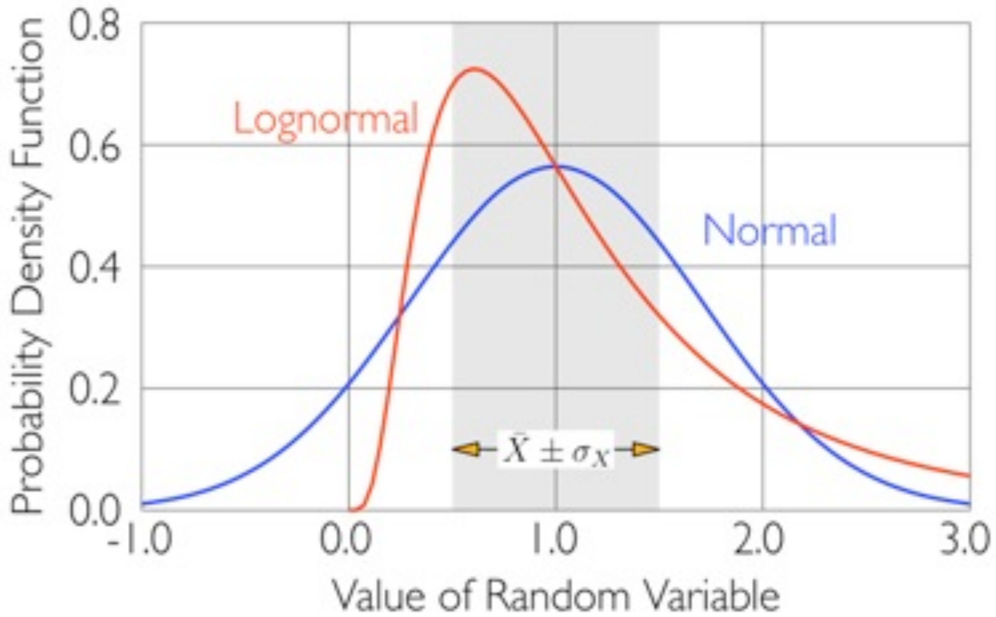
Statistics on Structures 3

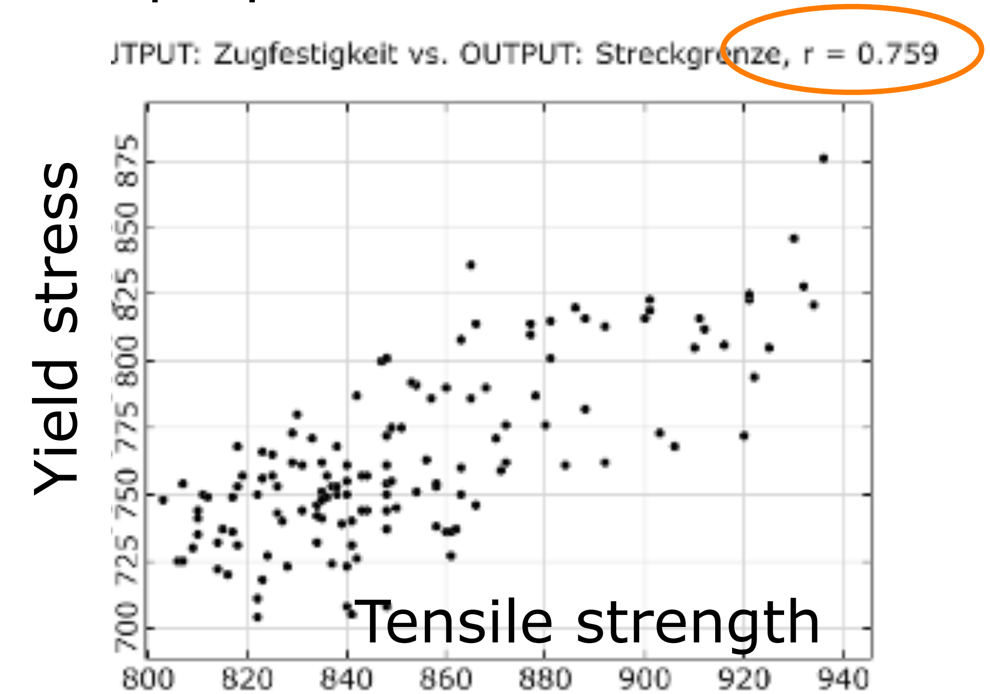
- Robustness evaluation in CAE with software optiSLang and Statistics on Structures
- Application examples
- New features

Robustness: Definition of uncertainties

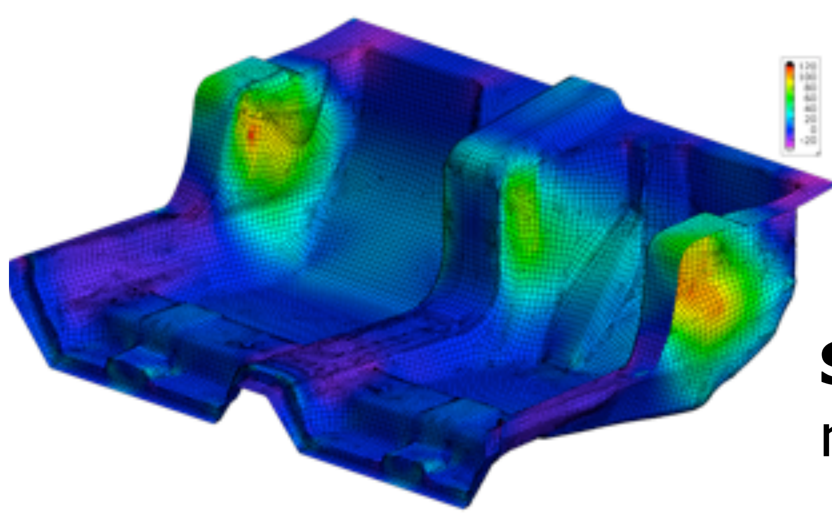
- Translate knowledge about uncertainties into proper definition of randomness



Distribution functions define variable scatter



Correlation is an important characteristic of stochastic variables



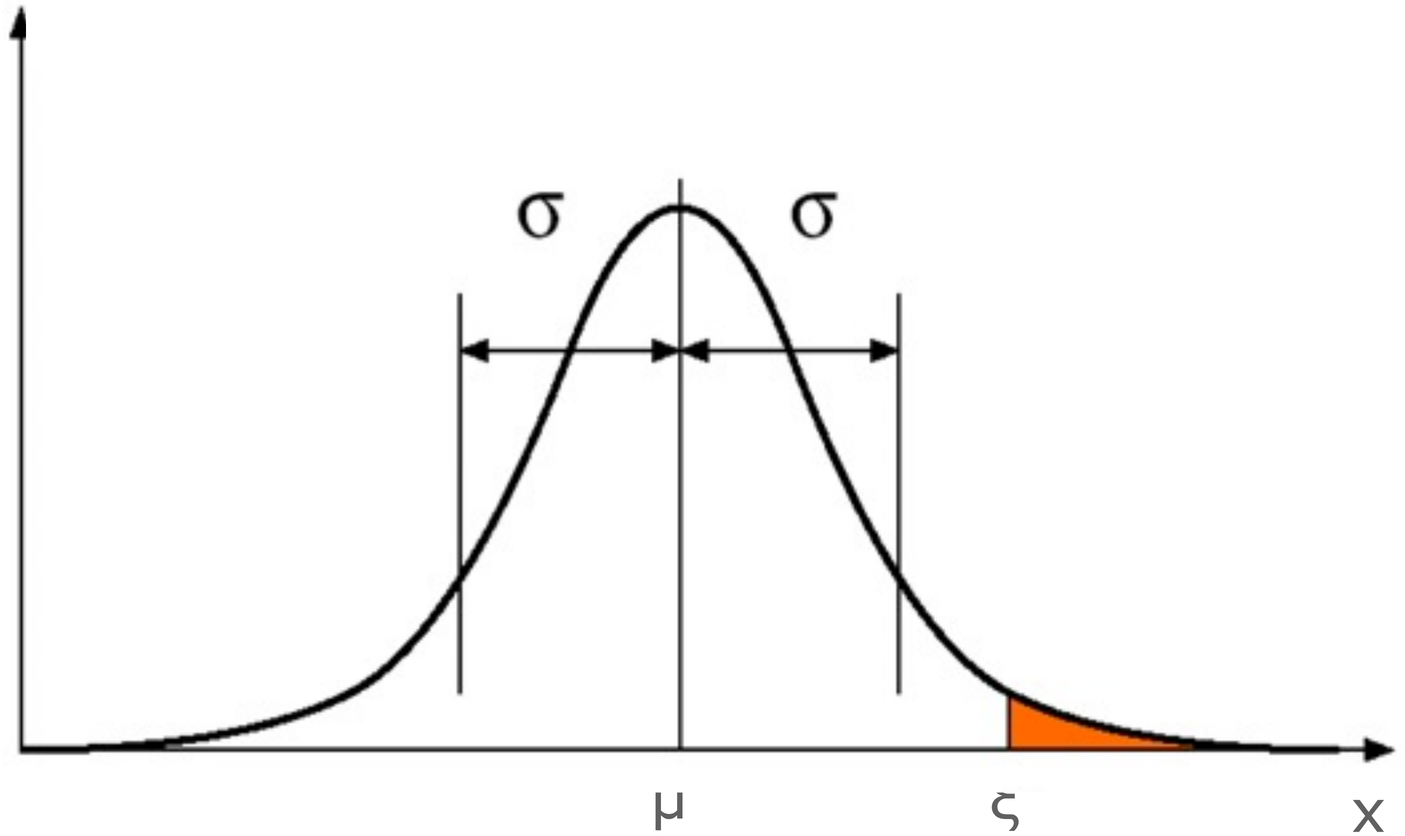
Spatial Correlation = random fields

Typical quantities being random fields

- Examples
  - geometric perturbations
    - node coordinates
    - shell thickness
    - thickness of composite layers
  - material properties
    - concrete: mortar, admixtures (gravel)
  - damage
    - plastic strain
    - cracks
  - loading
  - state variables
    - stresses
    - strains
    - displacements

