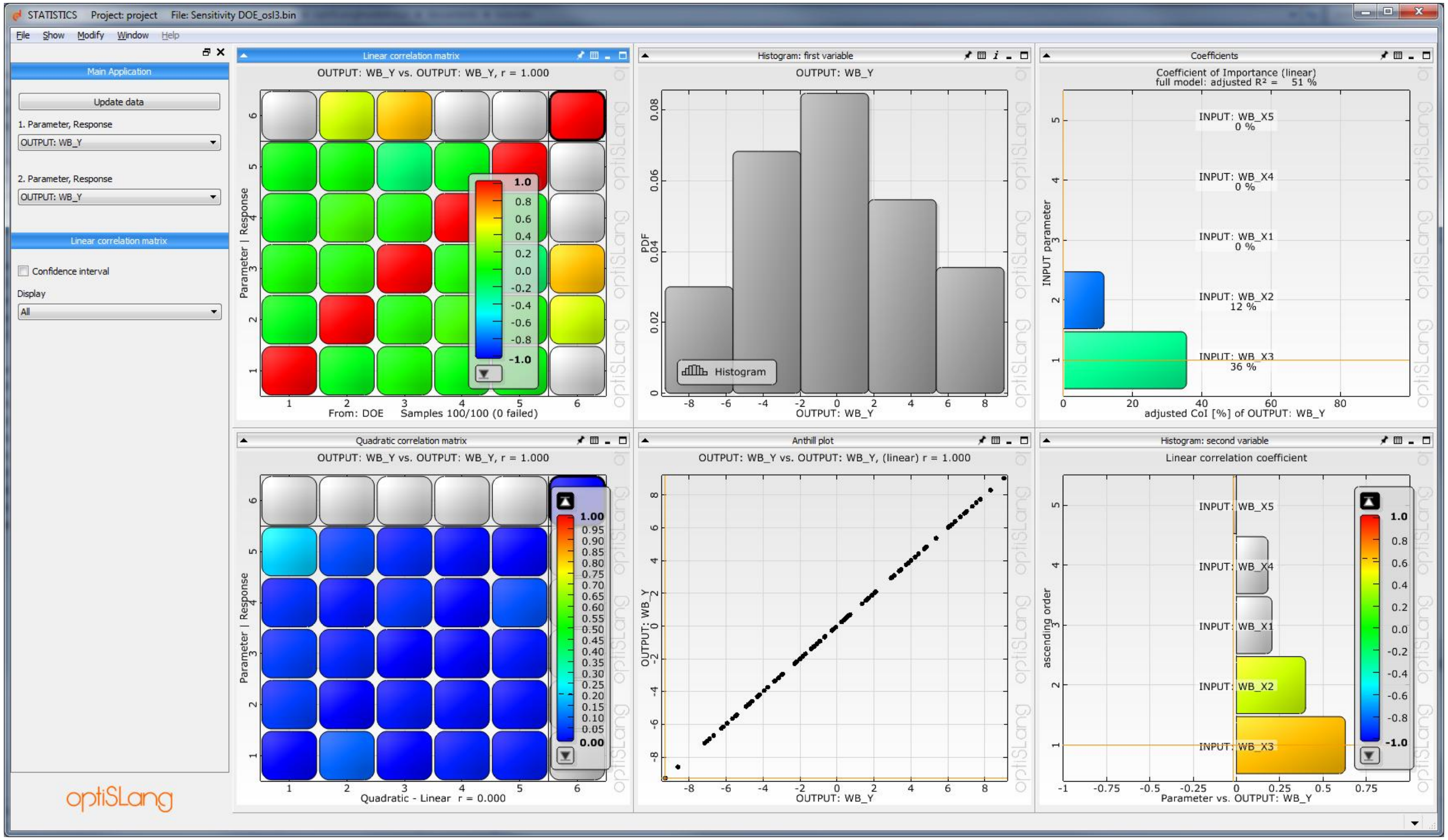
PRACE Autumn School 2013 - Industry Oriented HPC Simulations, September 21-27, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

Content

- Typical Questions
  - How to evaluate 1000 designs?
  - Accuracy and numerical noise
  - Robust parameter settings
  - Which settings are the best for my design improvement?

How to evaluate 1000 designs?

- Context senstive overview of all results.

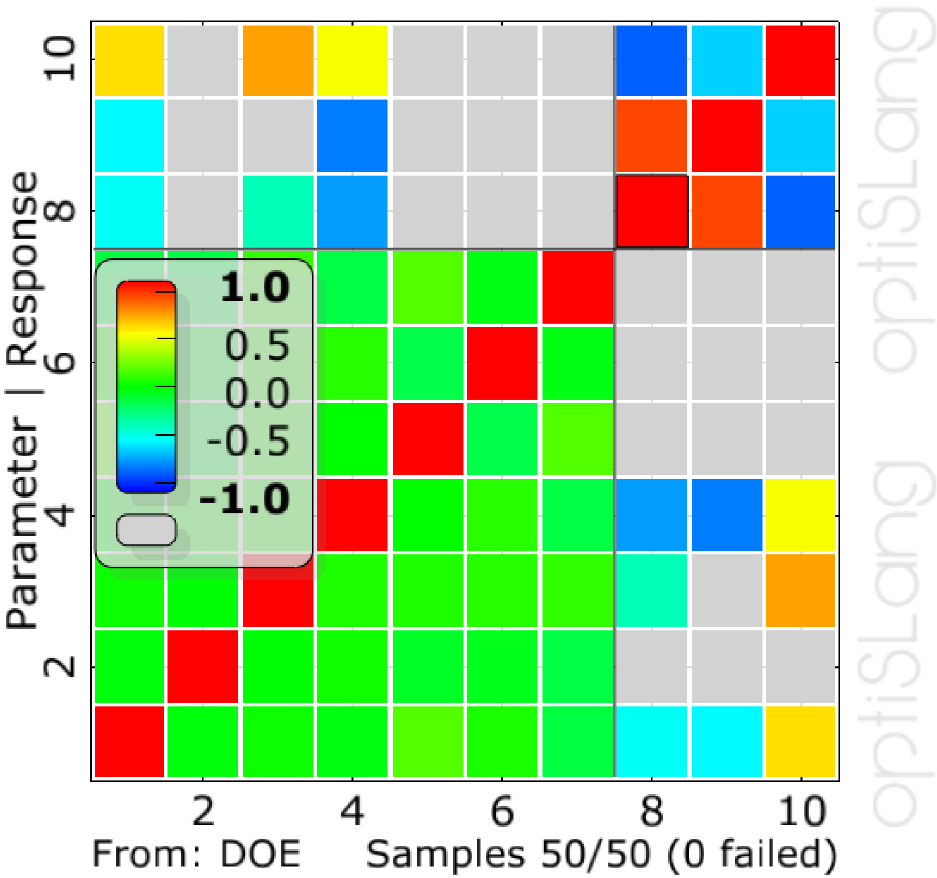


How to evaluate 1000 designs?

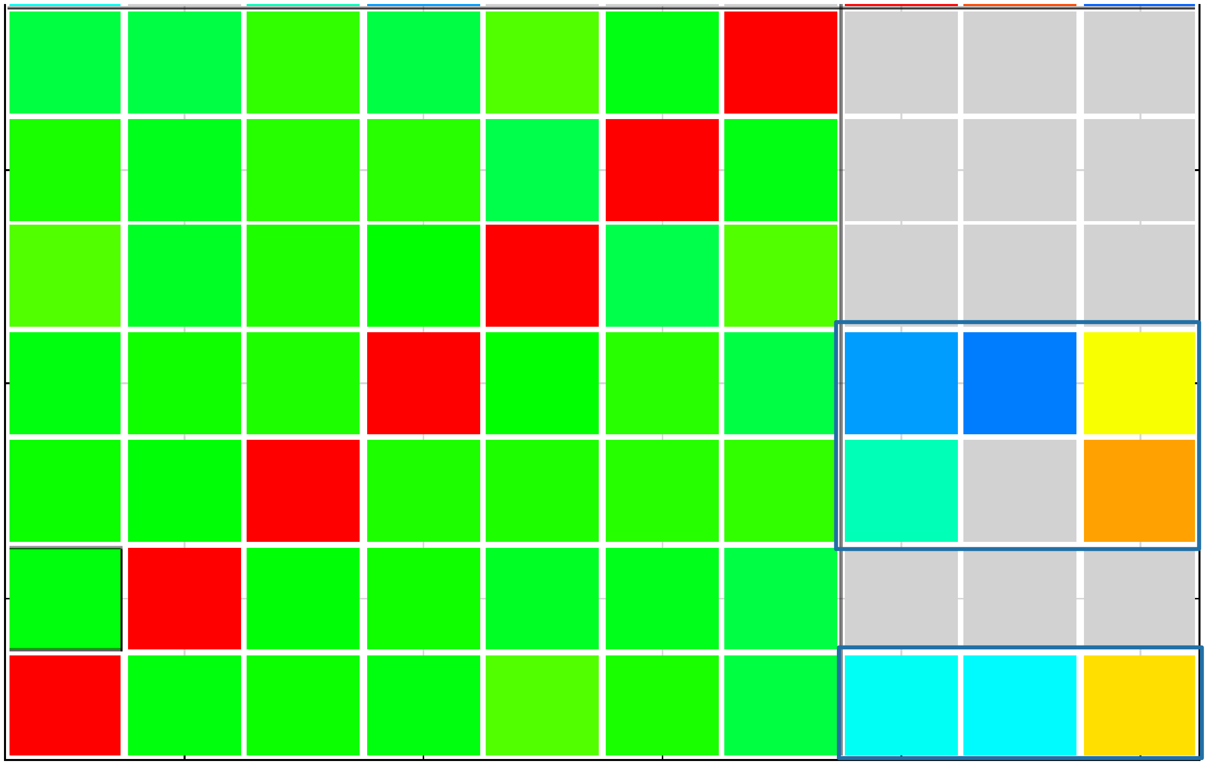
- The correlation matrix
- Red: Positive correlation
- Blue: Negative correlation
- Grey: No significant correlation.

Check:

- Correlations not only between input and output but also between the different results!



How to evaluate 1000 designs?



- Three input parameters show influence on the results.
- Four parameters show no influence.

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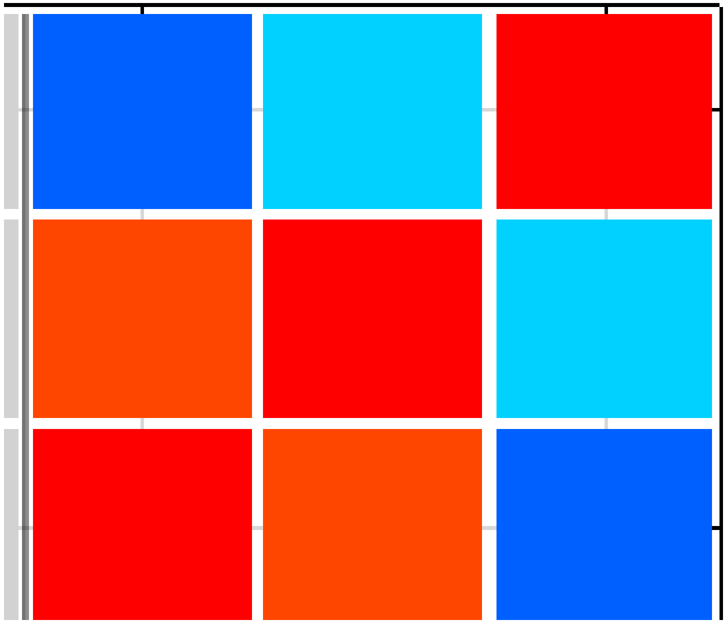
How to evaluate 1000 designs?



Deformation and Stress: positive correlated
Mass: negative correlation to stress and deformation
→Important for future design improvement.

