



PARTNERSHIP FOR  
ADVANCED COMPUTING IN EUROPE

# Understand your design

Dipl.-Ing. (FH) Andreas Veiz,  
CADFEM GmbH

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

# 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

$$\bar{\Pi} = \frac{1}{2} \sum_e \{u\}^T \cdot [K] \cdot \{u\} - \{u\}^T \cdot \{F\}$$

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# Understand your Design

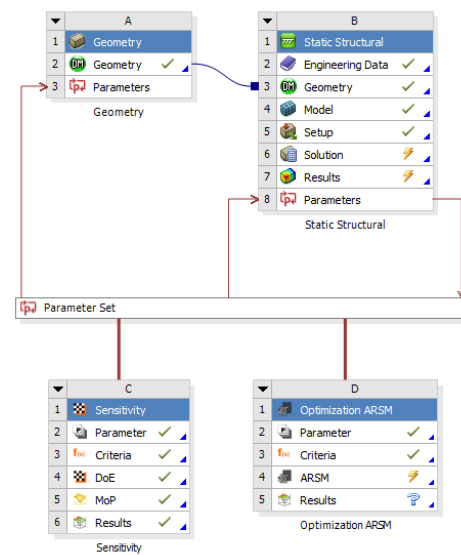
Motivation for parametric variation

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# Motivation

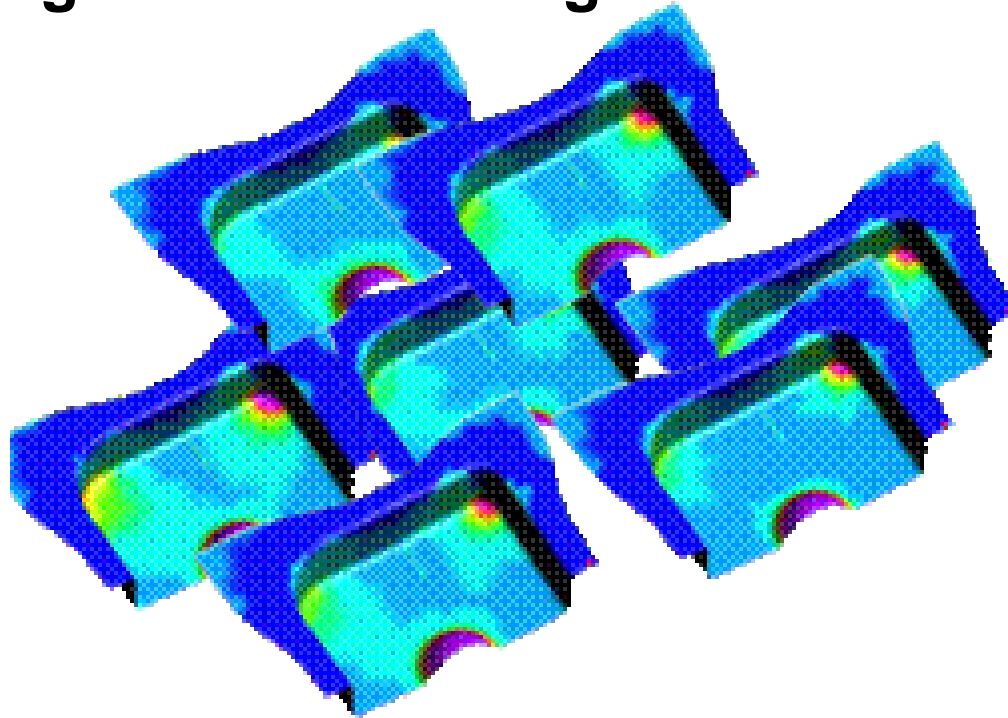
- Understand a Design
- Match Tests and Simulation
- System Behavior
- Design Improvement
- Safe Designs

## optiSLang





## Understanding alternative designs



....

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

## Understand a Design



Design

Part Assembly

Brake Pressure

Friction

Material

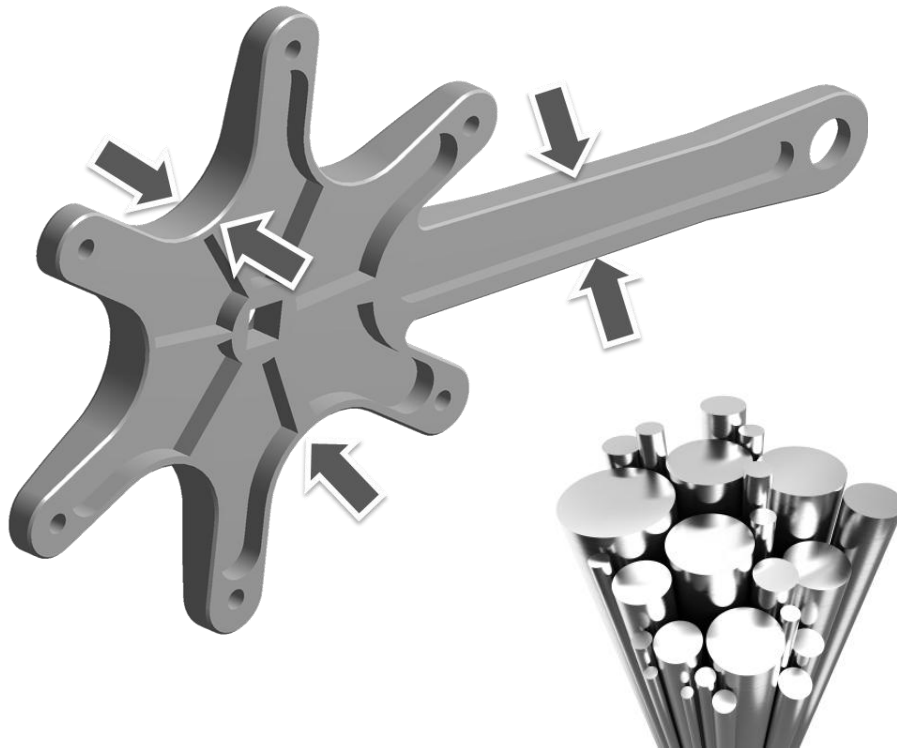
Manufacturing



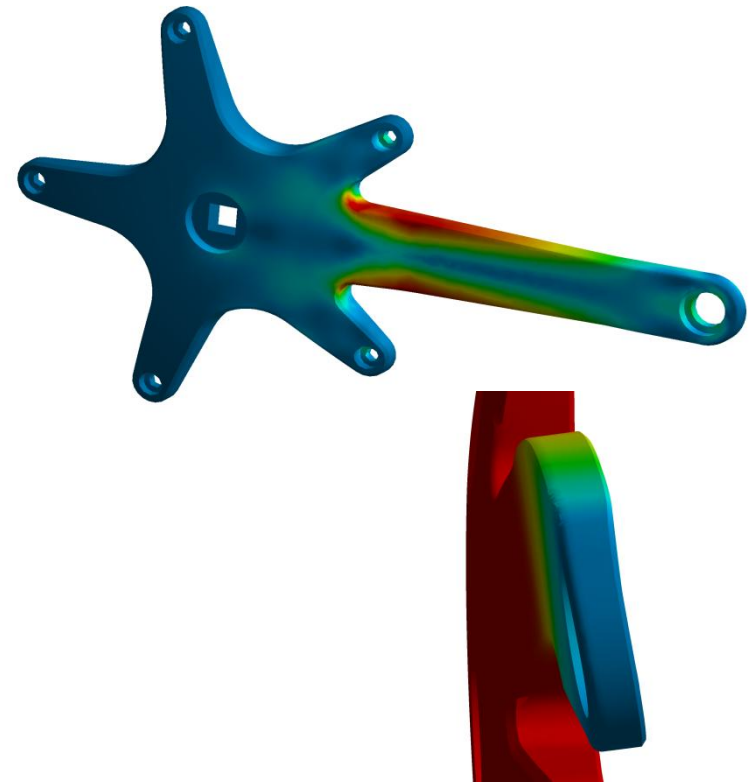
Which one is most important?

Is a larger value better or a smaller value?

## Engineering a Design



Input of engineers  
defines a final design

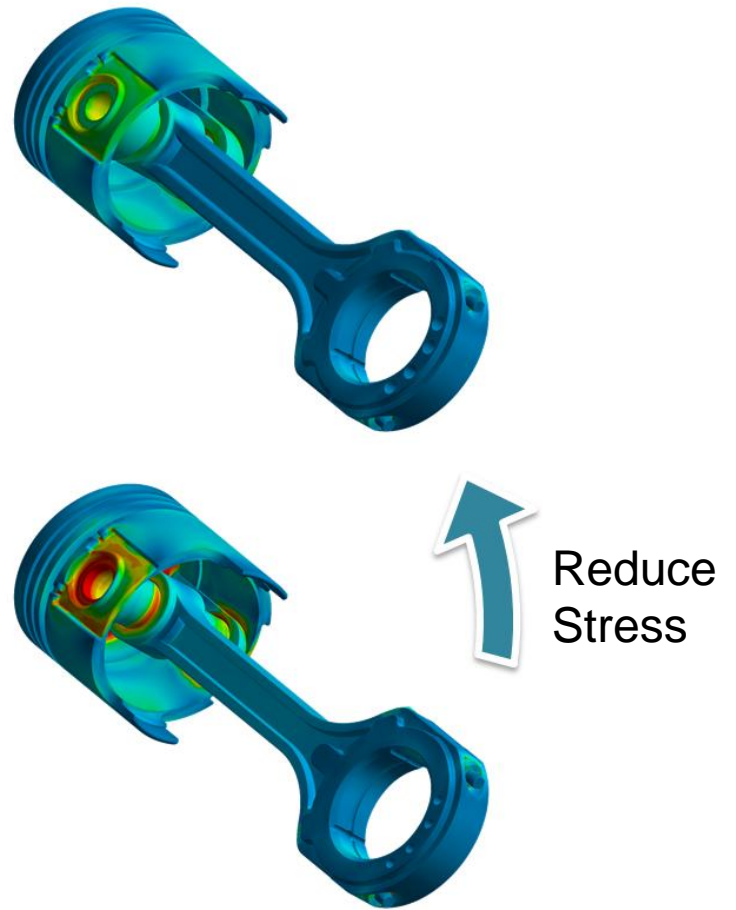
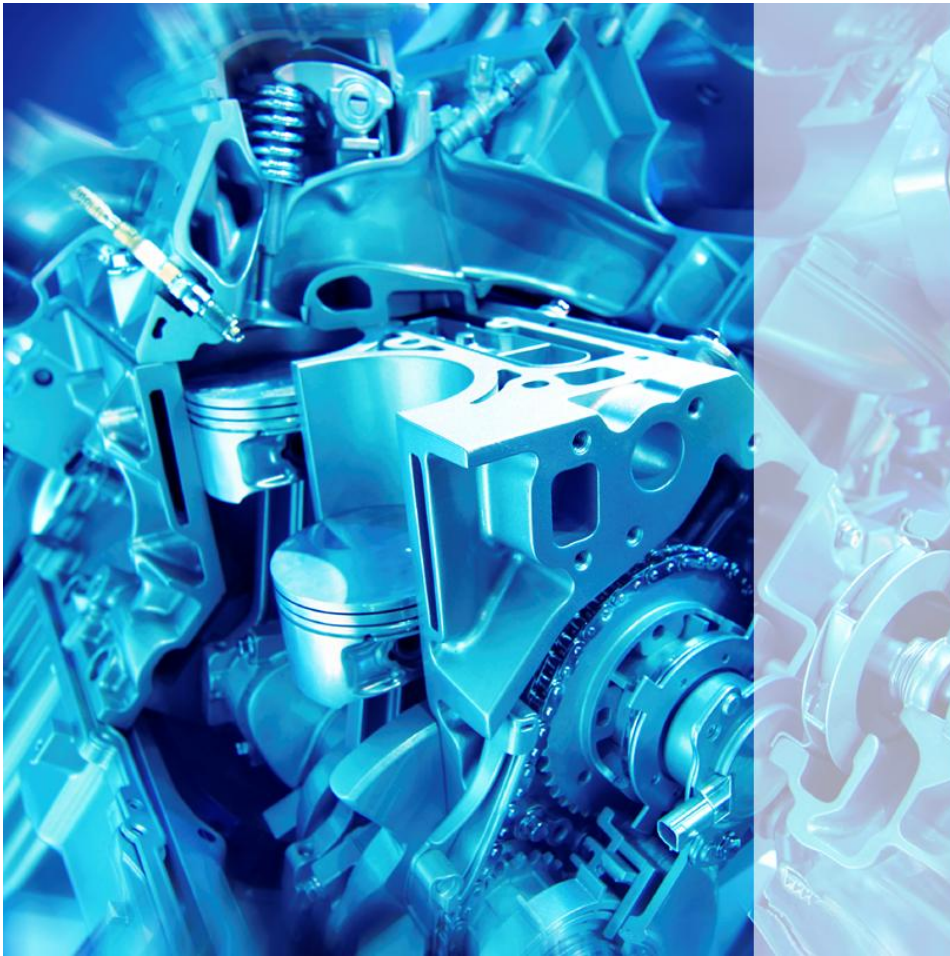


Input is based on design  
evaluations and results

## Benefits of a parametric design variation

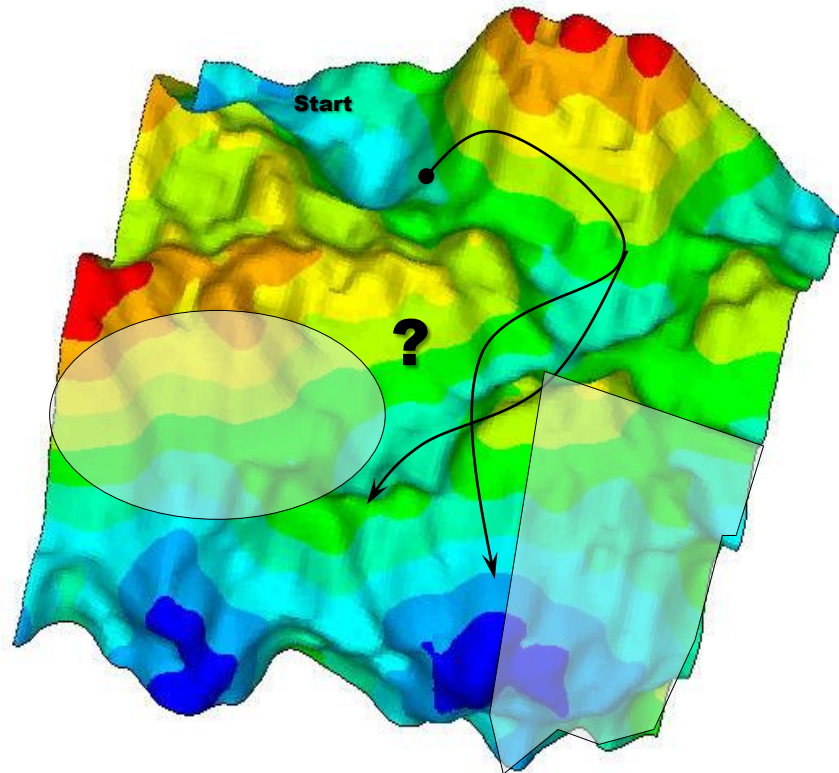
- Get the most significant parameters.
- Check correlations.
- Estimate numerical noise.
- Determine difficulties in extracting results.
- Estimate numerical stability.
- Check your geometrical validity.
- Check potential design improvement.

# Design Improvement



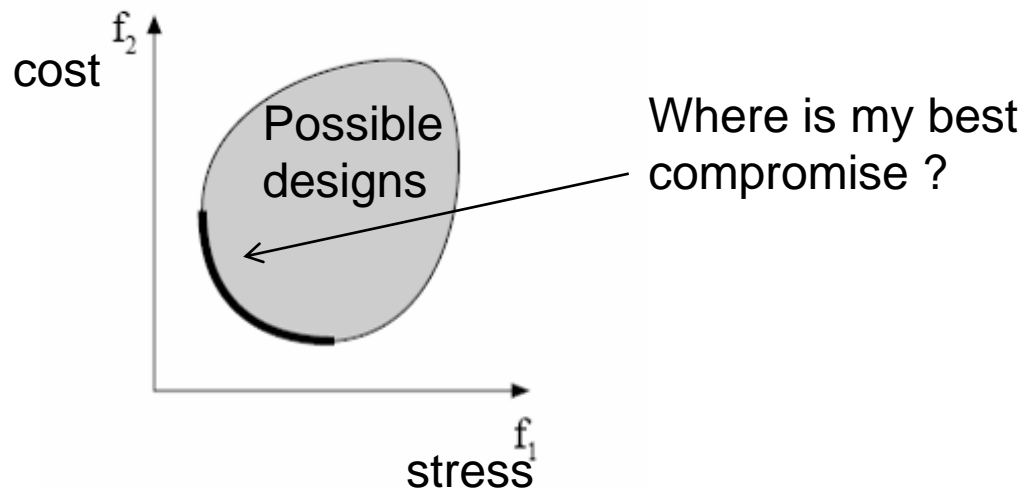
# Design Improvement

- Define improvement goals
- Insert constraints to fulfill additional conditions



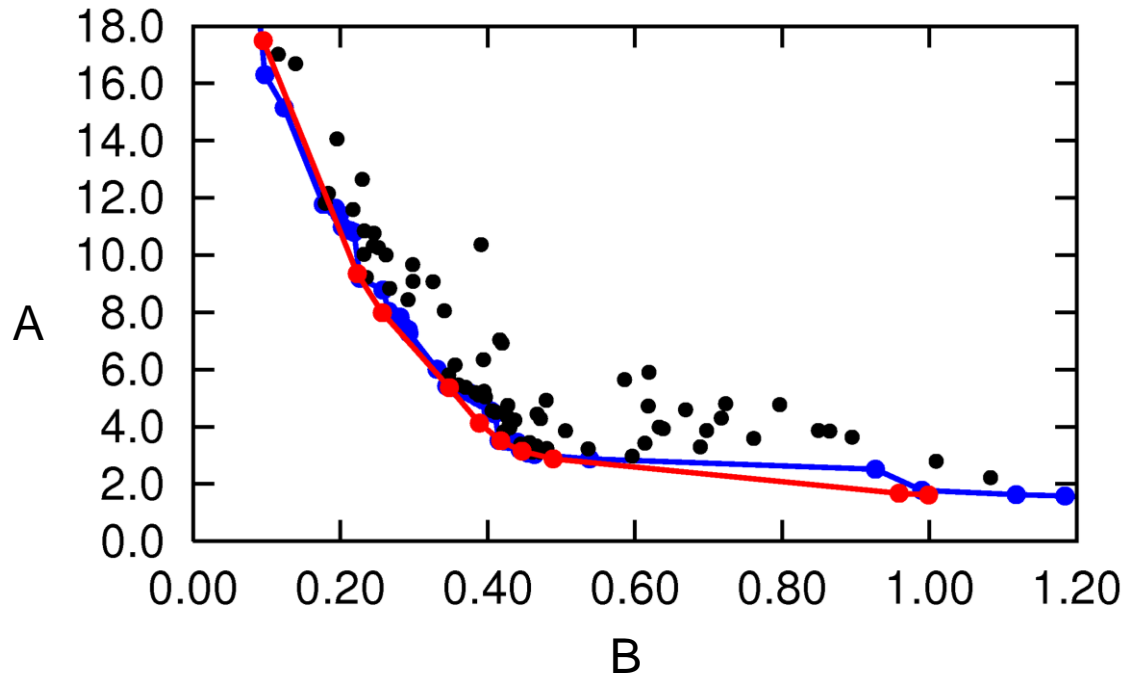
# Improve conflicting properties

- 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.



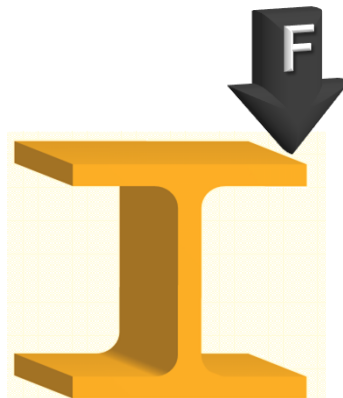
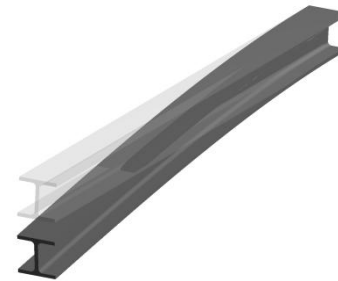
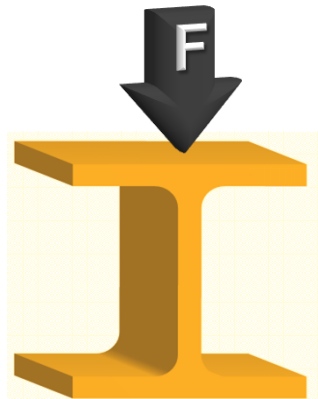
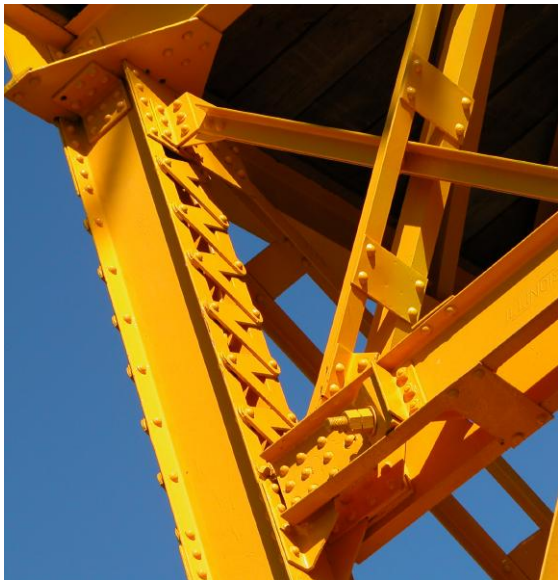


## Improve conflicting properties



- 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

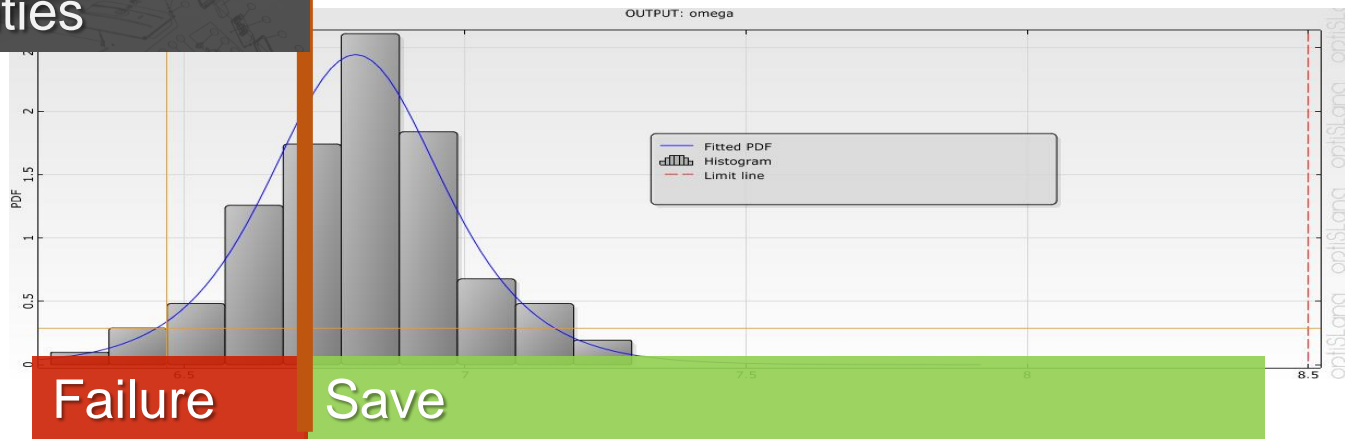
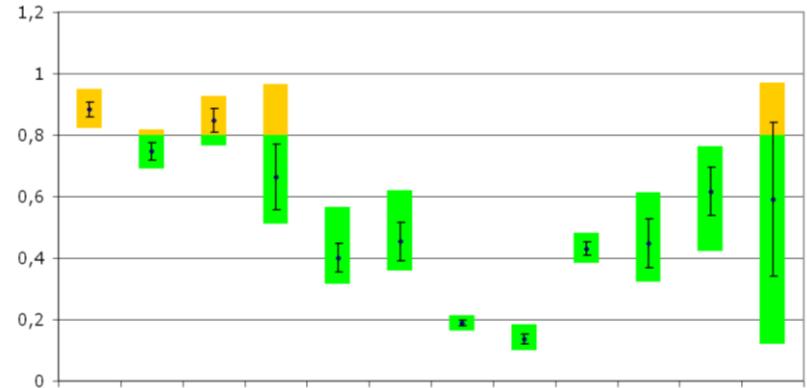


Uncertainties

# Dealing with tolerances

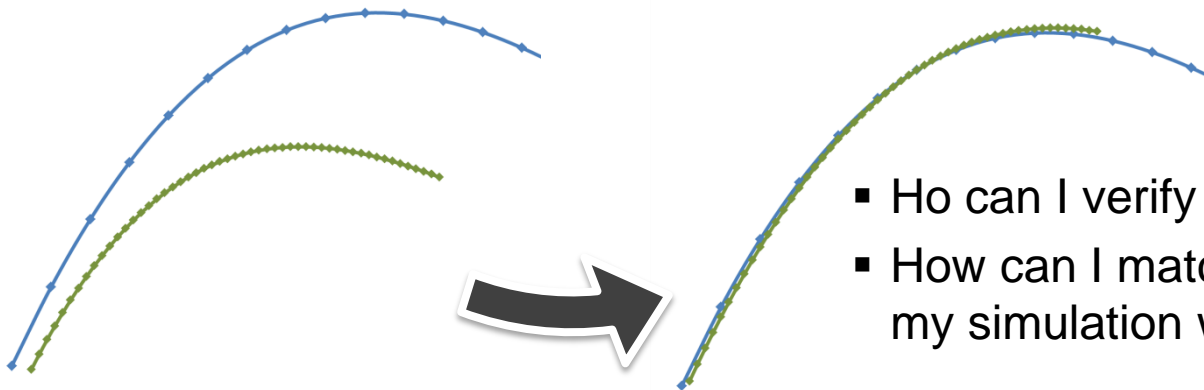
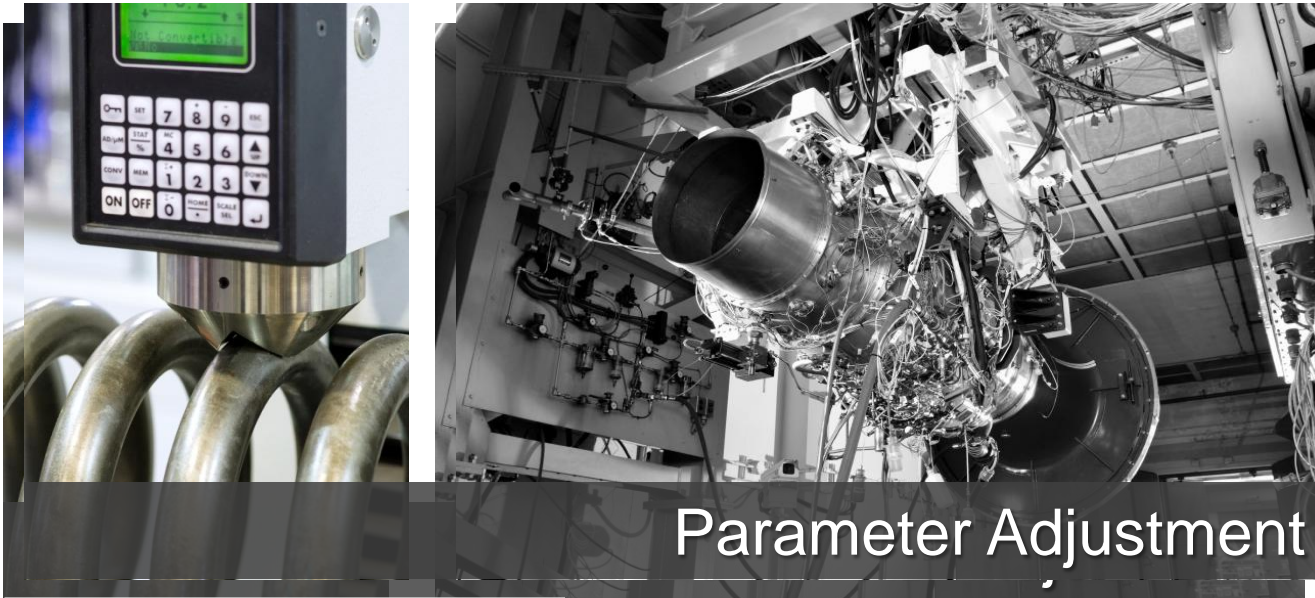


Uncertainties



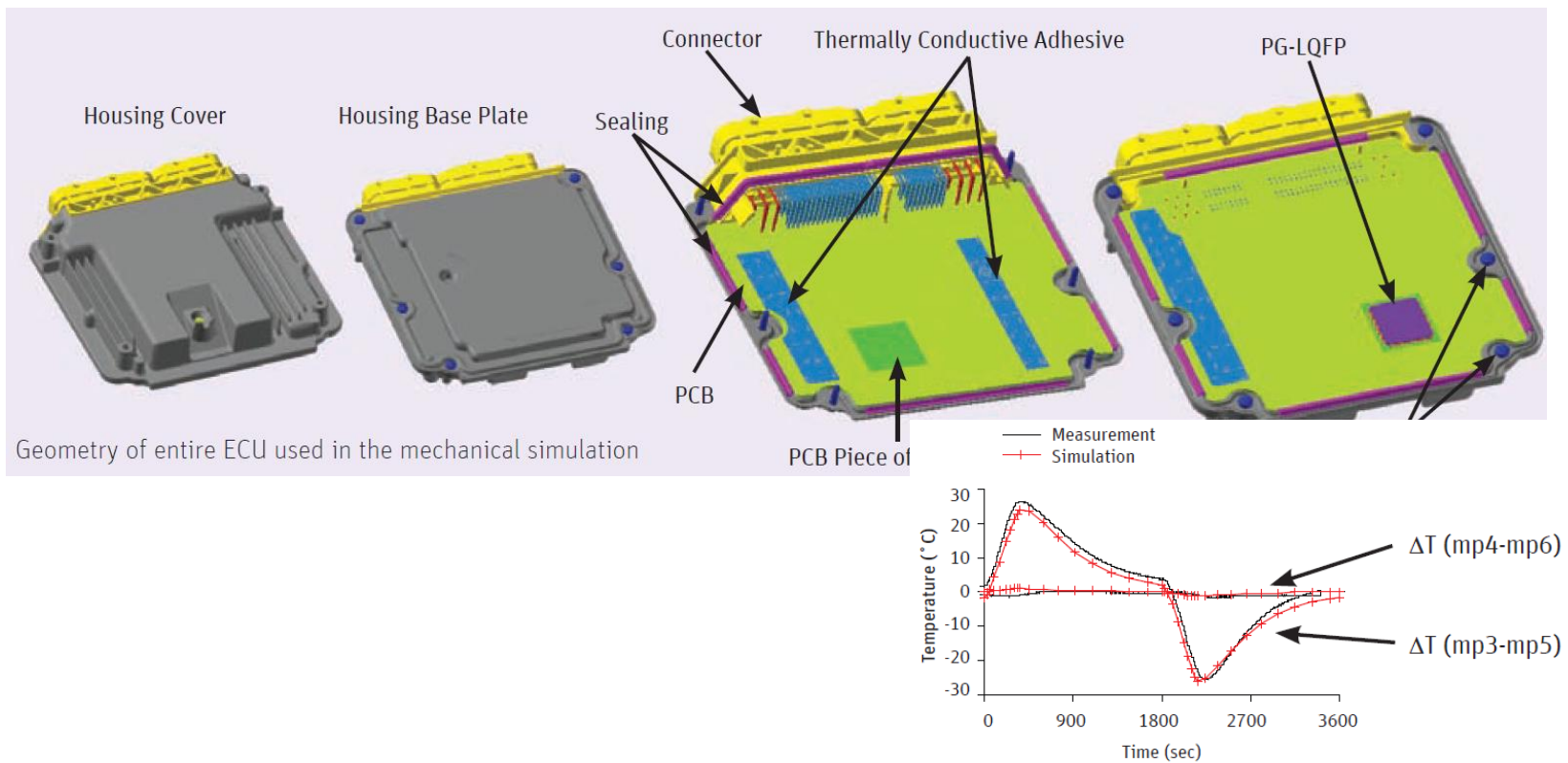
- How does my product react when tolerances occur?
- How safe is my product?