Robustness: Exceedance probability

Probability of reaching values above a limit



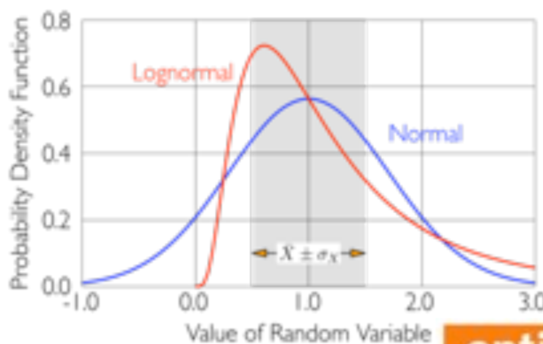
Gaussian distribution:

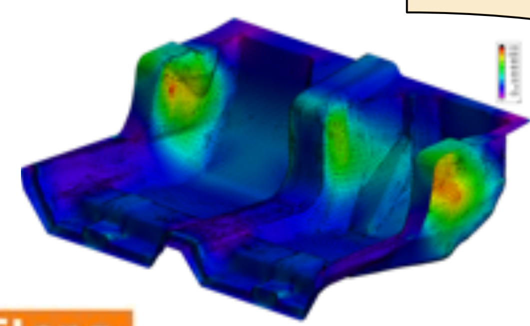
$$P_\xi = P[X \geq \xi]$$

ξ	μ	$\mu + \sigma$	$\mu + 2\sigma$	$\mu + 3\sigma$	$\mu + 4\sigma$
P_ξ	$5 \cdot 10^{-1}$	$1.6 \cdot 10^{-1}$	$2.3 \cdot 10^{-2}$	$1.4 \cdot 10^{-3}$	$3.2 \cdot 10^{-5}$

Variance based robustness analysis

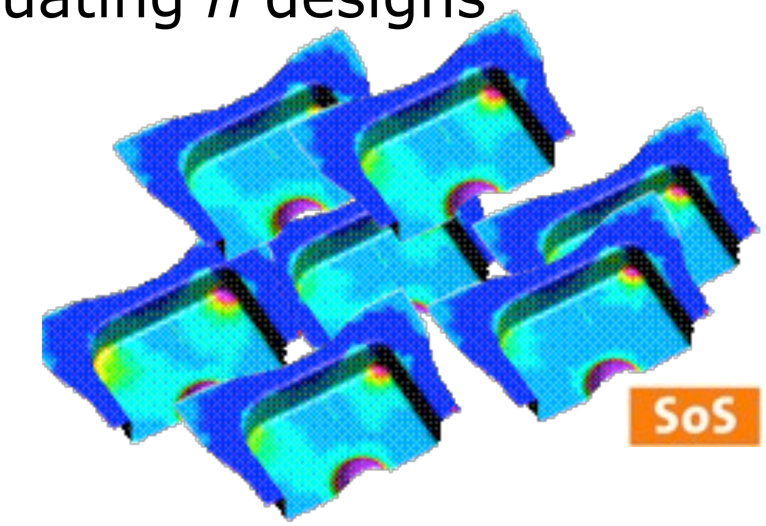
1) Define the robustness space using scatter range, distribution and correlation





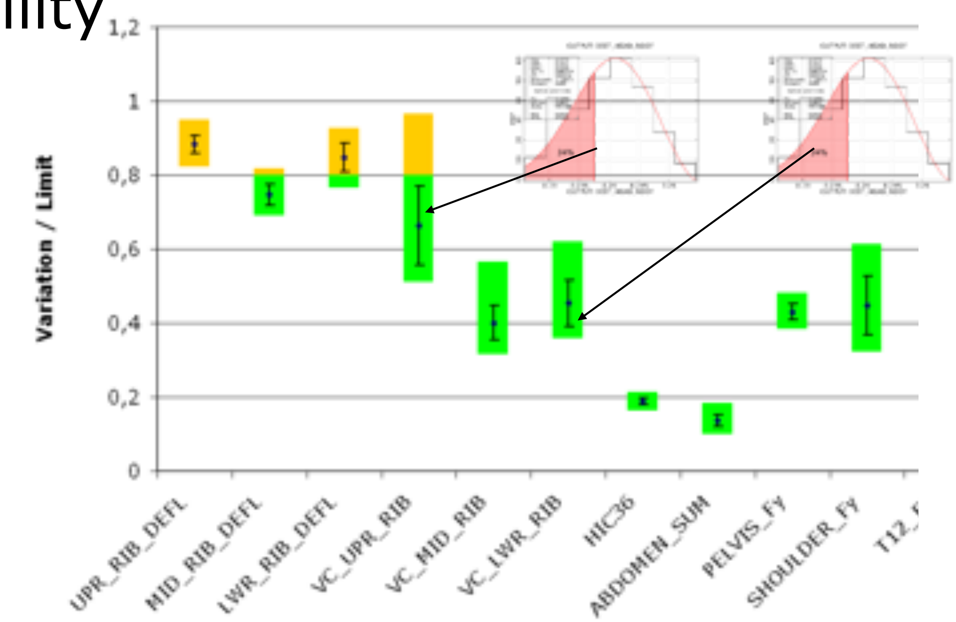
optiSLang

2) Sampling: Scan the robustness space by producing and evaluating *n* designs

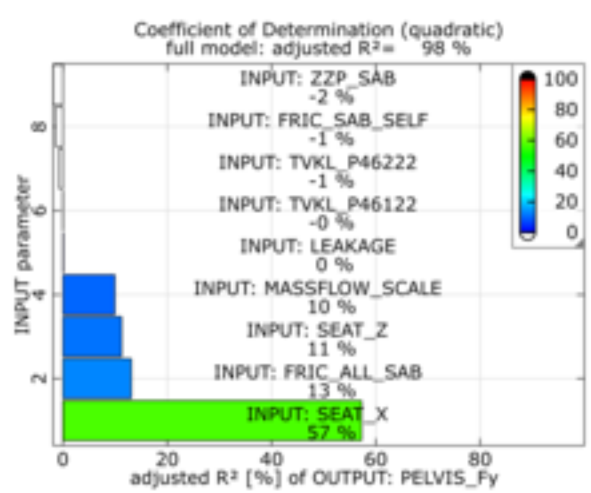


SoS

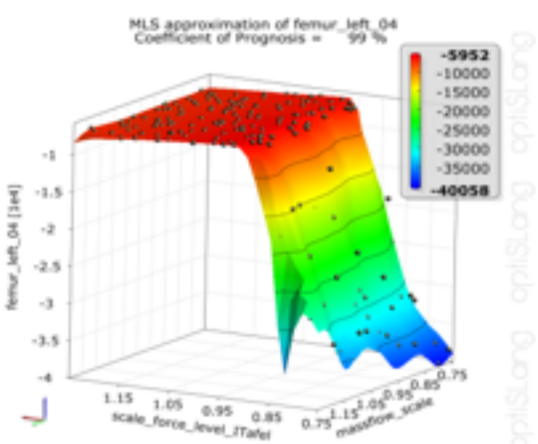
3) Check the variation



4) Check the explainability of the model



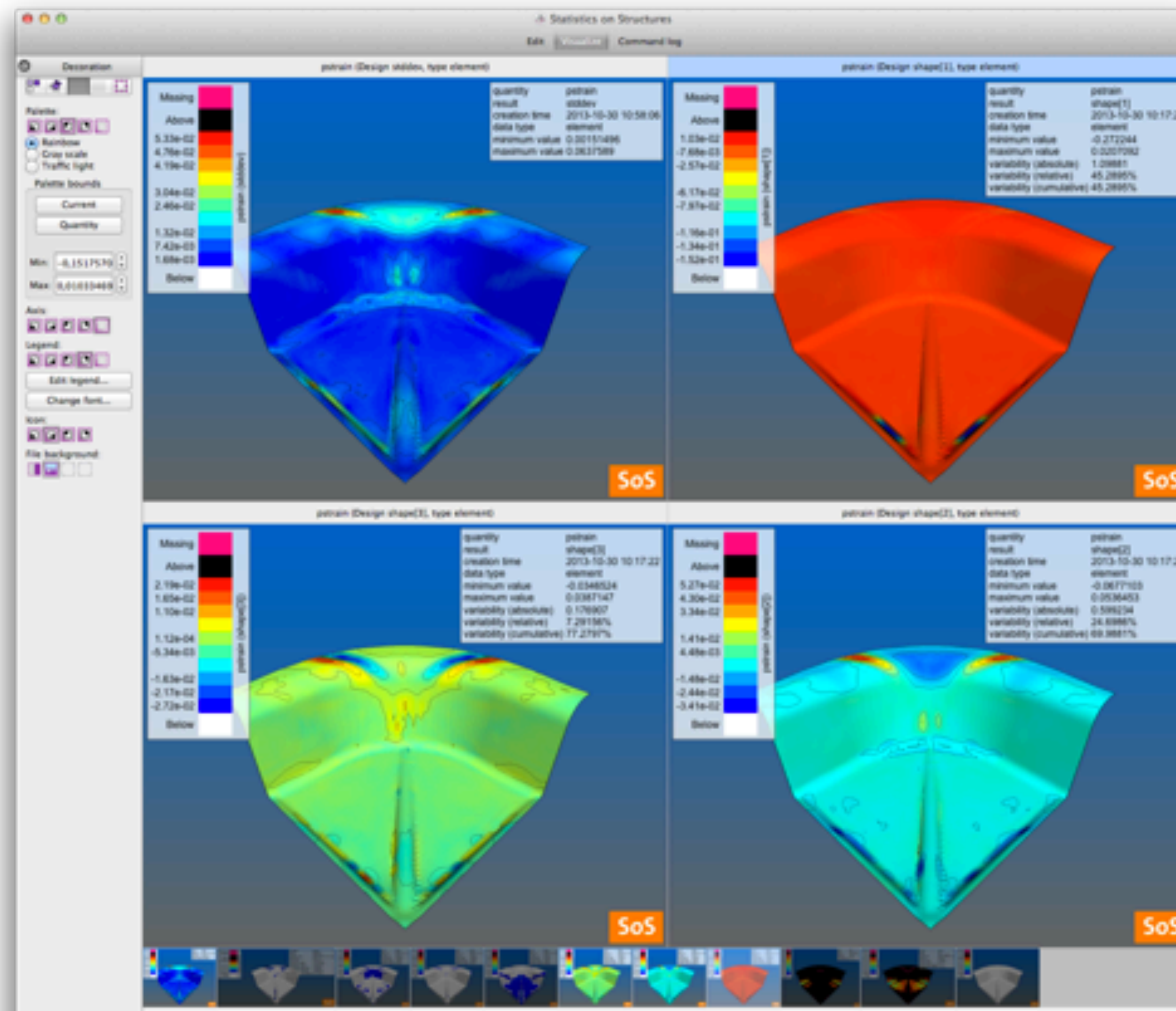
5) Identify the most important scattering variables



optiSLang

Software tool: Statistics on Structures (SoS)

