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
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
Motivation

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

Reduce Stress
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.

![Diagram showing possible designs in a 3D space with axes for cost, stress, and another unspecified axis. A question mark represents the uncertainty of finding the 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

Uncertainties
Dealing with tolerances

- 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

Behavior Model

INPUT

OUTPUT

System Behavior

Behavior Model
Multiphysics simulation based on system coupling

- Dynamic interaction of multiple components in a system
  - Nonlinear components → Nonlinear Characteristics
Model Reduction for Nonlinear Components

- Transfer function as characterization
  - $n$ simulations (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 – dynardo

- 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
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
Where to get the parameters

**CAD**

- CAD data

**ANSYS APDL**

- Analysis settings

**Mesh**

- Element size

**Material properties**

- Property values

**Boundaries**

- Analysis settings

**Excel**

- Microsoft Office Excel

Overview of all parameters in the parameter set

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
- ANSYS SpaceClaim Direct Modeler
- Autodesk Inventor
- Creo Parametric (früher ProE)
- CATIA V5
- NX
- Solid Edge
- 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!
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.
Understand your Design

Manual Variation
Example: Notch

Which parameter shall be taken for a manual variation?

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

<table>
<thead>
<tr>
<th>Thck</th>
<th>Stress</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>141.6</td>
<td>0.0239</td>
</tr>
<tr>
<td>6</td>
<td>107.34</td>
<td>0.0258</td>
</tr>
<tr>
<td>7</td>
<td>91.2</td>
<td>0.0277</td>
</tr>
<tr>
<td>8</td>
<td>81.5</td>
<td>0.0298</td>
</tr>
<tr>
<td>9</td>
<td>75</td>
<td>0.032</td>
</tr>
</tbody>
</table>
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?

<table>
<thead>
<tr>
<th>cThck</th>
<th>Thck</th>
<th>Stress</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5</td>
<td>127.9</td>
<td>0.0176</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>95.1</td>
<td>0.0213</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>82.1</td>
<td>0.0255</td>
</tr>
<tr>
<td>2.75</td>
<td>5</td>
<td>135.4</td>
<td>0.0223</td>
</tr>
<tr>
<td>2.75</td>
<td>7</td>
<td>91.9</td>
<td>0.0260</td>
</tr>
<tr>
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<td>9</td>
<td>76.9</td>
<td>0.0303</td>
</tr>
<tr>
<td>3.5</td>
<td>5</td>
<td>181.4</td>
<td>0.0274</td>
</tr>
<tr>
<td>3.5</td>
<td>7</td>
<td>96.5</td>
<td>0.0311</td>
</tr>
<tr>
<td>3.5</td>
<td>9</td>
<td>74.5</td>
<td>0.0354</td>
</tr>
</tbody>
</table>
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
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The automatic sampling
Understand your Design

Systematic variation using optiSLang inside Workbench

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Example: Notch

Parametrization

- \( \text{force} = \text{const.} \ 1000\text{N} \)
- \( \text{cylinder\_radius} = 7 \ (5-8) \)
- \( \text{thickening\_length} = 5 \ (2-6) \)
- \( \text{cylinder\_thickness} = 3 \ (2-3.5) \)
- \( \text{thickening\_thickness} = 8 \ (5-9) \)
- \( \text{notch\_thickness} = 0.42 \ (0.3-0.5) \)
- \( \text{notch\_radius} = 1 \ (0.6-1.2) \)
- \( \text{ausrundung} = 10 \ (4-12) \)

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

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.
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How it Works

Drag and Drop optiSLang inside Workbench modules
Understand your Design

How it Works

Define your parameter variation and criteria in a wizard
Understand your Design

Example: Notch

CAD Parametrization in ANSYS DesignModeler
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.

![Sensitivity Parameters Table](image)