# Matching simulation and test



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

# Matching simulation and test





# System Simulation

## System Behavior

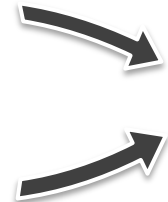


A	B	C
1 Steady-State Thermal	1 Static Structural	1 Design Assessment
2 Engineering Data ✓	2 Engineering Data ✓	2 Engineering Data ✓
3 Geometry ✓	3 Geometry ✓	3 Geometry ✓
4 Model ✓	4 Model ✓	4 Model ✓
5 Setup ✓	5 Setup ✓	5 Setup ✓
6 Solution ✓	6 Solution ✓	6 Solution ✓
7 Results ✓	7 Results ✓	7 Results ✓

INPUT



OUTPUT

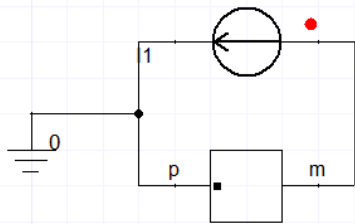


Behavior Model

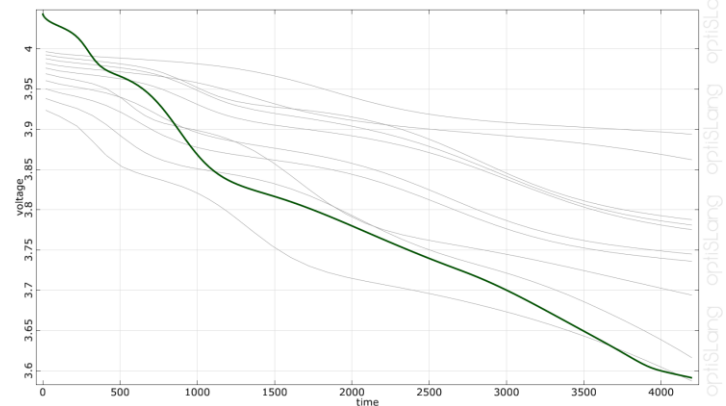
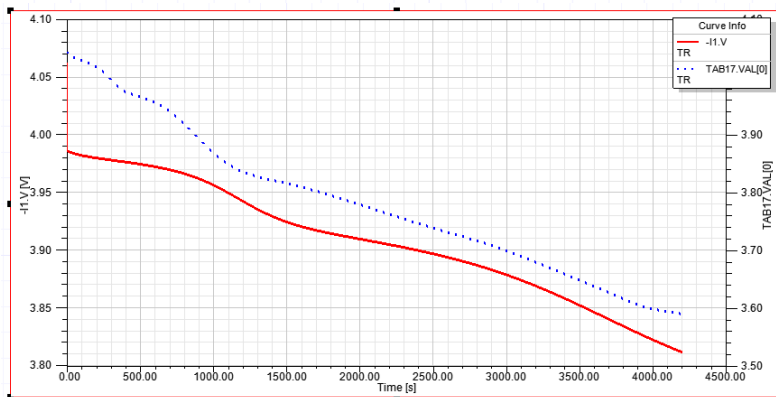
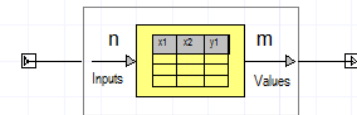


# Multiphysics simulation based on system coupling

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



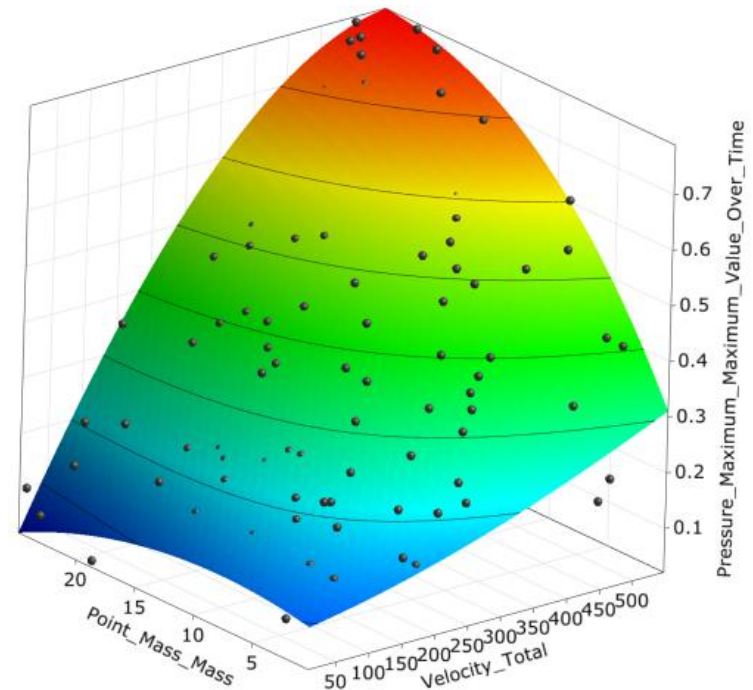
V\_cutOff





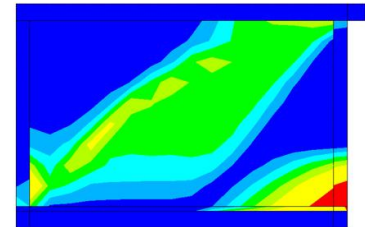
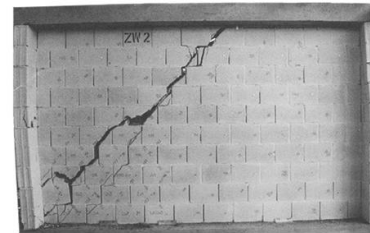
# Model Reduction for Nonlinear Components

- 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



# Behind optiSLang –

- Software
  - optiSLang
  - mutiPlas
  - Statistics on Structures
- Consulting
  - Sensitivity, Optimization, Robust Design
  - Classroom and individual Trainings
- WOSD – Weimar Optimization and Stochastic Days
  - >70 attendees
  - >20 talks



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



$$\bar{\Pi} = \frac{1}{2} \sum_e \{u\}^T \cdot [K] \cdot \{u\} - \{u\}^T \cdot \{F\}$$

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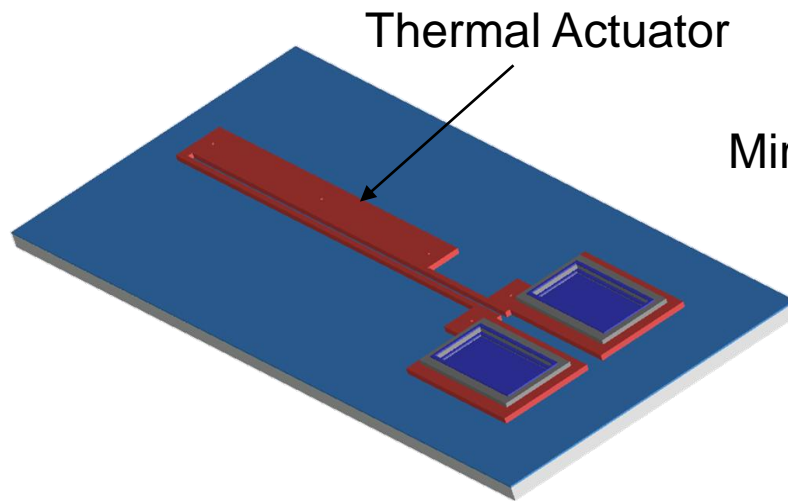
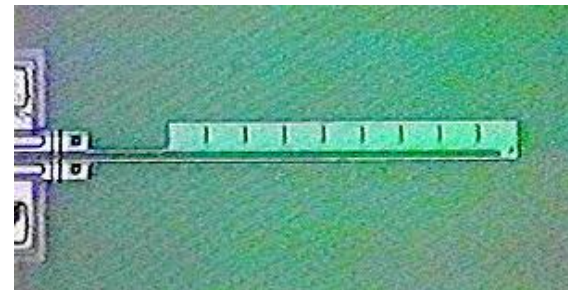
# Understand Your Design

## Parametric Workflow in ANSYS

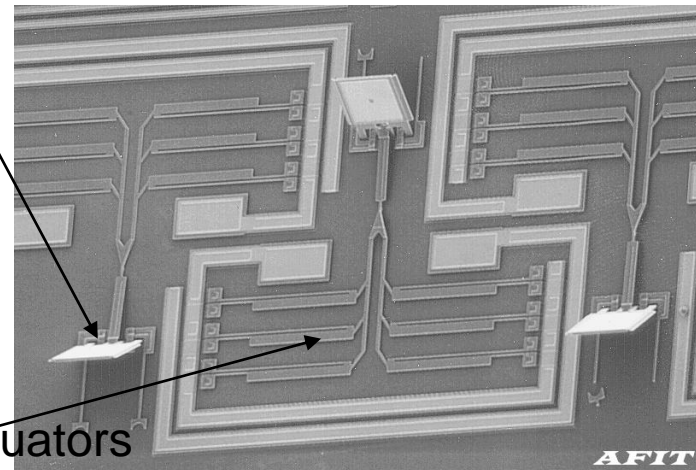
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# Multiphysics Analysis of an Electric-Thermal Actuator

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

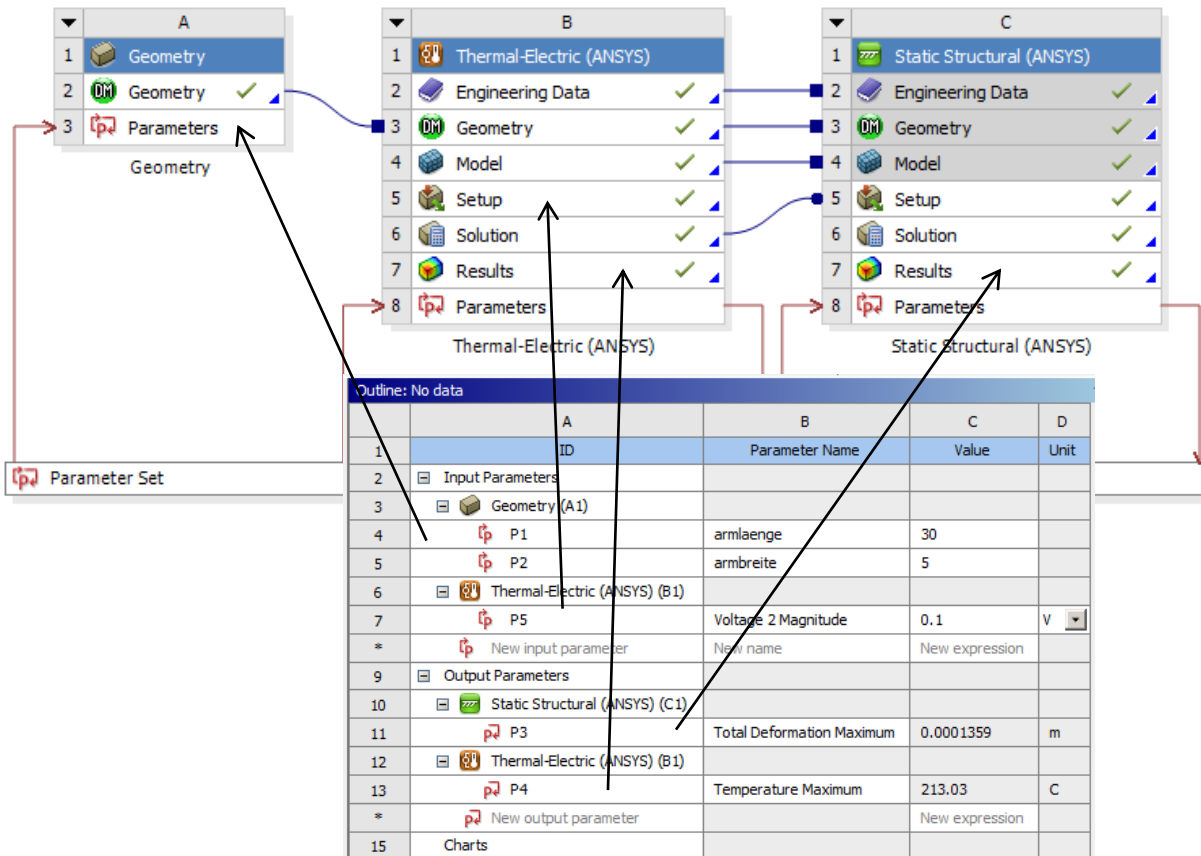


Array of Thermal Actuators



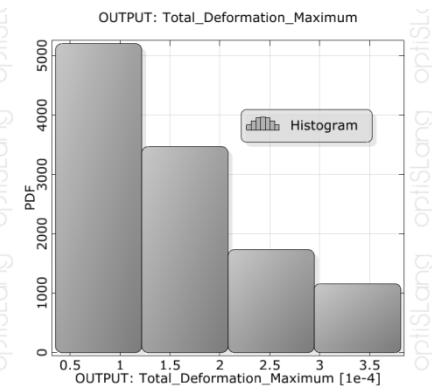
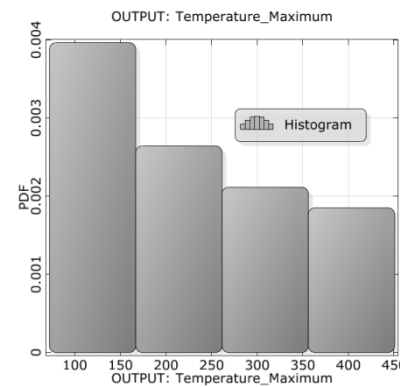
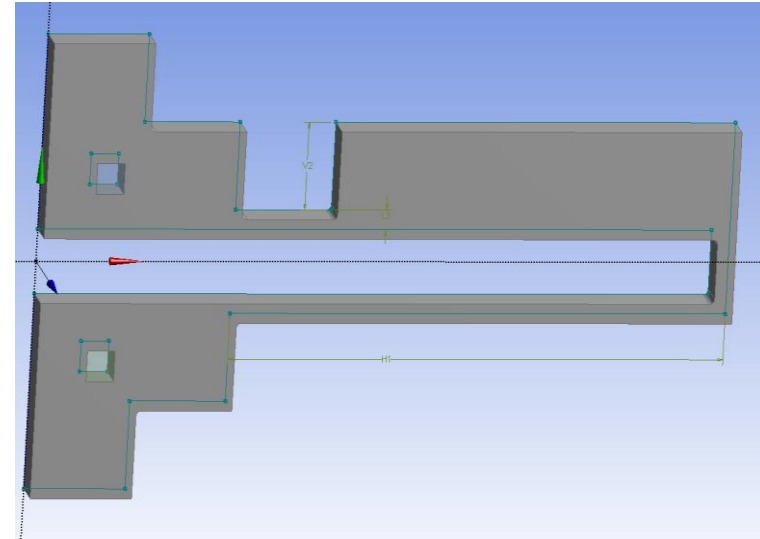
# The ANSYS Workbench philosophy:

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



# Thermal-electric Actuator

- Silizium
- Thermal-electric analysis for joule heating
  - 0.1 V on Pins
  - Convection  $11\text{W}/\text{m}^2\text{K}$  on actuator
  - $22^\circ$  on Pins
- Parametric persistency
  - From electric-thermal to structural FEA
  - Understand variation
    - of Voltage, Length, Thickness
    - on Temperature, Deformation





# Where to get the parameters

### CAD

ANSYS  
APDL

### Overview of all parameters in the parameter set

ID	Parameter Name	Value	Unit
P1	DS_Thickness	3	
P2	DS_Depth	7.1099	
P3	DS_Width	18.165	
P6	DS_Laenge1	68.44	
P7	DS_Laenge2	68.44	
P8	DS_Radius	32.257	
P4	Total Deformation Maximum	10.614	mm
P5	Solid Mass	0.0078167	tonne

### Boundaries

Project

- Model (B4)
  - Geometry
  - Coordinate Systems
  - Connections
- Static Structural (B5)
  - Analysis Settings
  - Force
- Solution (B6)

Details of "Force"

<b>Scope</b>	
Scoping Method	Geometry Selection
Geometry	1 Face
<b>Definition</b>	
Type	Force
Define By	Vector
Magnitude	223. N (ramped)
Direction	Click to Change
Suppressed	No

### Mesh

Details von "Elementgröße" - Elementg

<b>Definition</b>	
Unterdrückt	Nein
Elementgröße	Elementgröße
Elementgröße	3. mm
Verhalten	Flexibel

### Material properties

Property	Value	Unit
Density	7850	kg m <sup>-3</sup>
Coefficient of Thermal Expansion		
Isotropic Elasticity		
Bilinear Isotropic Hardening		
Alternating Stress Mean Stress	Tabular	
Strain-Life Parameters		
Tensile Yield Strength	2.5E+08	Pa
Compressive Yield Strength	2.5E+08	Pa
Tensile Ultimate Strength	4.6E+08	Pa
Compressive Ultimate Strength	0	Pa

### Excel

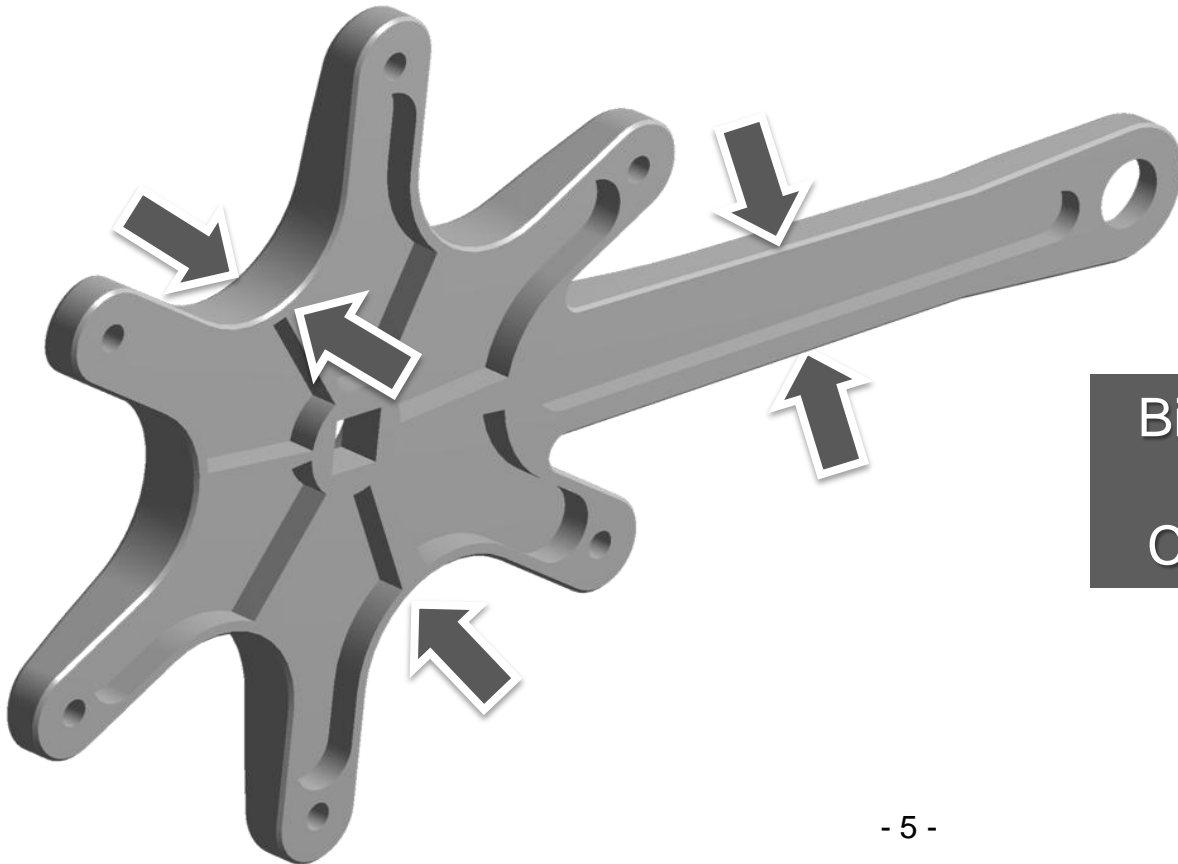
	G
1	Microsoft Office Excel
2	Analyse

Microsoft Office Excel



## 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)

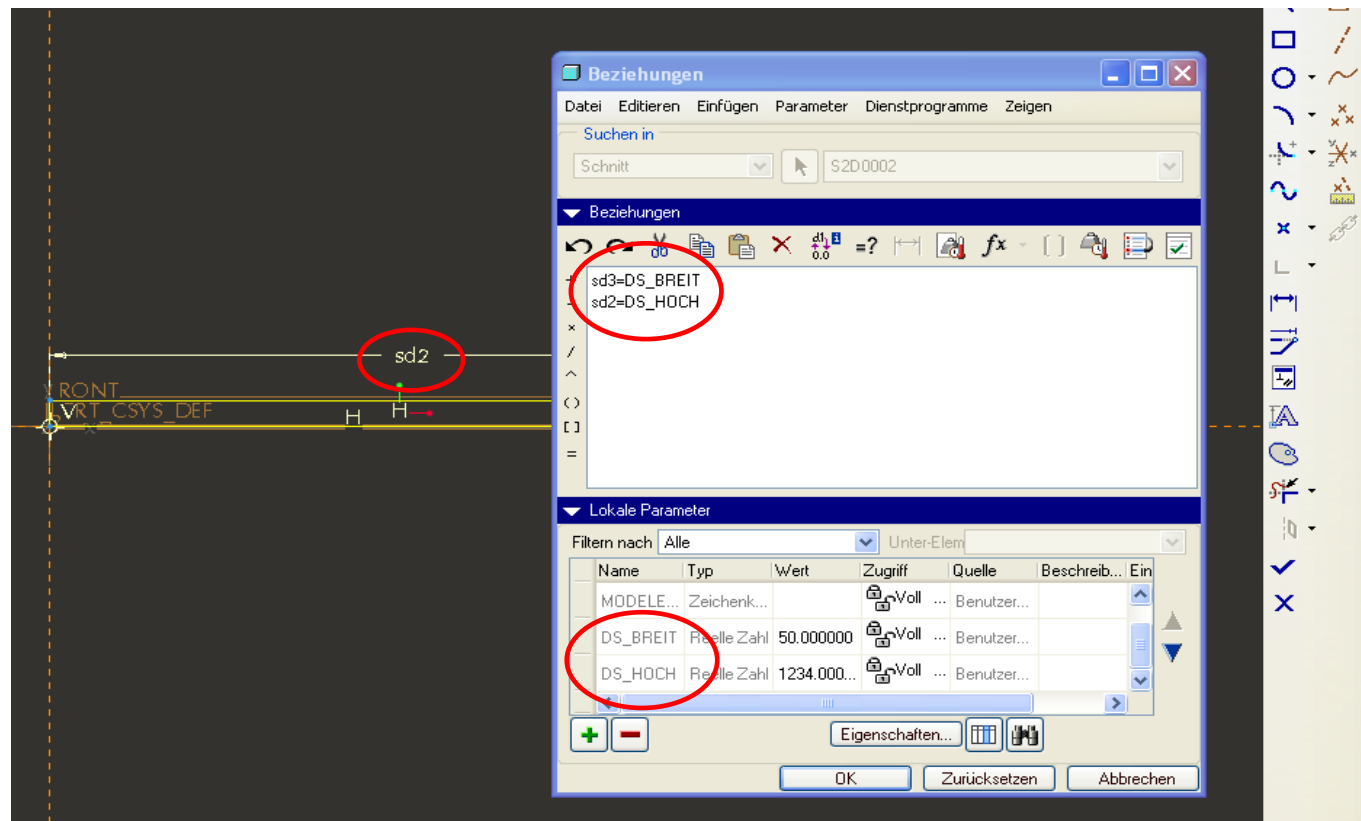


Solid Works



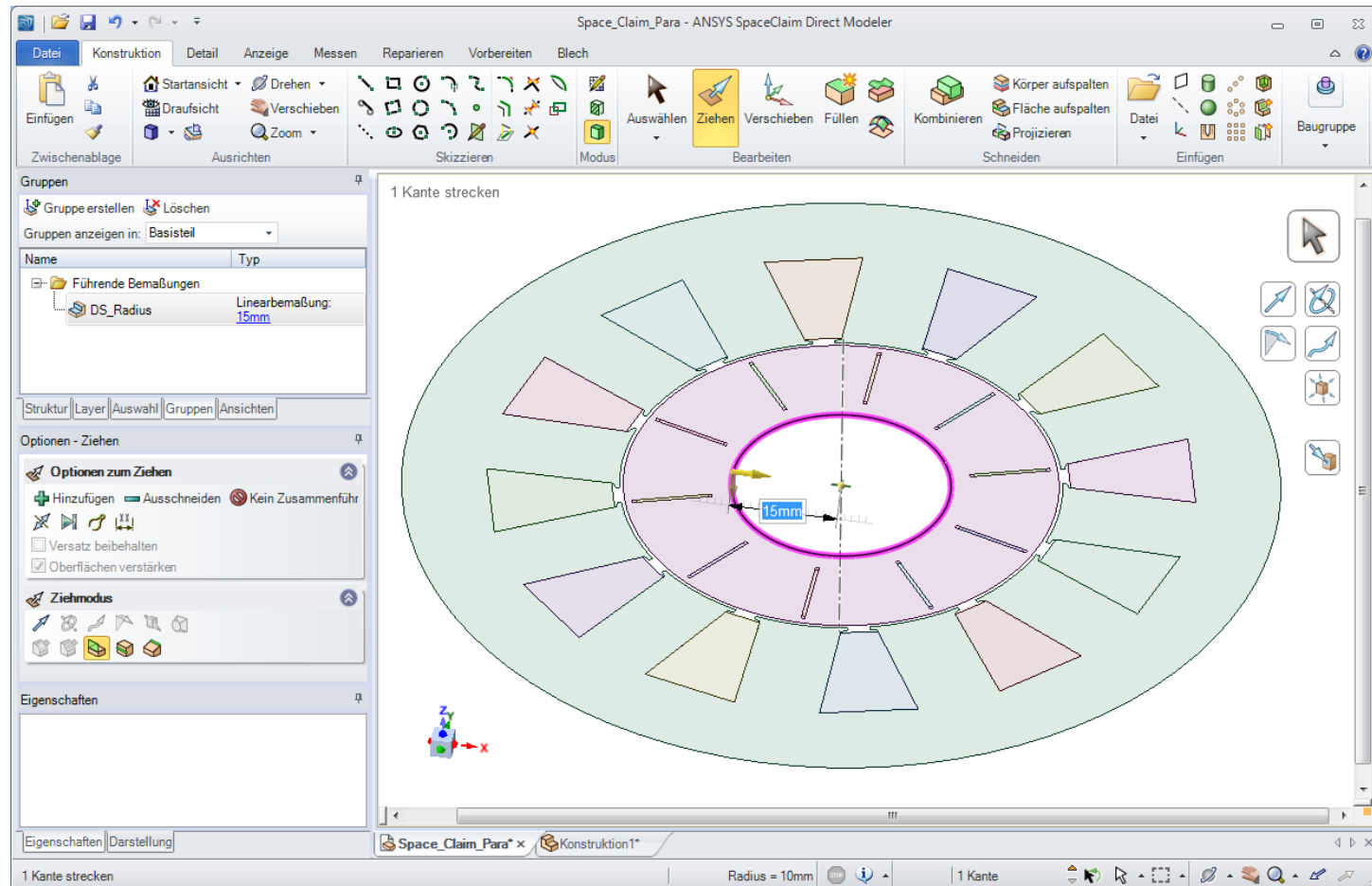
# CAD Parameters

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



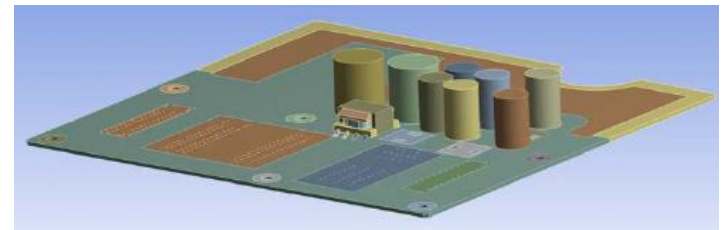
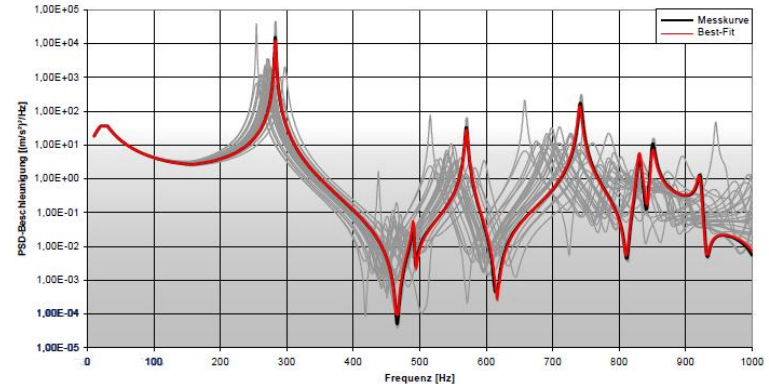
# Use the SpaceClaim Direct Modeler

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



# Parametric Material Modeling

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



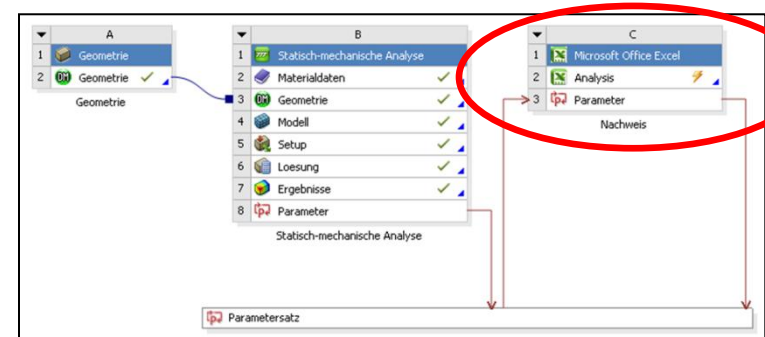
Source: Microconsult Engineering

# 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?



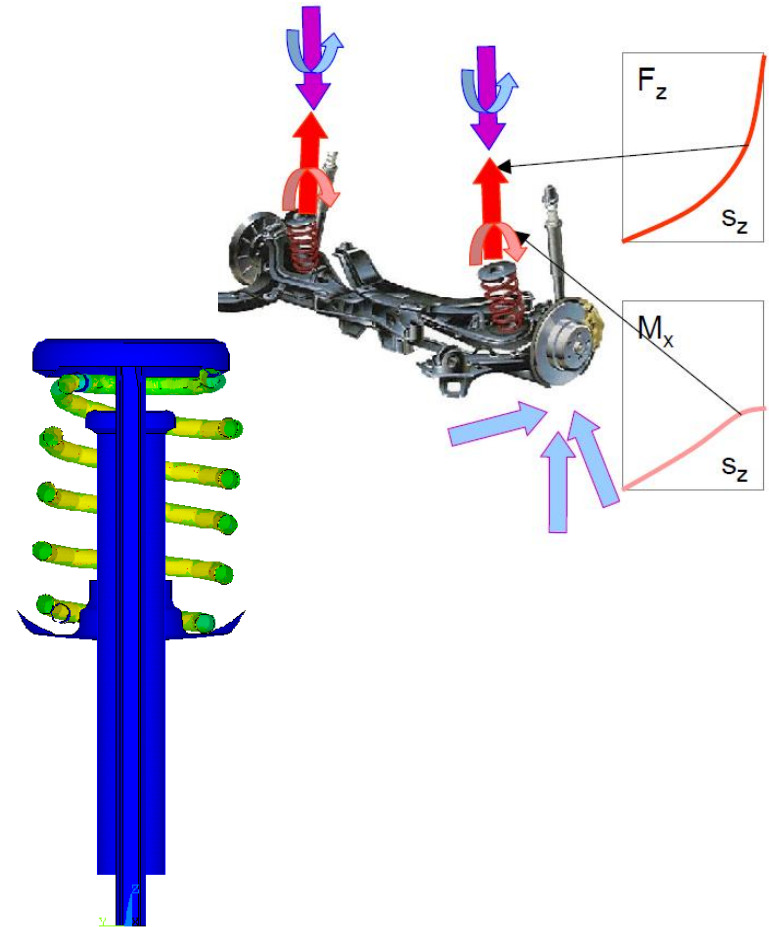
Use and link MS Excel for additional pre- and postprocessing!