- post processor for statistical analysis of data distributed on FEM meshes
- import/export meshes and data to LS-Dyna, NASTRAN, photos et al
- integration with optiSLang
- computes statistical quantities (mean, stddev, min, max, range, eroded data/cracks, quantile, etc.)
- determination of “hot spots”
- identification of spatial correlations through random fields, noise elimination, improved determination of input-output relations
- main area of applications: metal forming, car crash, brake pads

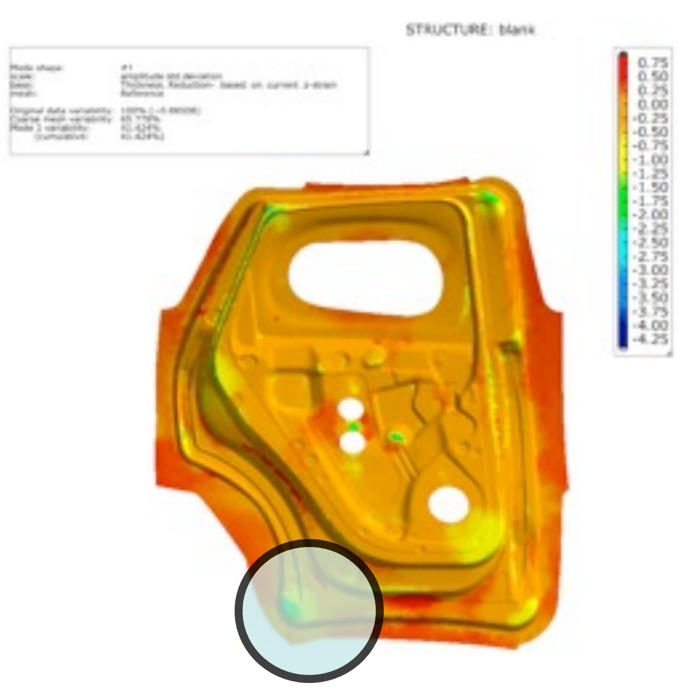


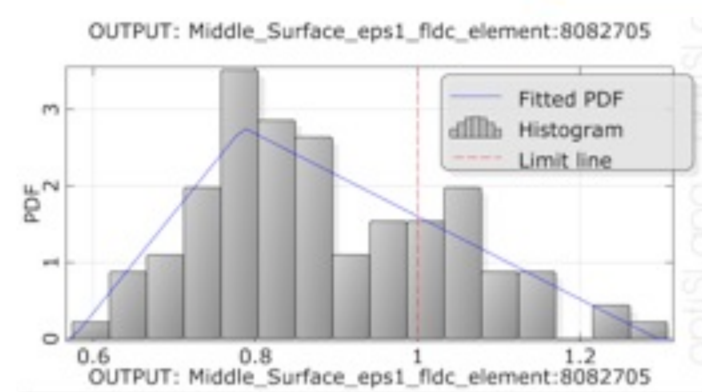
Statistics on Structures: Objectives

- Analyze random properties of structures
- Identify consequences of manufacturing tolerances and random loads
- Inspect statistics directly on the structure
- Improve robustness and product quality
- Easily detect hot spots and potential failure locations
- Improve analysis of the cause of scatter
- Create random designs
- Eliminate random noise
- Detect geometric perturbations

Robustness evaluation at hot spots

- Identify "hot spots", eg. locations with large mean, large stddev or extremal quantile values
- Robustness evaluation at hot spots
- Sensitivity analysis at hot spots to find responsible input parameters

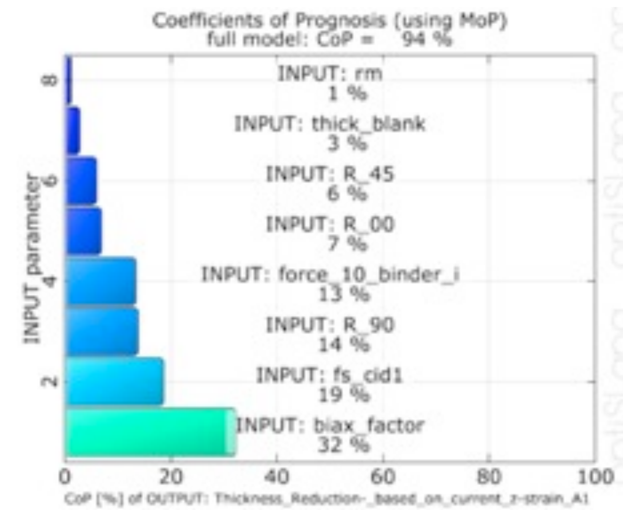


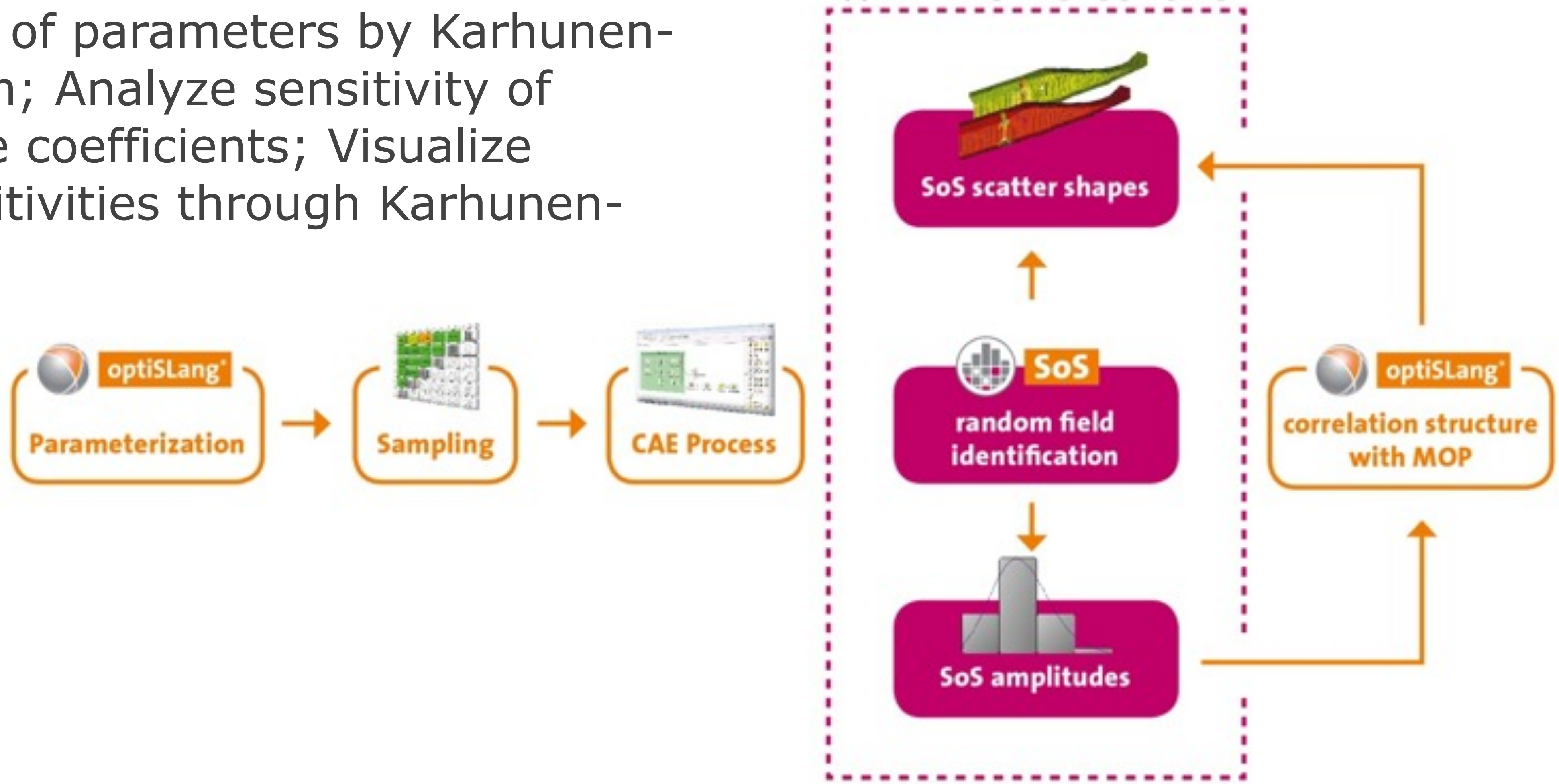


Statistic data			
Min:	0.5739	Max:	1.308
Mean:	0.8851	Sigma:	0.1517
CV:	0.1714		
Skewness:	0.5547	Kurtosis:	2.736
Fitted PDF: Triangular			
Mean:	0.8851	Sigma:	0.1517
Lower cut:	0.5739		
Limit x = 1			
P_rel:	0.737374	1 - P_rel:	0.262626
P_fit:	0.762163	1 - P_fit:	0.237837
Sigma-Level:	0.757313		