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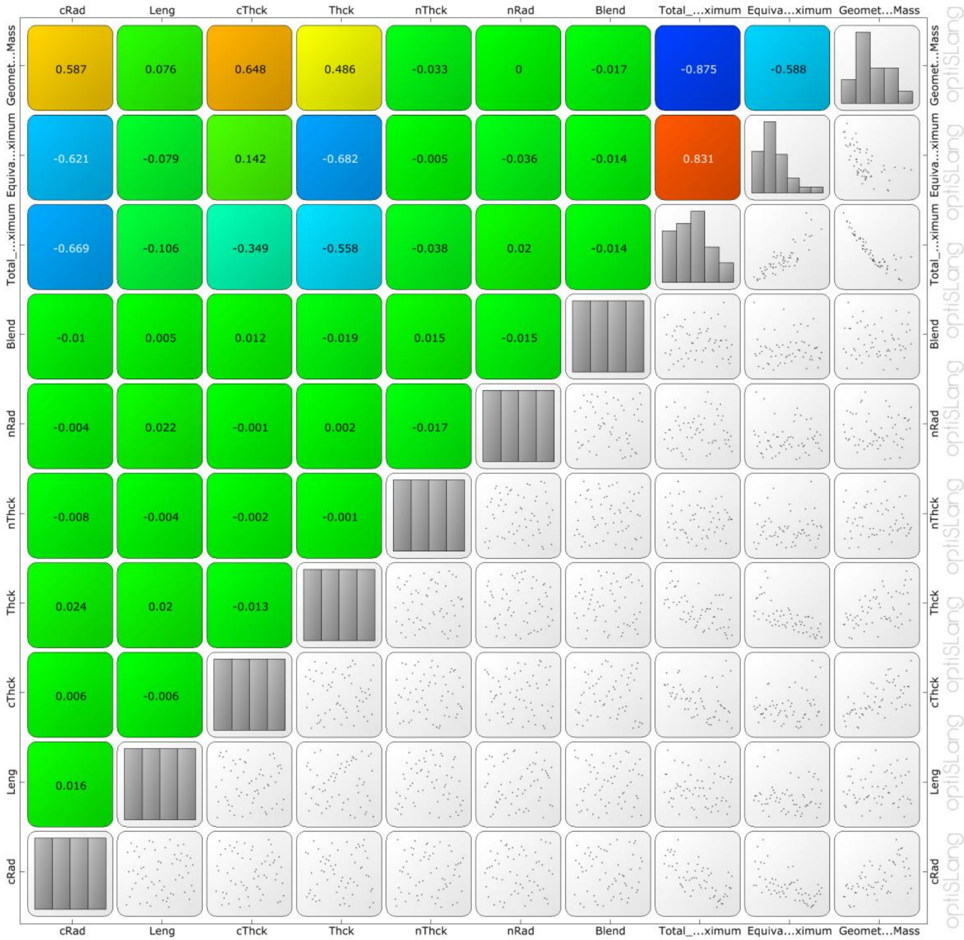
How to evaluate 1000 designs?

- Get the overview of all correlations using the extended correlation matrix!



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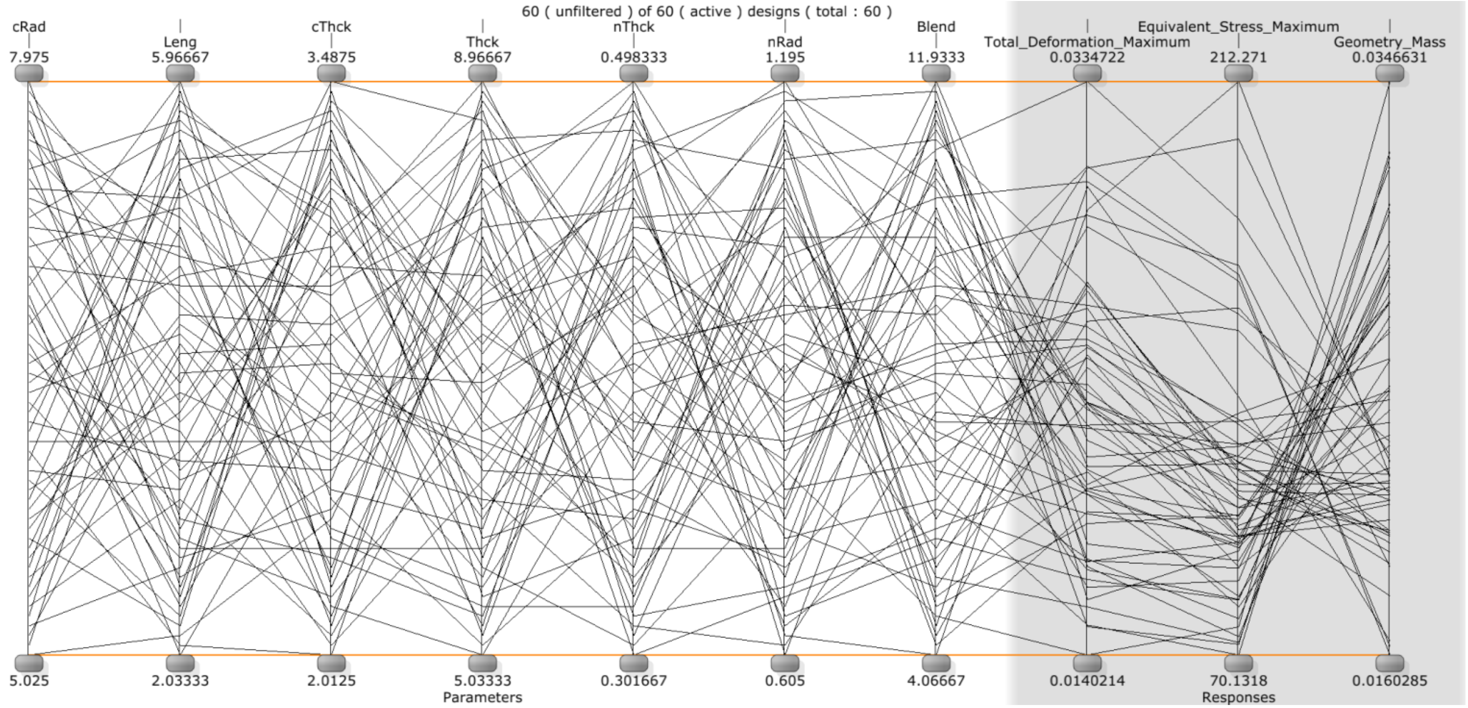
How to evaluate 1000 designs?

Parallel Coordinates Plot:

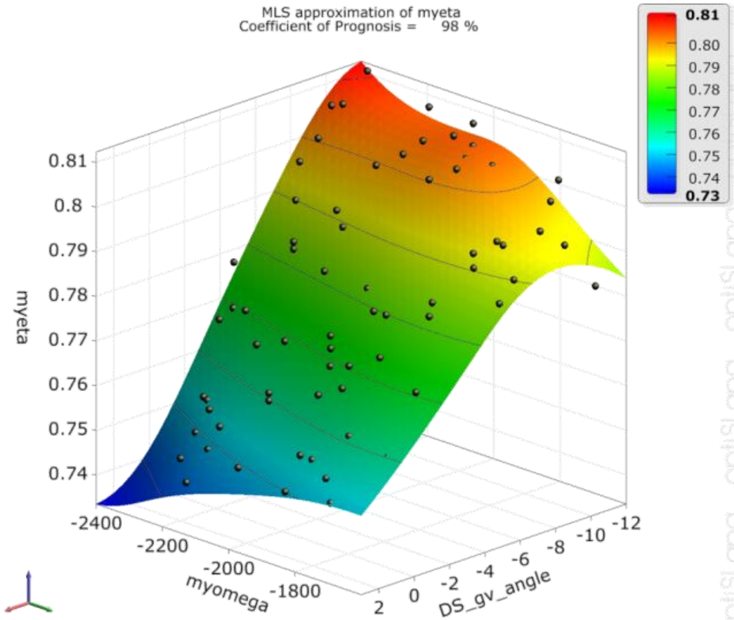
- Good for a quick exploration of input/output trends
- Check whether desired design improvement goals can be reached.



CADFEM

The optiSLang Meta-model of Optimal Prognosis (MOP)

- Characterize the system behavior by a mathematical description
- Determination of the best approximation model
- The response surface visualizes the behavior model
- Filter out the unimportant parameters
- Asses the forecast quality of the model:
  The Coefficient of Prognosis (CoP)
- Estimate occuring numerical noise
- Check concerning nonlinear correlation
- Explore improvement possibilites



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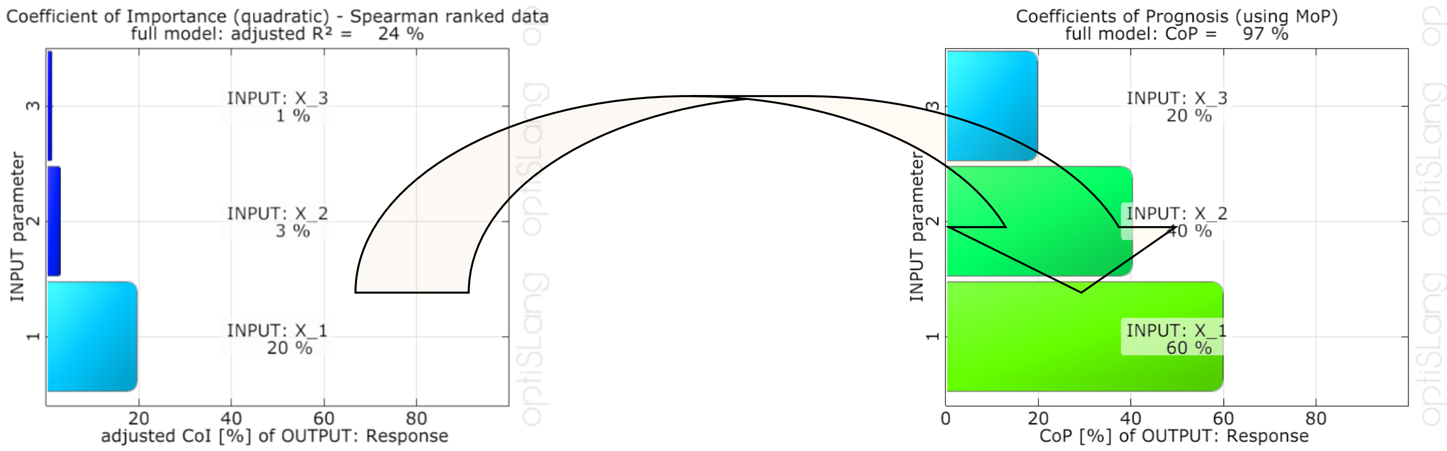
The Coefficient of Prognosis (CoP)

- Estimation of the forecast quality of the approximation model
- Explain the model behavior with a reduced parameter set
- Handle nonlinearities
- Determine coupled correlation – some parameters boost or efface each other
- A low CoP indicates occuring numerical noise



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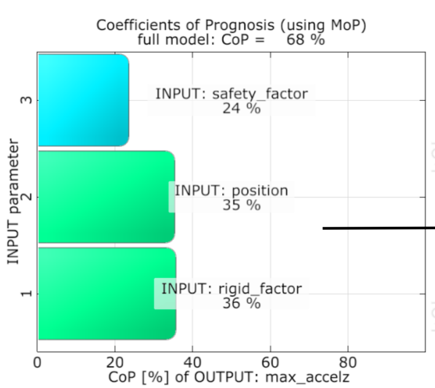
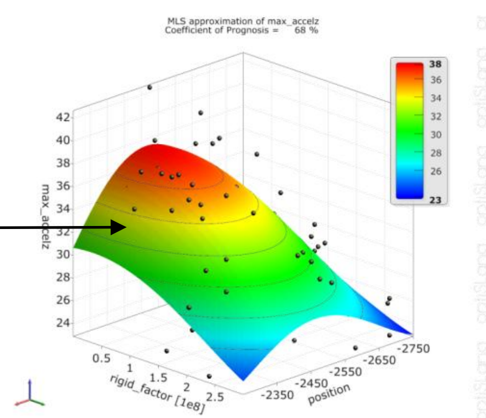
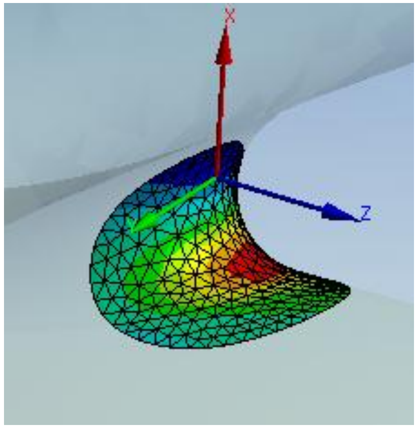
Accuracy and numerical noise

- Check accuracy using the Coefficient of Prognosis
  - A CoP of larger than ~80% is a good start value for further design improvement
- What if CoP is < 60..70% ?
  - Check variation space (to big / small)?
  - Forget some very important parameters?
  - Too much numerical noise in my model?
  - Too less samples?
  - Difficulties in result extraction?