Outline of Cell B2: Analysis			
	A	B	C
1		Input	Output
2	Setup		
3	Nachweis.xlsx		
4	WB_Moment_Z	<input checked="" type="checkbox"/>	<input type="checkbox"/>
5	WB_Moment_Y	<input checked="" type="checkbox"/>	<input type="checkbox"/>
6	WB_Moment_X	<input checked="" type="checkbox"/>	<input type="checkbox"/>
7	WB_Kraft_Z	<input checked="" type="checkbox"/>	<input type="checkbox"/>
8	WB_Kraft_Y	<input checked="" type="checkbox"/>	<input type="checkbox"/>
9	WB_Kraft_X	<input checked="" type="checkbox"/>	<input type="checkbox"/>
10	WB_Auslastungsgrad	<input type="checkbox"/>	<input checked="" type="checkbox"/>

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Name	Schub in X	Schub in Y	Zug/Druck in Z	Biegung um X	Biegung um Y	Biegung um Z	Beanspruchungsgruppe	FAT Klasse	Auslastungsgrad				
3	Grandplatte Bis Dom 6.1									100				
4	Geometrie	268 mm	330 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	76%				
5	Zrall / Moment	154 N	146 N	1187 N	8652 Nmm	1813 Nmm	958 Nmm							
6	Spannung MPa	1.65Pa	0.8Pa	4.4 MPa	46 MPa	17 MPa	8 MPa							
7	Grandplatte Bis Dom 6.1									100				
8	Geometrie	268 mm	368 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	76%				
9	Zrall / Moment	154 N	146 N	1187 N	8652 Nmm	1813 Nmm	958 Nmm							
10	Spannung MPa	1.65Pa	0.8Pa	4.4 MPa	46 MPa	17 MPa	8 MPa							
11	Grandplatte Bis Dom 5.6									100				
12	Geometrie	268 mm	300 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	76%				
13	Zrall / Moment	152 N	177 N	1273 N	7332 Nmm	2056 Nmm	132 Nmm							
14	Spannung MPa	4.86Pa	4.0Pa	12 MPa	13 MPa	31 MPa	0.8Pa							
15	Grandplatte Bis Dom 4.5									100				
16	Geometrie	268 mm	268 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	53%				
17	Zrall / Moment	1076 N	74 N	655 N	1017 Nmm	7132 Nmm	4133 Nmm							
18	Spannung MPa	4.86Pa	2 MPa	24 MPa	1 MPa	45 MPa	1 MPa							
19	Grandplatte Bis Dom 3.4									100				
20	Geometrie	268 mm	268 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	96%				
21	Zrall / Moment	144 N	134 N	1209 N	3251 Nmm	2029 Nmm	1295 Nmm							
22	Spannung MPa	1.65Pa	1.45Pa	4.6 MPa	32 MPa	13 MPa	0.8Pa							
23	Grandplatte Bis Dom 3.1									100				
24	Geometrie	268 mm	268 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	96%				
25	Zrall / Moment	144 N	134 N	1209 N	3251 Nmm	2029 Nmm	1295 Nmm							
26	Spannung MPa	1.65Pa	1.45Pa	4.6 MPa	32 MPa	13 MPa	0.8Pa							
27	Grandplatte Bis Dom 2.3									100				
28	Geometrie	268 mm	268 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	99%				
29	Zrall / Moment	124 N	127 N	1244 N	1666 Nmm	6288 Nmm	289 Nmm							
30	Spannung MPa	0.86Pa	0.8Pa	5.16Pa	8 MPa	3 MPa	0.1Pa							
31	Grandplatte Bis Dom 1.2									100				
32	Geometrie	268 mm	268 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	96%				
33	Zrall / Moment	61 N	63 N	584 N	2247 Nmm	6424 Nmm	3025 Nmm							
34	Spannung MPa	4 MPa	4 MPa	21 MPa	1 MPa	5 MPa	1 MPa							
35	Dom 6.1 Bis Deckplatte									100				
36	Geometrie	268 mm	300 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	105%				
37	Zrall / Moment	123 N	137 N	1244 N	5500 Nmm	2260 Nmm	2112 Nmm							
38	Spannung MPa	0.86Pa	0.86Pa	4.6 MPa	10 MPa	5 MPa	1 MPa							
39	Dom 6.1 Bis Deckplatte									100				
40	Geometrie	268 mm	268 mm	268 mm	240 mm	1570 mm	330 mm	B6	FAT	105%				
41	Zrall / Moment	123 N	137 N	1244 N	5500 Nmm	2260 Nmm	2112 Nmm							
42	Spannung MPa	0 MPa	0 MPa	4.6 MPa	10 MPa	5 MPa	1 MPa							

# Fully Automated Simulation Workflows in APDL

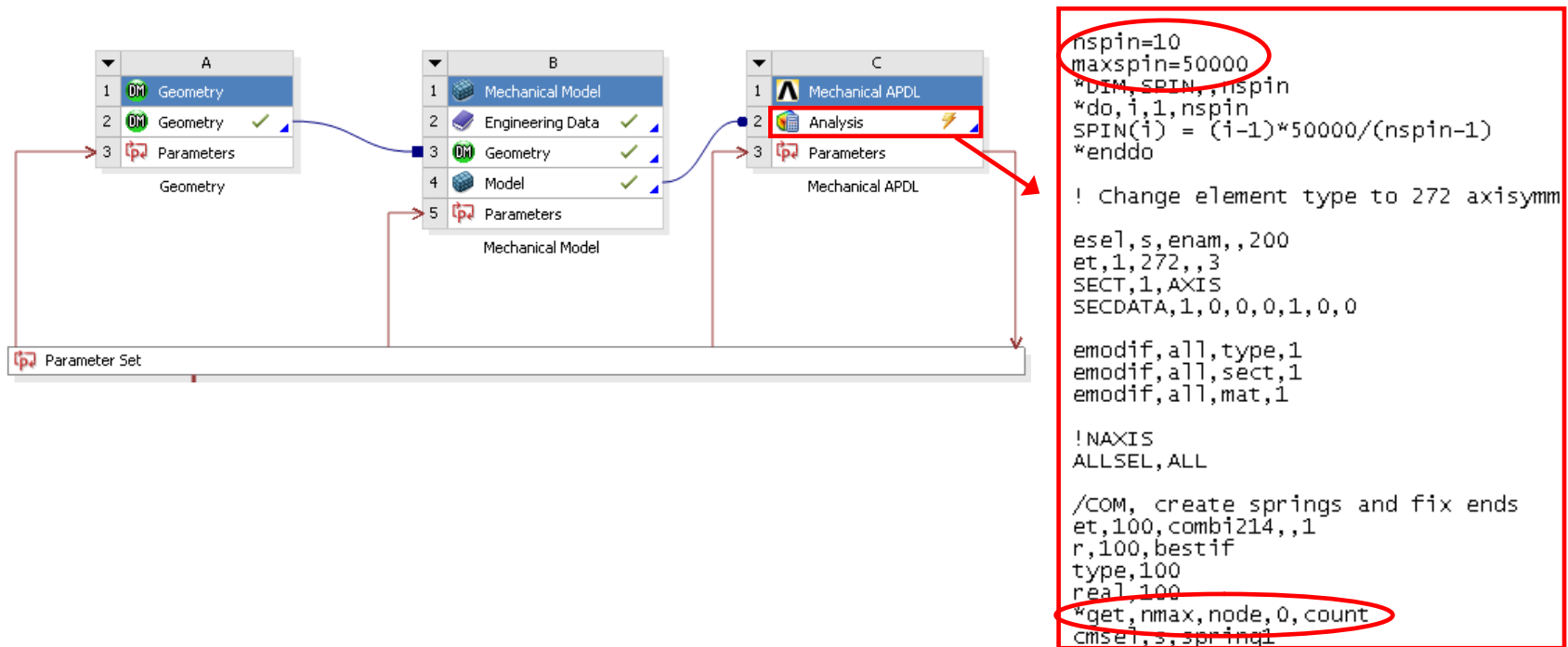
- Example: Spring simulation at Muhr und Bender
  - Complete workflow
    - Geometry modeling
    - Loads
    - Simulation
    - Result calculation
  - Classic model setup by ANSYS Parametric Design Language APDL
    - Text file drives workflow
    - Numbers in text files can be set as parameters





# Fully Automated Simulation Workflows in APDL

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



$$\bar{\Pi} = \frac{1}{2} \sum_e \{u\}^T \cdot [K] \cdot \{u\} - \{u\}^T \cdot \{F\}$$

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# Understand your Design

## Manual Variation

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# Understand your Design

## 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?

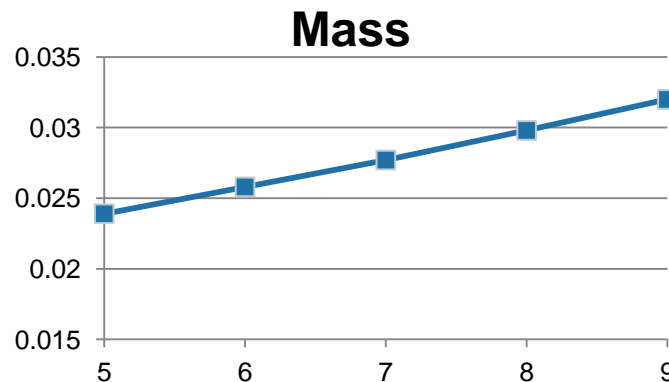
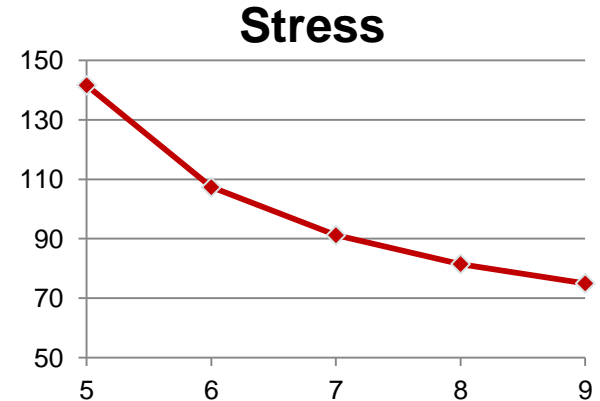


# Understand your Design

## 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



# Understand your Design

## Example: Notch

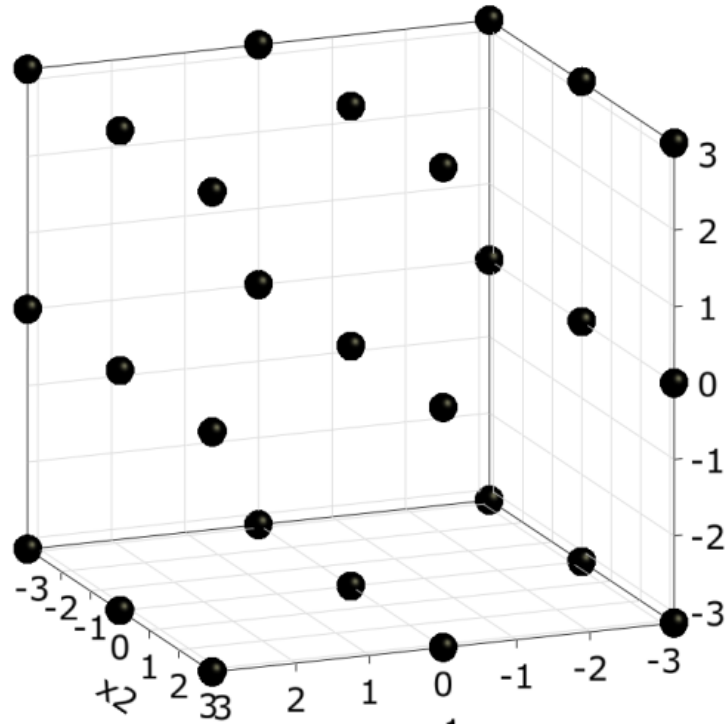
- 2nd parameter: cThck, variation: 2 ... 3.5
- Which combination to create?
- 3 Designs per Parameter (low-mid-high):  $2^3 = 8$  designs.
- Check the effect.
- Taken the right parameter?

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

# Understand your Design

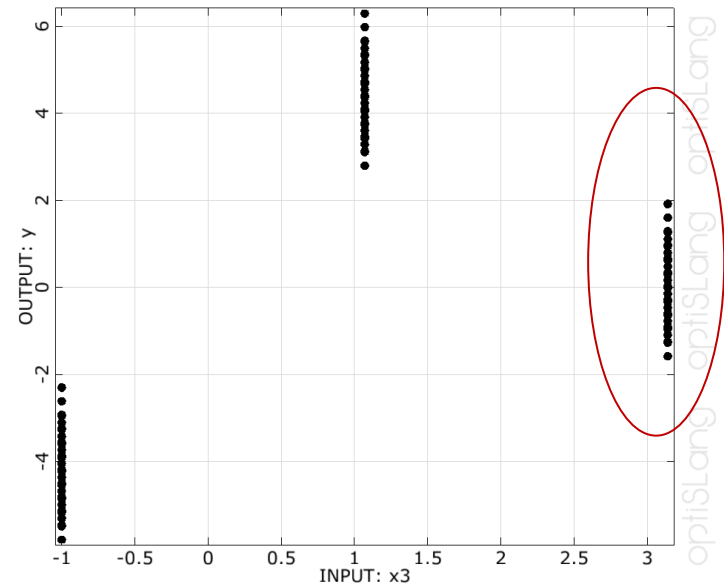
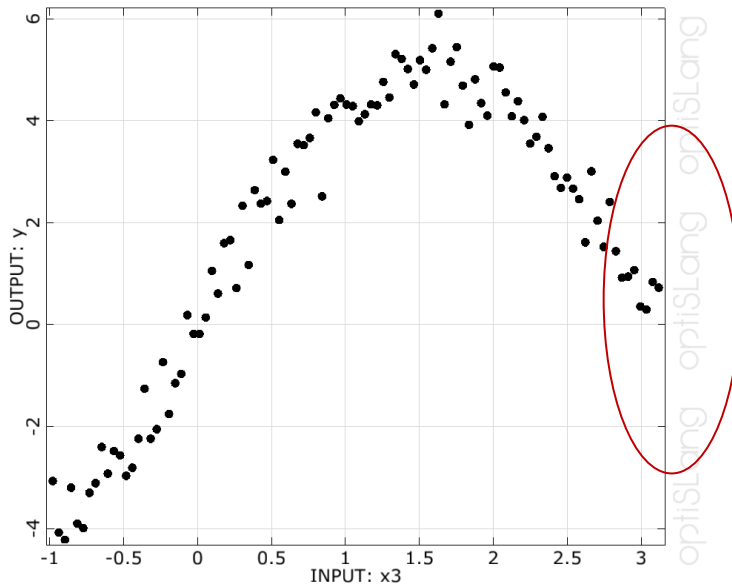
## Manual variations

- 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!

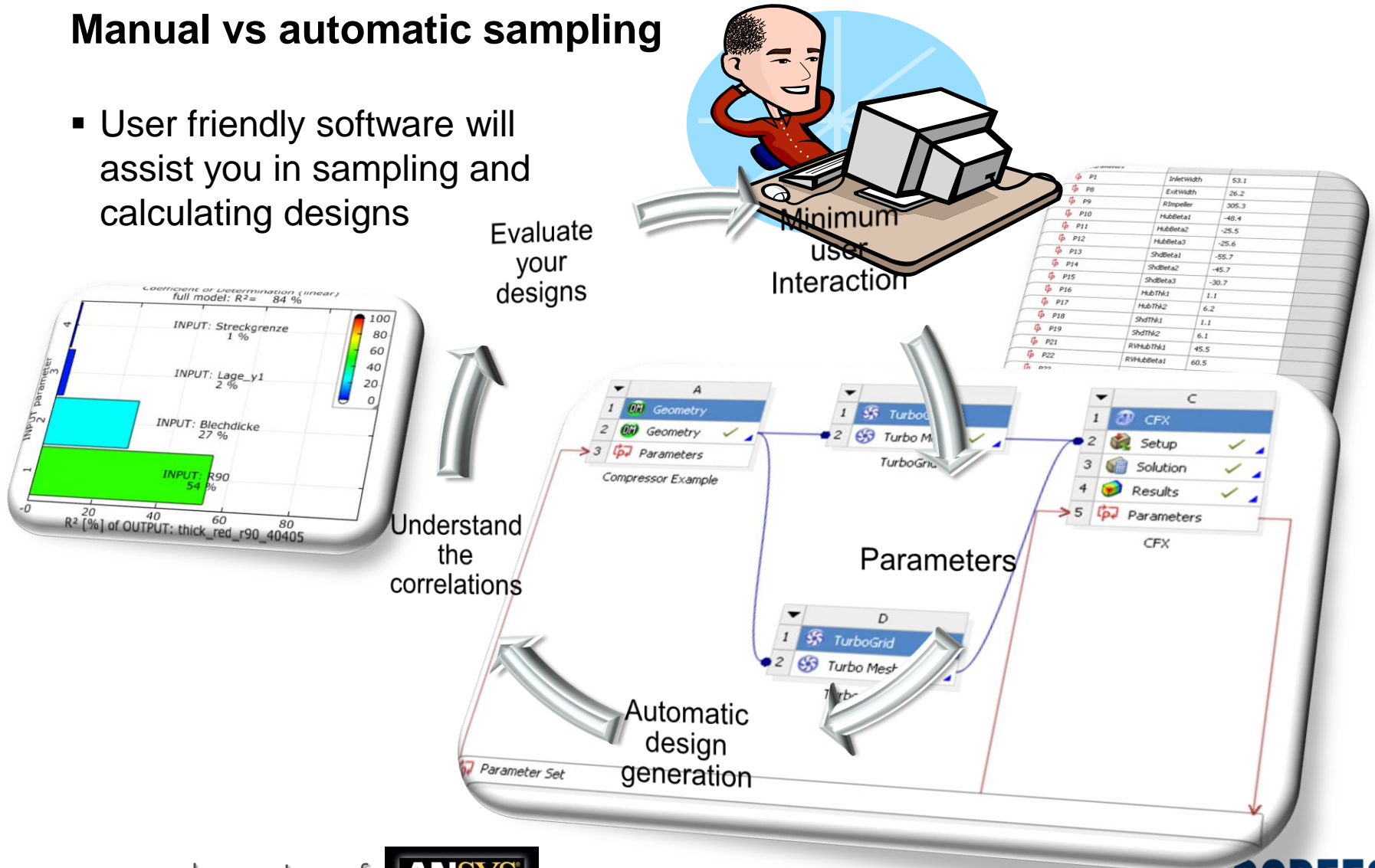




# Understand your Design

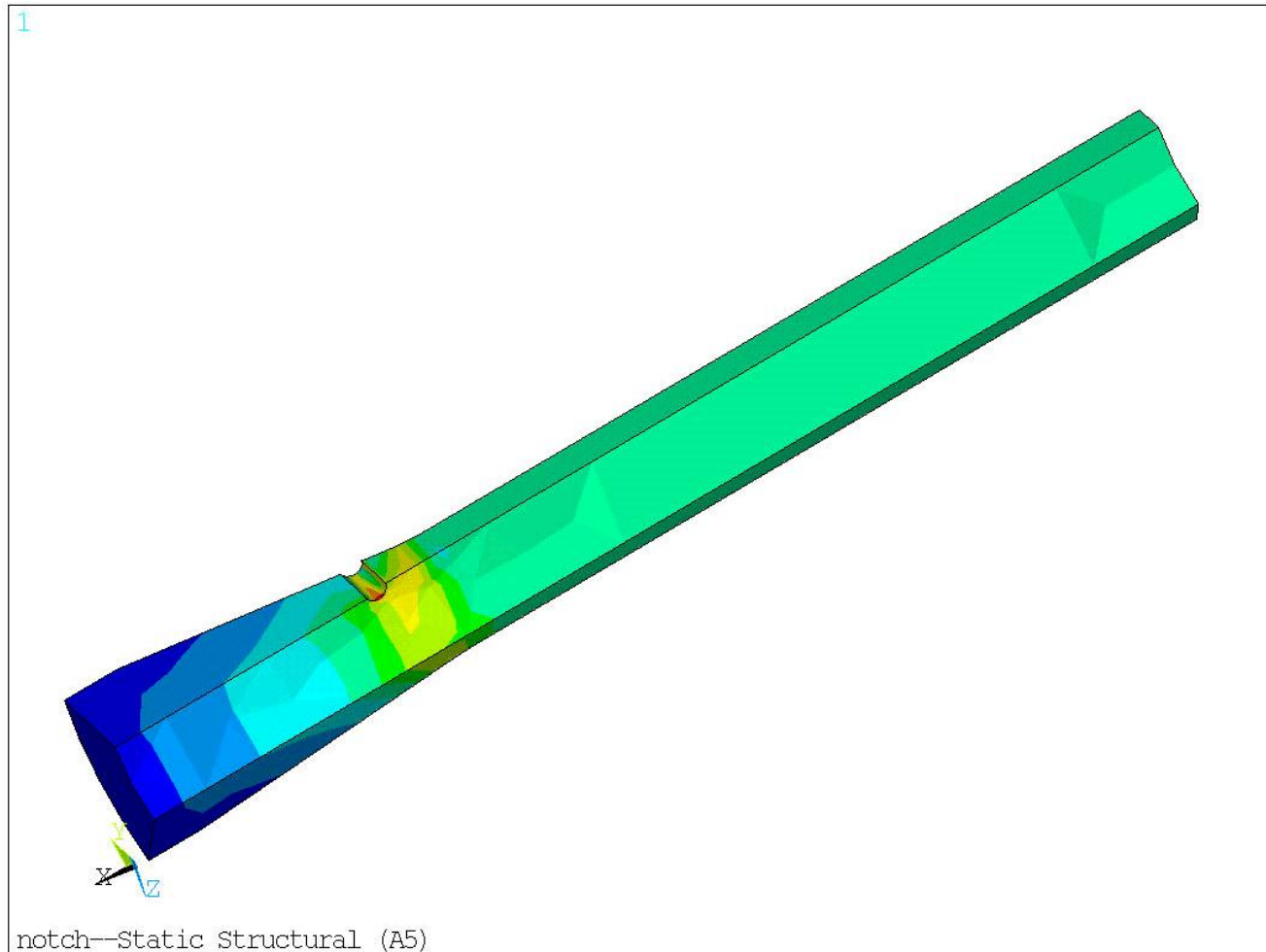
## Manual vs automatic sampling

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



# Understand your Design

## The automatic sampling



$$\bar{\Pi} = \frac{1}{2} \sum_e \{u\}^T \cdot [K] \cdot \{u\} - \{u\}^T \cdot \{F\}$$

FEM SOFTWARE AND SERVICES



# Understand your Design

Systematic variation using  
optiSLang inside Workbench

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

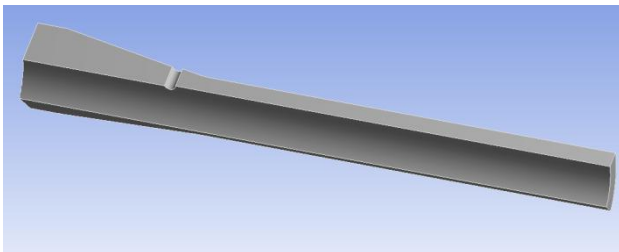
# Understand your Design

## 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.

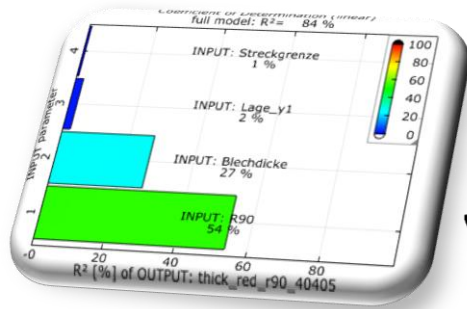
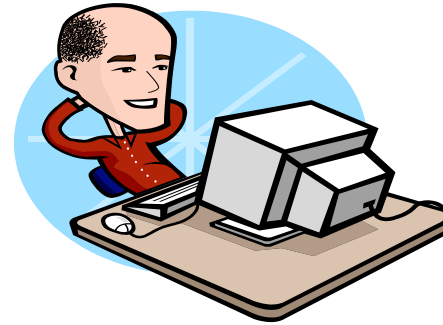
# Understand your Design

## 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.



Check Forecast Quality

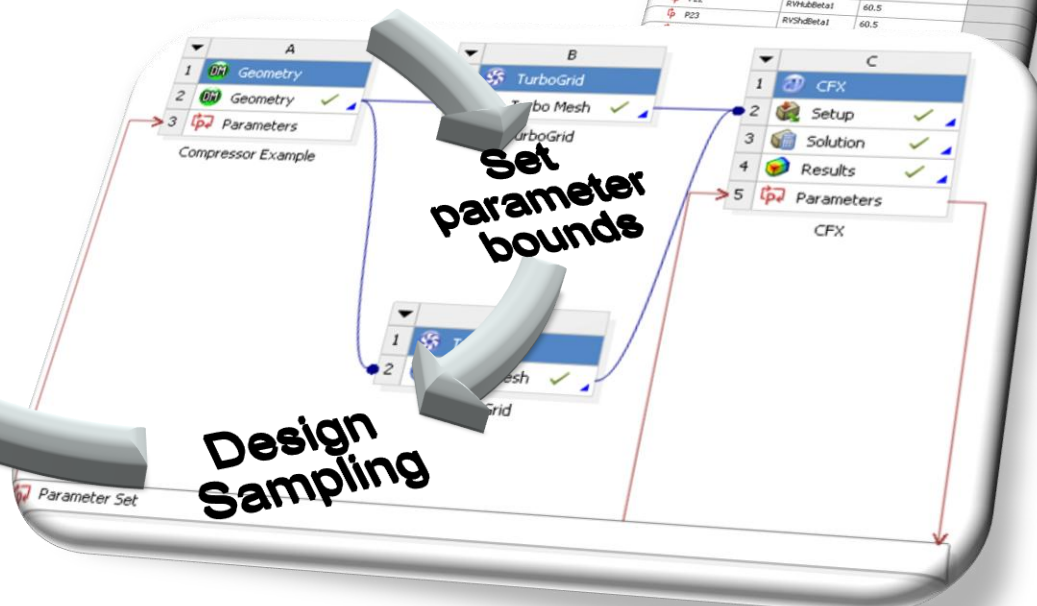
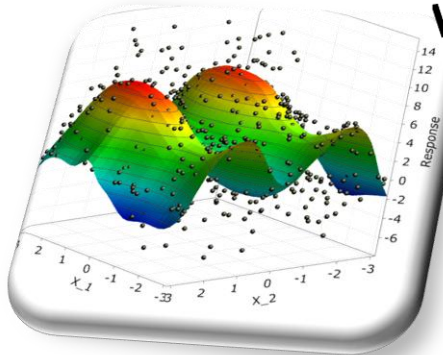
First user Interaction

P1	InletWidth	53.1
P8	ExtWidth	26.2
P9	Rbnpeller	305.3
P10	HbBeta1	-48.4
P11	HbBeta2	-25.5
P12	HbBeta3	-25.6
P13	ShdBeta1	-55.7
P14	ShdBeta2	-45.7
P15	ShdBeta3	-30.7
P16	HbTH1	1.1
P17	HbTH2	6.2
P18	ShdTH1	1.1
P19	ShdTH2	6.1
P21	RvHbTH1	45.5
P22	RvHbBeta1	60.5
P23	RvShBeta1	60.5

Identify the significant parameters

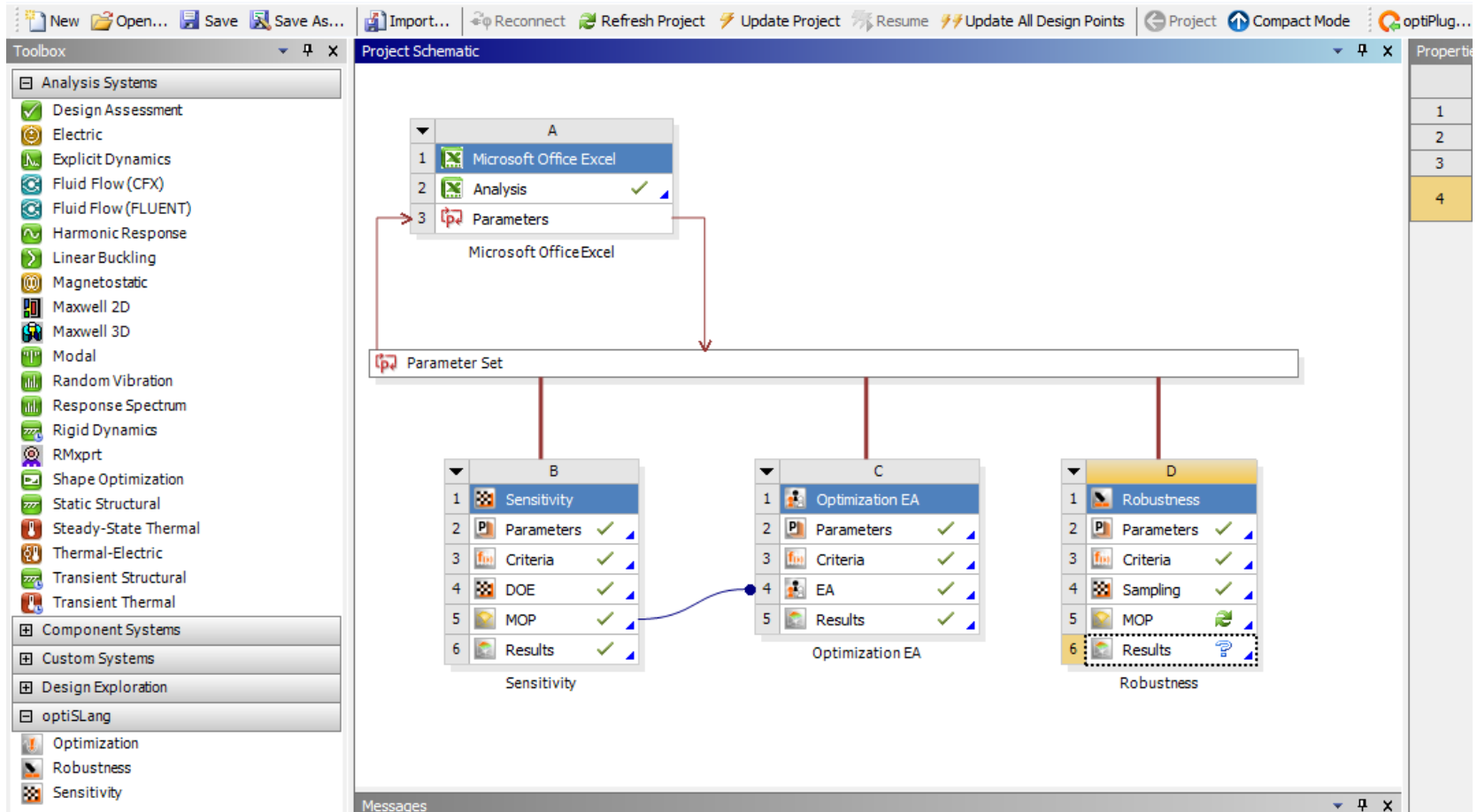
Set parameter bounds

Design Sampling



# Understand your Design

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





# Understand your Design

## How it Works

The screenshot displays the ANSYS Workbench interface for a project named "bike\_shaft". The "Project Schematic" area shows a hierarchical structure of analysis systems:

- System A: Geometry**
  - 1 Geometry
  - 2 Geometry
  - 3 Parameters
- System B: Static Structural**
  - 1 Static Structural
  - 2 Engineering Data
  - 3 Geometry
  - 4 Model
  - 5 Setup
  - 6 Solution
  - 7 Results
  - 8 Parameters
- System C: Sensitivity**
  - 1 Sensitivity
  - 2 Parameter
  - 3 Criteria
  - 4 DoE
  - 5 MoP
  - 6 Results
- System D: Optimization ARSM**
  - 1 Optimization ARSM
  - 2 Parameter
  - 3 Criteria
  - 4 ARSM
  - 5 Results
  - 6 Optimization ARSM

A "Parameter Set" component is connected to the "Parameters" of systems A and B. A large black arrow points from the "optiSLang" icon in the "Analysis Systems" toolbox to the "Optimization ARSM" component in system D. A text box on the right contains the text: "Drag and Drop optiSLang inside Workbench modules".