Robustness: Find input-output relations

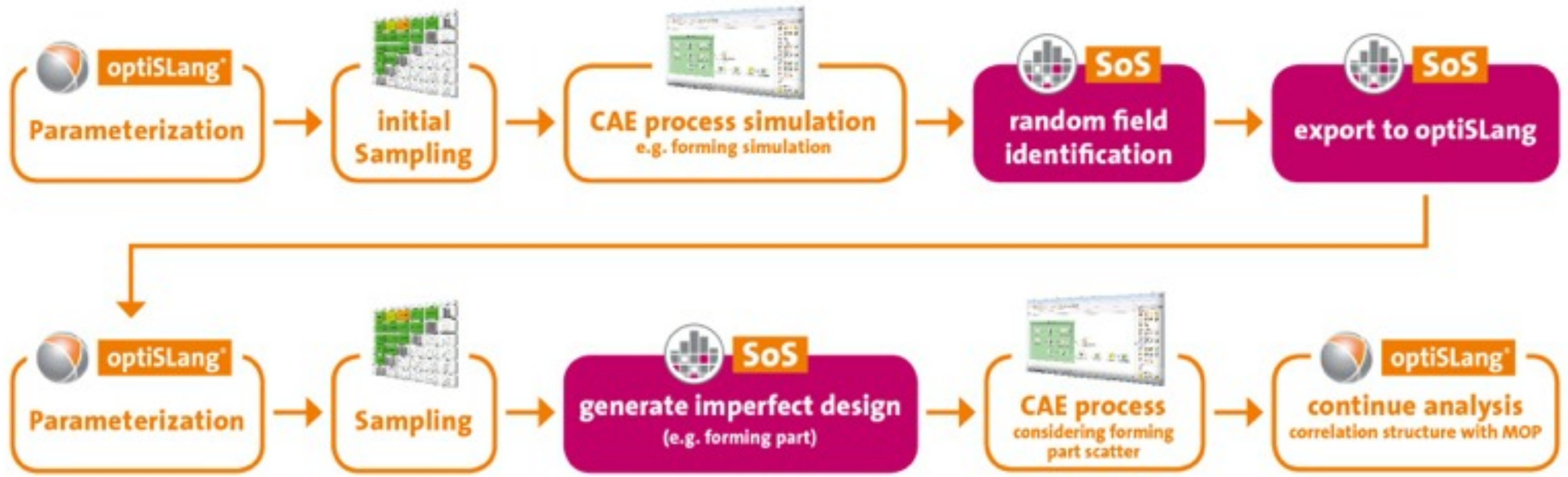
- Sensitivity measured by analyzing scalar parameters in optiSLang
- Problems: FEM field quantities with >>1000 individual parameters, varying location of extrema
- Reduce number of parameters by Karhunen-Loeve expansion; Analyze sensitivity of Karhunen-Loeve coefficients; Visualize location of sensitivities through Karhunen-Loeve shapes





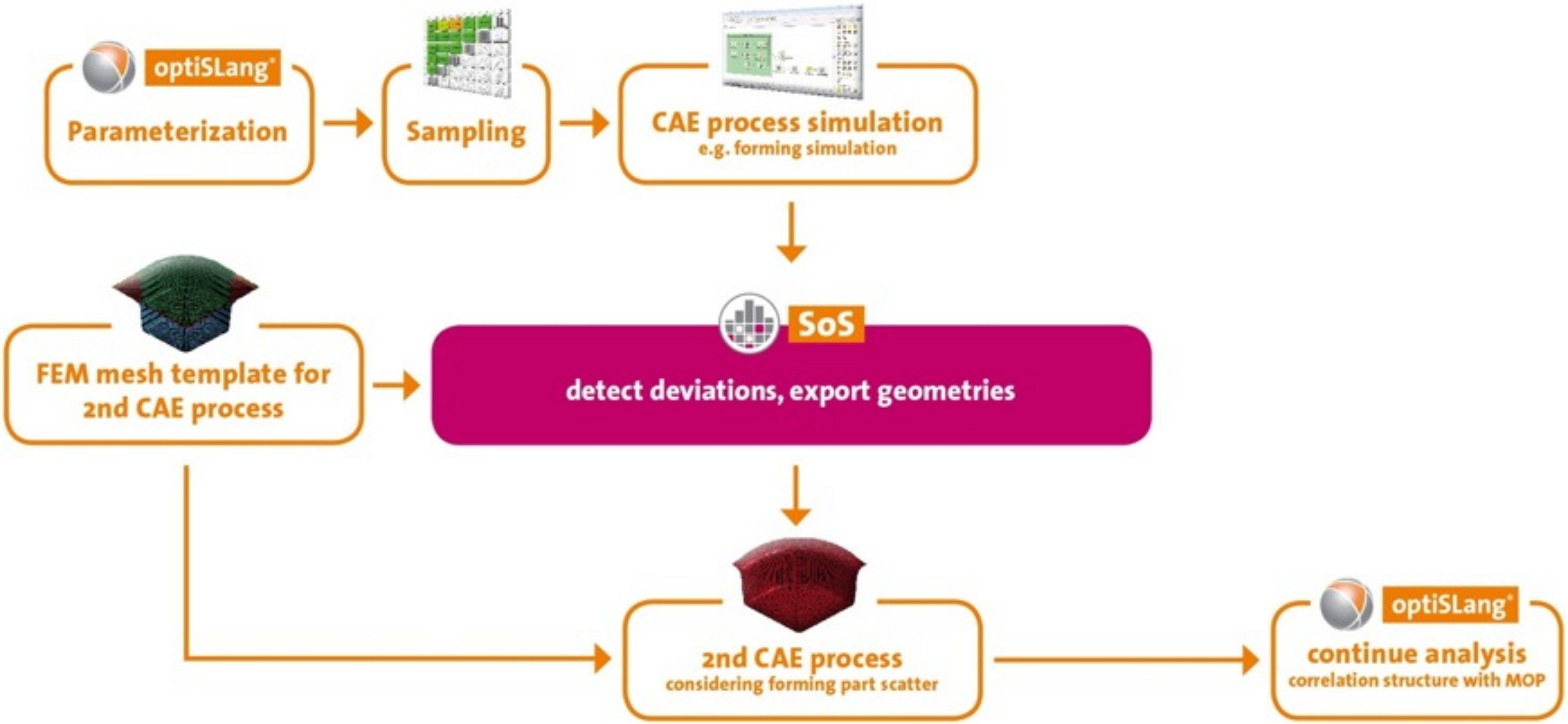
Simulation of random fields

- Simulation of random numbers at each FEM mesh point:
  - random geometric perturbations (node coordinates, shell thickness, layer thickness)
  - pre-damage/loading with random perturbations (plastic strain, pre-stress, etc.)
- Idea: 2 CAE processes: (1) Analyze random field (output), (2) Simulate random field (input)



Detection and export of geometric perturbations

- 2 CAE processes: Automation of using a random geometry (output of 1st) as input for the 2nd simulation
- Examples: 2 production steps or 1 production step + 1 load case, etc.

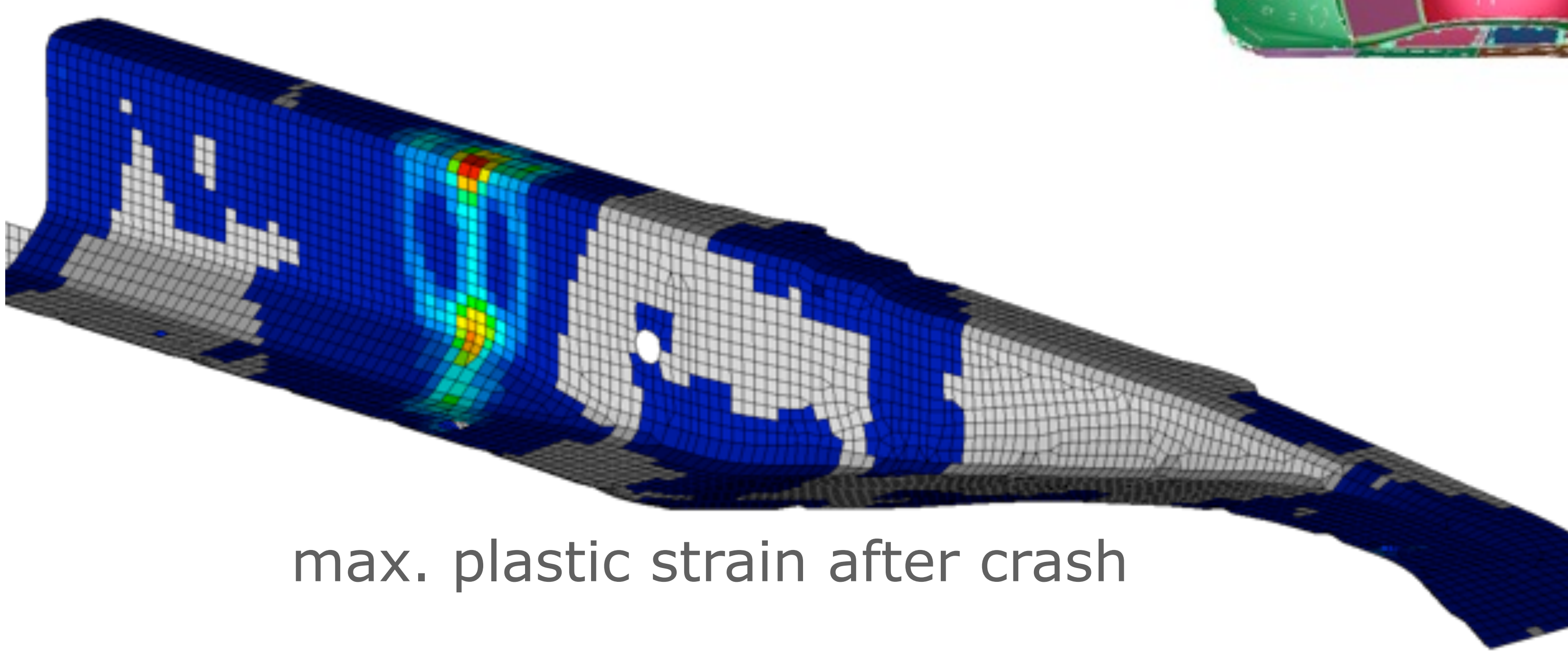


Statistics on Structures 3

Applications

Application: Crash simulation - cause analysis

- Stringer in a car body subject to crash simulation
- 55 random inputs: sheet thickness and material parameters (also of other parts), load parameters (velocity, barrier angle etc.)