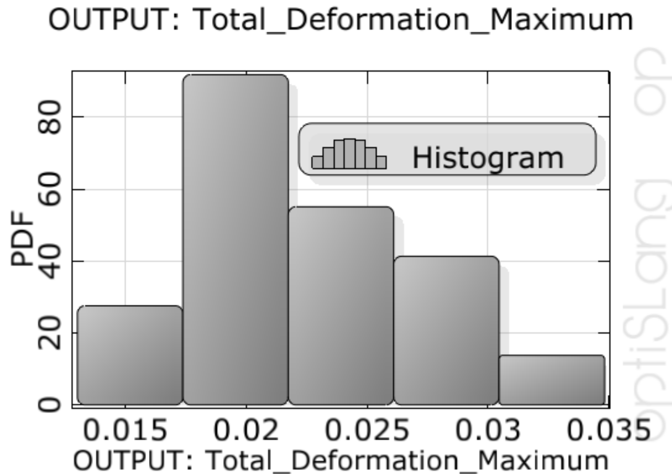






Reviewing the results

- Histograms:
  - Relative distribution of result values
  - Determination of critical stages
  - Check for possible design improvement



Statistic data			
Min:	0.01303	Max:	0.03481
Mean:	0.02288	Sigma:	0.004786
CV:	0.2092		
Skewness:	0.5064	Kurtosis:	3.104

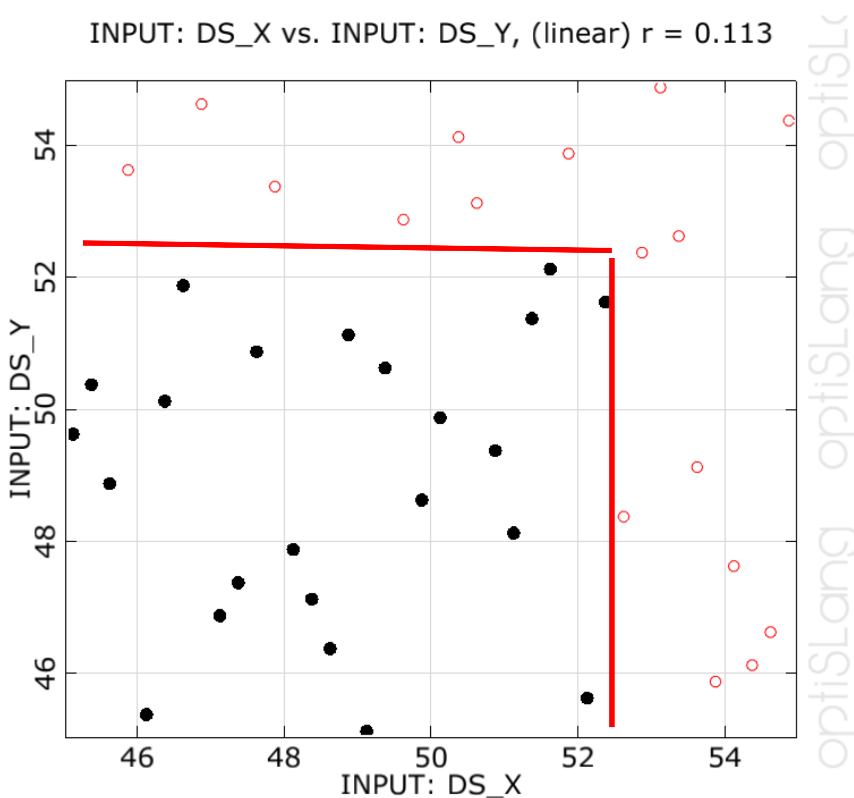
Robust parameter settings

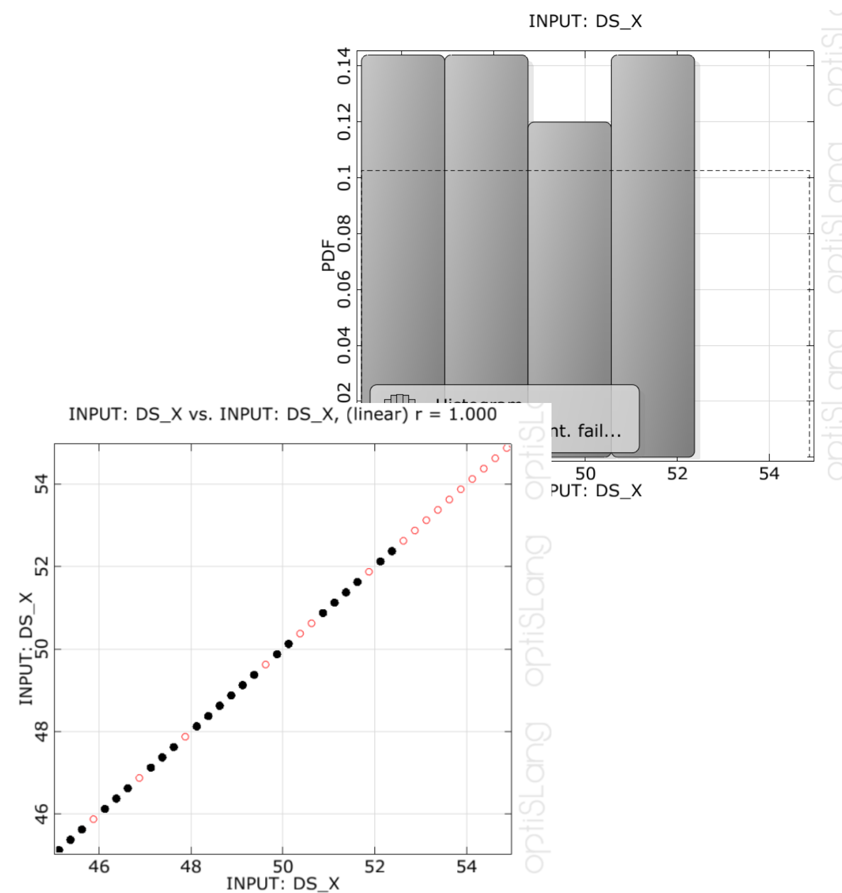
- What are robust parameter setting?
  - The solution always converges
  - The geometry can always be generated
  - The mesh can always be created

- Can we determine robust parameter settings in advance?
- Do we even need them?

Determining robust parameter settings

- optiSLang enables you to visualize failed designs to show the expected position in the variation space!





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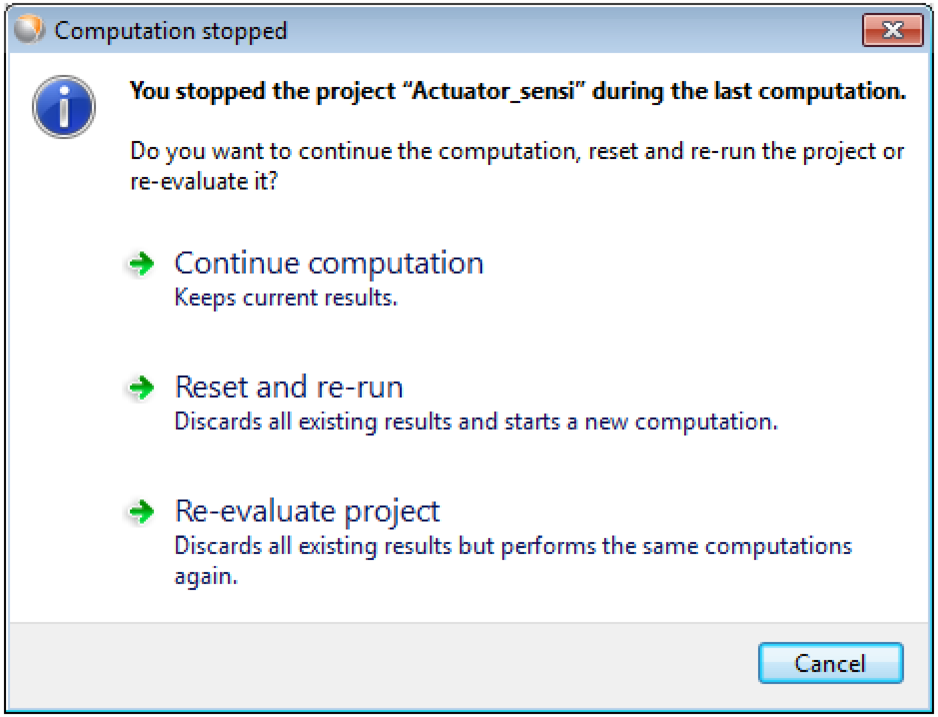
BUT - Do we need always converging and regeneratable models?

- optiSLang can deal with failed designs!
- Do not limit your variation space!
- Rather accept failed designs than loosing information!

Restart option

- What is if your computer system crashes or you need it for other purpose?
- optiSLang can be interrupted and restarted at any time.



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Understand your Design

Hard- and Software for Performant Design Variation

PRACE Autumn School 2013 - Industry Oriented HPC Simulations, September 21-27, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

Parallelize your calculations

- Use the optiSLang RSM Mode to send several designs in parallel to your solver system
- optiSLang inside Workbench uses the RSM technology and therfore you can combine it with your own jobmanagement systems.