# Understand your Design

## How it Works

bike\_shaft - Workbench

File Edit View Tools Units Help

Analysis Systems

- Design Assessment
- Electric
- Explicit Dynamics
- Harmonic Response
- Linear Buckling
- Linear Buckling (Samcef) (Beta)
- Magnetostatic
- Modal
- Modal (ABAQUS)(Beta)
- Modal (NASTRAN)(Beta)
- Modal (Samcef)
- Random Vibration
- Response Spectrum
- Rigid Dynamics
- Shape Optimization (Beta)
- Static Structural
- Static Structural (ABAQUS)(Beta)
- Static Structural (Samcef)
- Steady-State Thermal
- Steady-State Thermal (ABAQUS)(Beta)
- Steady-State Thermal (Samcef) (Beta)
- Thermal-Electric
- Transient Structural
- Transient Structural (ABAQUS)(Beta)
- Transient Structural (Samcef) (Beta)
- Transient Thermal
- Transient Thermal (ABAQUS)(Beta)
- Transient Thermal (Samcef) (Beta)

Component Systems

- Custom Systems
- Design Exploration
- optiSLang
- Optimization
- Robustness
- Sensitivity

Project Schematic

- A: Geometry (1. Geometry, 2. Geometry, 3. Parameters)
- B: Static Structural (1. Static Structural, 2. Engineering Data, 3. Geometry, 4. Model, 5. Setup, 6. Solution, 7. Results, 8. Parameters)
- C: Sensitivity (1. Sensitivity, 2. Parameter, 3. Criteria, 4. DoE, 5. MoP, 6. Results)
- D: Optimization ARSM (1. Optimization ARSM, 2. Parameter, 3. Criteria, 4. ARSM, 5. Results)
- Parameter Set

Messages

Updating the ARSM component in Optimization ARSM

	Name	Parameter type	Reference value	Resolution	Constant	Range	Range plot
1	cut_wall_thickn...	Deterministic	4	Continuous	<input type="checkbox"/> non const	3 5	
2	radius_pedal	Deterministic	0.5	Continuous	<input type="checkbox"/> non const	0.25 0.75	
3	outer_thickness	Deterministic	7	Continuous	<input type="checkbox"/> non const	5 10	
4	inner_thickness	Deterministic	7	Continuous	<input type="checkbox"/> non const	5 10	
5	th_red_pedal	Deterministic	15	Continuous	<input type="checkbox"/> non const	5 25	
6	inner_radius	Deterministic	15	Continuous	<input type="checkbox"/> non const	10 20	
7	sections	Deterministic	5	Discrete	<input checked="" type="checkbox"/> const	4 5 6	
8	thickness	Deterministic	10	Continuous	<input type="checkbox"/> non const	8 14	
9	cut_wall_thickn...	Deterministic	2	Continuous	<input type="checkbox"/> non const	1.5 4	
10	cut_depth	Deterministic	4	Continuous	<input type="checkbox"/> non const	3 5	
11	pedal_thickness...	Deterministic	20	Continuous	<input type="checkbox"/> non const	18 25	
12	pedal_thickness...	Deterministic	16	Continuous	<input type="checkbox"/> non const	12 20	
13	cut_depth_pedal	Deterministic	3	Continuous	<input type="checkbox"/> non const	2 4	

Use design as reference

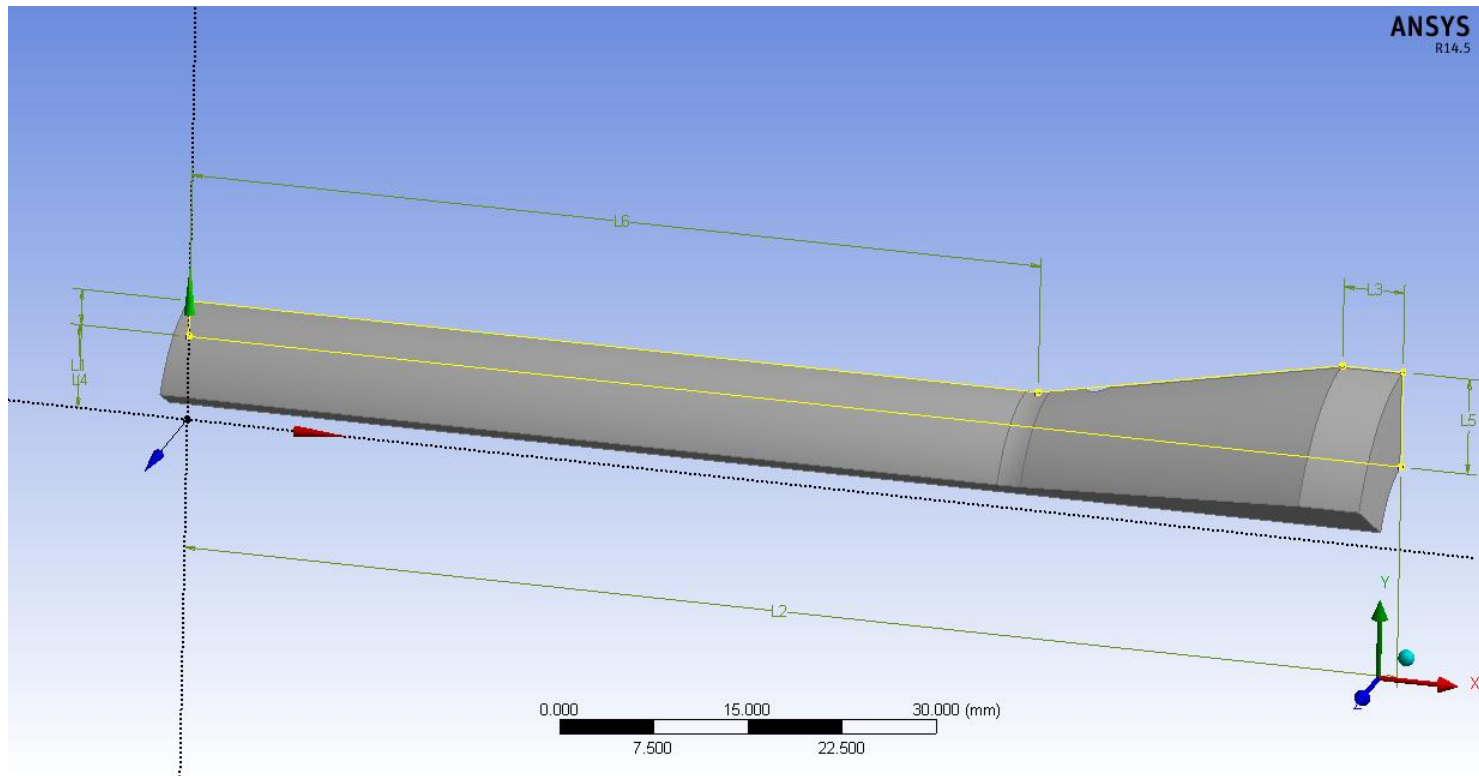
OK Cancel Apply

Define your parameter variation and criteria in a wizard

# Understand your Design

## Example: Notch

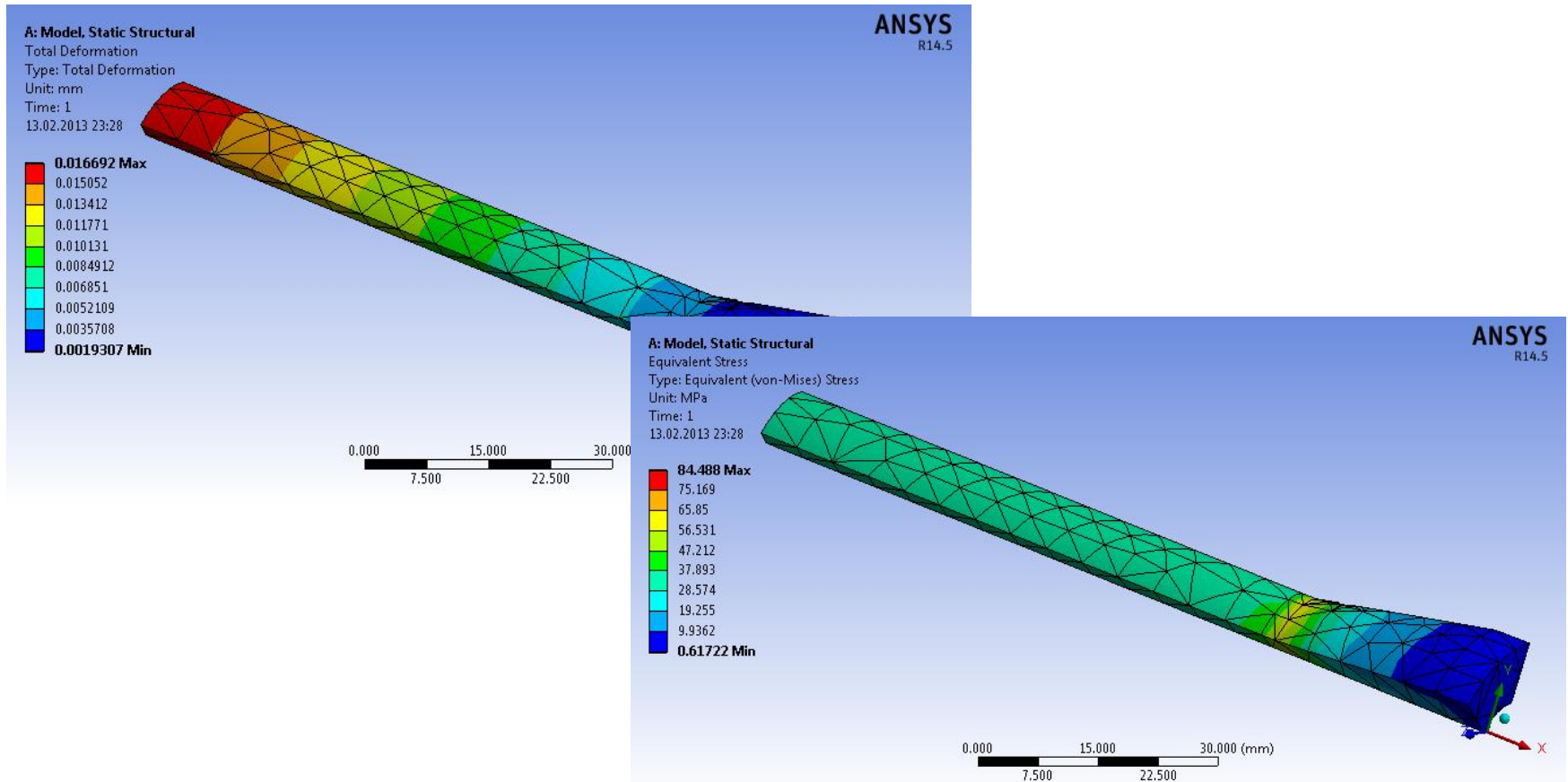
CAD Parametrization in ANSYS DesignModeler



# Understand your Design

## Example: Notch

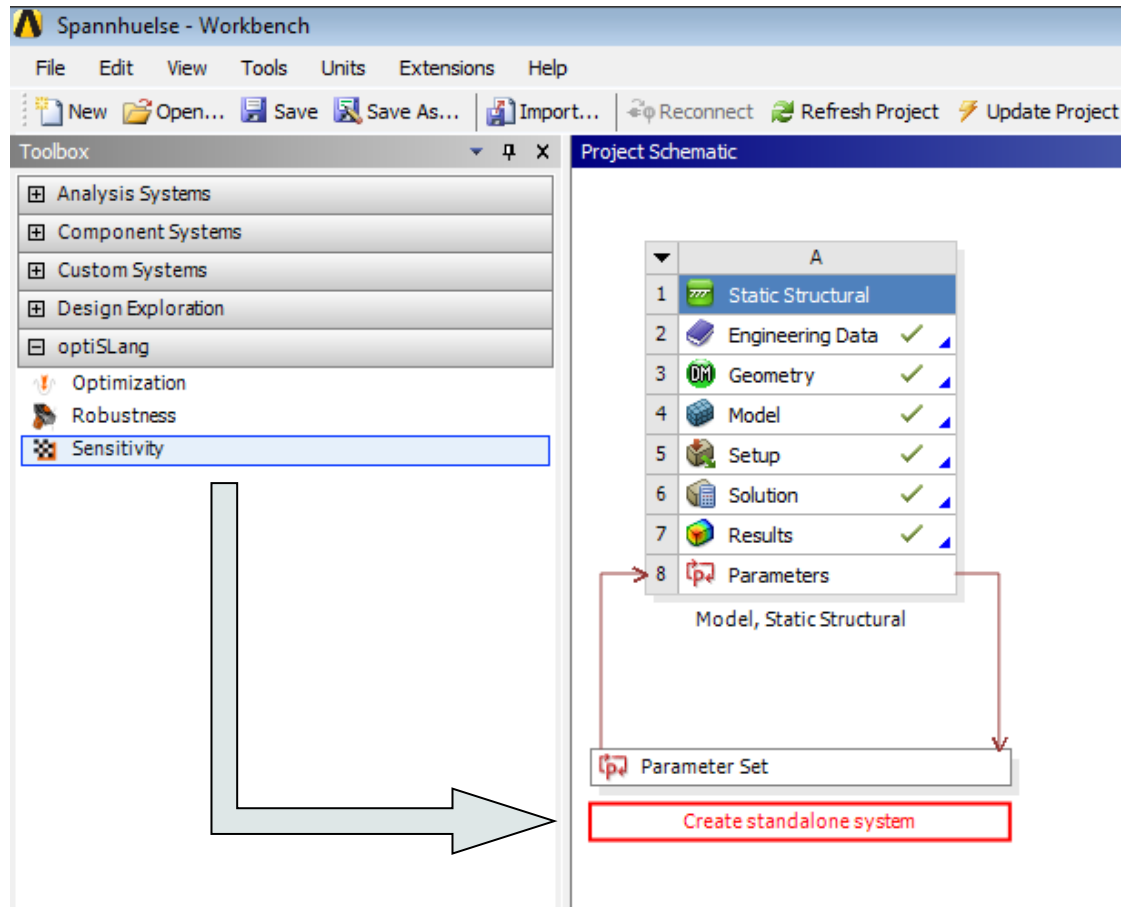
### Reference Results



# Understand your Design

## Example: Notch

Drag & Drop a new sensitivity analysis in ANSYS



# Understand your Design

## Example: Notch

The Wizard opens to insert the given parameter variations.

The screenshot shows the 'Sensitivity' dialog box with the 'Parameter' tab selected. The dialog contains a table with 11 columns: Name, Parameter type, Reference value, Constant, Resolution, Range, Range plot, PDF, Type, and Mean. There are 8 rows of parameters, all with 'Det+ Stoch' parameter type and 'UNIFORM' distribution. The 'Force\_Magnitude' parameter has a reference value of 1000 and is marked as a constant. The other parameters have their own reference values and ranges. The 'Range plot' column shows orange bars representing the distribution range for each parameter.

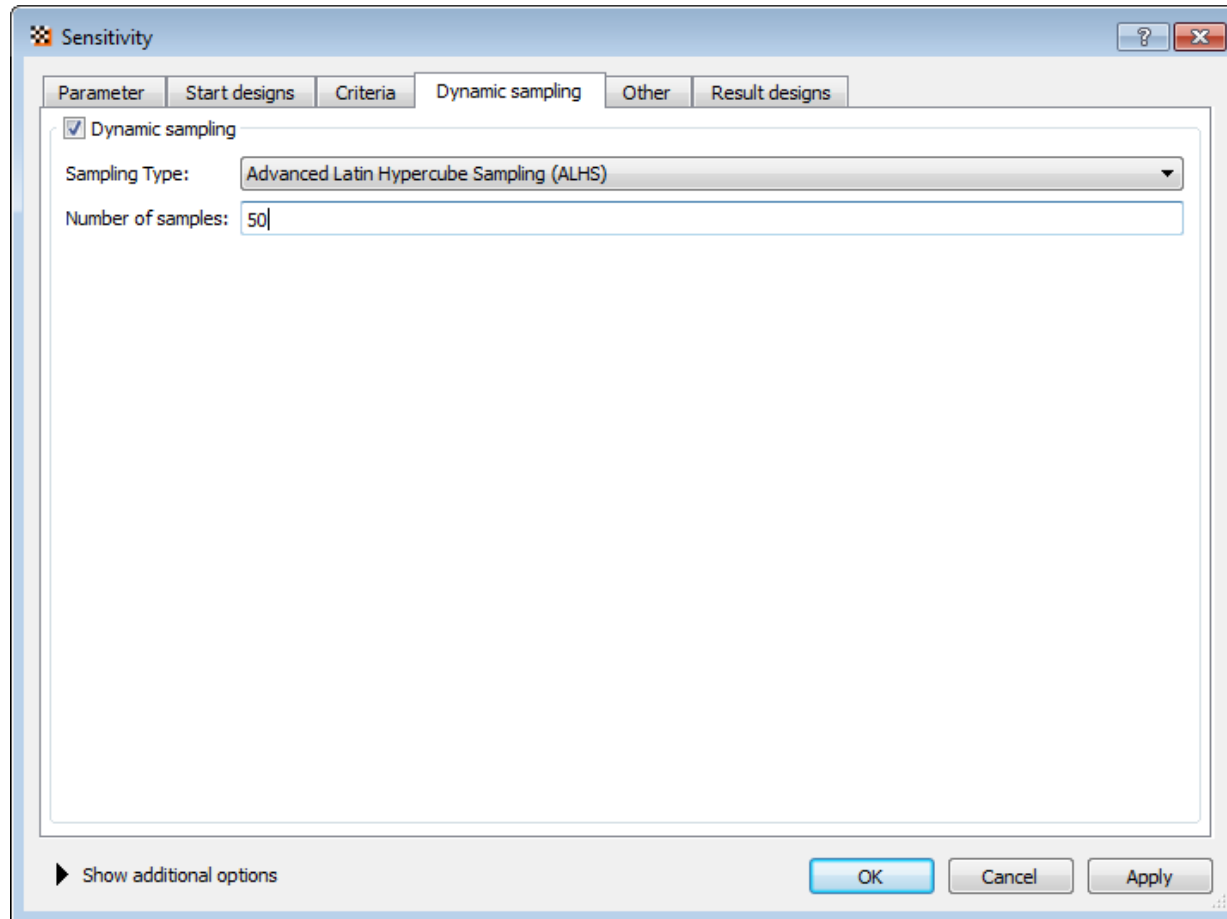
	Name	Parameter type	Reference value	Constant	Resolution	Range	Range plot	PDF	Type	Mean
1	Force_Magnitude	Det+ Stoch	1000	<input checked="" type="checkbox"/>	Continuous	900 1100			UNIFORM	1000
2	cylinder_radius	Det+ Stoch	7	<input type="checkbox"/>	Continuous	5 8			UNIFORM	7
3	thickening_len...	Det+ Stoch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

At the bottom of the dialog, there is a 'Show additional options' button, an 'Import parameter' dropdown menu, and 'OK', 'Cancel', and 'Apply' buttons.

# Understand your Design

## Example: Notch

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

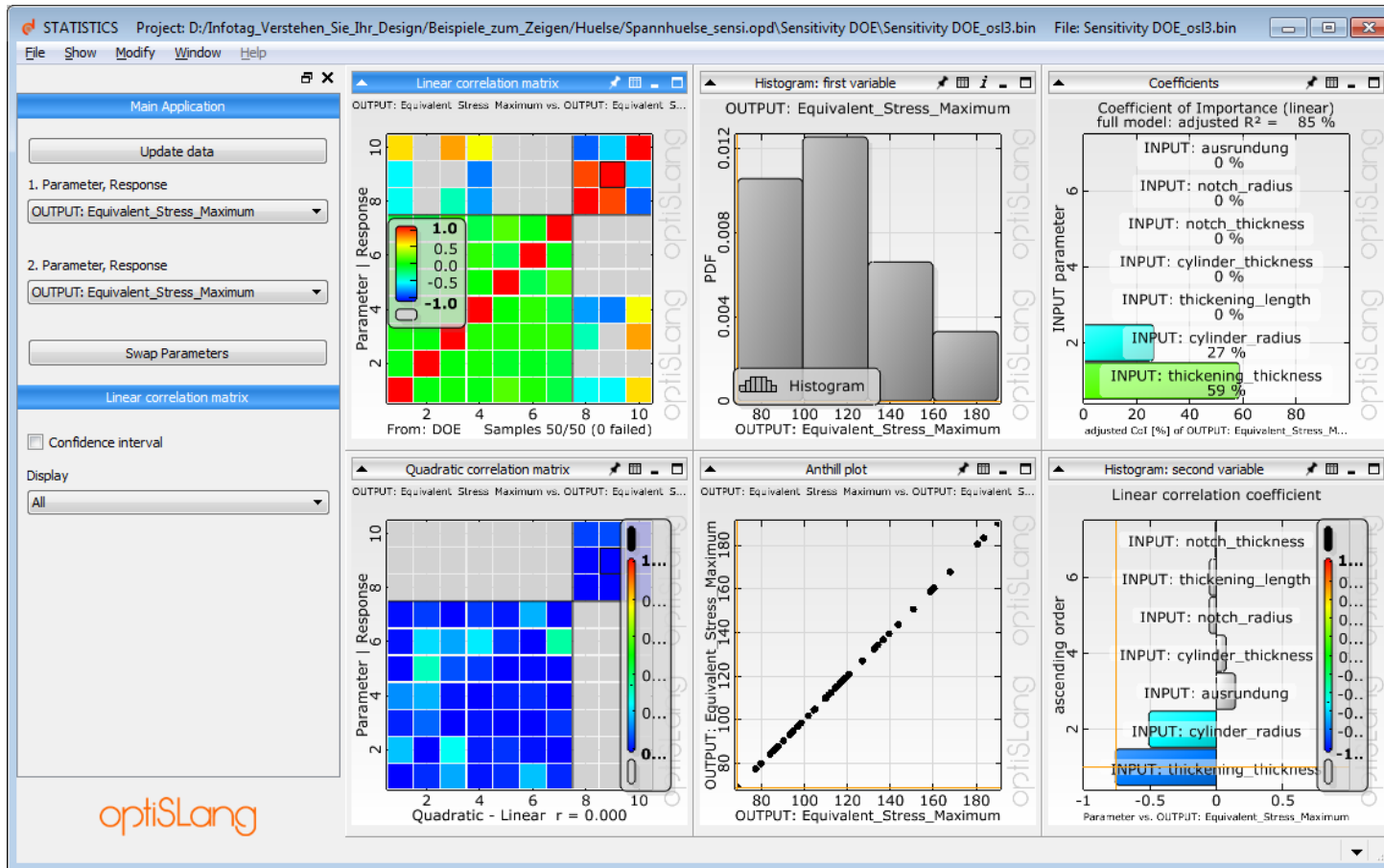




# Understand your Design

## Example: Notch

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



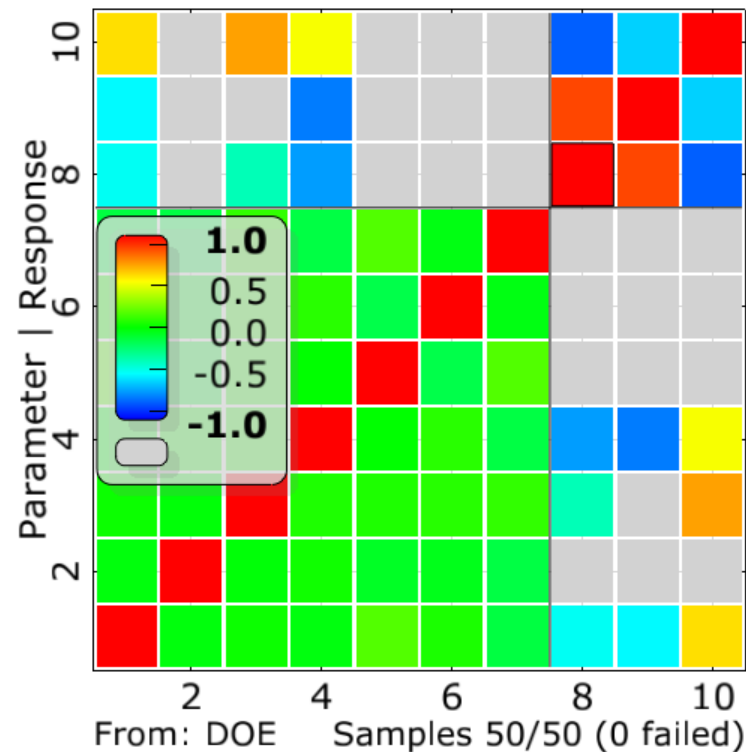
optiSlang

# Understand your Design

## Example: Notch

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

OUTPUT: Total\_Deformation\_Maximum vs. OUTPUT: Total\_Deform...