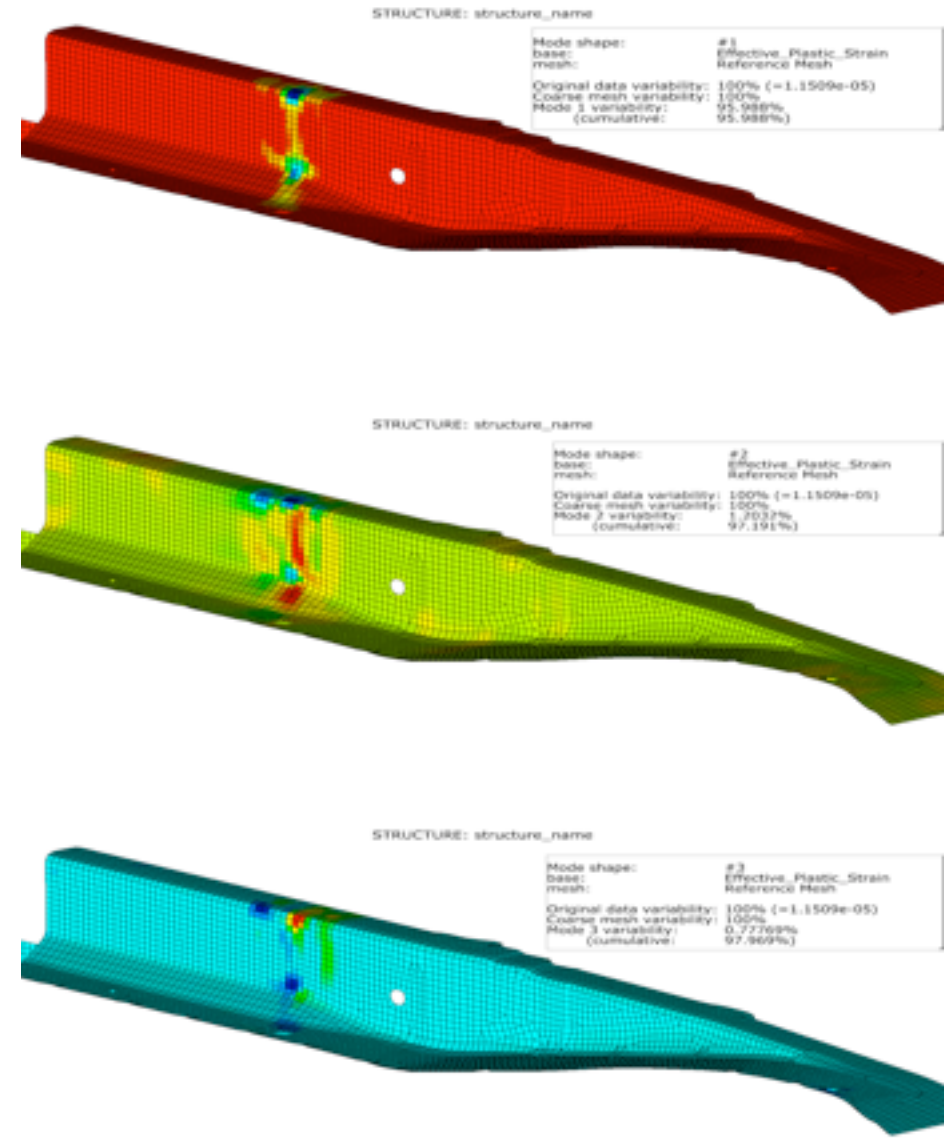
max. plastic strain after crash

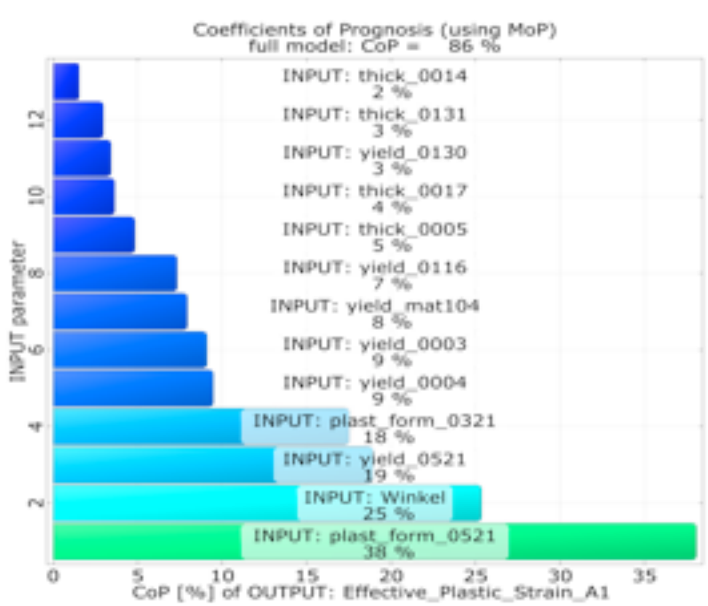
- Observed result: remaining effective plastic strain

Bayer, V.; Will, J.:
Random Fields in Robustness and Reliability Assessment of Structural Parts. SIMVEC, Verein Deutscher Ingenieure VDI, Baden-Baden 2010.,
Johannes Will (DYNARDO GmbH), Thomas Frank (Daimler AG), 2008
Robustness analysis of structural crash load cases at Daimler AG

Application: Crash simulation - cause analysis

- Analysis of a car structure subject to random crash load case
- Decomposition of plastic strain random field
- Analysis of largest influence by MoP/ CoP in optiSLang