Properties of Schematic D2: DOE

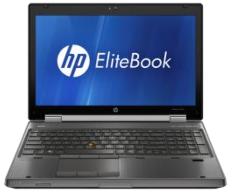
	A	B
1	Property	Value
2	⊟ General	
3	Component ID	DOE (optiSLang)
4	Directory Name	Sensitivity
5	Save Design Point Directories	☐
6	⊟ Notes	
7	Notes	
8	⊟ Update Options	
9	Use RSM Mode	☑
10	Preferred Number of Design Points in Parallel	10
11	Run Python Script for Update	☐

CADFEM

Hardware

- Workstation
  - Local High End Computing power
  - Local High End 3D Graphics
  - Up to 16 Cores and 512 GB Memory
- Benefit
  - All kind of *sequential* simulation processing

Desktop Workstation



Mobile Workstation

Z1 All-in-One Workstation

CADFEM

Hardware

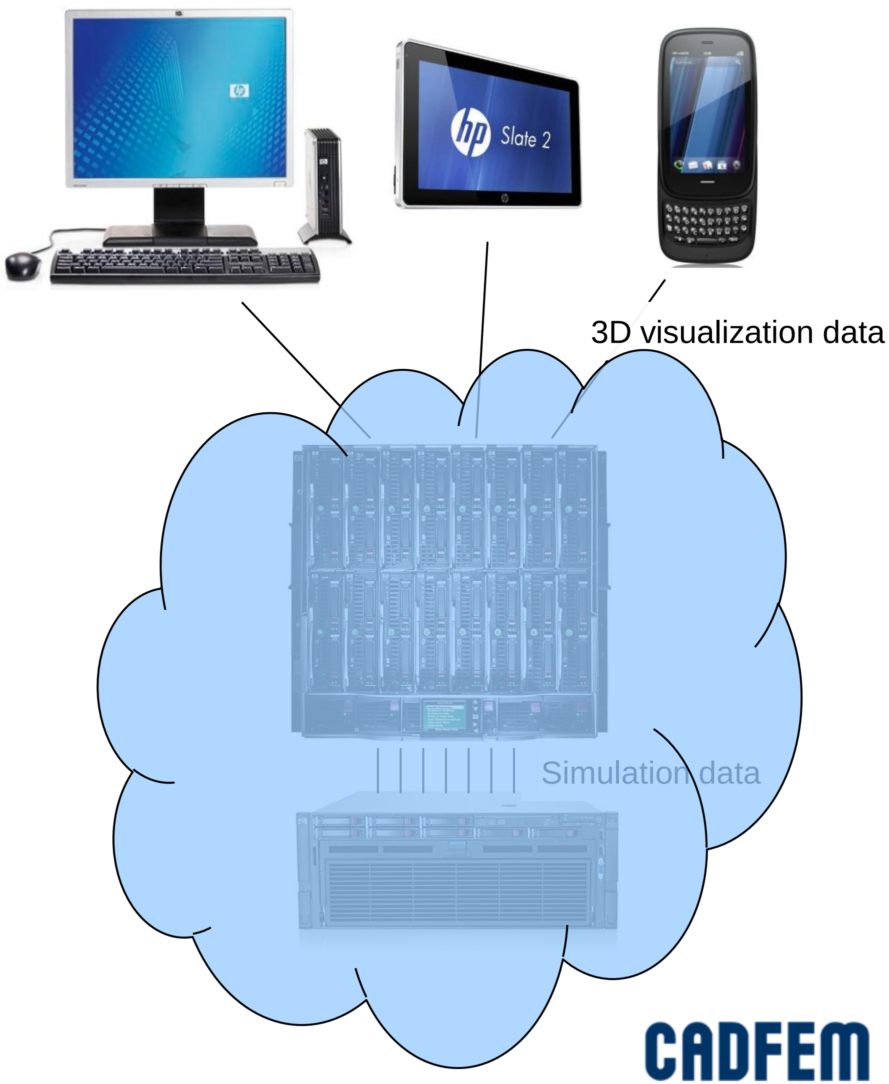
- Compute Server
  - Remote High End Computing power
  - No 3D Graphics
  - Scalable in cores, memory, disks
  - Redundant components
  - Service Level Agreements SLAs availible
  - Remote service access on hardware level → high availability
- Benefit
  - All kind of *sequential* **and** *simultaneous* simulation processing
    - Highly scalable in the number of cores per job
    - Highly scalable in the number of simultaneous jobs → large DoE's

CADFEM

Hardware

- Terminals & Cloud

- Benefit
  - High bandwidth connection from blade workstation to compute server → fast postprocessing
  - Flexible allocation of virtual workstations → cost effective „workstation“ usage by multiple users
  - Flexible scaling of hardware resources → better scaling and availability by external hardware sharing



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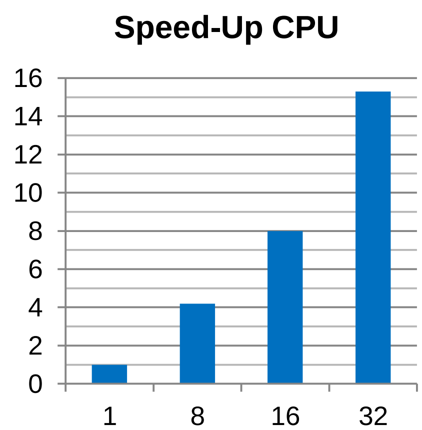
Parallel Processing → Multiple cores per Design

- Use multiple cores
  - Today, every computer is a parallel computer
  - 8 Cores → factor 4 on industry FEA models is typical average
  - HPC Pack with 1 additional GPU → additional factor 1.5
    - NVidia Tesla 2075 ~ 2-3000€
  - Total speedup Cores*GPU: 4 x 1.5 = 6
  - Important: SMP & DMP availible

# Cores	Speed-Up	computing h
1	1	24.0
2	1.4	17.1
4	2.4	10.0
6	3.5	6.9
8	4.2	5.7
16	8	3.0
32	15.3	1.6



Source: MicroConsult

- Benefit
  - 1 HPC-Pack: +200% corepower (300 % with GPU) for +35% costs (ANSYS/MECH)
  - 2 HPC-Pack: +990% corepower (1500% with GPU) for +70% costs (ANSYS/MECH)

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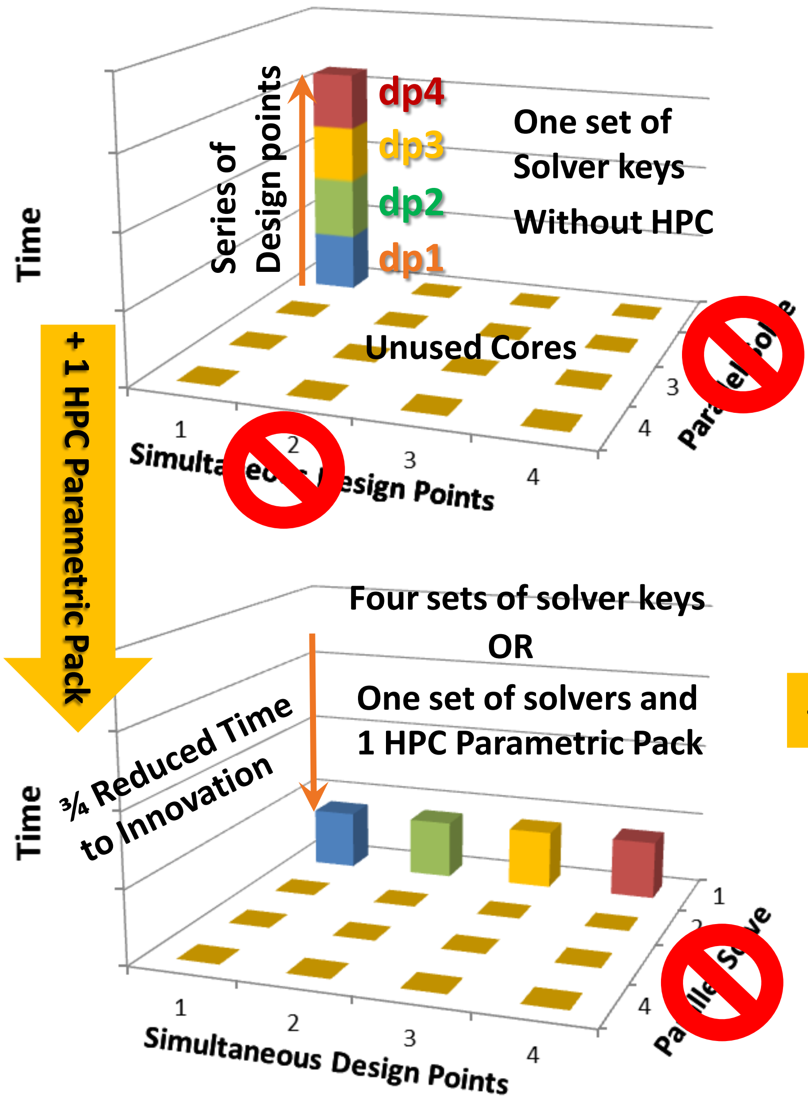
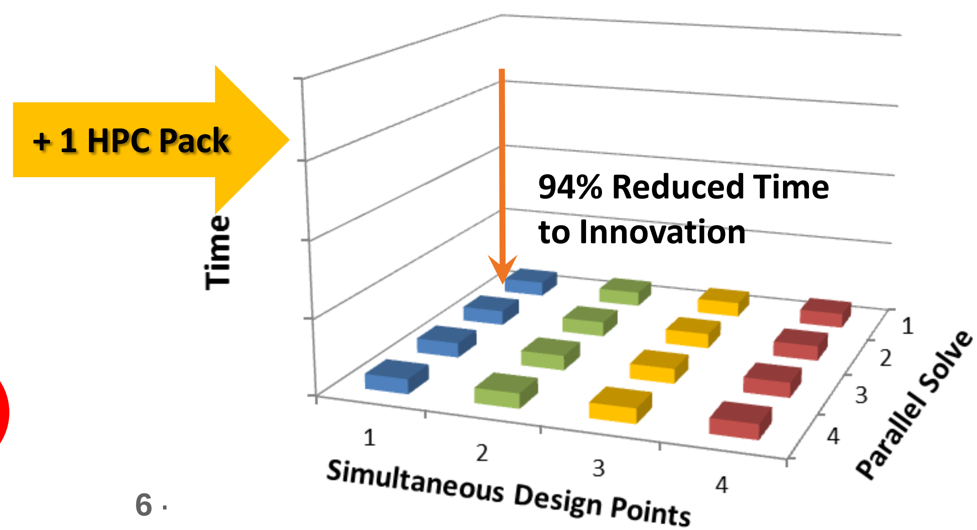
Simultaneous Processing → Multiple Designs at once

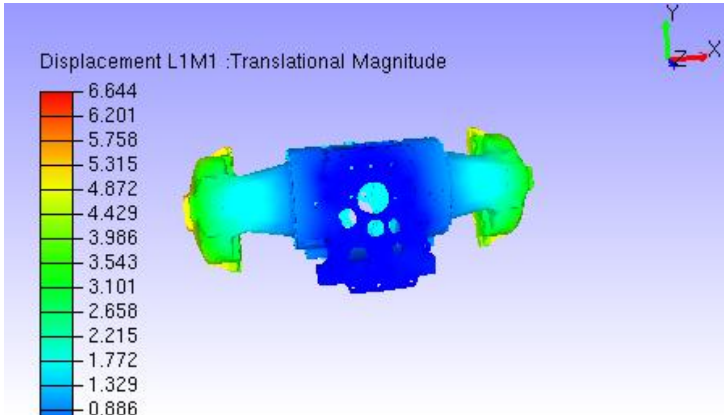
Multiplying licenses enables you to drastically reduce time to innovation





CADFEM C.A.V.E. - Why

- High number of simulation result sets → big data
- Workbench integration of VCollab (Visual Collaboration Technologies)
  - Reduced amount of data by factor 50 to 300 for cost effective archiving and sharing
  - High speed visualization
  - Flexibility by visualization independent from CAE software
  - Sharing of 3D result data for a better understanding of all project partners
  - Seamless integration into ANSYS Workbench and Office



Source: AGCO FENDT

Part	rst-File	cax-File
Injection Molding Tool (9 results)	529 MB	3.3 MB
Automotive Assembly (16 results)	68 GB	1.0 GB
Mechanical Part (8 results)	137 GB	0.4 GB

CADFEM C.A.V.E. - Summary

- High data compression rate
  - Minimized costs for archiving
  - High speed visualization
- Improves communication and understanding by sharing results
  - 3D Result viewing for everyone free of charge
- Seamless Workbench integration
  - Safety First: Automated consistency
  - Time effective result extraction