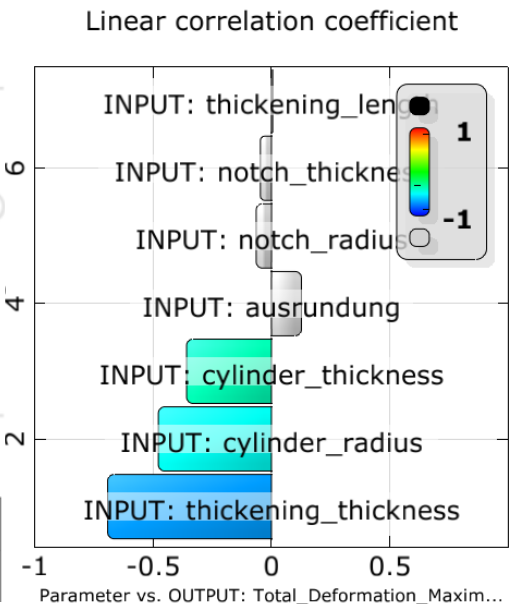
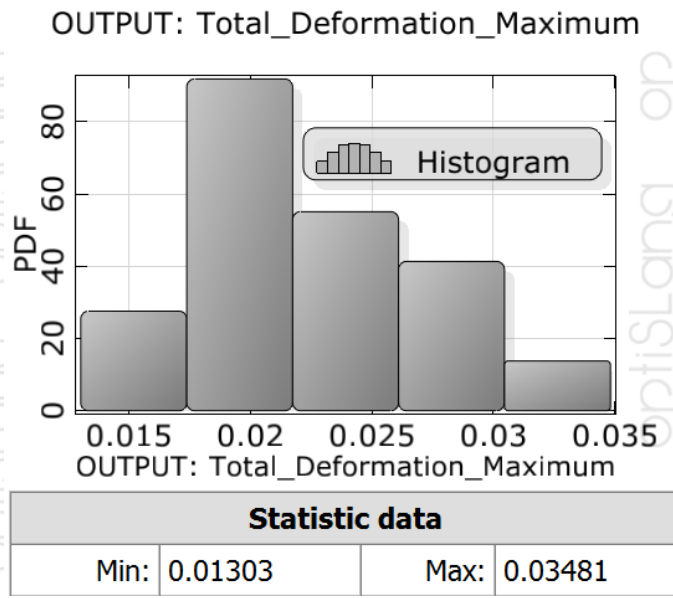
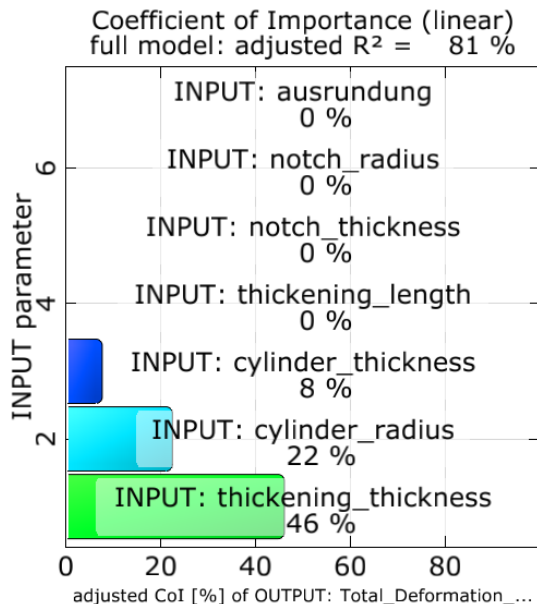
optisLang optisLang optisLang

# Understand your Design

## 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.

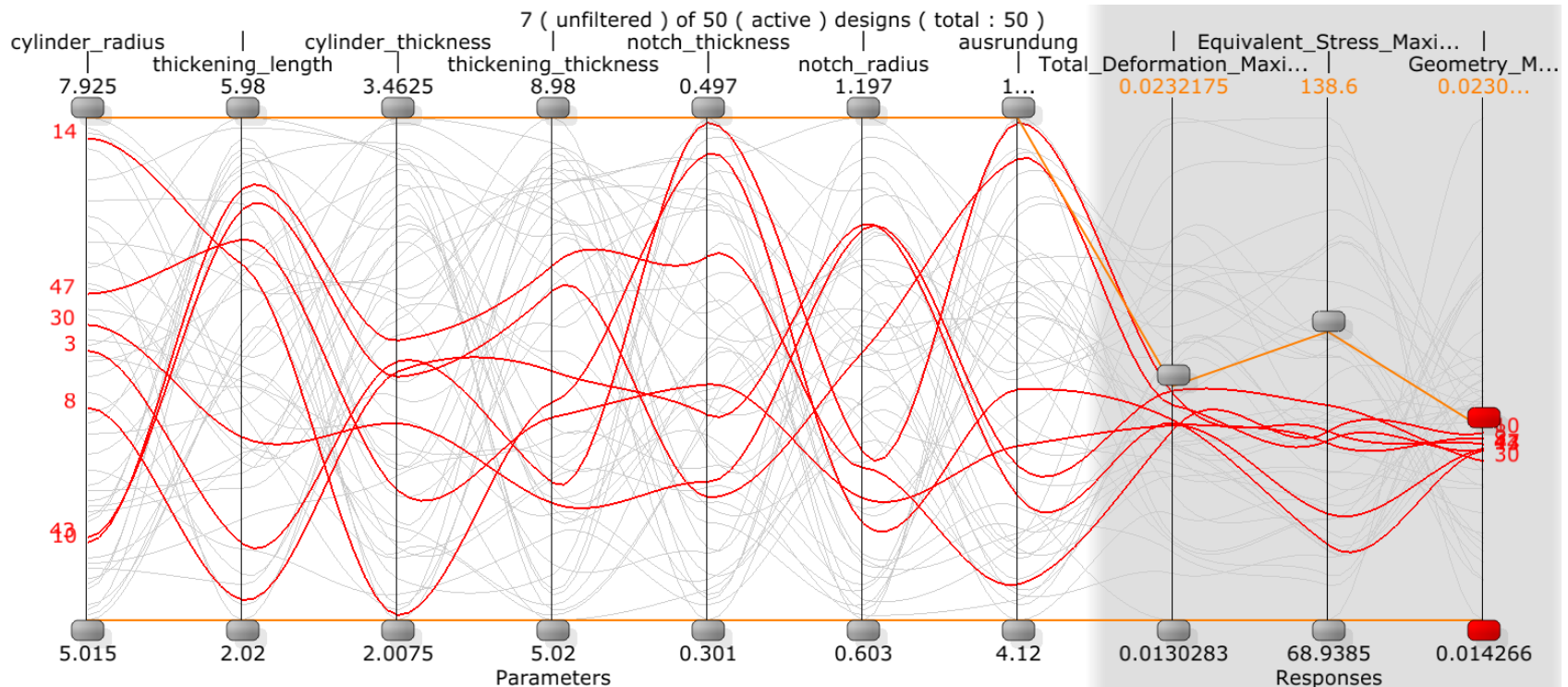


# Understand your Design

## Example: Notch

Remember the optimization goal of minimizing mass and deformation by considering a maximum stress of 140 Mpa?

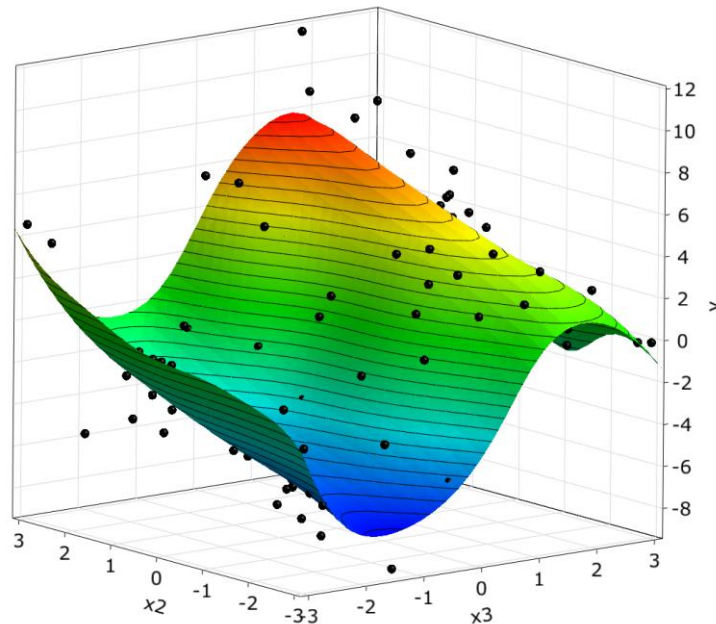
Open the parallel coordinates plot to check your optimization possibilities!



# Understand your Design

## Example: Notch

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



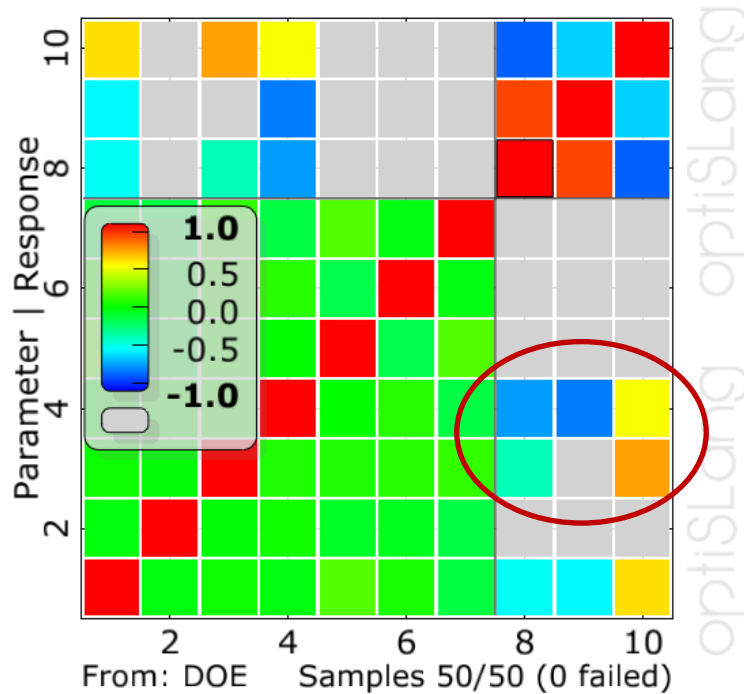
The model will be automatically reduced to the significant inputs.  
All noticeable correlations will be determined.  
The forecast quality is estimated.

# Understand your Design

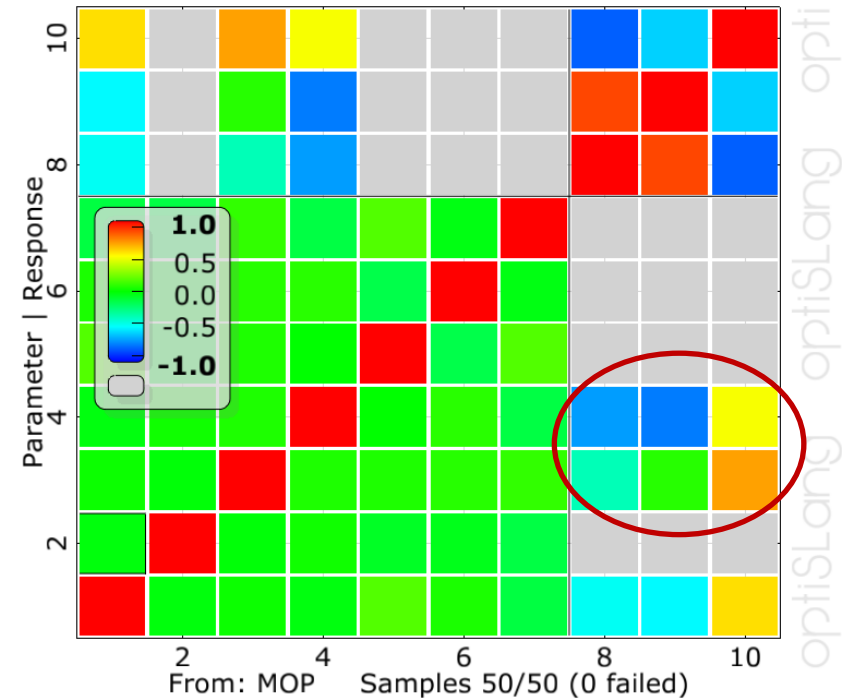
## Example: Notch

The correlations are determined more detailly

OUTPUT: Total\_Deformation\_Maximum vs. OUTPUT: Total\_Deform...



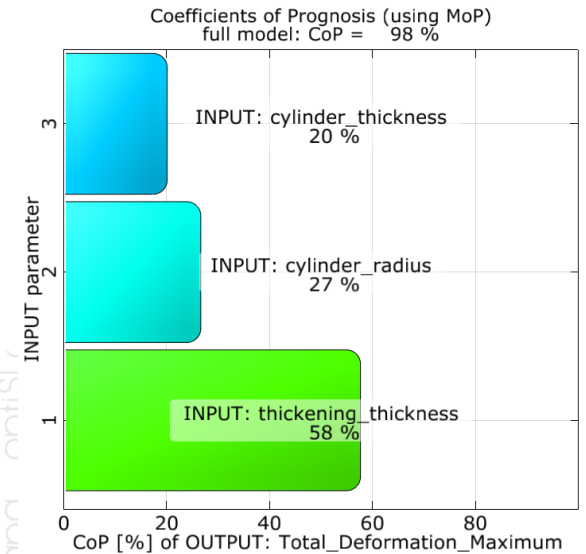
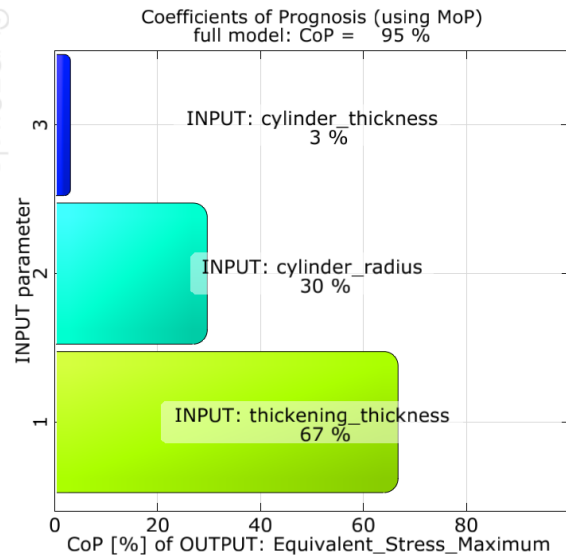
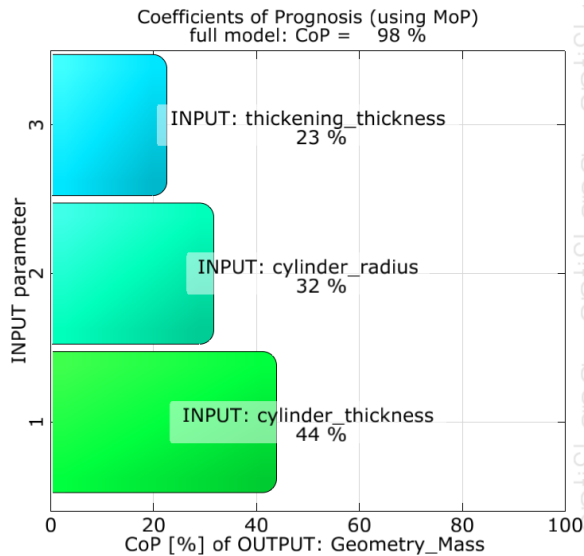
INPUT: cylinder\_radius vs. INPUT: thickening\_length,  $r = -0.024$



# Understand your Design

## COPs

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





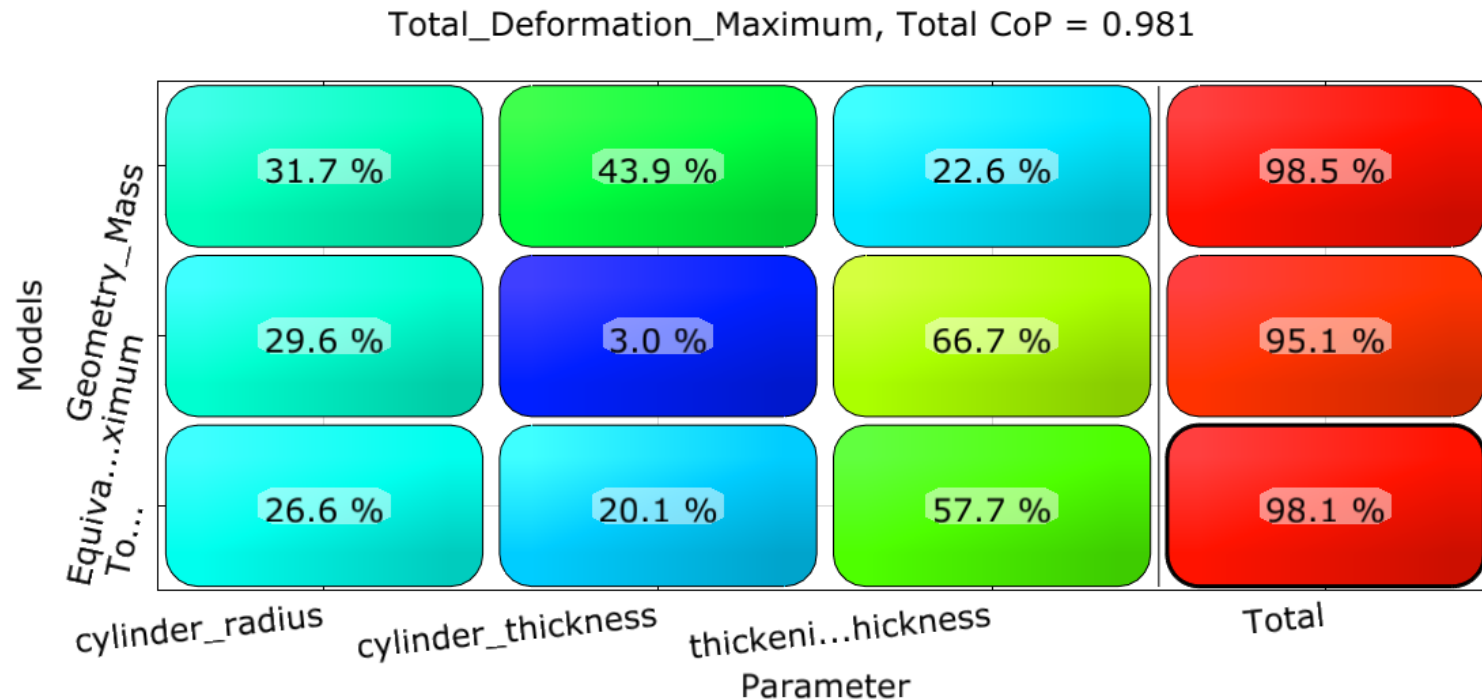
# Understand your Design

## 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.



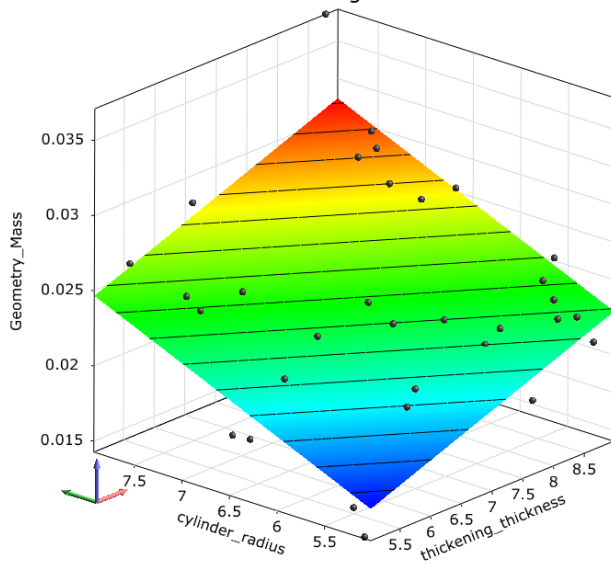
optiLang optiLang

# Understand your Design

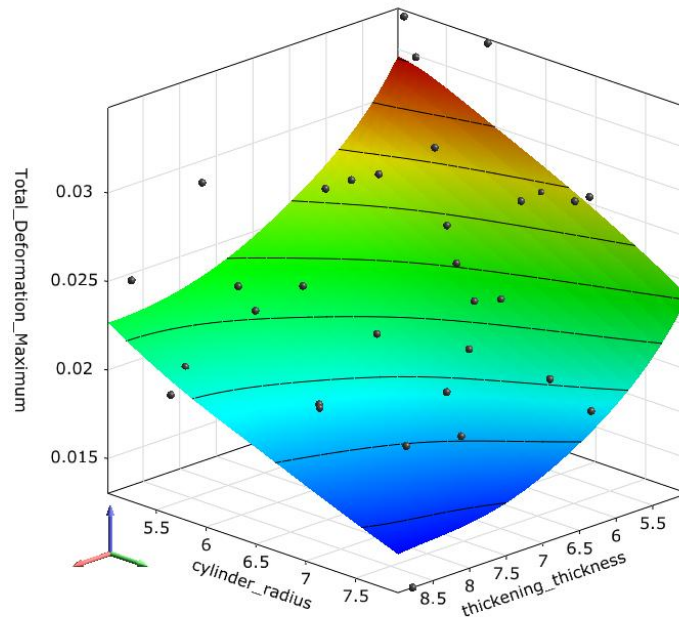
## Example: Notch

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

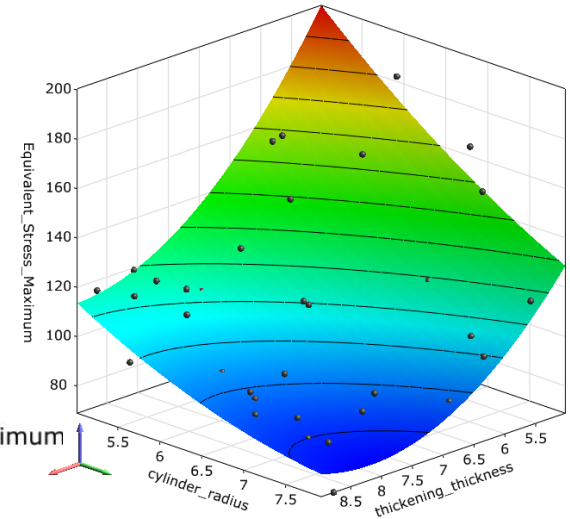
Linear regression of Geometry\_Mass  
Coefficient of Prognosis = 98 %



MLS approximation of Total\_Deformation\_Maximum  
Coefficient of Prognosis = 98 %



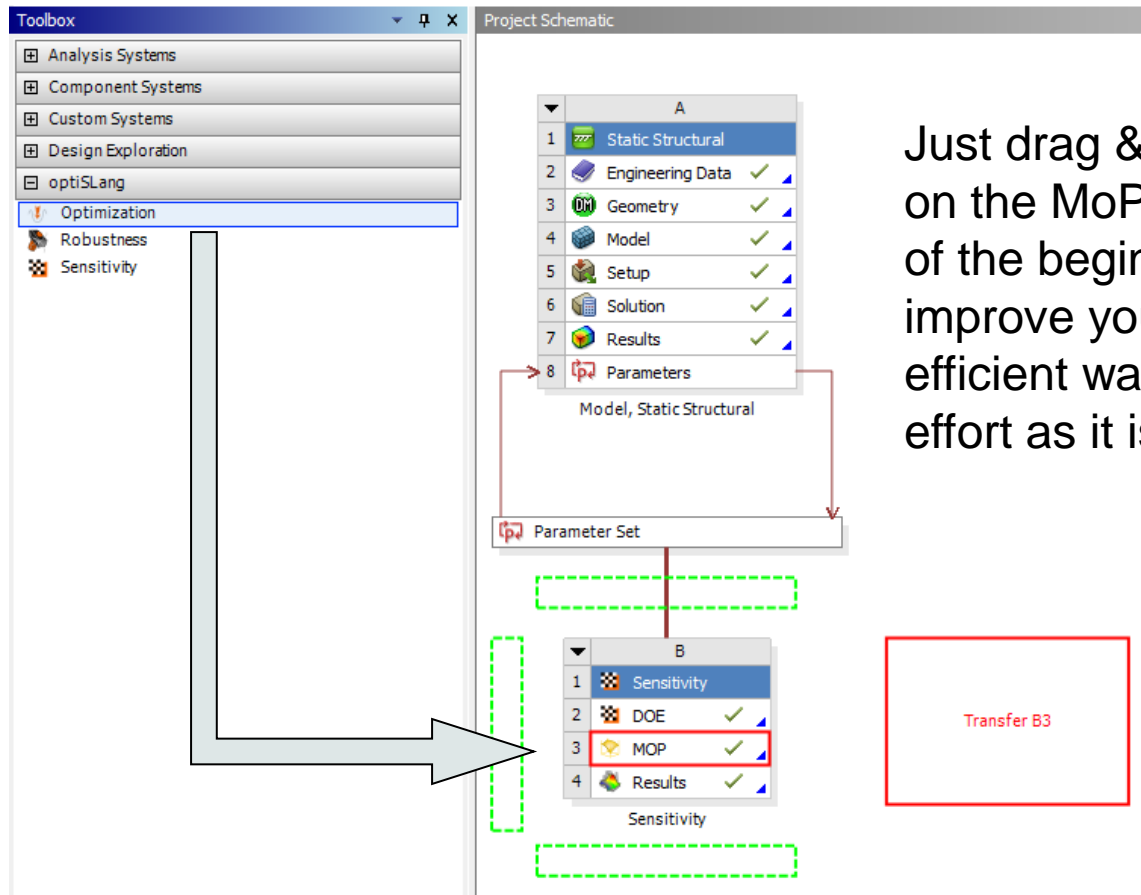
Polynomial regression of Equivalent\_Stress\_Maximum  
Coefficient of Prognosis = 95 %



# Understand your Design

## 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!

Optimization Wizard

Parametrize Inputs  
Parametrize the inputs

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

Import parameter ▾

Next > Cancel Help

# Understand your Design

## Example: Notch

Let's insert our goals using the wizard

The Optimization Wizard dialog box is titled "Optimization Wizard" and contains the following sections:

- Criteria:** Specify the algorithm criteria. Includes a small icon of a person with a lightbulb.
- Variables:** A table with columns Name, Expression, and Value. It contains one row with Name "new".
- Parameter:** A table with columns Name and Value. It contains two rows: "Force\_Magnit..." with value 1000, and "cylinder\_radius" with value 7.
- Responses:** A table with columns Name and Value. It contains two rows: "Equivalent\_St..." with value 77.3451326372, and "Geometry\_M..." with value 0.0301139899567.
- Objectives:** A table with columns Name, Criterion, Expression, and Value. It contains two rows: "Goal\_1" with Criterion "MIN" and Expression "Total\_Deformation\_Maximum", and "Goal\_2" with Criterion "MIN" and Expression "Geometry\_Mass" and value 0.030114.
- Constraints:** A table with columns Name, Left side expression, Criterion, Right side expression, and Value. It contains one row: "Constraint" with Left side expression "Equivalent\_Stress\_Maximum", Criterion "<=", Right side expression "140", and Value "62.6549".

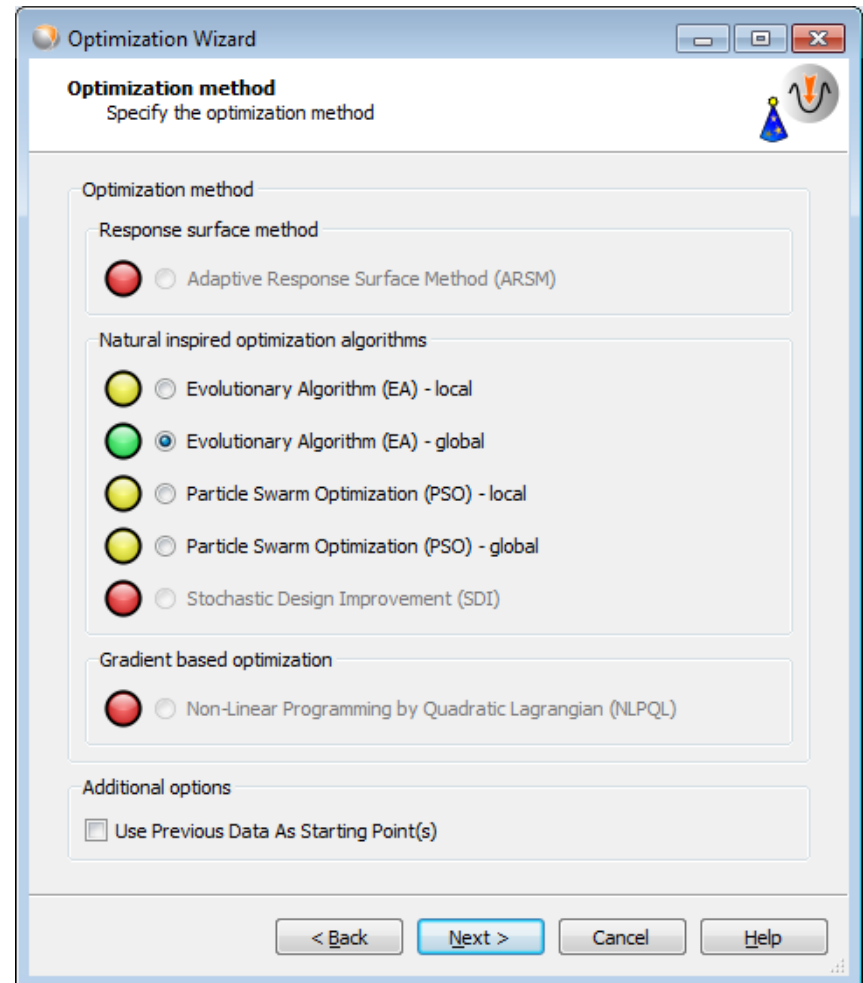
At the bottom right, there is a button labeled "Import criteria" with a dropdown arrow. At the bottom center, there are four buttons: "< Back", "Next >", "Cancel", and "Help".

# Understand your Design

## Example: Notch

optiSLang suggests automatically the best suiting method!

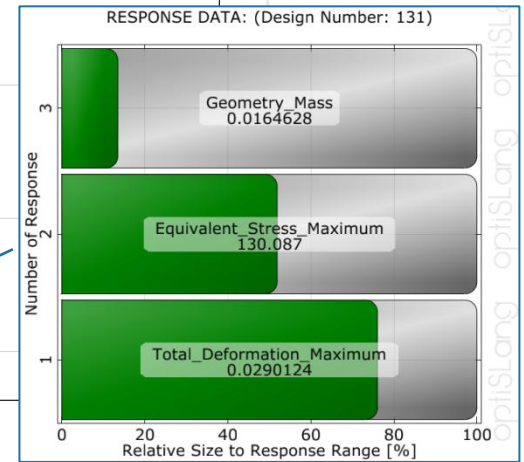
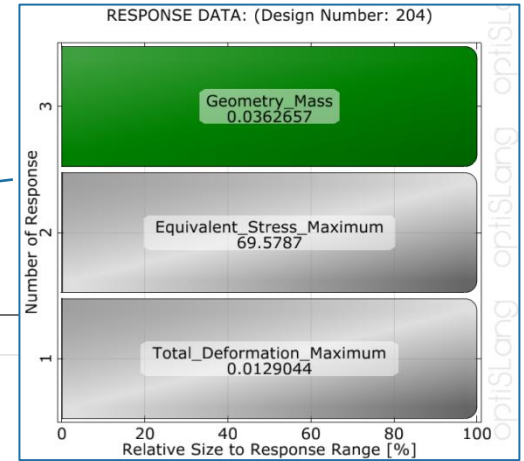
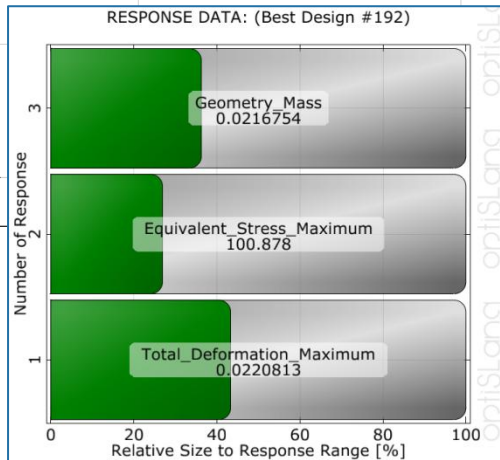
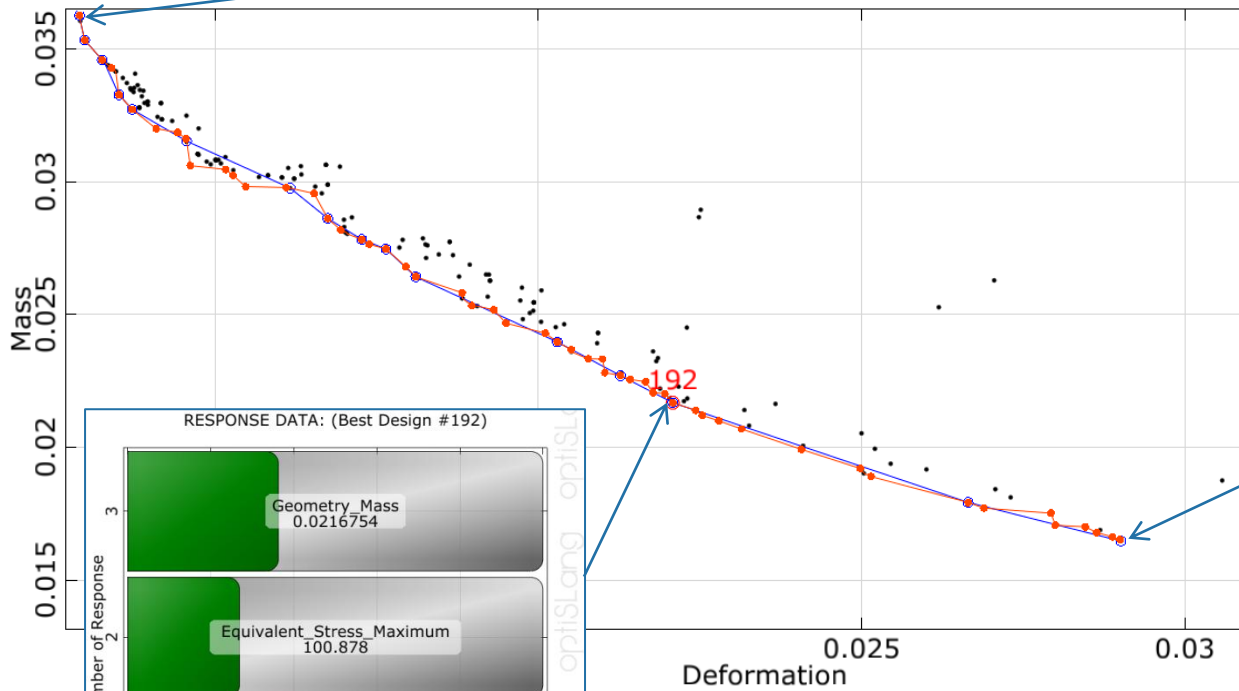
Therefore you do not have to care about different algorithms or sophisticated settings. This is done by the software!