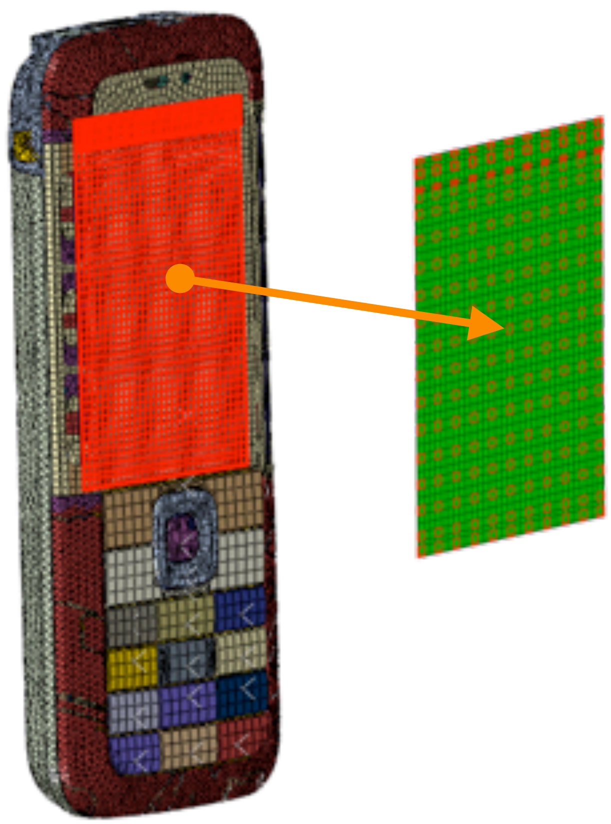


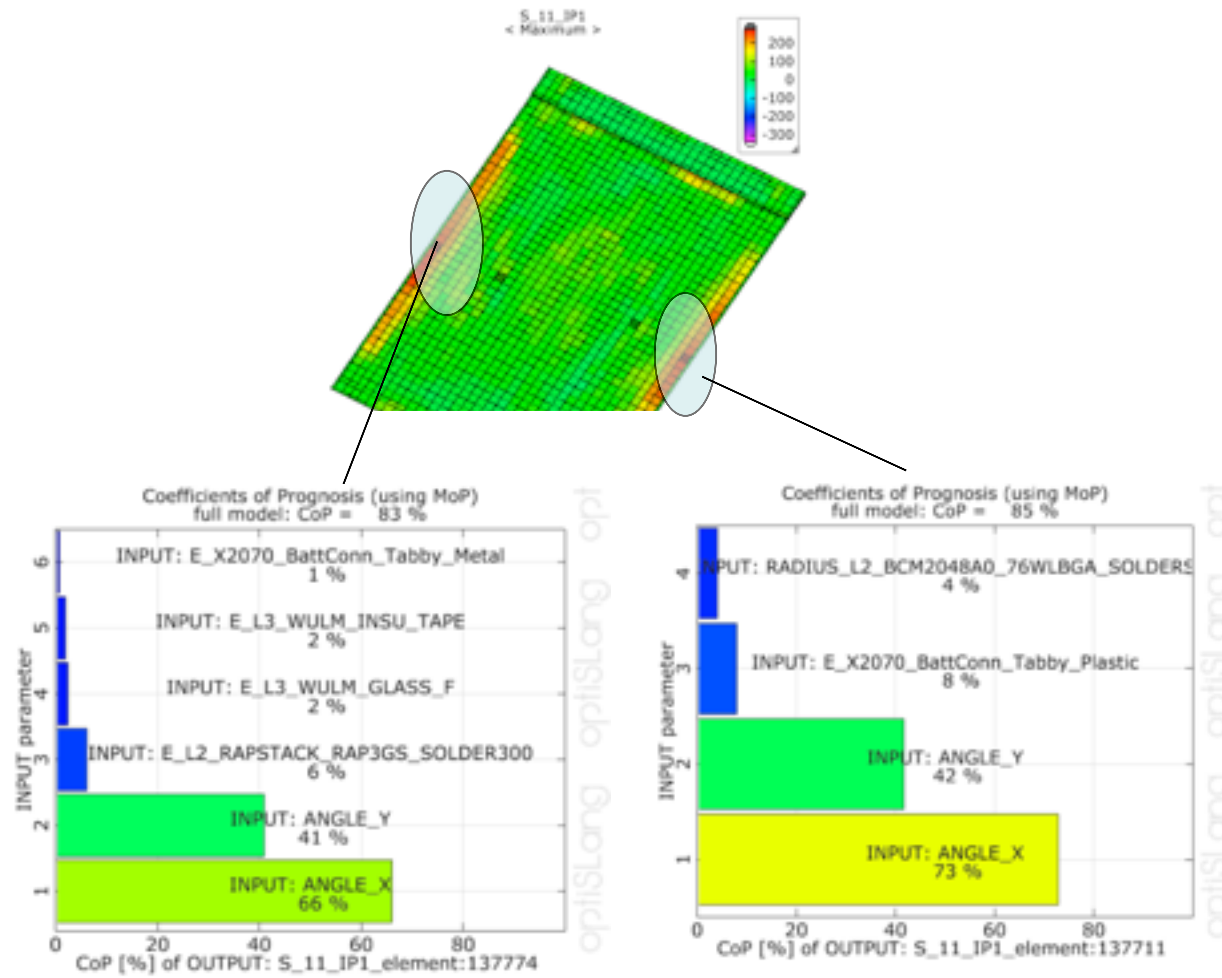


Bayer, V.; Will, J.:
Random Fields in Robustness and Reliability Assessment of Structural Parts. SIMVEC, Verein Deutscher Ingenieure VDI, Baden-Baden 2010.,
Johannes Will (DYNARDO GmbH), Thomas Frank (Daimler AG), 2008
Robustness analysis of structural crash load cases at Daimler AG

Application: Drop test of a cell phone

- Tasks:
  - Find the most critical drop test position (angle) - sensitivity analysis
  - Robustness analysis with respect to material and production parameters

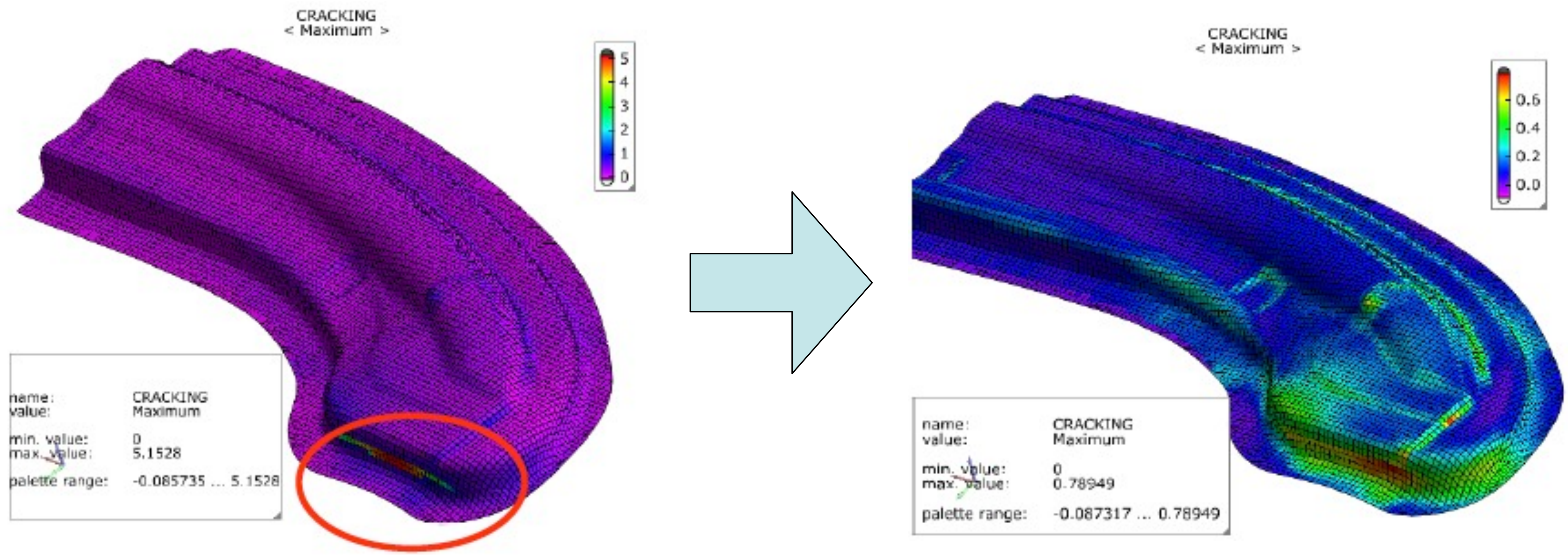




Alexander Ptchelintsev, Gerald Grewolls, Marcus Theman (NOKIA Corporation), Johannes Will (DYNARDO GmbH)
Applying sensitivity analysis and robustness evaluation in virtual prototyping on product level using optiSLang
SIMULIA Customer Conference, 2010

Application: RDO of a forming part (car body)

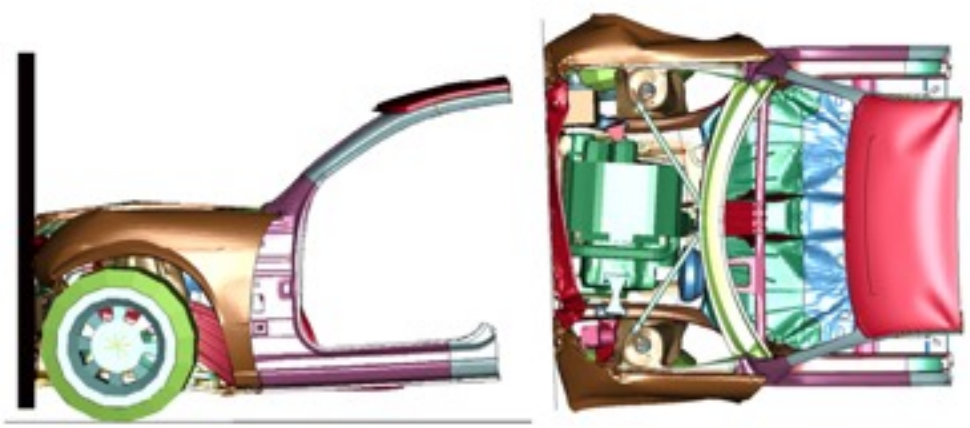
- sensitivity analysis, robustness evaluation and optimization
- LS-DYNA for forming simulation (50 min)
- parameters: 12 bead forces (0...350 N), tool binder force (50...300 kN)

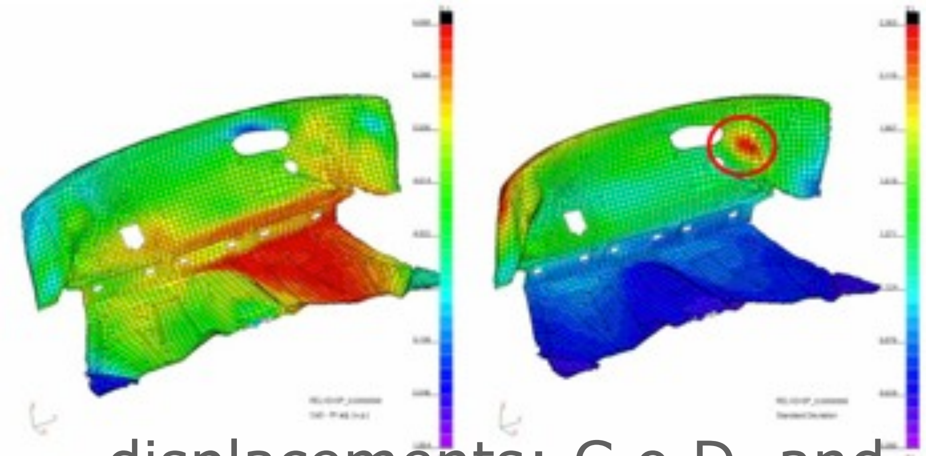


Johannes Will (DYNARDO GmbH)
Robust Design Optimization in forming process simulation
Weimarer Optimierungs- und Stochastiktage 4.0, 2007

Application: Robustness evaluation in car crash

- Estimation of scatter of important result variables
- Identification of sensitive scattering input variables
- Quantification of influence of numerical noise on variation of result variables



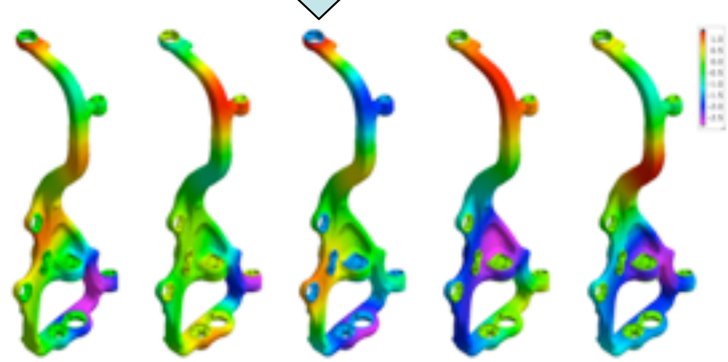


displacements: C.o.D. and standard deviation

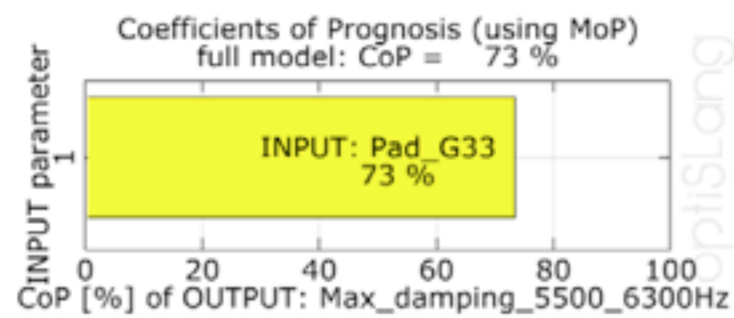
Johannes Will (DYNARDO GmbH), Uli Stelzmann (CADFEM GmbH)
Robustness Evaluation of Crashworthiness using LS-DYNA and optiSLang
25. CADFEM Users' Meeting, 2007