<table>
<thead>
<tr>
<th>Name</th>
<th>Parameter Type</th>
<th>Reference Value</th>
<th>Constant</th>
<th>Resolution</th>
<th>Range</th>
<th>Range Plot</th>
<th>PDF</th>
<th>Type</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force_Magnitude</td>
<td>Det+Stoch</td>
<td>1000</td>
<td>✅</td>
<td>Continuous</td>
<td>900</td>
<td>1100</td>
<td></td>
<td>UNIFORM</td>
<td>1000</td>
</tr>
<tr>
<td>cylinder_radius</td>
<td>Det+Stoch</td>
<td>7</td>
<td></td>
<td>Continuous</td>
<td>5</td>
<td>8</td>
<td></td>
<td>UNIFORM</td>
<td>7</td>
</tr>
<tr>
<td>thickening_len...</td>
<td>Det+Stoch</td>
<td>5</td>
<td></td>
<td>Continuous</td>
<td>2</td>
<td>6</td>
<td></td>
<td>UNIFORM</td>
<td>5</td>
</tr>
<tr>
<td>cylinder_thickn...</td>
<td>Det+Stoch</td>
<td>3</td>
<td></td>
<td>Continuous</td>
<td>2</td>
<td>3.5</td>
<td></td>
<td>UNIFORM</td>
<td>3</td>
</tr>
<tr>
<td>thickening_thic...</td>
<td>Det+Stoch</td>
<td>8</td>
<td></td>
<td>Continuous</td>
<td>5</td>
<td>9</td>
<td></td>
<td>UNIFORM</td>
<td>8</td>
</tr>
<tr>
<td>notch_thickness</td>
<td>Det+Stoch</td>
<td>0.42</td>
<td></td>
<td>Continuous</td>
<td>0.3</td>
<td>0.5</td>
<td></td>
<td>UNIFORM</td>
<td>0.42</td>
</tr>
<tr>
<td>notch_radius</td>
<td>Det+Stoch</td>
<td>1</td>
<td></td>
<td>Continuous</td>
<td>0.6</td>
<td>1.2</td>
<td></td>
<td>UNIFORM</td>
<td>1</td>
</tr>
<tr>
<td>ausrundung</td>
<td>Det+Stoch</td>
<td>10</td>
<td></td>
<td>Continuous</td>
<td>4</td>
<td>12</td>
<td></td>
<td>UNIFORM</td>
<td>10</td>
</tr>
</tbody>
</table>
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.
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_Defor...
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.

![Graph showing the influence of parameters on deformation]

- INPUT: ausrundung 0%  
- INPUT: notch_radius 0%  
- INPUT: notch_thickness 0%  
- INPUT: thickening_length 0%  
- INPUT: cylinder_thickness 8%  
- INPUT: cylinder_radius 22%  
- INPUT: thickening_thickness 46%

Coefficient of Importance (linear)  
full model: adjusted $R^2 = 81\%$

OUTPUT: Total_Deformation_Maximum

Histogram

PDF

Statistic data

Min: 0.01303  
Max: 0.03481

Linear correlation coefficient

0  1  
-1  1

INPUT: thickening_length

INPUT: notch_thickness

INPUT: notch_radius

INPUT: ausrundung

INPUT: cylinder_thickness

INPUT: cylinder_radius

INPUT: thickening_thickness

Parameter vs. OUTPUT: Total_Deformation_Maximum
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!
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.
Understand your Design

Example: Notch

The correlations are determined more detailly

OUTPUT: Total_Deformation_Maximum vs. OUTPUT: Total_Defor...

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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>cylinder_radius</td>
<td>31.7 %</td>
</tr>
<tr>
<td>cylinder_thickness</td>
<td>43.9 %</td>
</tr>
<tr>
<td>thicknessthickness</td>
<td>22.6 %</td>
</tr>
<tr>
<td>Total</td>
<td>98.5 %</td>
</tr>
<tr>
<td>Total_Deformation_Mean</td>
<td>3.0 %</td>
</tr>
<tr>
<td>Total CoP</td>
<td>95.1 %</td>
</tr>
<tr>
<td>Total</td>
<td>98.1 %</td>
</tr>
</tbody>
</table>
Example: Notch

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

<table>
<thead>
<tr>
<th>Name</th>
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<th>Reference value</th>
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<th>Range</th>
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</tr>
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<tbody>
<tr>
<td>1 ForceMagnitude</td>
<td>Det+Stoch</td>
<td>1000</td>
<td></td>
<td>Continuous</td>
<td>900</td>
<td>UNIFORM</td>
</tr>
<tr>
<td>2 cylinder_radius</td>
<td>Det+Stoch</td>
<td>7</td>
<td></td>
<td>Continuous</td>
<td>5</td>
<td>UNIFORM</td>
</tr>
<tr>
<td>3 thickening_len</td>
<td>Det+Stoch</td>
<td>5</td>
<td></td>
<td>Continuous</td>
<td>2</td>
<td>UNIFORM</td>
</tr>
<tr>
<td>4 cylinder_thick</td>
<td>Det+Stoch</td>
<td>3</td>
<td></td>
<td>Continuous</td>
<td>2</td>
<td>UNIFORM</td>
</tr>
<tr>
<td>5 thickening_thic</td>
<td>Det+Stoch</td>
<td>8</td>
<td></td>
<td>Continuous</td>
<td>5</td>
<td>UNIFORM</td>
</tr>
<tr>
<td>6 notch_thickness</td>
<td>Det+Stoch</td>
<td>0.42</td>
<td></td>
<td>Continuous</td>
<td>0.3</td>
<td>UNIFORM</td>
</tr>
<tr>
<td>7 notch_radius</td>
<td>Det+Stoch</td>
<td>1</td>
<td></td>
<td>Continuous</td>
<td>0.6</td>
<td>UNIFORM</td>
</tr>
<tr>
<td>8 ausrundung</td>
<td>Det+Stoch</td>
<td>10</td>
<td></td>
<td>Continuous</td>
<td>4</td>
<td>UNIFORM</td>
</tr>
</tbody>
</table>
Understand your Design