# Understand your Design

## Example: Notch

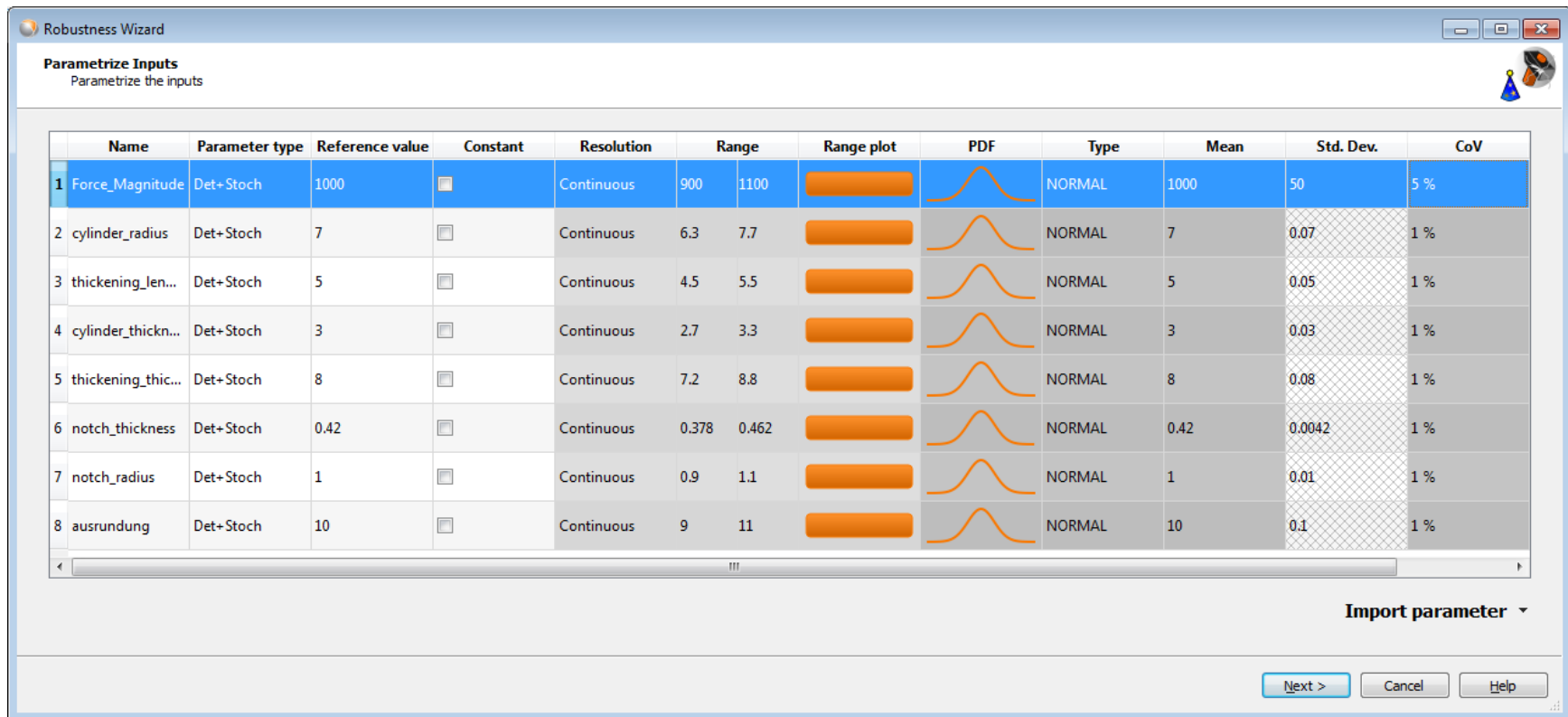
What is the best compromise?



# Understand your Design

## Example: Notch

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



The screenshot shows the 'Robustness Wizard' software interface, specifically the 'Parametrize Inputs' step. The window title is 'Robustness Wizard' and the subtitle is 'Parametrize Inputs'. Below the title bar, there is a table with 13 columns: Name, Parameter type, Reference value, Constant, Resolution, Range, Range plot, PDF, Type, Mean, Std. Dev., and CoV. The table contains 8 rows of parameters. The first row is highlighted in blue. Below the table, there is a scroll bar and an 'Import parameter' button. At the bottom right, there are three buttons: 'Next >', 'Cancel', and 'Help'.

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

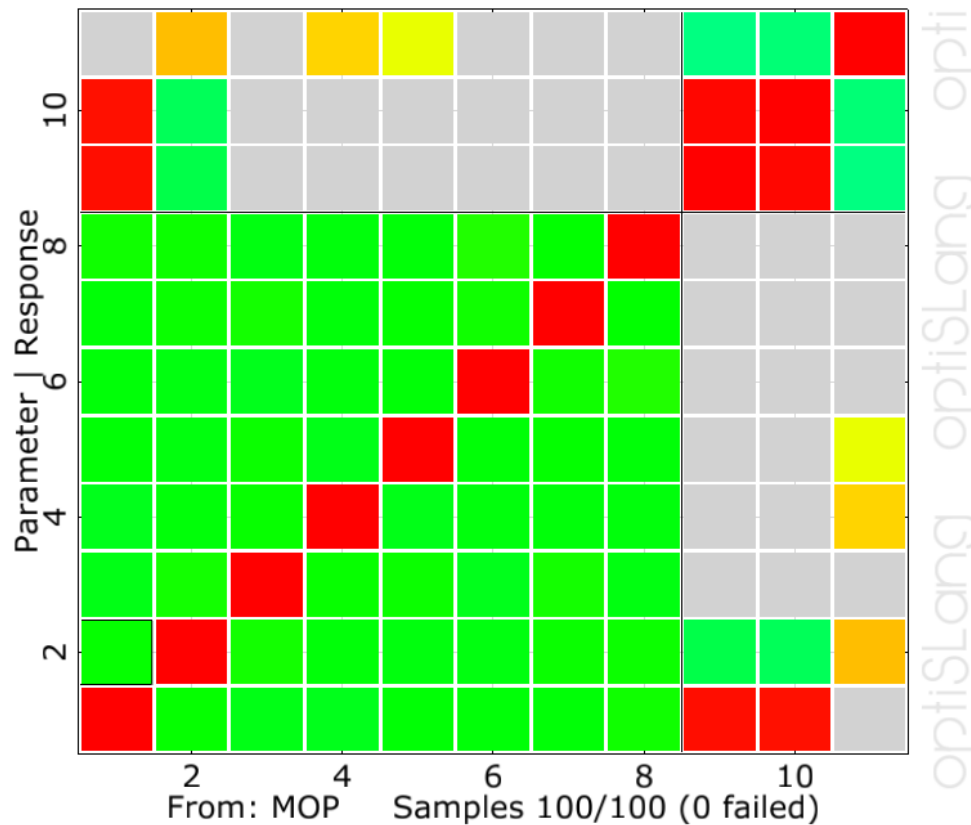


# Understand your Design

## Example: Notch

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

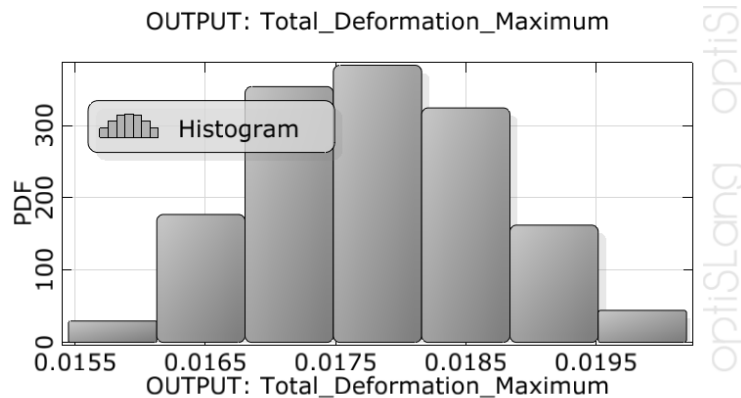
INPUT: Force\_Magnitude vs. INPUT: cylinder\_radius,  $r = 0.010$



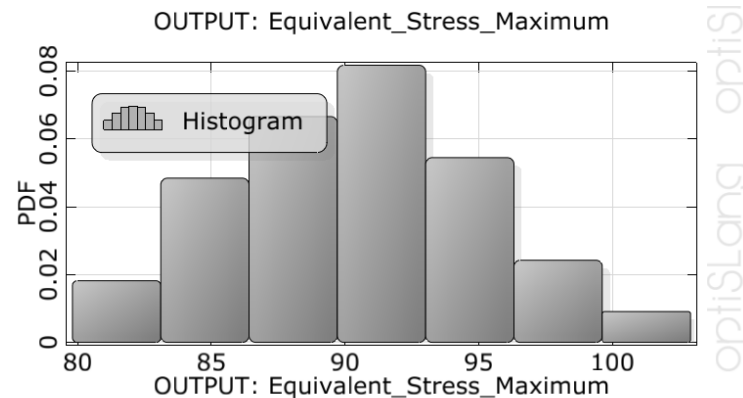
# Understand your Design

## 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: 0.01702	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

$$\bar{\Pi} = \frac{1}{2} \sum_e \{u\}^T \cdot [K] \cdot \{u\} - \{u\}^T \cdot \{F\}$$

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# Understand your Design

Typical Questions

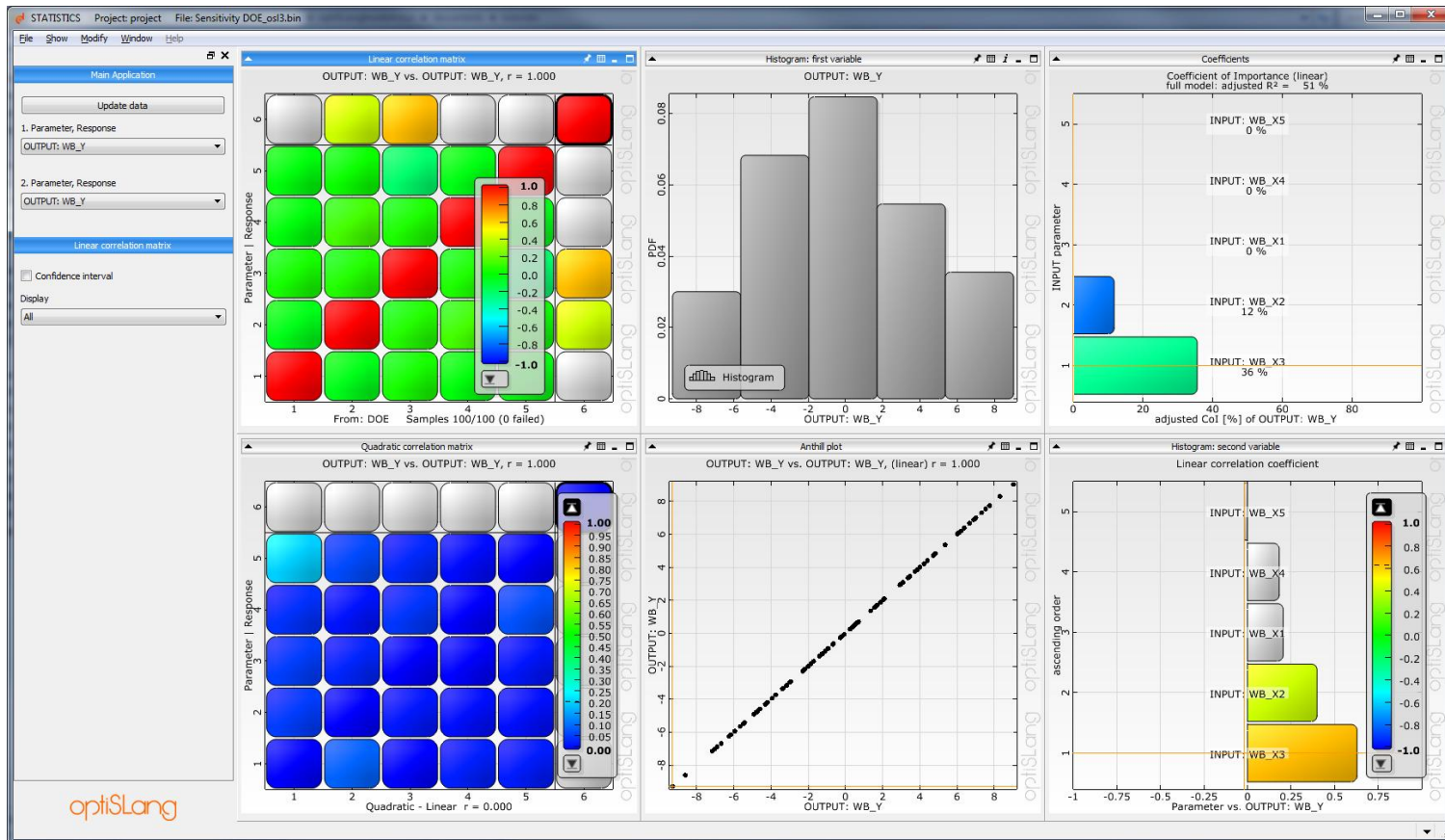
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# Content

- 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 sensitive overview of all results.

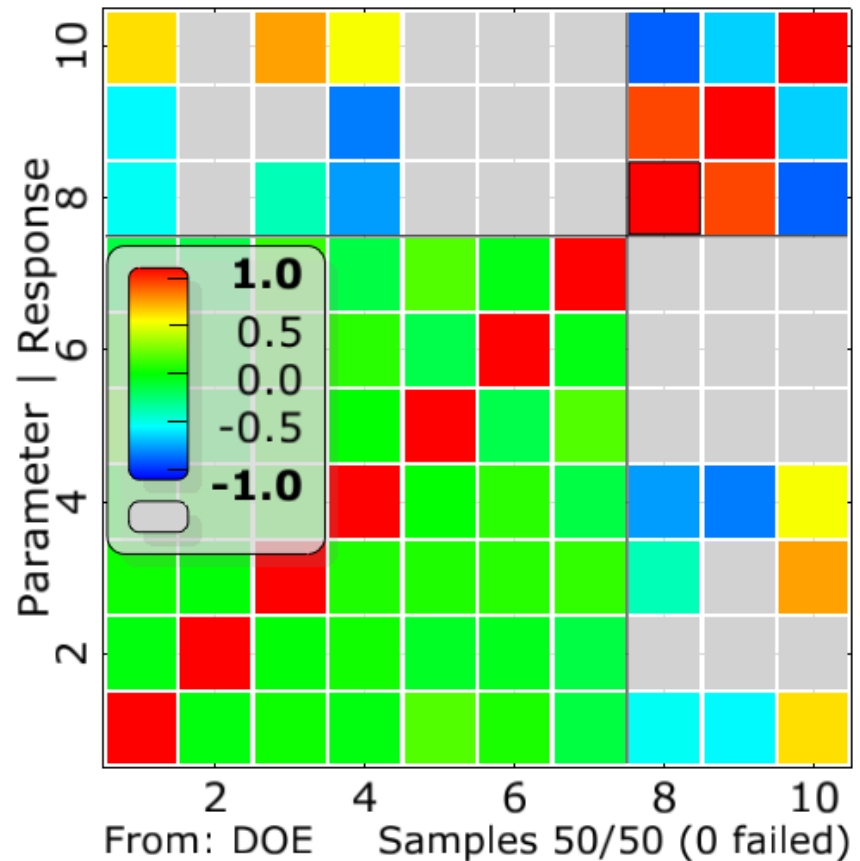


# How to evaluate 1000 designs?

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

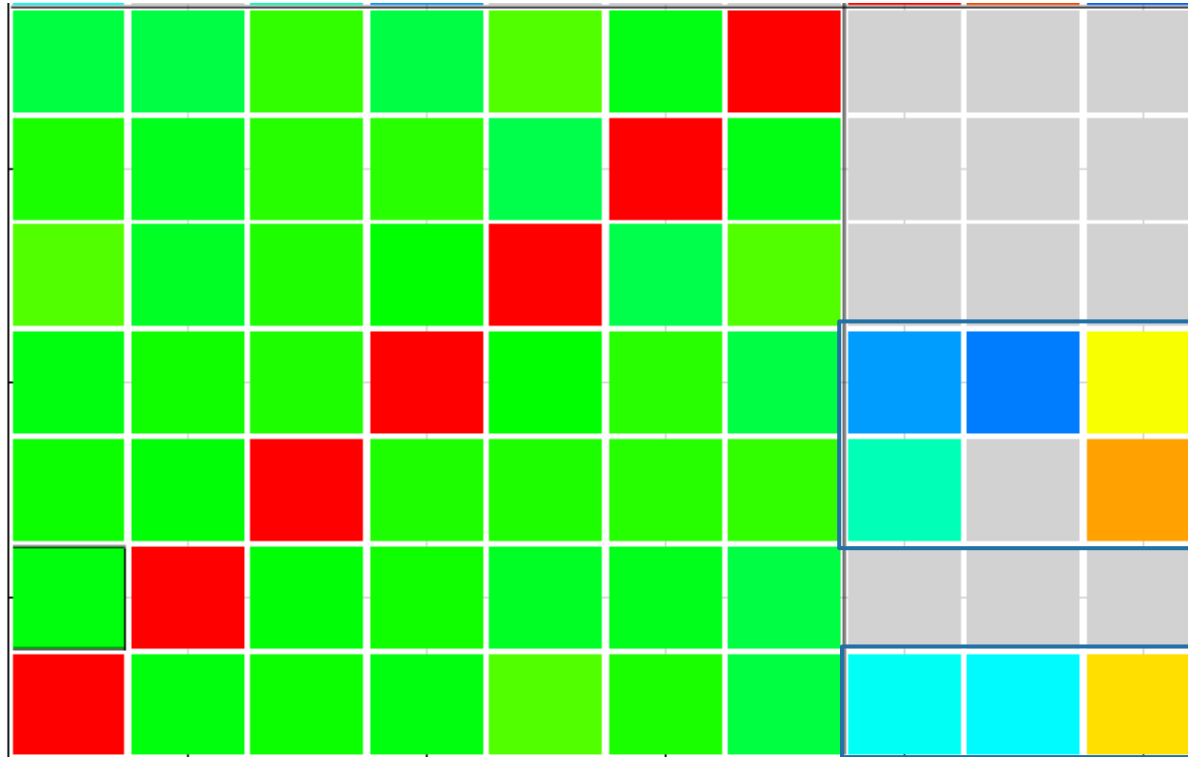
Check:

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



optiSlang optiSlang

## How to evaluate 1000 designs?



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

## How to evaluate 1000 designs?

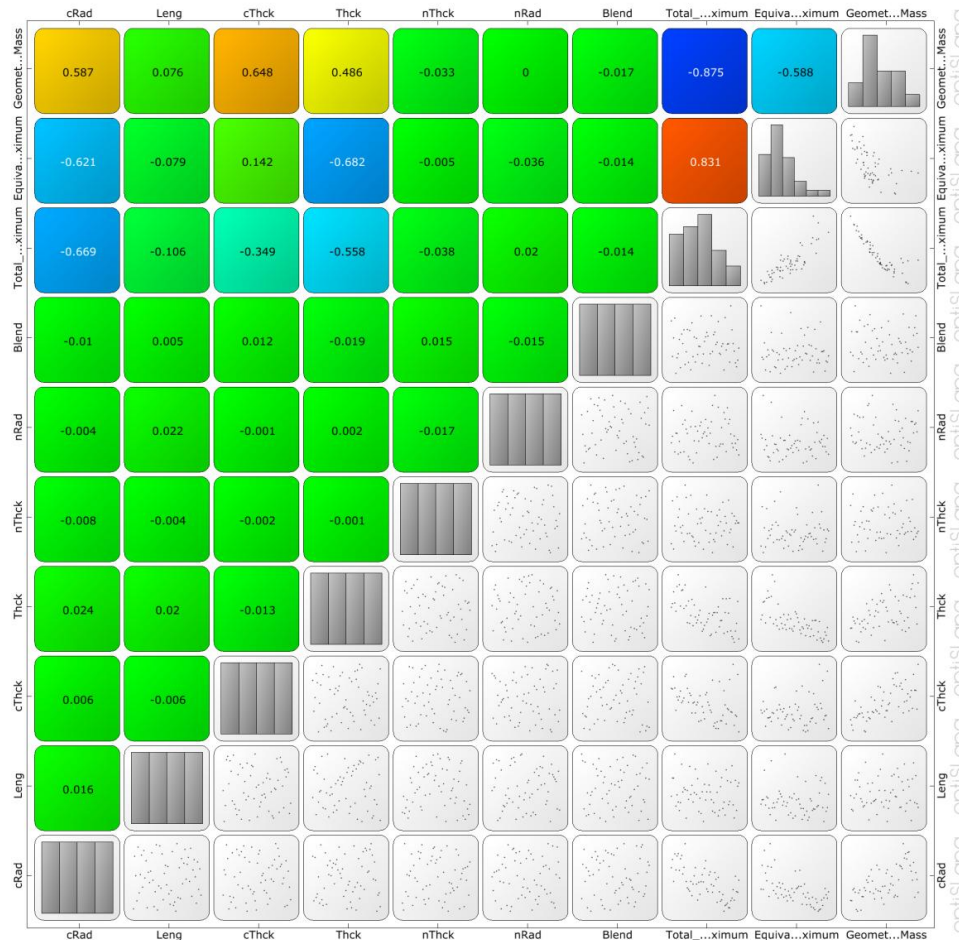


Deformation and Stress: positive correlated  
Mass: negative correlation to stress and deformation  
→ Important for future design improvement.



# How to evaluate 1000 designs?

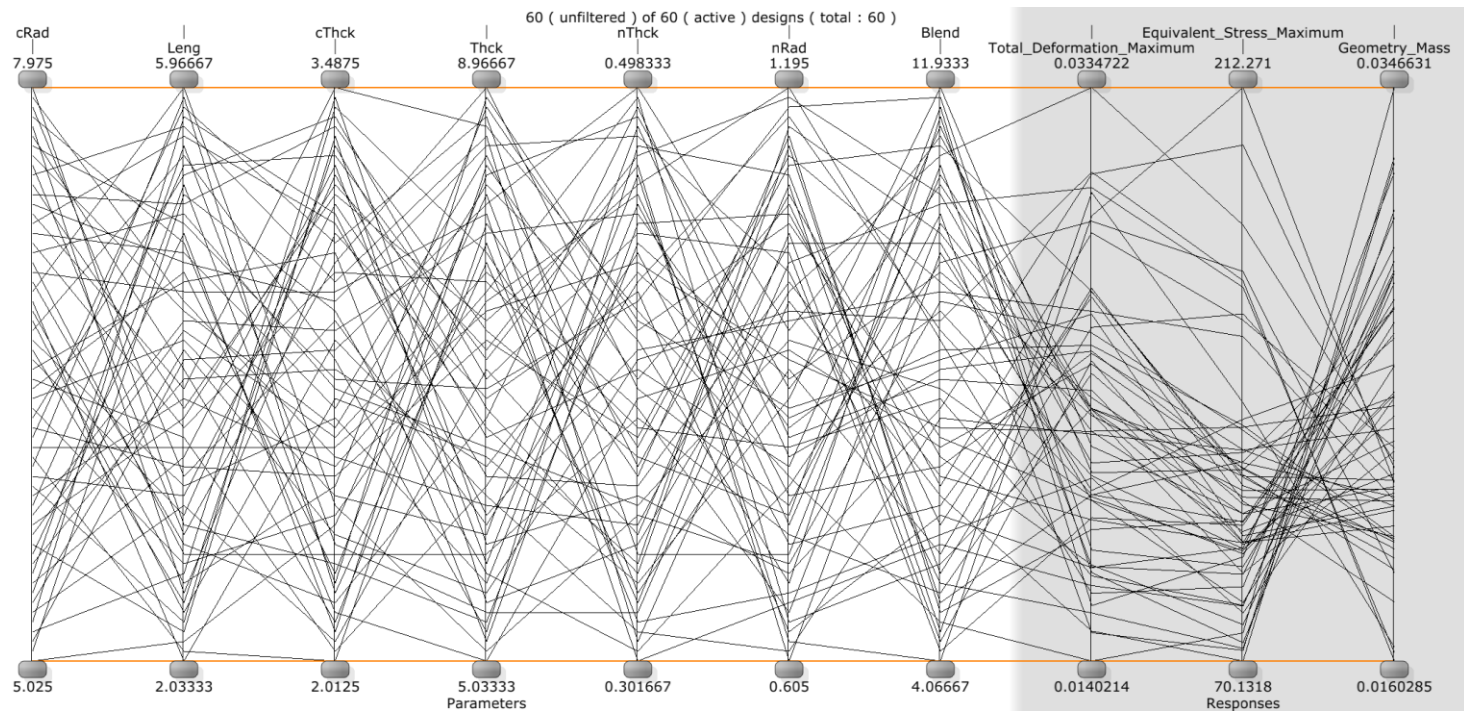
- Get the overview of all correlations using the extended correlation matrix!



# How to evaluate 1000 designs?

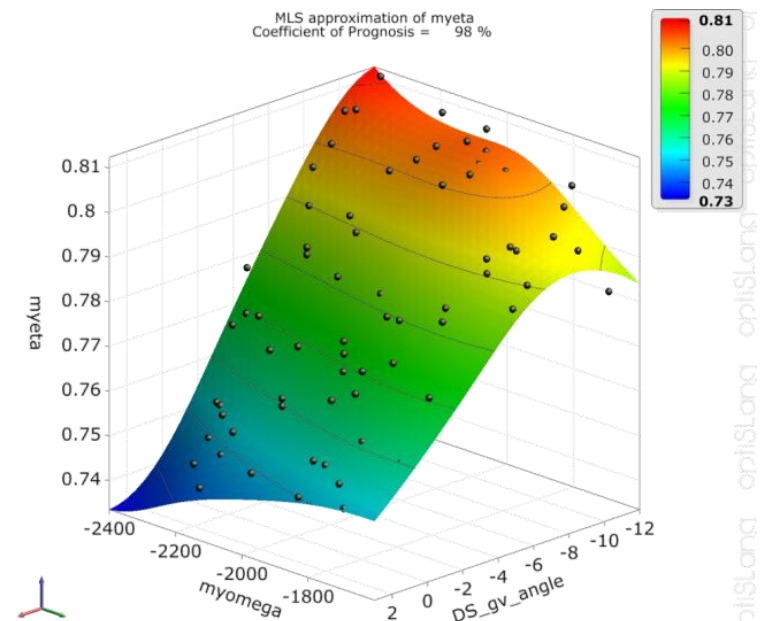
## Parallel Coordinates Plot:

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



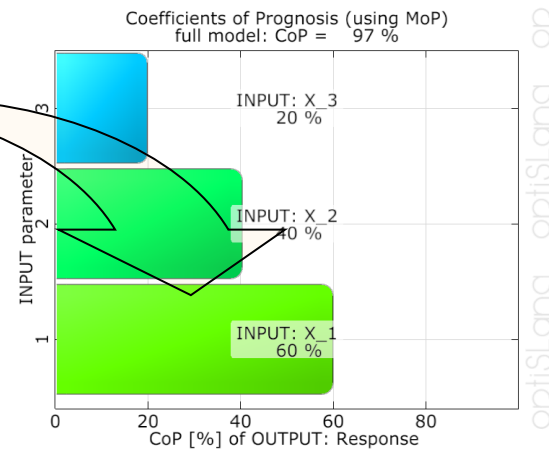
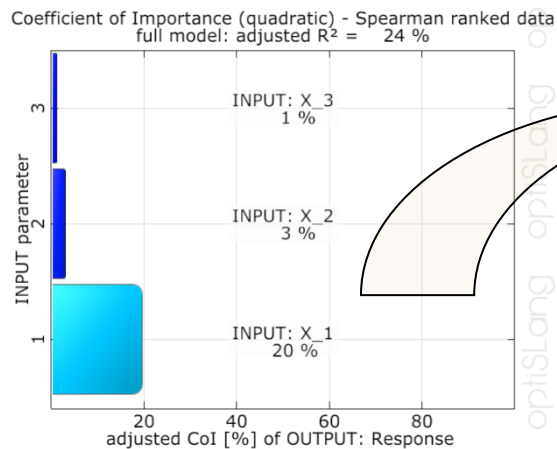
# The optiSLang Meta-model of Optimal Prognosis (MOP)

- 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



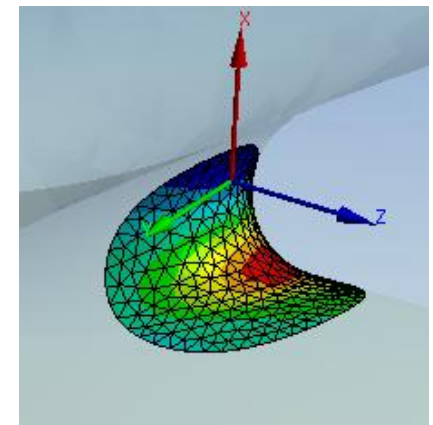
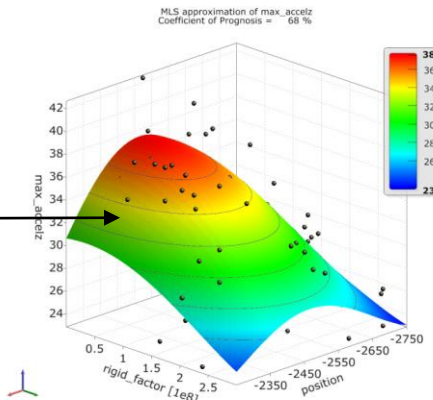
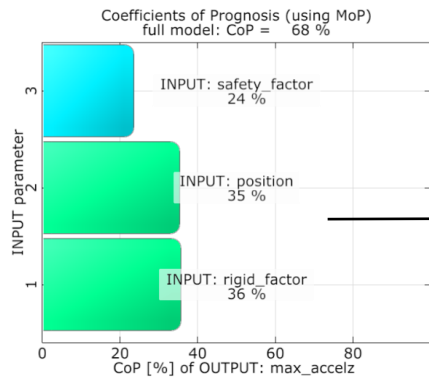
# The Coefficient of Prognosis (CoP)

- 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 occurring numerical noise