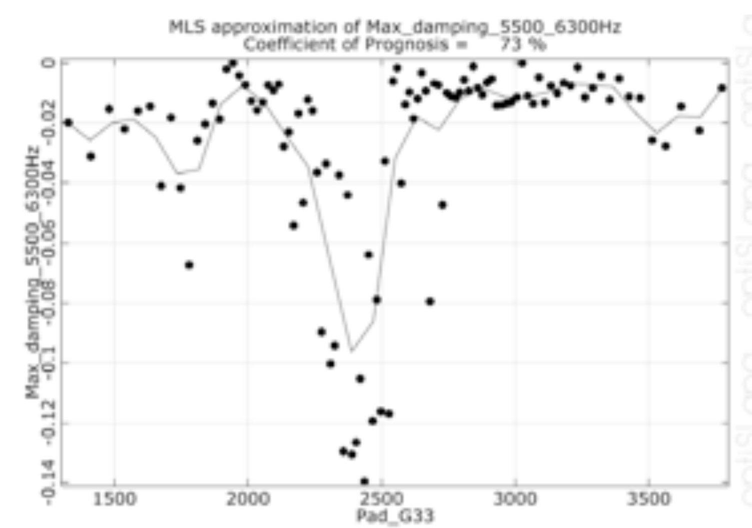
Robustness of brake system to squeal noise

difference between measured and modeled geometry of a knuckle



Simulation of imperfect geometries



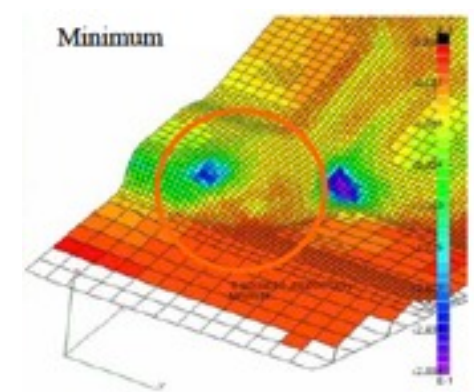


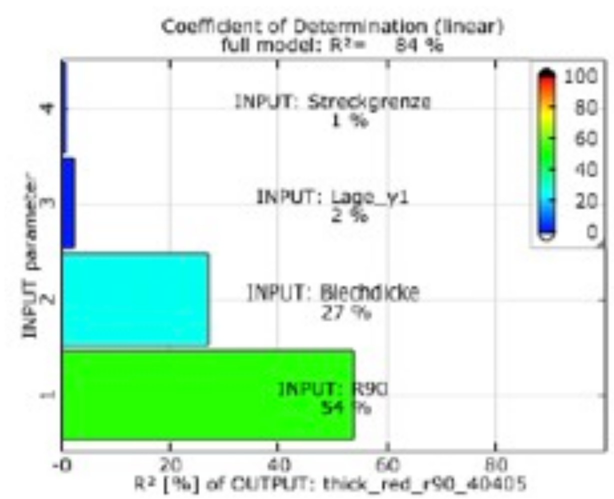
Identify a narrow range of values of the Young's modulus of the pad being responsible for small damping

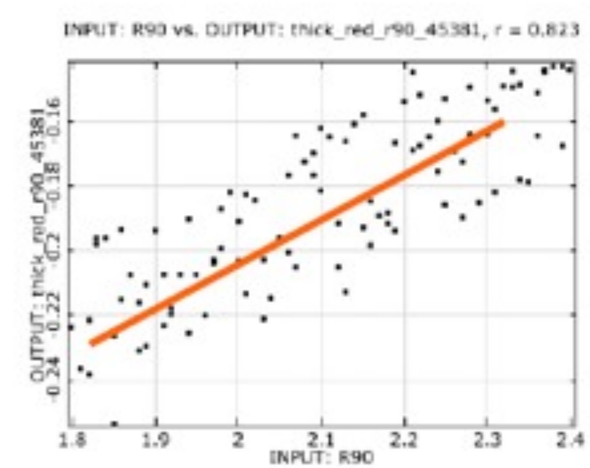
Ronaldo Nunes (Daimler AG), Johannes Will, Veit Bayer, Karthik Chittepu (DYNARDO GmbH)
Robustness evaluation of brake systems concerned to squeal noise problem
Weimarer Optimierungs- und Stochastiktage 6.0, 2009

Robustness of consecutive production processes

- multiple production steps:
  1. deep drawing
  2. several forming steps
- large failure rates during last forming step
- Simulation with FASTFORM
- observed quantity: thinning at critical location
- material parameter r90 as most sensitive input parameter







Johannes Will (DYNARDO GmbH), Tobias Menke, Andre Stühmeyer (CADFEM GmbH)
Rechnerische Robustheitsbewertungen von Umformprozessen
Internationale Konferenz "Neuere Entwicklungen in der Blechumformung", 2006

Johannes Will (DYNARDO GmbH), Prof. Christian Bucher (Bauhaus-Universität Weimar), Markus Ganser, Kathrin Grossenbacher (BMW AG), 2005
Computation and Visualization of Statistical Measures on FE Structures for Forming Simulations

Application: Robustness evaluation of a car door

- car door - produced by metal forming
- original simulation: predict good robustness (Pf 1%), reality: different
- Identify better statistical description of parameters from 39 experiments
- simulation (sampling) and find hot spots
- compute Pf at hot spot 2: 25%
- Identify responsible input scatter:
  - MOP at hot spot with bad CoP
  - MOP based on Karhunen-Loeve expansion: high CoP

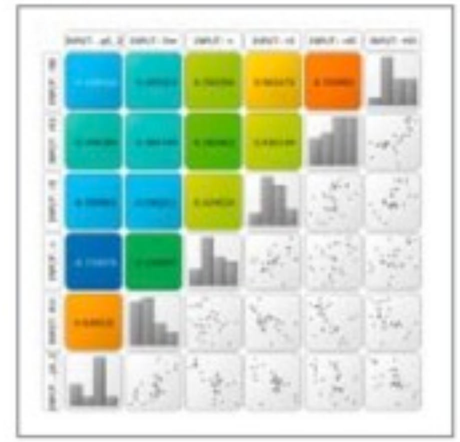


Fig. 1: Identification of random distribution type and correlation (optiSLang)

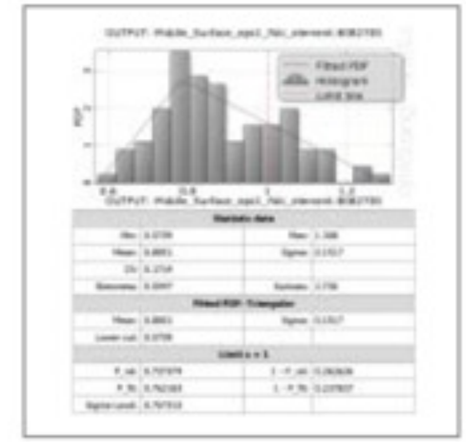


Fig. 2: Robustness analysis at hot spot 2 (optiSLang)

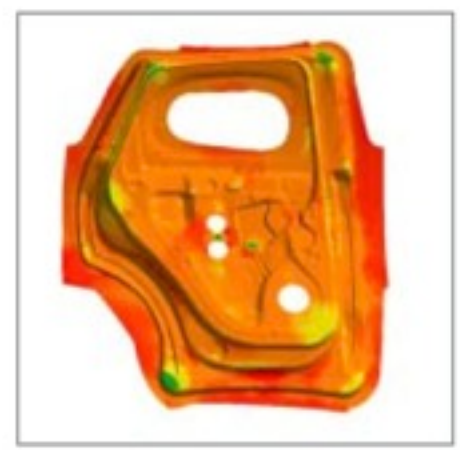


Fig. 3: 1st scatter shape of thickness reduction (SoS)

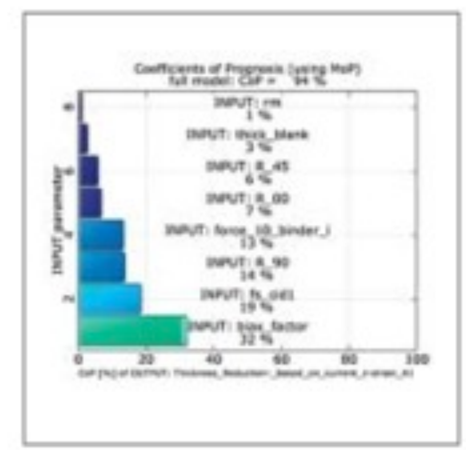
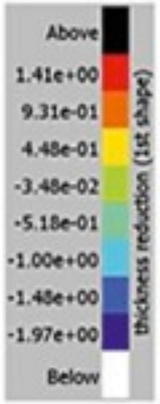


Fig. 4: Individual CoP for 1st scatter shape (optiSLang/ SoS)

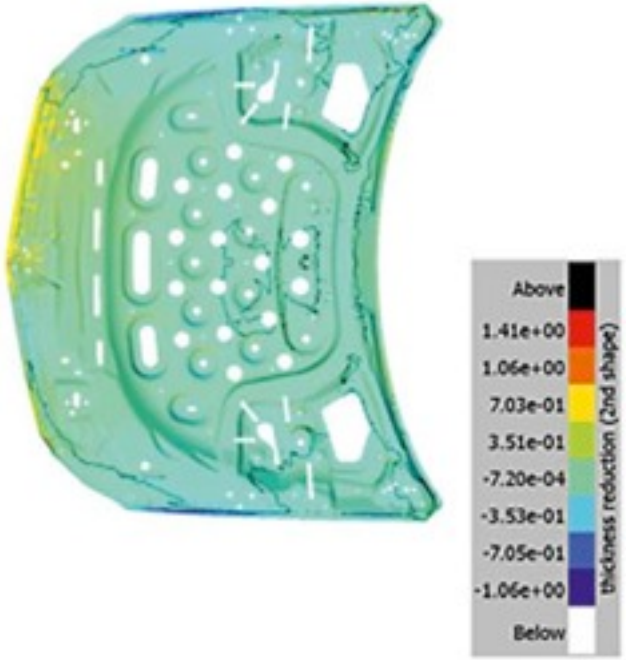
Hansjörg Lehmkuhl, Johannes Will, Vera Sturm, and Jörg Gerlach.
Which discretization level for uncertainties do we need for reliable robustness evaluations in forming application?
In 9th Weimar Optimization and Stochastic Days, Weimar, Germany, 2012. Dynardo GmbH.