CADFEM

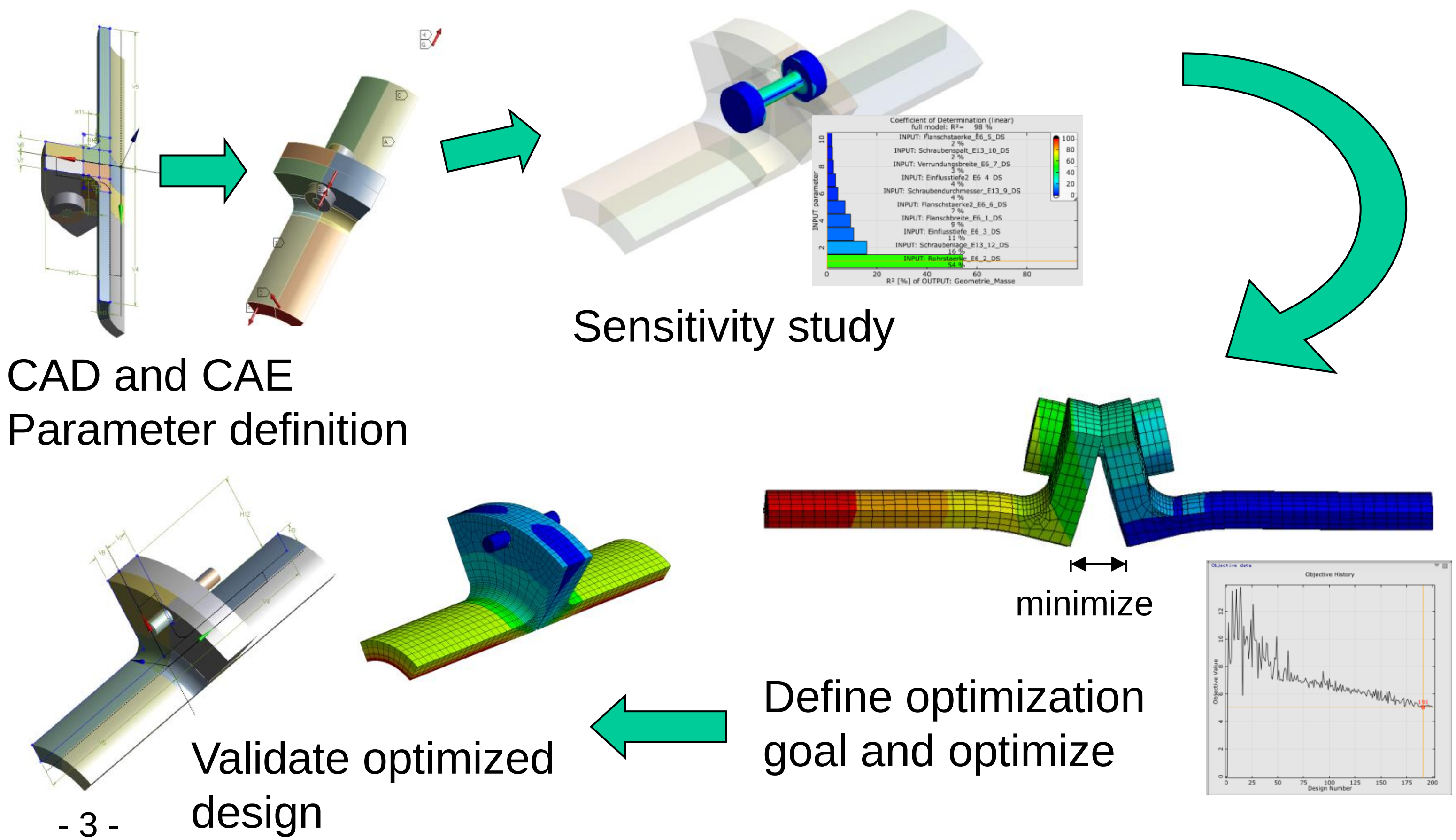
Understand your design

Optimization

Table of contents

1. General Information

Workflow:



General Information

- Design variables

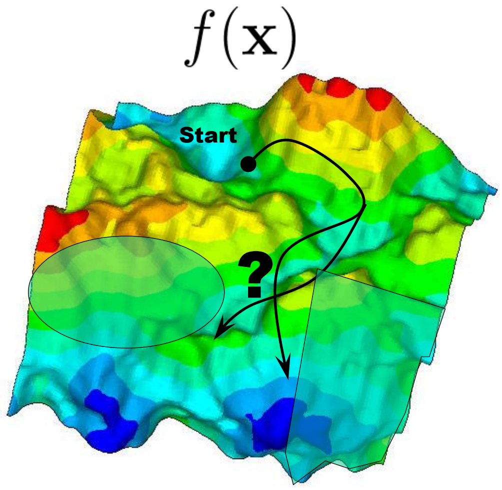
  Variables defining the design space (continuous, discrete, binary)

- Objective function

  Function $f(\mathbf{x})$ has to be minimized

- Constraints, State variables

  Constrain the design space, Equality/Inequality restrictions are possible



$$f\left(x_1, x_2, ..., x_N\right) \rightarrow \min$$

$$g_k(x_1, x_2, \ldots x_N) = 0; \; k = 1, m_e$$

$$h_l(x_1, x_2, \ldots x_N) \geq 0; \; l = 1, m_u$$

$$x_i \in [x_l, x_u] \subset \mathbb{R}^N$$

$$x_l \leq x_i \leq x_u$$

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2. Optimization Algorithms

Available Optimization algorithms in optiSLang:

Deterministic methods

- Hill climbing methods
- Simplex strategies
- **Gradient-based strategies**
- **Surrogate models**
    - **Global response surface methodology**
    - **Adaptive response surface methodology**

Stochastic methods

- **Sampling methods**
    - **Plain Monte Carlo**
    - Markov Chain Monte Carlo
    - **Latin Hypercube Sampling**
    - **Simple Design improvement**
- Physical process procedures
    - Simulated annealing
    - Tunneling algorithm
- **Artificial life approaches**
    - **Evolution strategies**
    - **Genetic algorithms**
    - **Particle swarm optimization**

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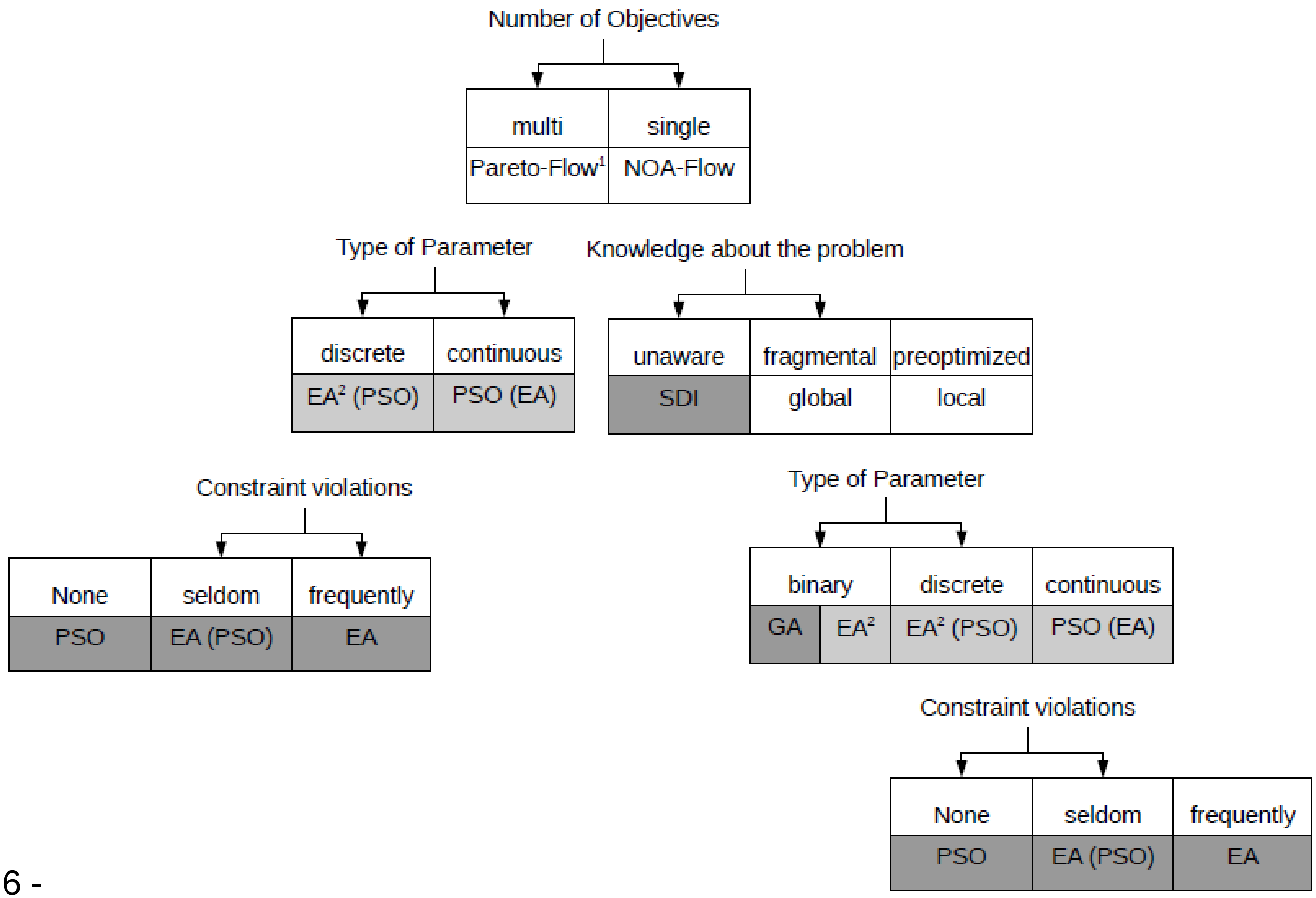
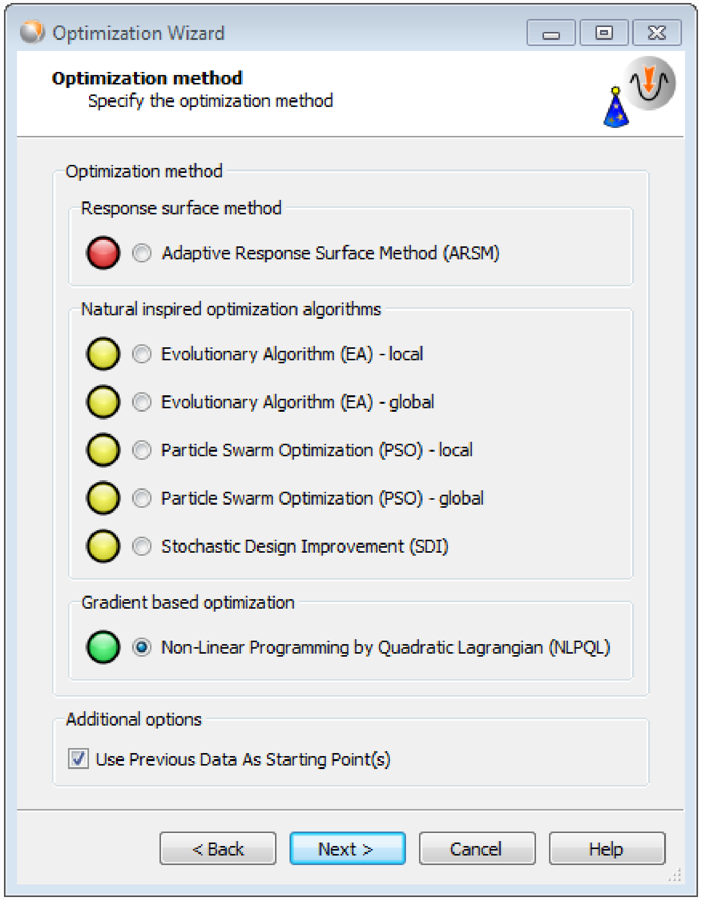
Optimization Algorithms

Decision Tree:



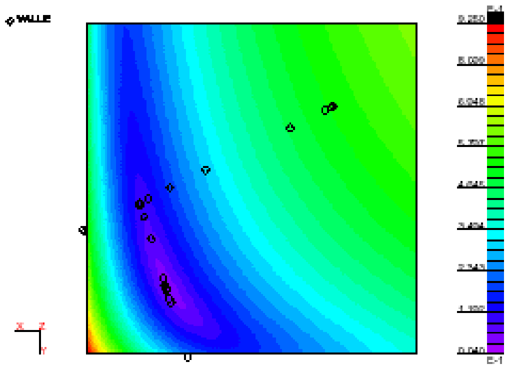
Optimization Algorithms

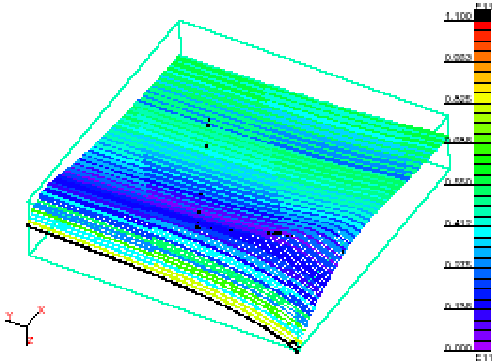
optiSLang inside Workbench chooses the best algorithm by a wizard:

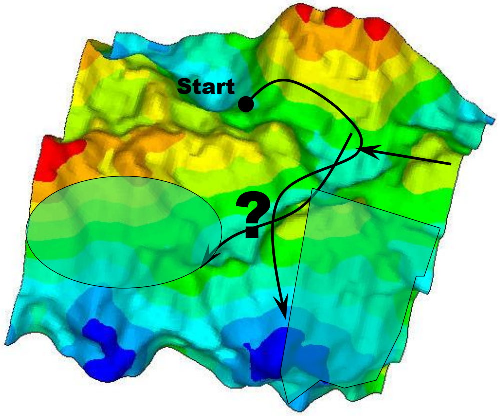


Optimization Algorithms

Nonlinear Programming Quadratic Line Search (NLPQL)





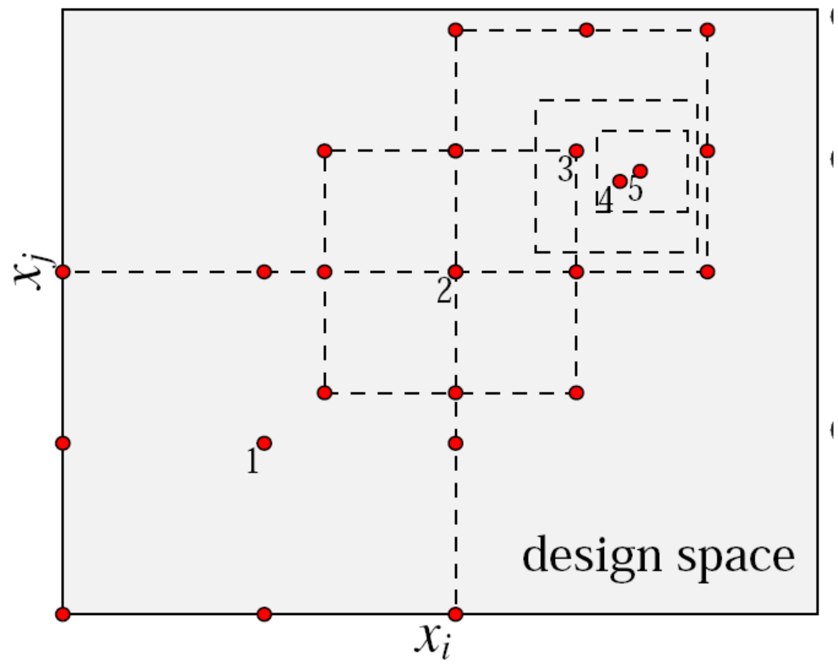


Recommended area of application:
reasonable smooth problems

Remark:
The gradient optimizer sometimes stucks in local optima
Also use with care for binary/discrete variables

Optimization Algorithms

Adaptive Response Surface Method:

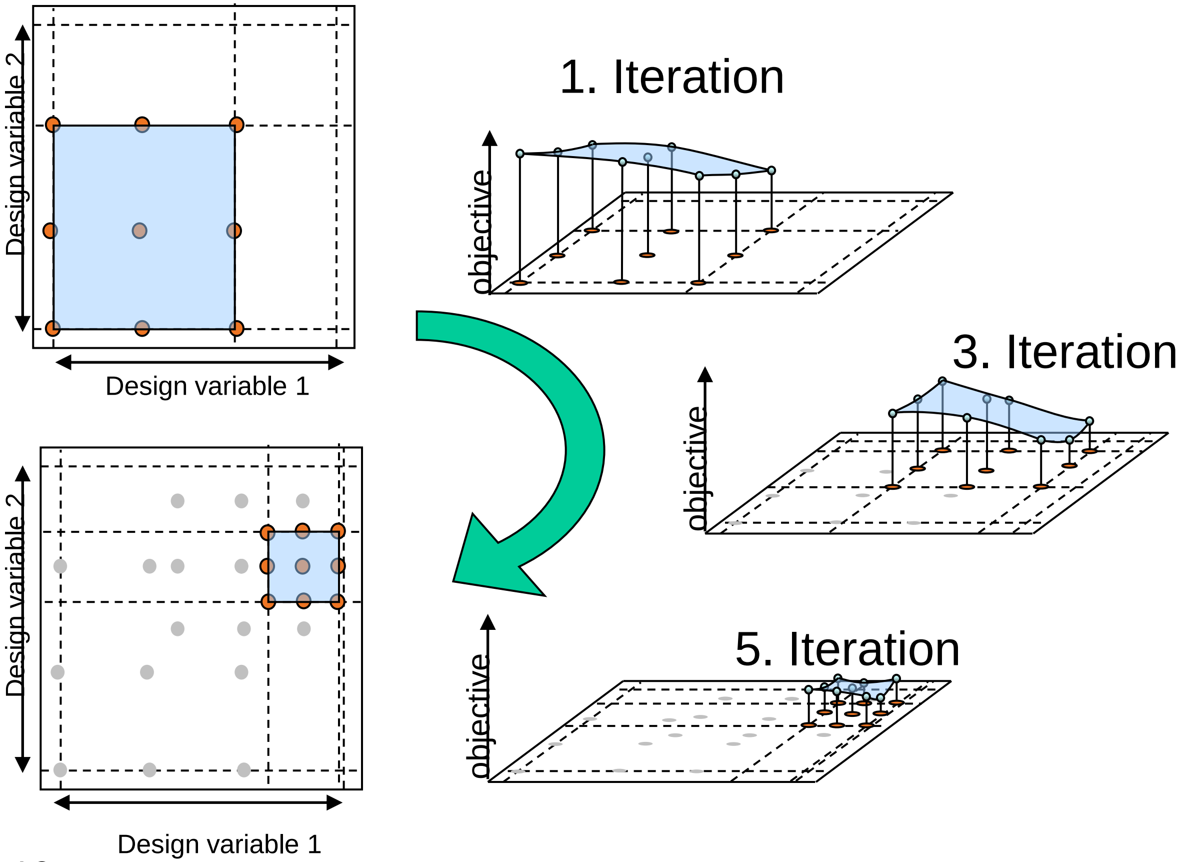


+ Fast catch of global trends, smoothing of noisy answers

+ Adaptive RSM with D-optimal linear DOE/approximation functions for optimization problems with up to 5…15 continuous variables is possible

Optimization Algorithms

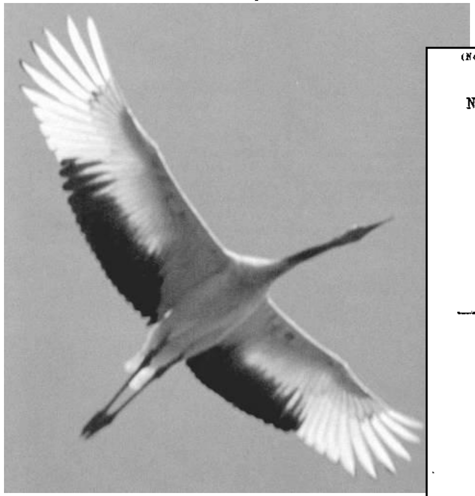
Adaptive Response Surface Method:

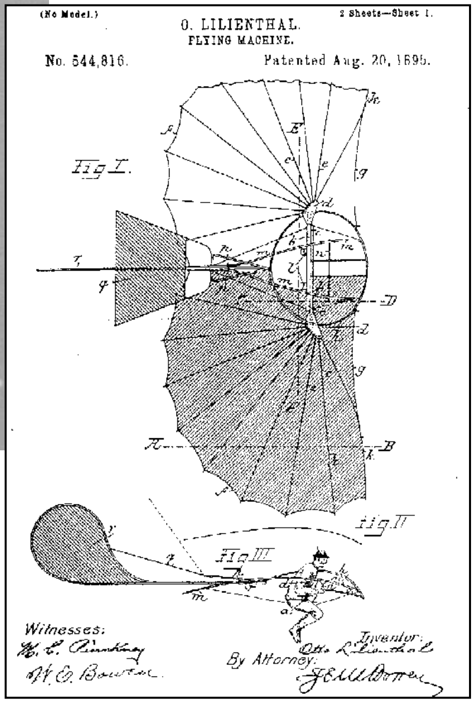


Evolutionary algorithm (EA)

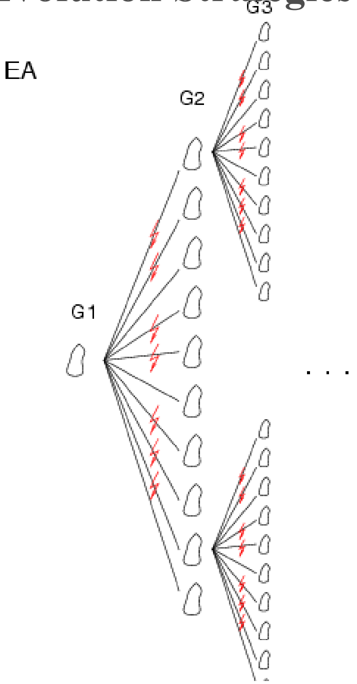
It imitates Evolution (“Optimization”) in Nature:

- Survival of the fittest
- Evolution due to mutation, recombination and selection
- Developed for optimization problems where no gradient information is available, like binary or discrete search spaces

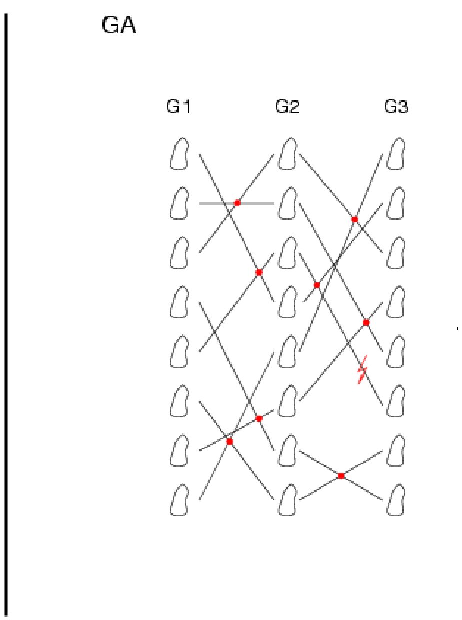




Evolution Strategies [ES]



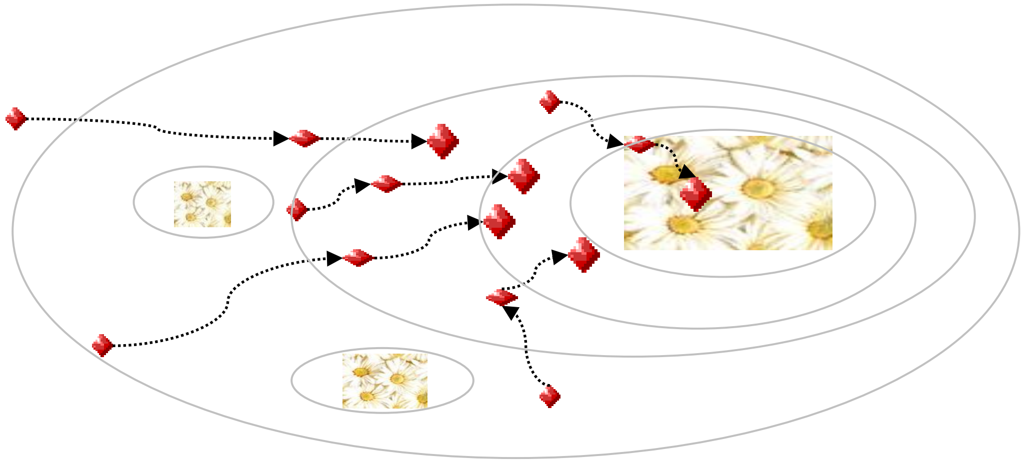
Genetic Algorithms [GA]