Example: Notch

Let's insert our goals using the wizard

![Optimization Wizard]

- Variables:
  - Name: new
  - Expression: Force
  - Value: 1000
  - Expression: cylinder_radius
  - Value: 7

- Objectives:
  - Goal 1: MIN Total_Deformation_Maximum
  - Goal 2: MIN Geometry_Mess
    - Value: 0.030114

- Constraints:
  - Constraint: Equivalent_Stress_Maximum
    - Left side expression: <=
    - Right side expression: 140
    - Value: 62.0549
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!
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%
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
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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!
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
- Assess the forecast quality of the model: The Coefficient of Prognosis (CoP)
- Estimate occurring numerical noise
- Check concerning nonlinear correlation
- Explore improvement possibilities
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
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 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.
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.
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
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 x 1.5 = 6
  - Important: SMP & DMP available

- 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

- 94% Reduced Time to Innovation
- 1 HPC Pack

Series of Design Points
- dp1
- dp2
- dp3
- dp4

Unused Cores

One set of Solver keys
Without HPC

Four sets of solver keys
OR
One set of solvers and 1 HPC Parametric Pack

Multiplying licenses enables you to drastically reduce time to innovation

- 94% Reduced Time to Innovation
- 1 HPC Pack

Series of Design Points
- dp1
- dp2
- dp3
- dp4
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
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
Understand your design
Optimization

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

Workflow:

- CAD and CAE
- Parameter definition
- Sensitivity study
- Define optimization goal and optimize
- Validate optimized design
- Minimize
Optimization

General Information

- **Design variables**
  Variables defining the design space
  (continuous, discrete, binary)

- **Objective function**
  Function $f(x)$ has to be minimized

- **Constraints, State variables**
  Constrain the design space,
  Equality/Inequality restrictions are possible

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

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

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

$x_l \leq x_i \leq x_u$
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:

1. **Number of Objectives**
   - multi
   - single
     - Pareto-Flow
     - NOA-Flow

2. **Type of Parameter**
   - discrete
   - continuous

3. **Knowledge about the problem**
   - unaware
   - fragmental
   - preoptimized
     - SDI
     - global
     - local

4. **Constraint violations**
   - None
   - seldom
   - frequently
     - PSO
     - EA (PSO)
     - EA

5. **Type of Parameter**
   - binary
   - discrete
   - continuous
     - GA
     - EA
     - EA (PSO)
     - PSO (EA)

6. **Constraint violations**
   - None
   - seldom
   - frequently
     - PSO
     - EA (PSO)
     - EA
Optimization Algorithms

optiSLang inside Workbench chooses the best algorithm by a wizard:
Optimization

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
Optimization

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

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 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, …

Start
Optimization

1) Start with a sensitivity study using the LHS Sampling

2) Identify the important parameters and responses
   - understand the problem
   - reduce the parameters

3) Run the suiting optimization algorithm

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

- 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
Multiobjective minimization problem:

- Minimize $f_1$
- Minimize $f_2$
- ...$
- Minimize $f_M$

Subject to constraints.

Multiobjective optimizer

Pareto-optimal trade-off front

Optimization phase

Decision phase

Higher-level information

Selection of one solution
• Only for conflicting objectives a Pareto frontier exists
• For positively correlated objective functions exactly one optimum exists
Optimization

Objective Pareto Plot

Conflicting objectives

Correlated objectives
Optimization

Gradient-based algorithms

Response surface method (RSM)

Local adaptive RSM

Global adaptive RSM

Biologic Algorithms

Pareto Optimization
Understand your Design

Outlook

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Do you want to get deeper into optiSLang?

- Take a look at our seminar!

Strukturmechanik mit ANSYS

- Praesenz-Seminar: Optimierung und Reverse Engineering mit optiSLang inside ANSYS Workbench

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Tomorrow

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