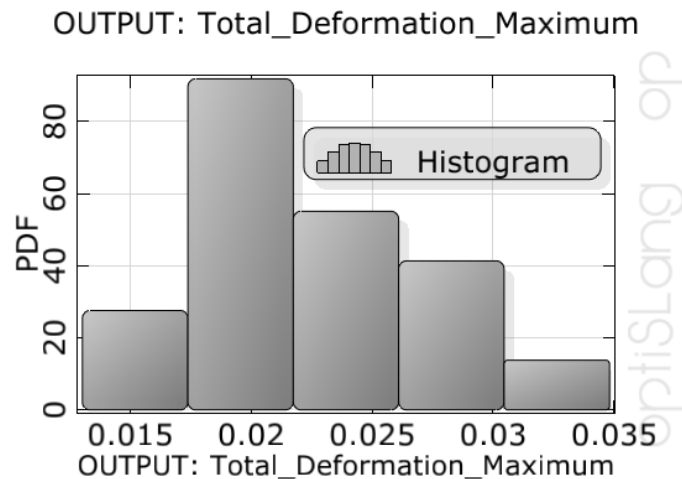
# Accuracy and numerical noise

- 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



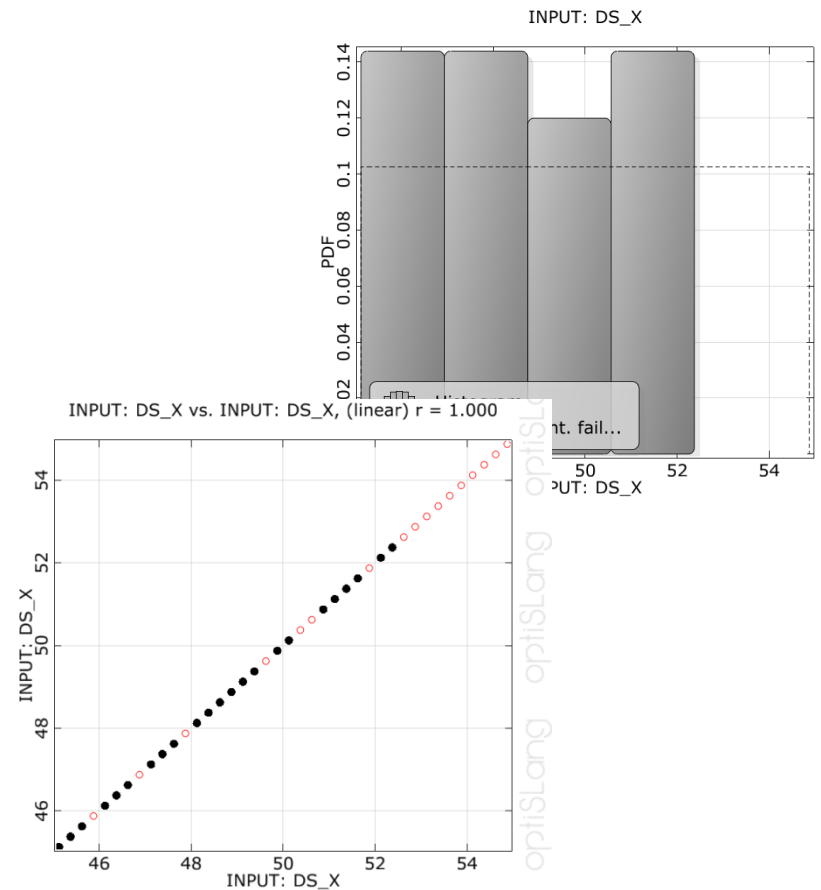
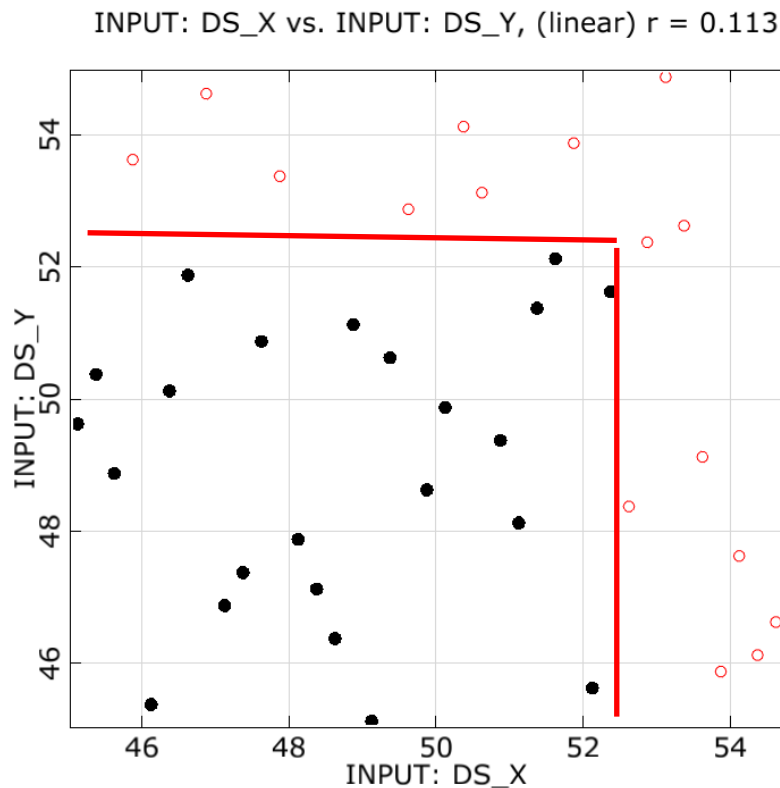
Statistic data			
Min:	0.01303	Max:	0.03481
Mean:	0.02288	Sigma:	0.004786
CV:	0.2092		
Skewness:	0.5064	Kurtosis:	3.104

## 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!



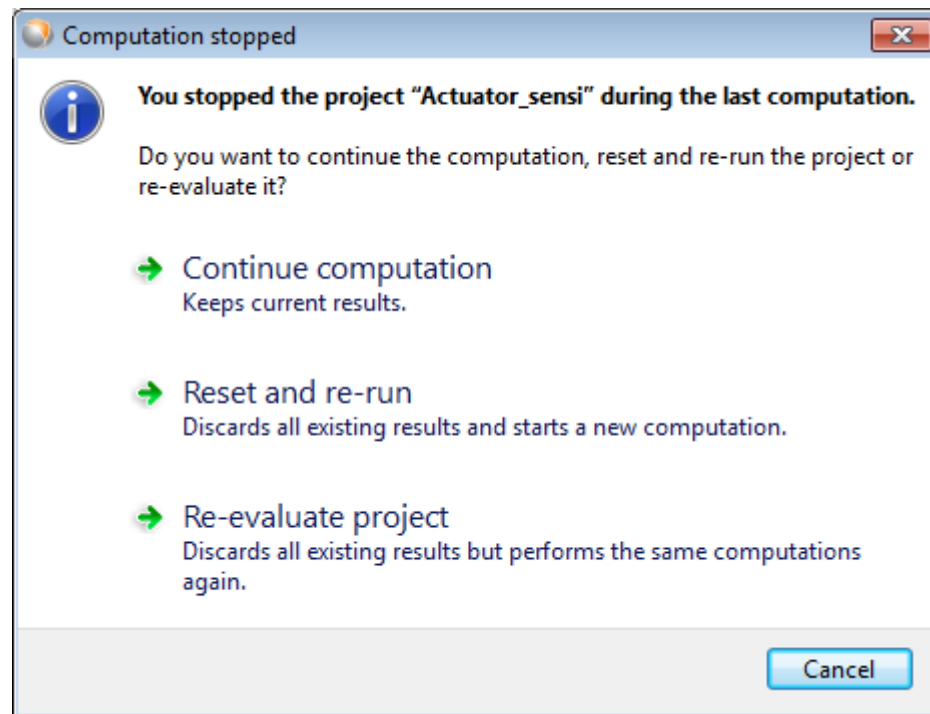


## **BUT - Do we need always converging and regeneratable models?**

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



$$\bar{\Pi} = \frac{1}{2} \sum_e \{u\}^T \cdot [K] \cdot \{u\} - \{u\}^T \cdot \{F\}$$

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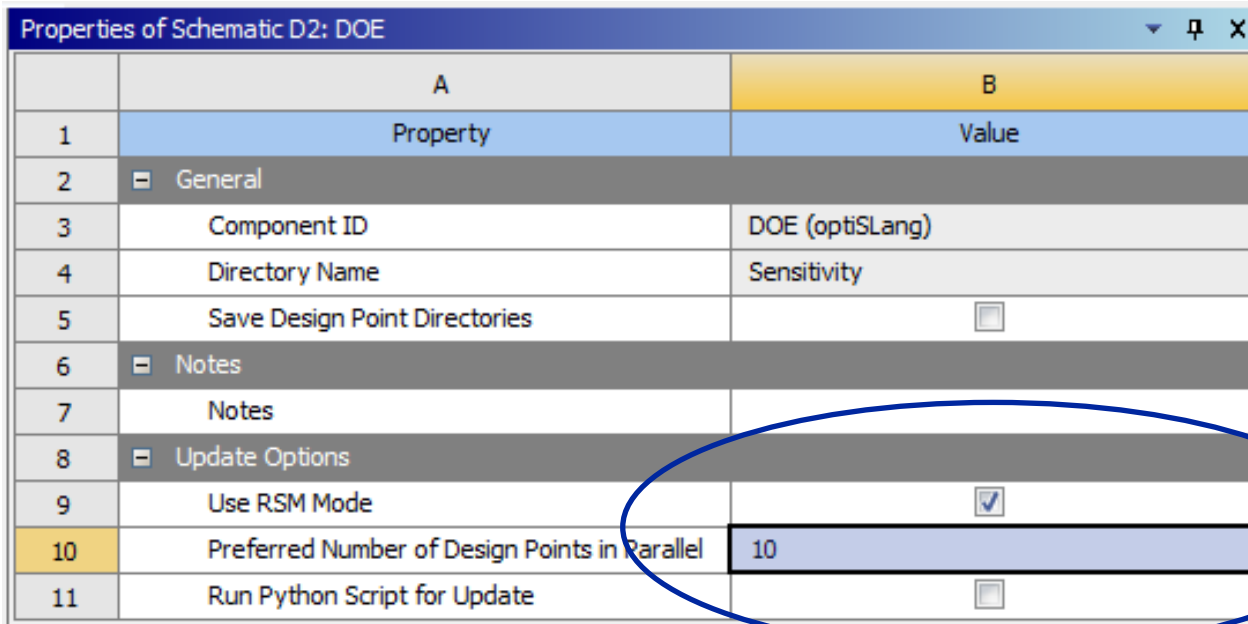
# Understand your Design

Hard- and Software for Performant Design Variation

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# 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 therefore you can combine it with your own jobmanagement systems.



	A	B
1	Property	Value
2	General	
3	Component ID	DOE (optiSLang)
4	Directory Name	Sensitivity
5	Save Design Point Directories	<input type="checkbox"/>
6	Notes	
7	Notes	
8	Update Options	
9	Use RSM Mode	<input checked="" type="checkbox"/>
10	Preferred Number of Design Points in Parallel	10
11	Run Python Script for Update	<input type="checkbox"/>

# 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

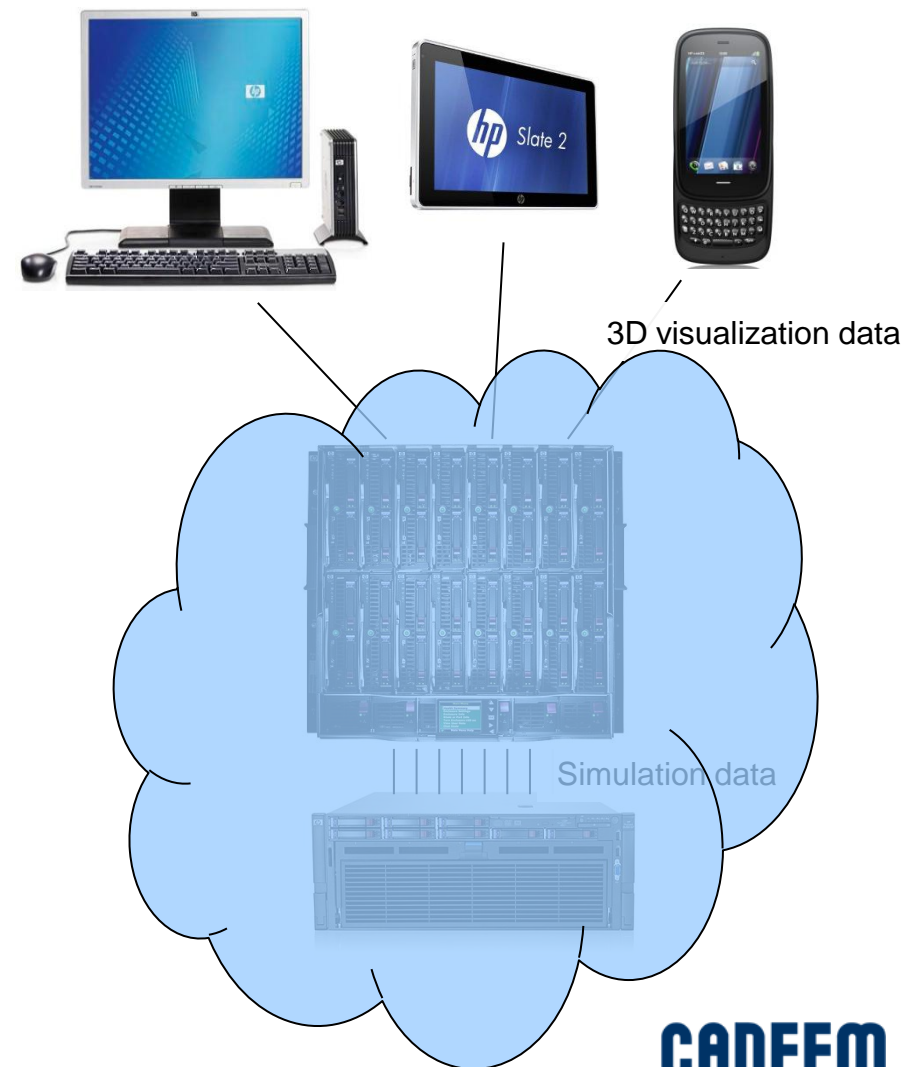
# Hardware

- Compute Server
  - Remote High End Computing power
  - No 3D Graphics
  - Scalable in cores, memory, disks
  - Redundant components
  - Service Level Agreements SLAs available
  - 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



# Hardware

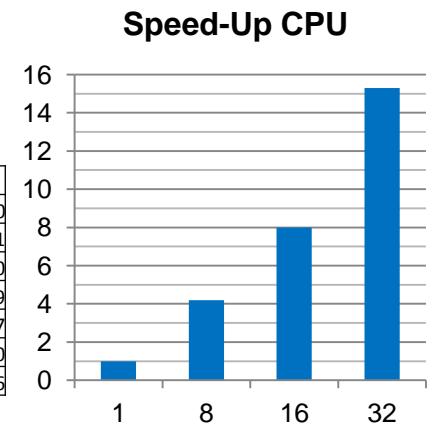
- Terminals & Cloud
- Benefit
  - High bandwidth connection from blade workstation to compute server → fast postprocessing
  - Flexible allocation of virtual workstations → cost effective „workstation“ usage by multiple users
  - Flexible scaling of hardware resources → better scaling and availability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



# 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:  $4 \times 1.5 = 6$
  - Important: SMP & DMP available

# 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

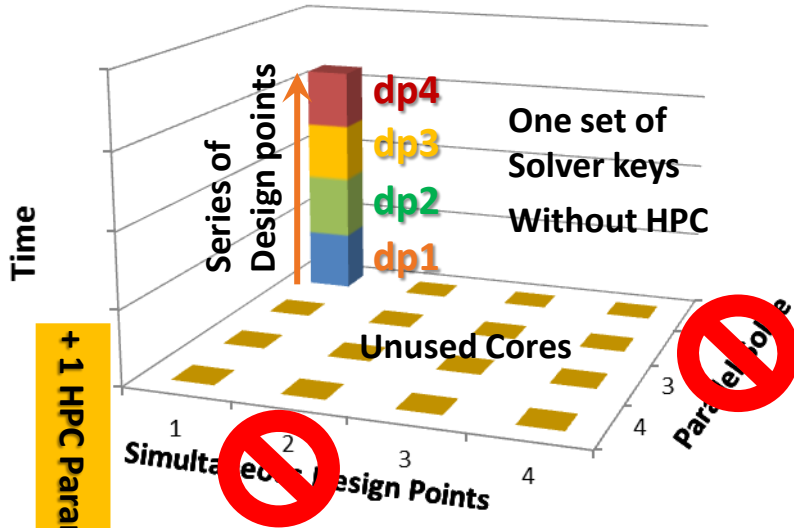


Source: MicroConsult

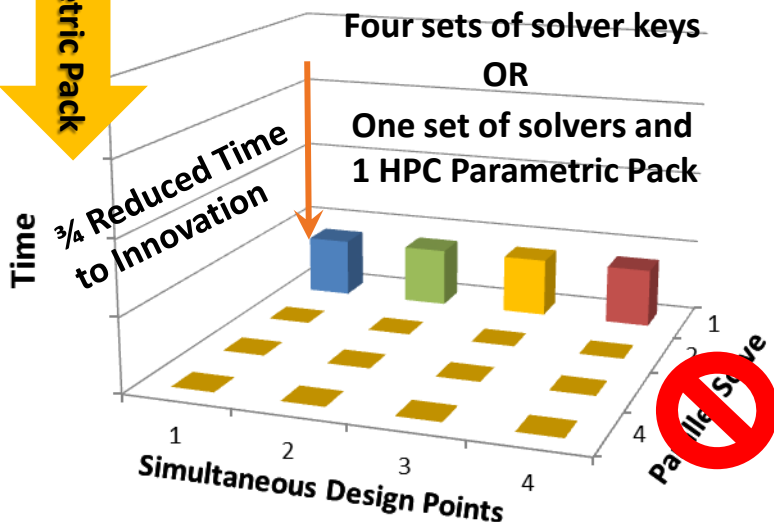
- Benefit
  - 1 HPC-Pack: +200% corepower (300 % with GPU) for +35% costs (ANSYS/MECH)
  - 2 HPC-Pack: +990% corepower (1500% with GPU) for +70% costs (ANSYS/MECH)



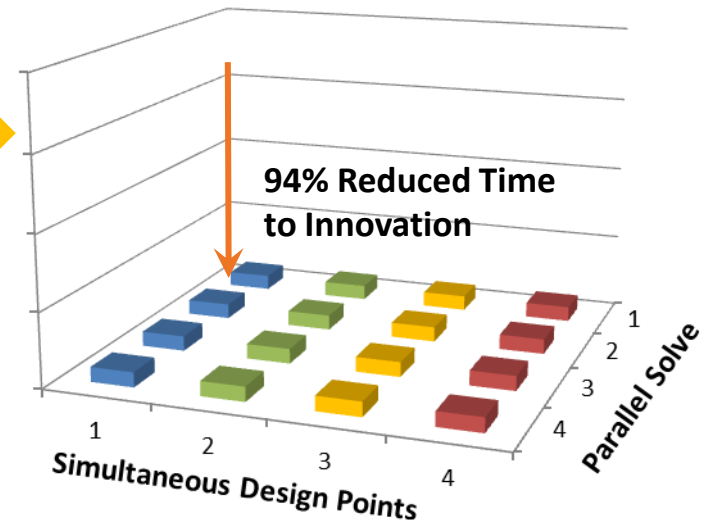
# Simultaneous Processing → Multiple Designs at once



Multiplying licenses enables you to drastically reduce time to innovation

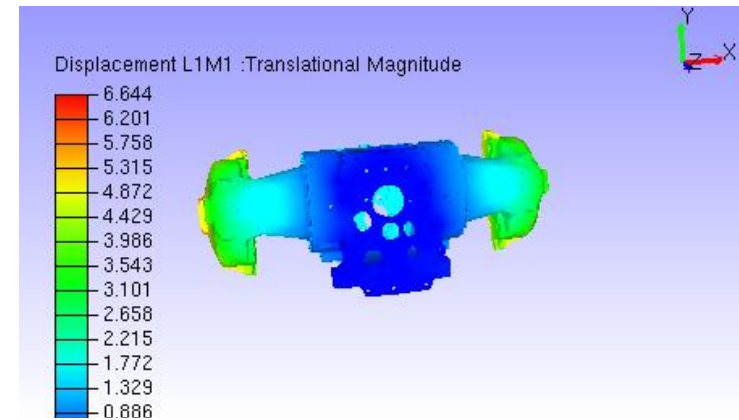


+ 1 HPC Pack



# 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



$$\bar{\Pi} = \frac{1}{2} \sum \{u\}^T \cdot [K] \cdot \{u\} - \{u\}^T \cdot \{F\}$$



# Understand your design Optimization

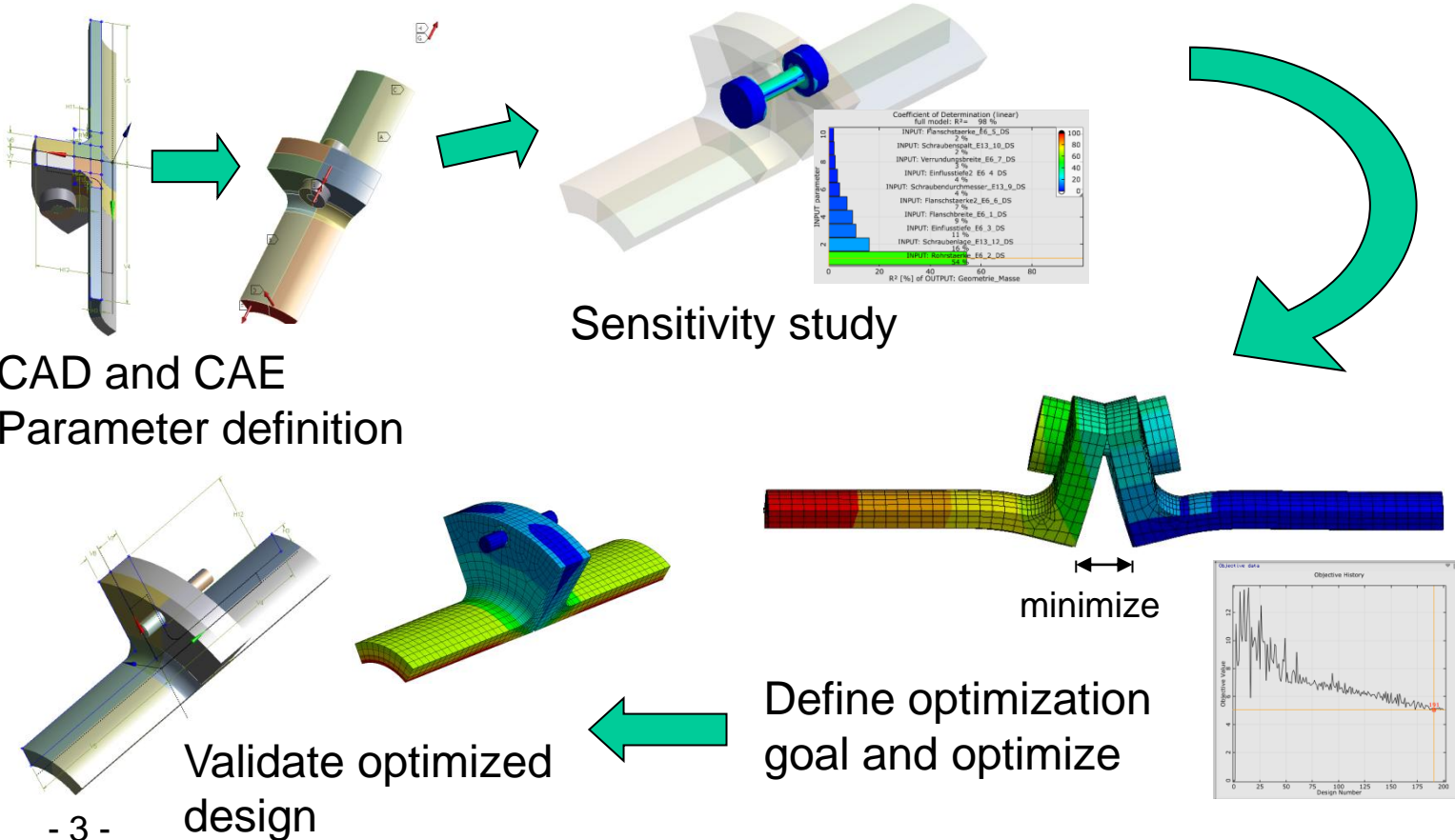
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## Table of contents

1. General Information
2. Optimization Algorithms

## 1. General Information

Workflow:



## General Information

- Design variables

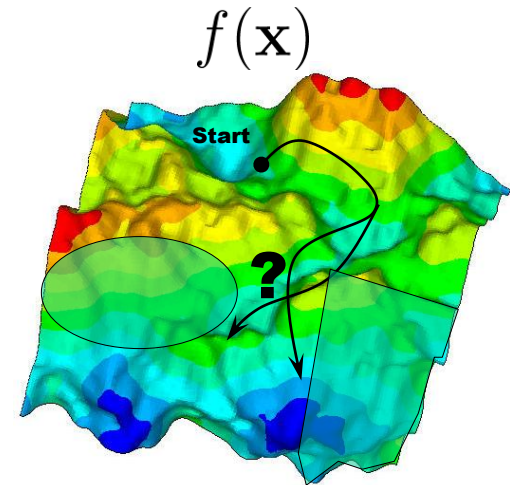
Variables defining the design space  
(continuous, discrete, binary)

- Objective function

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

- Constraints, State variables

Constrain the design space,  
Equality/Inequality restrictions  
are possible



$$f(x_1, x_2, \dots, x_N) \rightarrow \min$$

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

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

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

$$x_l \leq x_i \leq x_u$$

## 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**

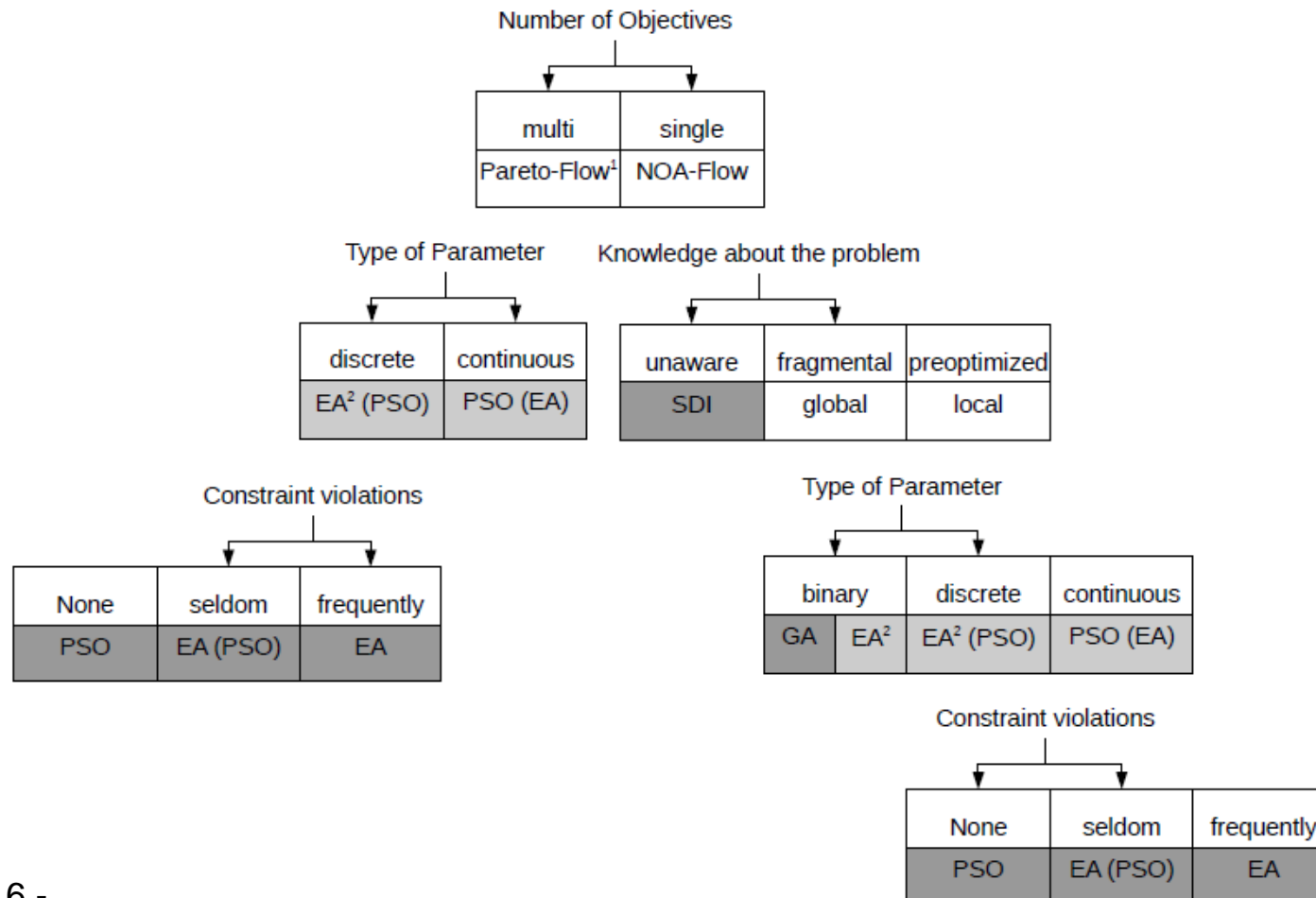
### **Stochastic methods**

- **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**



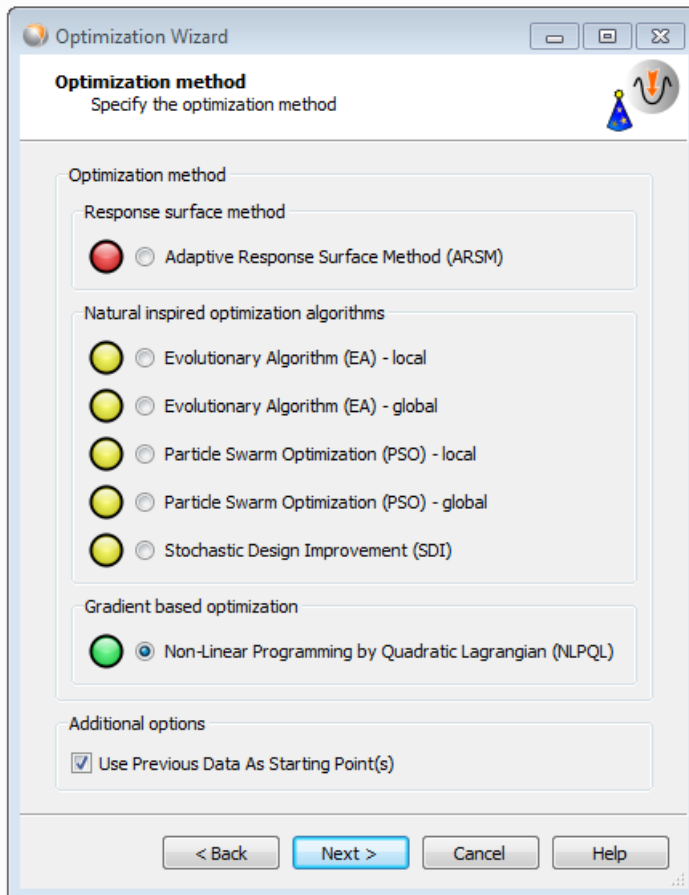
## Optimization Algorithms

Decision Tree:



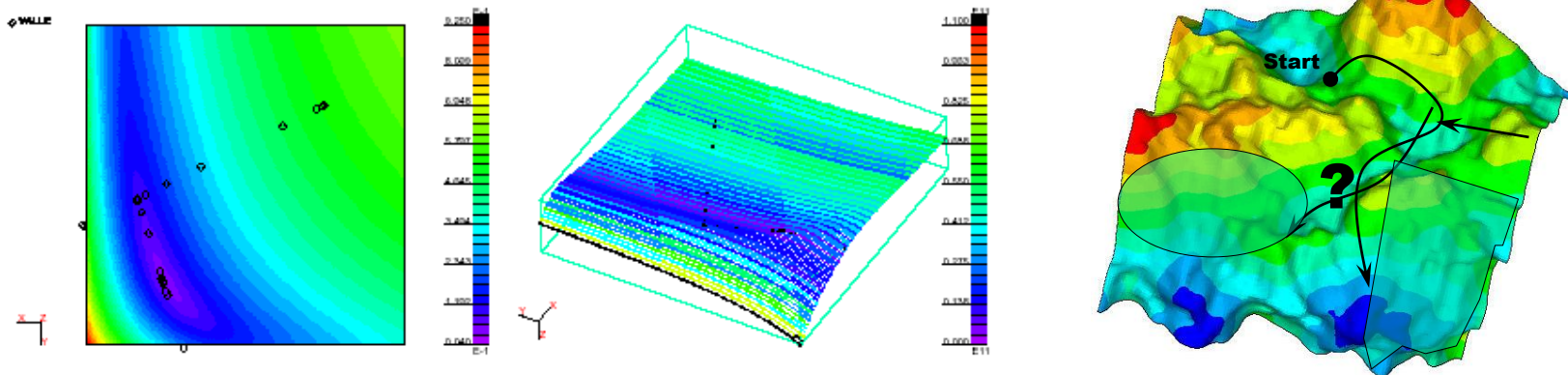
## Optimization Algorithms

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

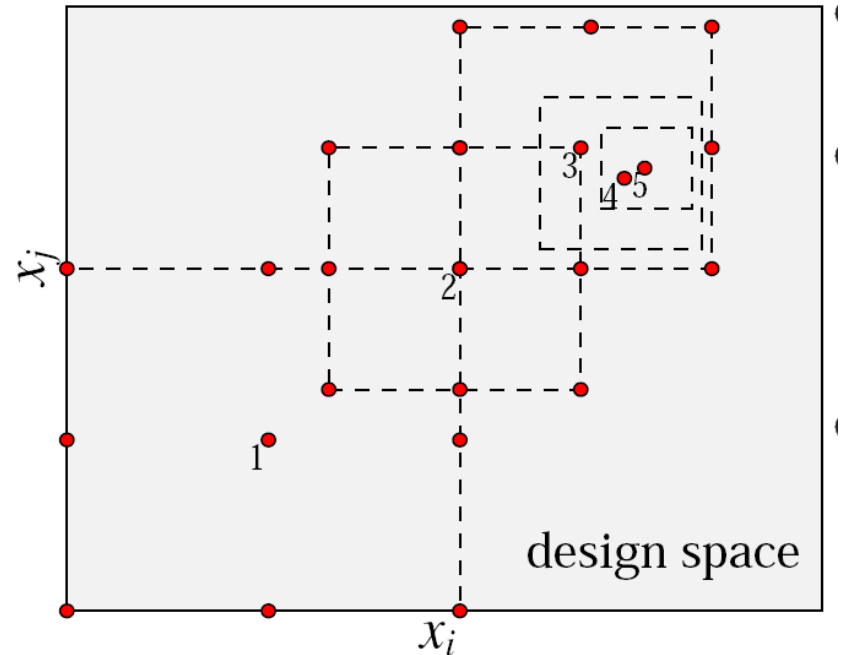
Remark:

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

## Optimization Algorithms

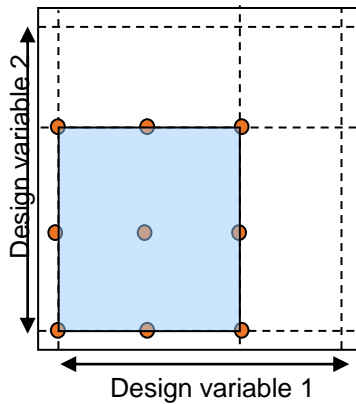
Adaptive Response Surface Method:

- + 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

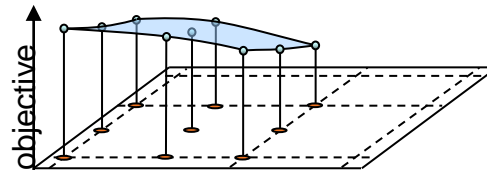


## Optimization Algorithms

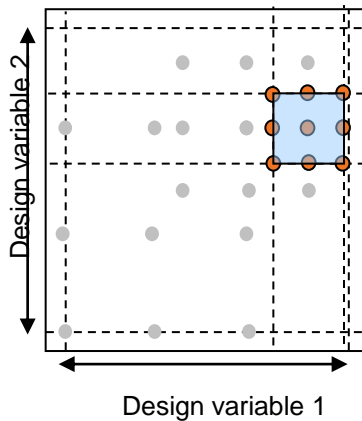
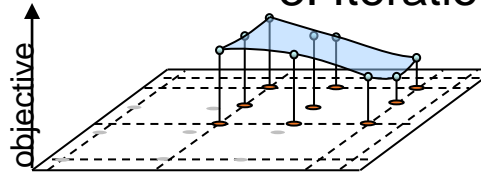
Adaptive Response Surface Method:



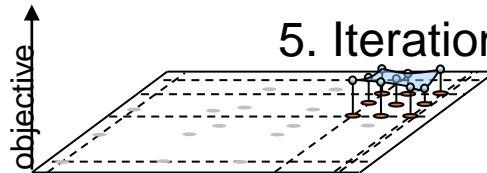
1. Iteration



3. Iteration



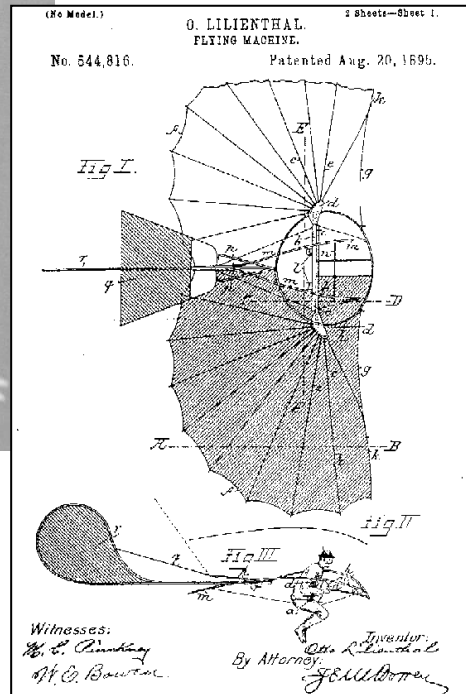
5. Iteration



## Evolutionary algorithm (EA)

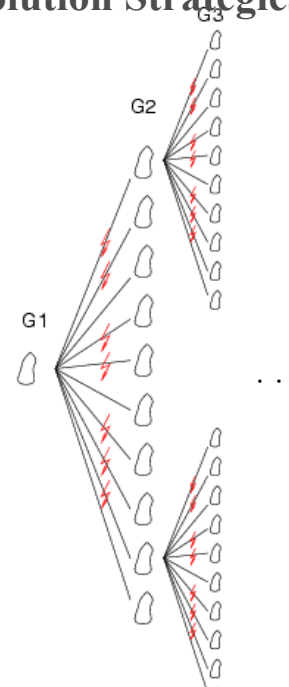
It imitates Evolution (“Optimization”) in Nature:

- 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

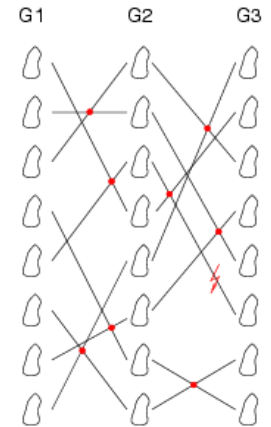


## Evolution Strategies [ES] Genetic Algorithms [GA]

EA

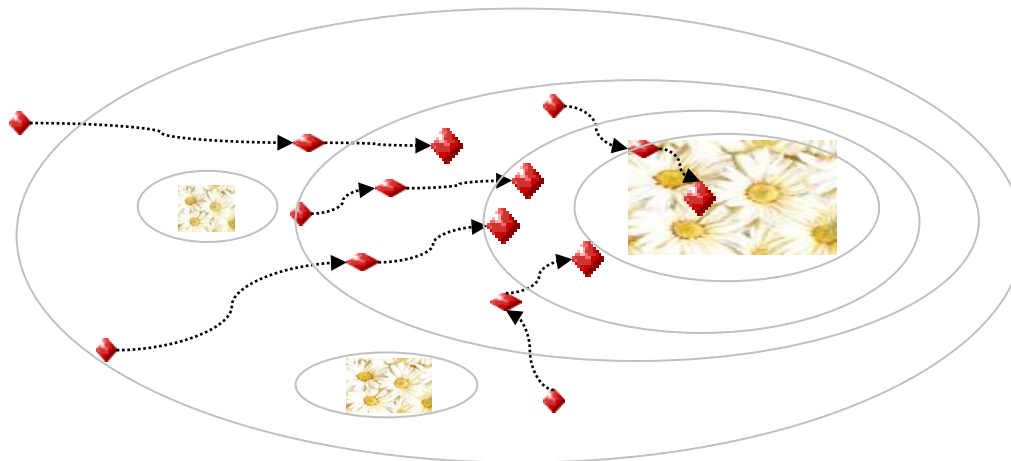


GA

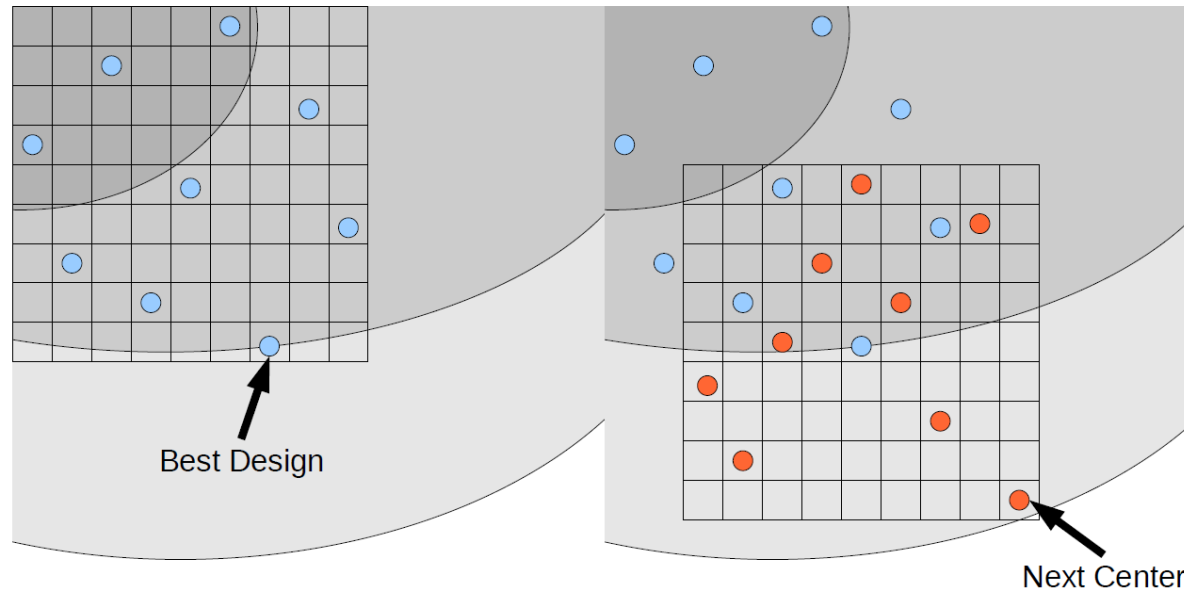


## Particle Swarm Optimization (PSO)

- 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



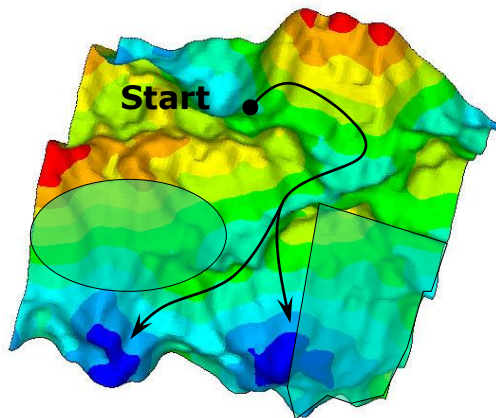
- Improves a proposed design without extensive knowledge about interactions in design space
- Start population by uniform LHS around given start design
- The best design is selected as center for the next sampling
- The sampling ranges decrease with every generation



# Optimization

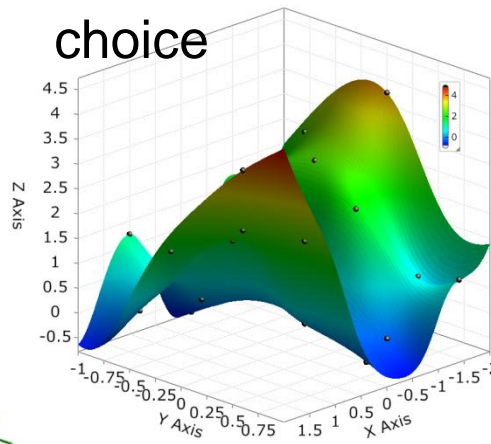
## Gradient-based algorithms

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



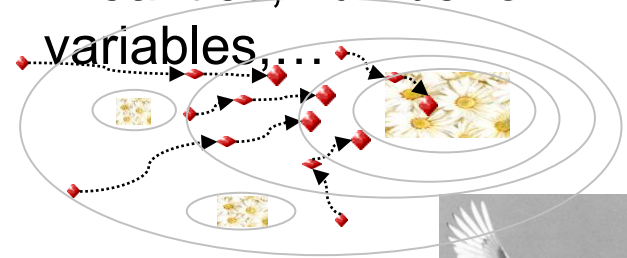
## Response surface method

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



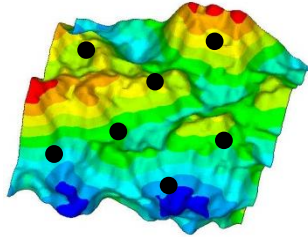
## Biologic Algorithms

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



# Optimization

1) Start with a sensitivity study using the LHS Sampling



2) Identify the important parameters and responses

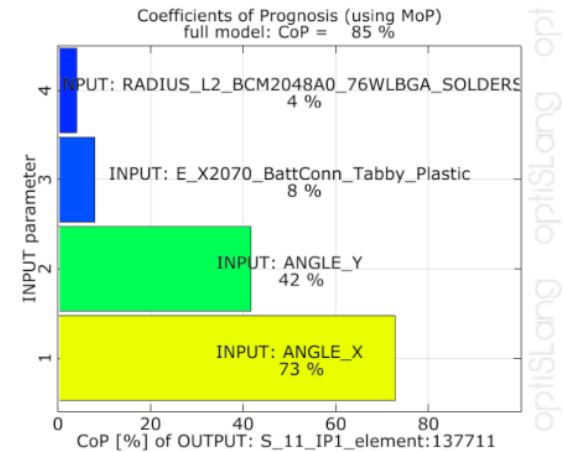
- understand the problem
- reduce the parameters

Scan the whole Design Space

Understand the Problem using CoP/MoP

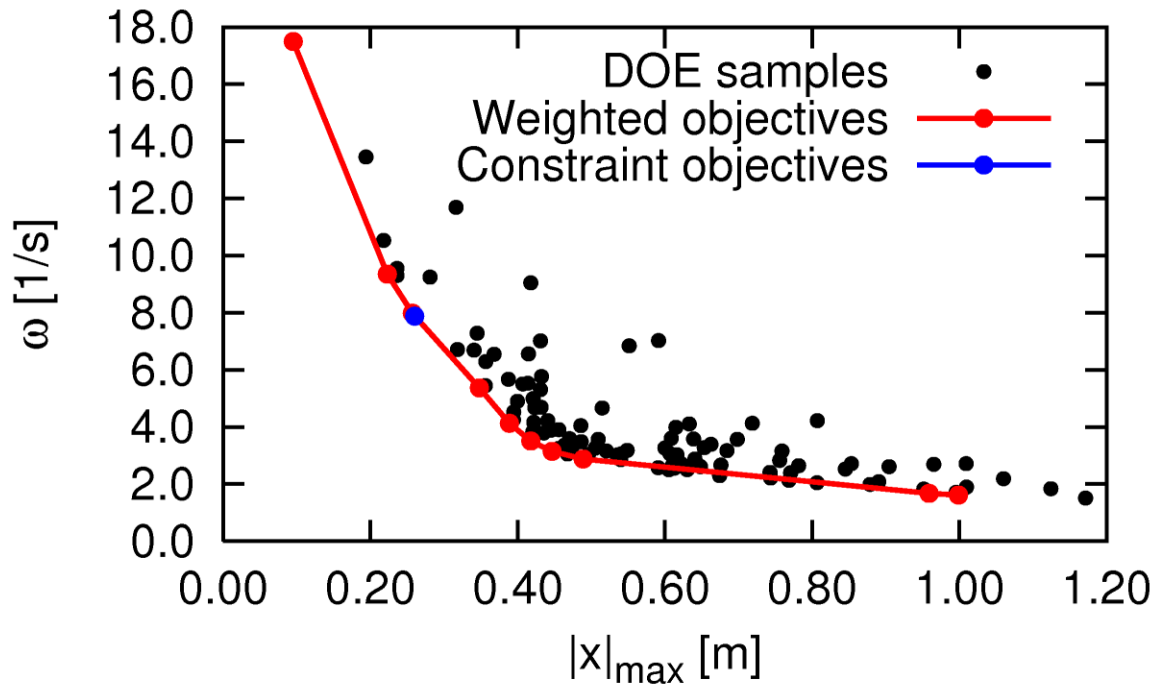
optiSLang

Search for Optima



3) Run the suiting optimization algorithm

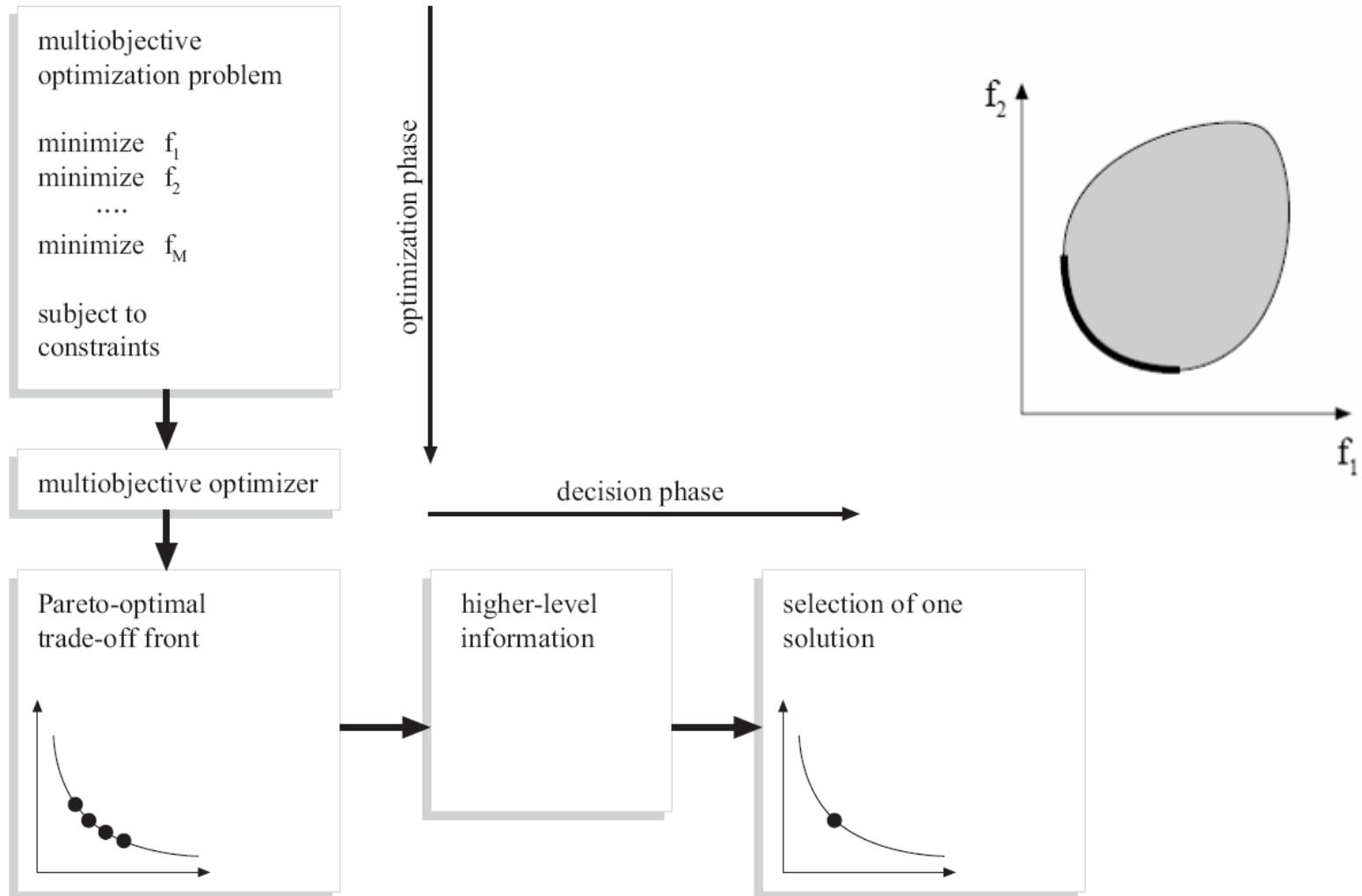
4) Goal: user-friendly procedure provides as much automatism as possible



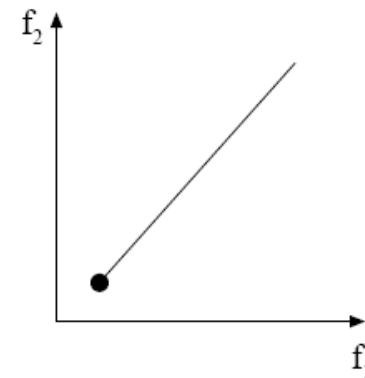
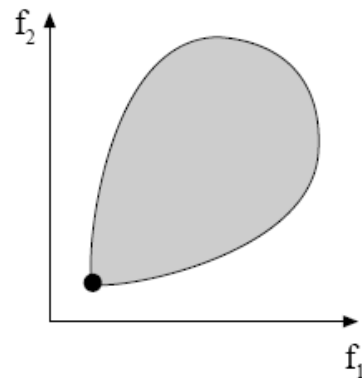
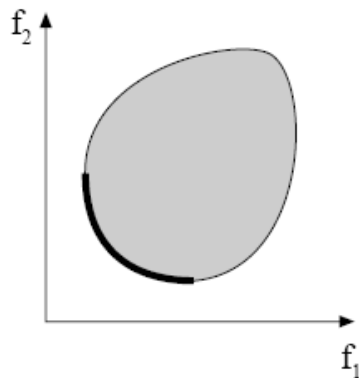
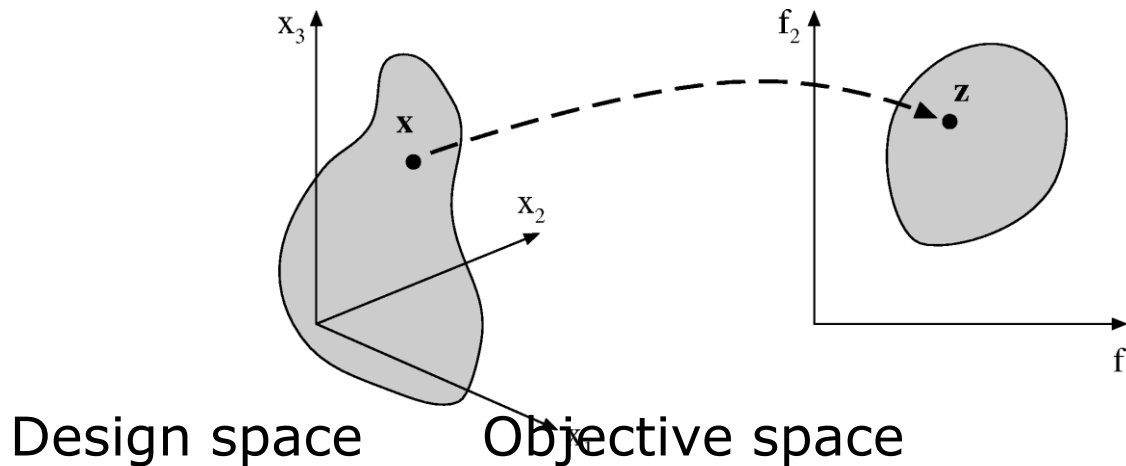
- Objective 1: minimize maximum amplitude after 5s
- Objective 2: minimize eigen-frequency
- DOE scan with 100 LHS samples gives good problem overview
- Weighted objectives require about 1000 solver calls

# Optimization

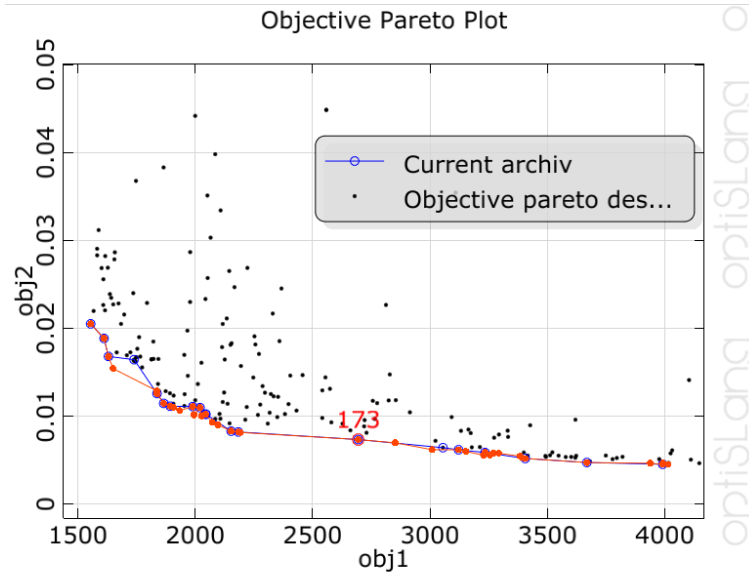
## Strategy C: Pareto Optimization



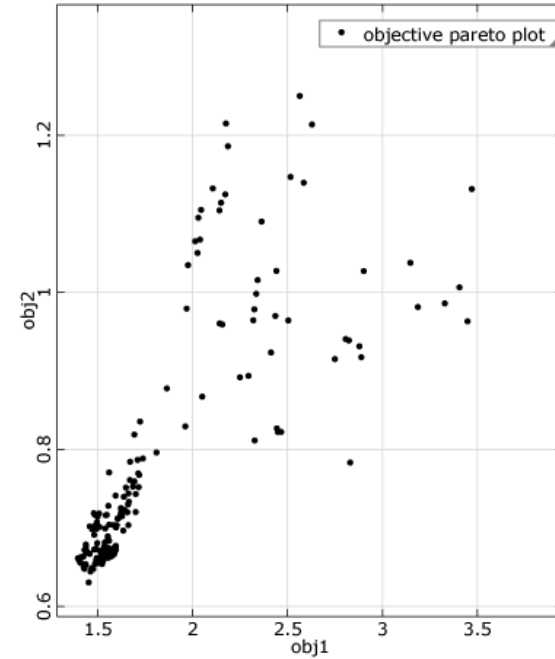
# Optimization



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



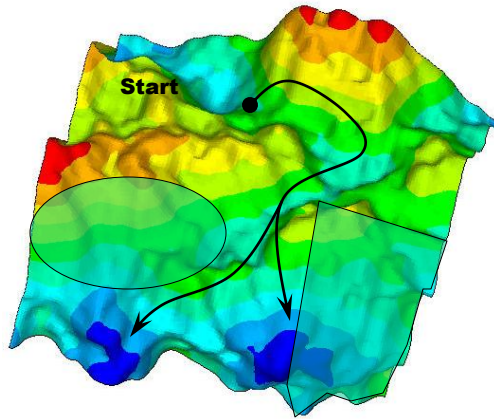
Conflicting objectives



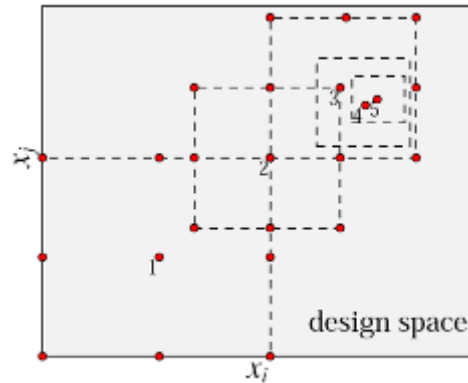
Correlated objectives

# Optimization

## Gradient-based algorithms



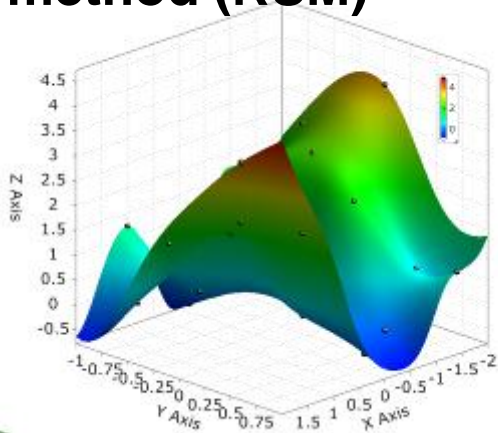
## Local adaptive RSM



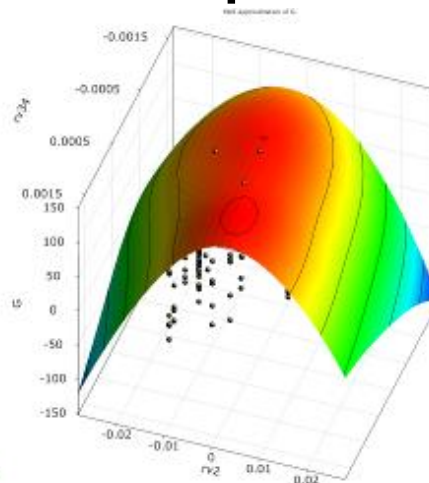
## Biologic Algorithms



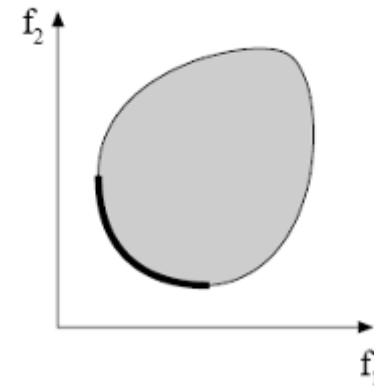
## Response surface method (RSM)



## Global adaptive RSM



## Pareto Optimization



$$\bar{\Pi} = \frac{1}{2} \sum_e \{u\}^T \cdot [K] \cdot \{u\} - \{u\}^T \cdot \{F\}$$

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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



## Do you want to get deeper into optiSLang?

- Take a look at our seminar!

### Strukturmechanik mit ANSYS

- [Präsenz-Seminar: Optimierung und Reverse Engineering mit optiSLang inside ANSYS Workbench](#)

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# Tomorrow

Your feedback!

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