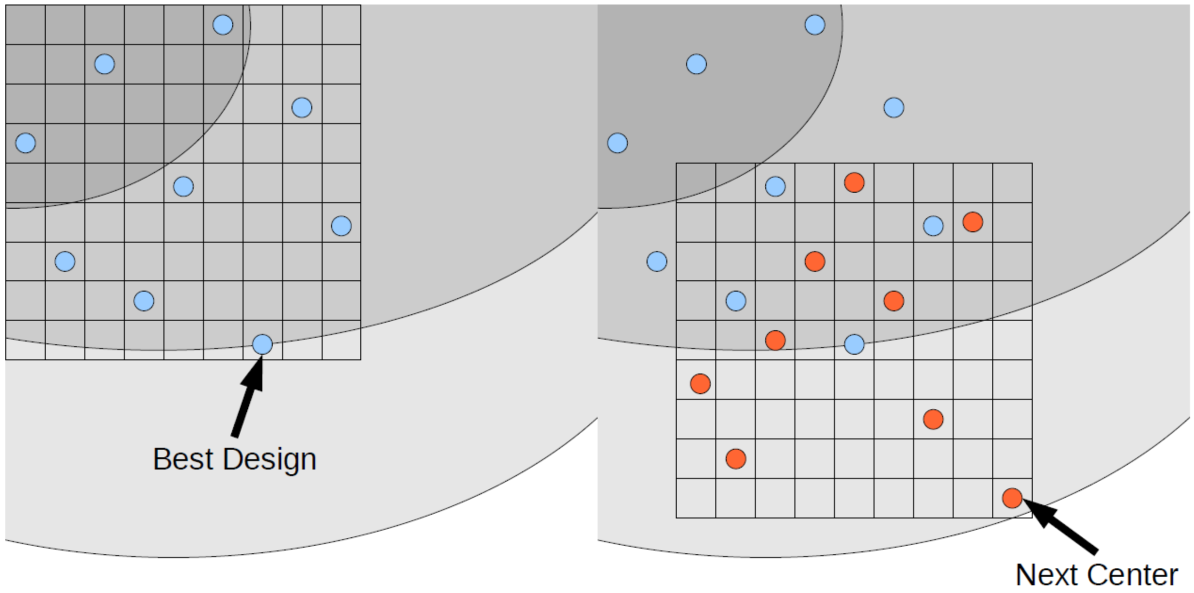
Particle Swarm Optimization (PSO)

- swarm intelligence based biological algorithm
- imitates the social behaviour of a bees swarm searching for food

- **Selection** of swarm leader including archive strategy
- **Adaption of** fly direction
- **Mutation of** new position
- Available for **single/multi objective Optimization**



Simple Design Improvement



- Improves a proposed design without extensive knowledge about interactions in design space
- Start population by uniform LHS around given start design
- The best design is selected as center for the next sampling
- The sampling ranges decrease with every generation

Optimization

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Gradient-based algorithms

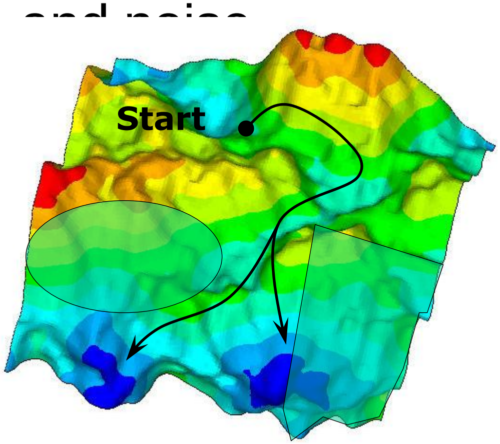
- Most efficient method if gradients are accurate enough
- Consider its restrictions like local optima, only continuous variables and noise

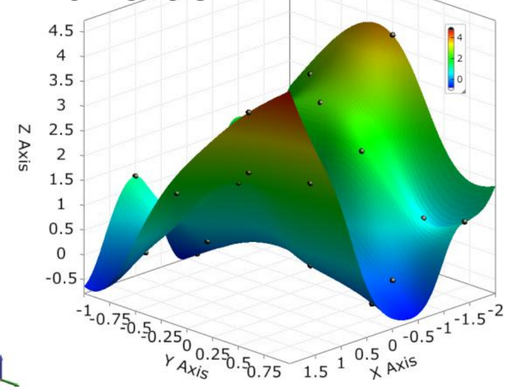
Response surface method

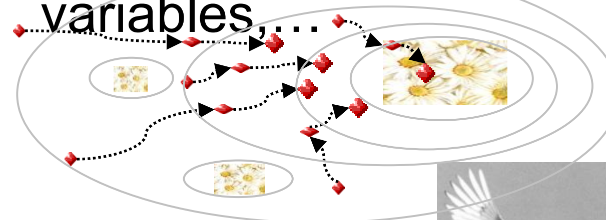
- Attractive method for a small set of continuous variables (<15)
- Adaptive RSM with default settings is the method of choice

Biologic Algorithms

- GA/EA/PSO copy mechanisms of nature to improve individuals
- Method of choice if gradient or ARSM fails
- Very robust against numerical noise, non-linearities, number of variables,…







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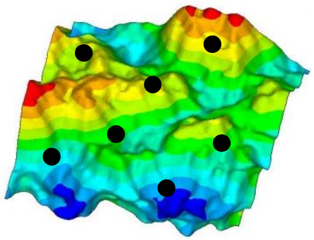
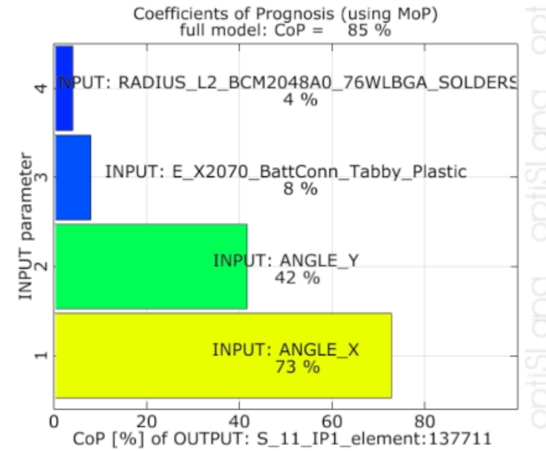
Optimization

1) Start with a sensitivity study using the LHS Sampling

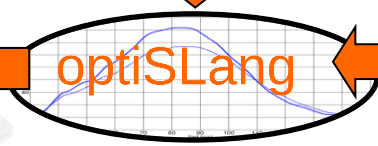


2) Identify the important parameters and responses

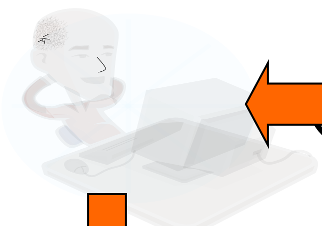
- understand the problem
- reduce the parameters



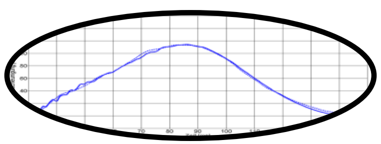
Scan the whole Design Space



Understand the Problem using CoP/MoP



Search for Optima



3) Run the suiting optimization algorithm

4) Goal: user-friendly procedure provides as much automatism as possible

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Optimization

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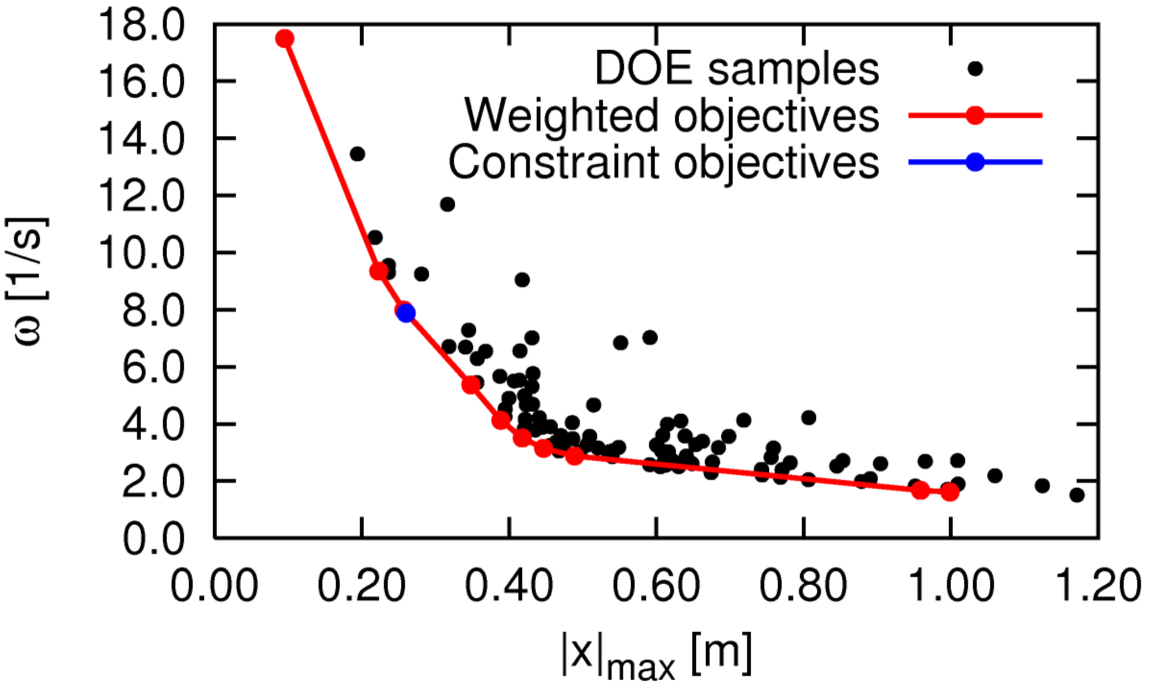

- Objective 1: minimize maximum amplitude after 5s
- Objective 2: minimize eigen-frequency
- DOE scan with 100 LHS samples gives good problem overview
- Weighted objectives require about 1000 solver calls

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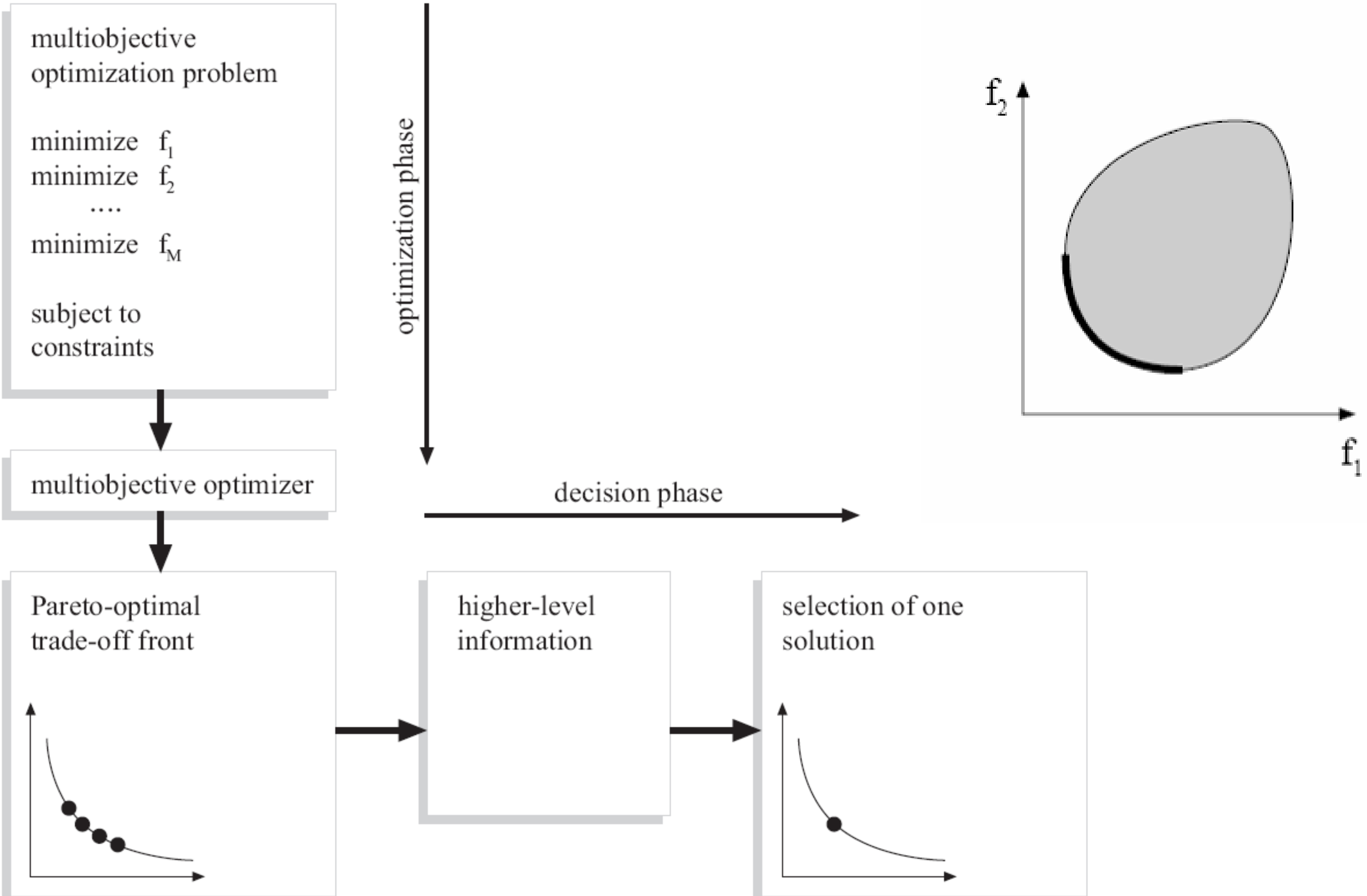
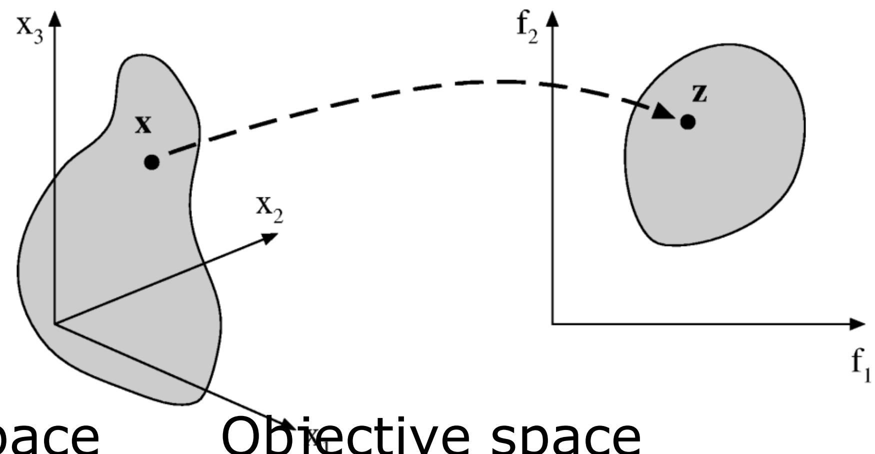
Optimization

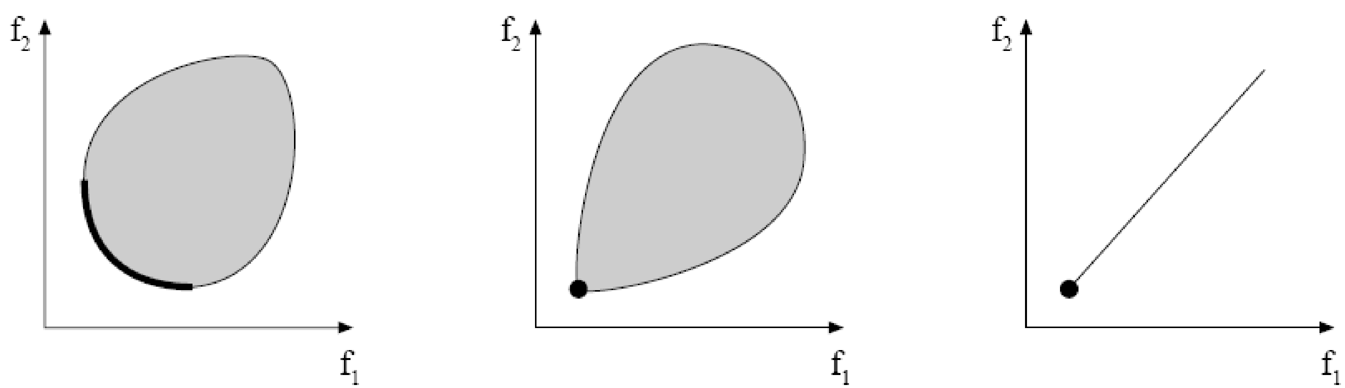
Strategy C: Pareto Optimization



Optimization

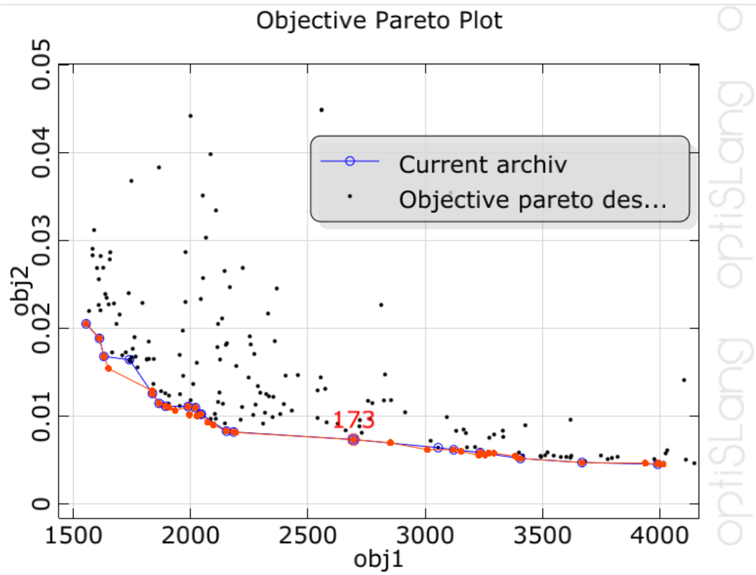


Design space   Objective space

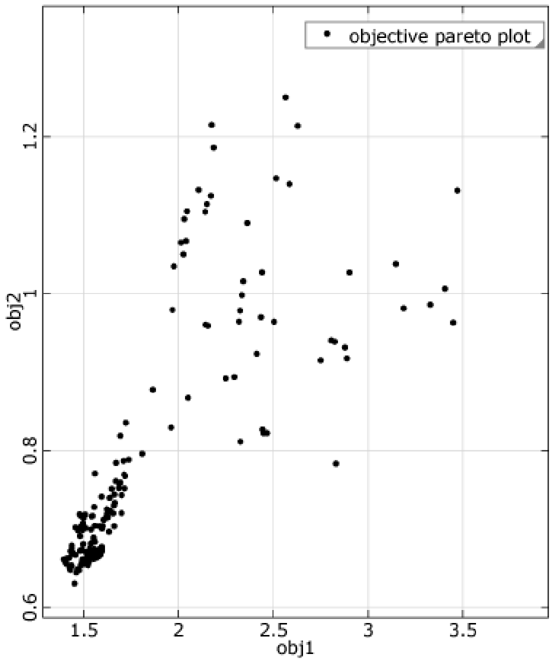


- Only for conflicting objectives a Pareto frontier exists
- For positively correlated objective functions exactly one optimum exists

Optimization



Conflicting objectives



Correlated objectives

Optimization

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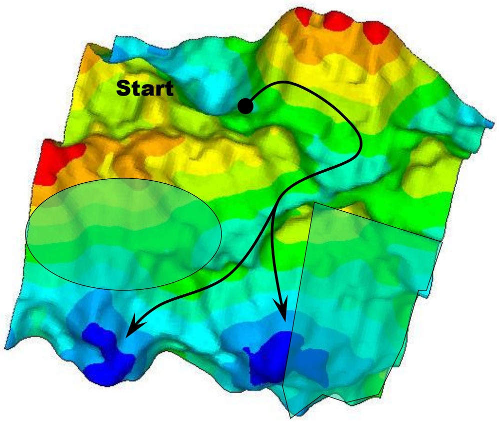
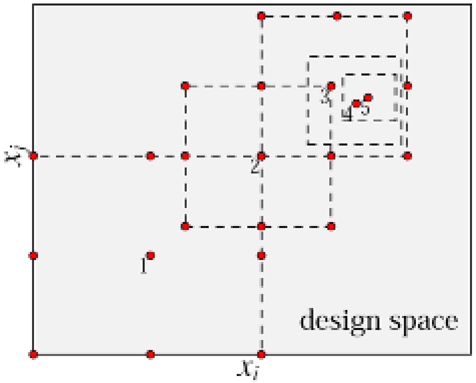
Gradient-based algorithms

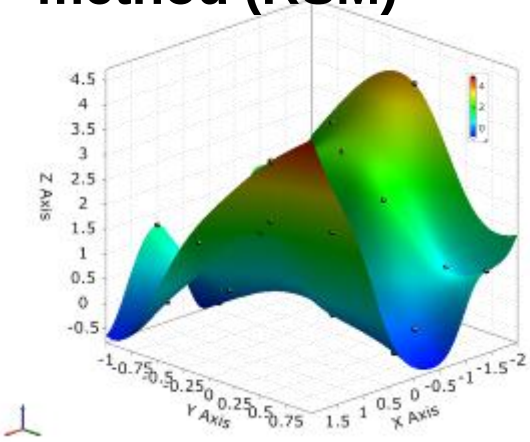


Local adaptive RSM

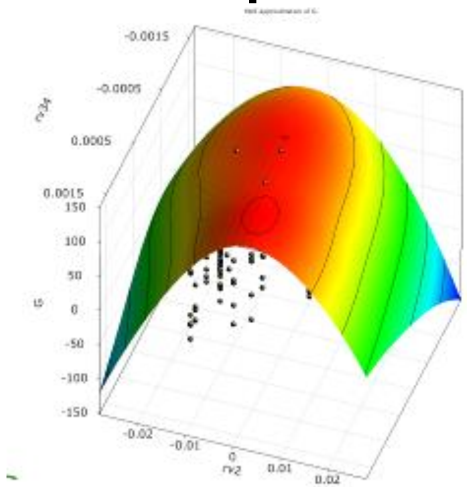


Biologic Algorithms

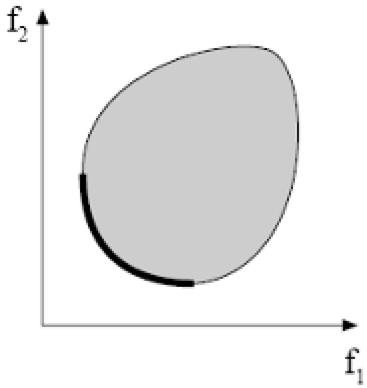
Response surface method (RSM)



Global adaptive RSM



Pareto Optimization



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Understand your Design

Outlook

PRACE Autumn School 2013 - Industry Oriented HPC Simulations, September 21-27, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

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