Application: Identify geometry perturbations

- Given: deformed geometries of a metal forming simulation of a car cowling
- Detect deviations from the ideal reference geometry
- Karhunen-Loeve expansion of the deviations and create MOP for the respective scatter shapes
- Identify input parameters responsible for the perturbations



1st and 2nd scatter shapes



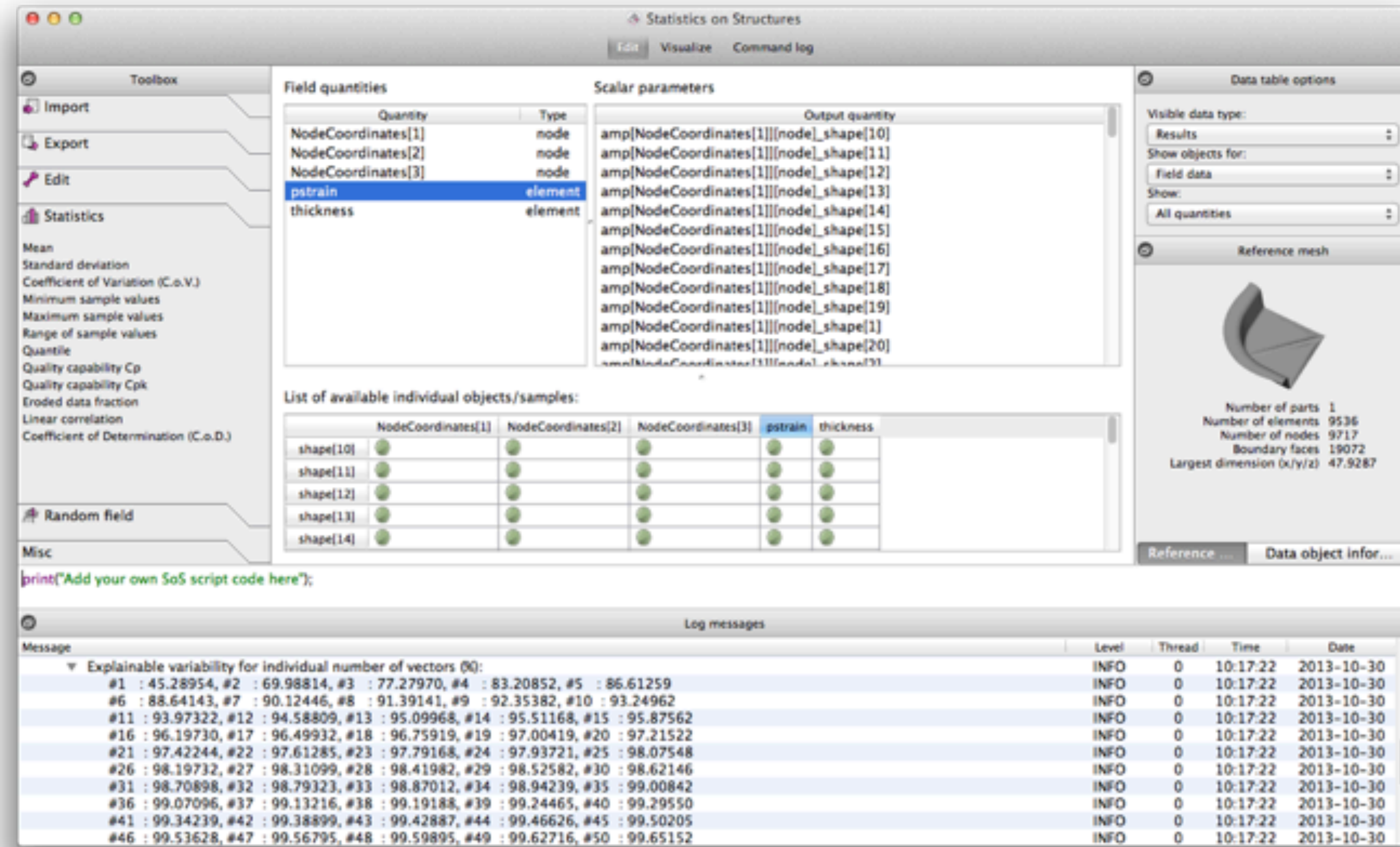
Will,J.
Integration of CAE-based optimization and robustness evaluation in virtual prototyping processes at Daimler using optiSLang,
Daimler EDM Forum, Stuttgart, 2013

Statistics on Structures 3

New features

New graphical user interface

- flexible
- SoS stores all imported designs and temporary results
- import additional designs after first analysis
- deactivate statistical outliers during analysis

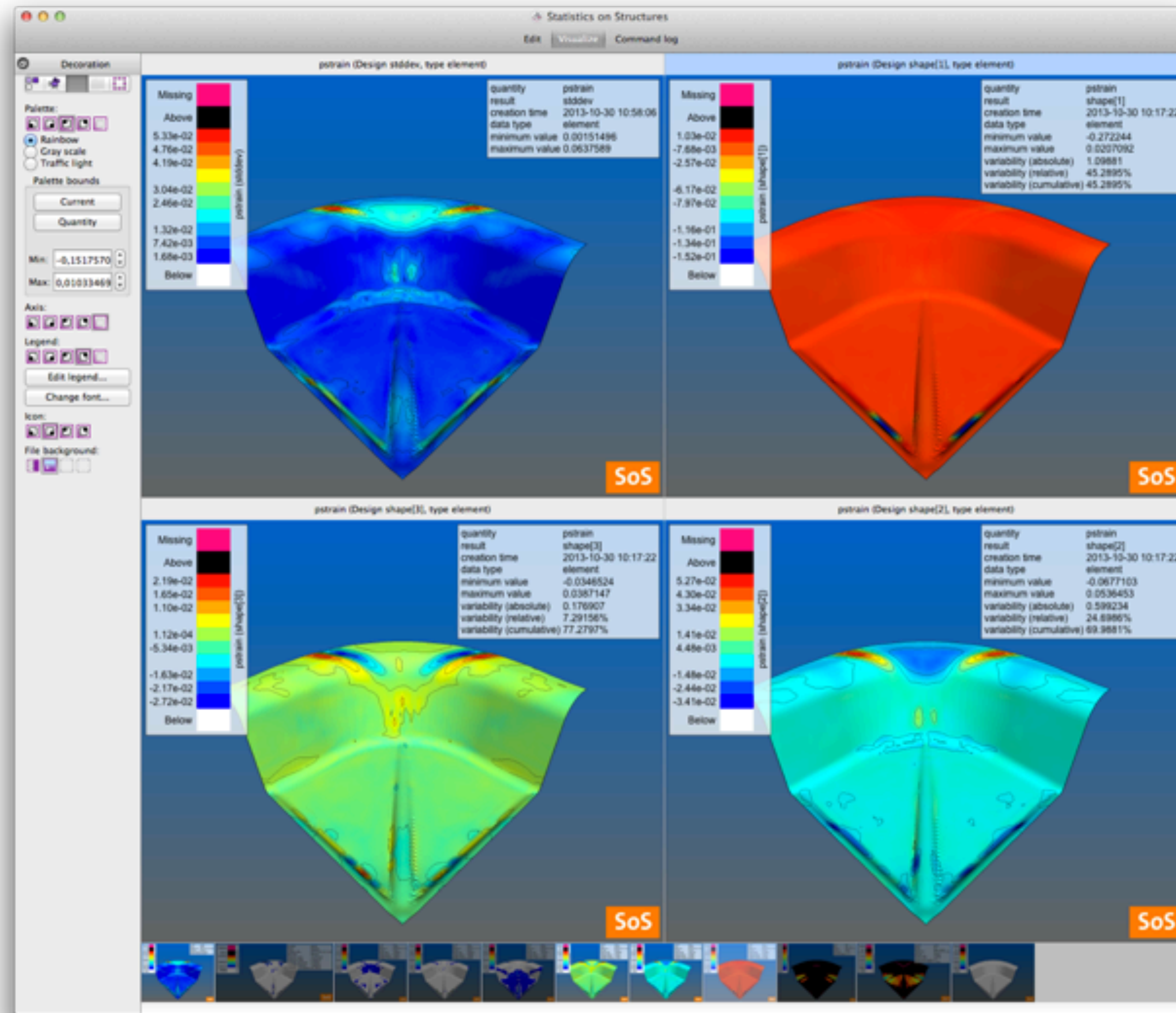


Algorithms

- descriptive statistics (mean, stddev, cov, linear correlation, etc.)
- variable range (min, max, range)
- robustness measures (quantiles, QCS, exceedance probability, etc.)
- random fields, Karhunen-Loeve expansion (amplitudes, scatter shapes, noise elimination, generate random fields)
- eroded data (frequency of erosion)
- detection of geometric deviations between non-matching meshes

Visualization

- visualize up to 4 field objects at once
- highly configurable
- export renderings by various image formats or high resolution PDF



Technical features

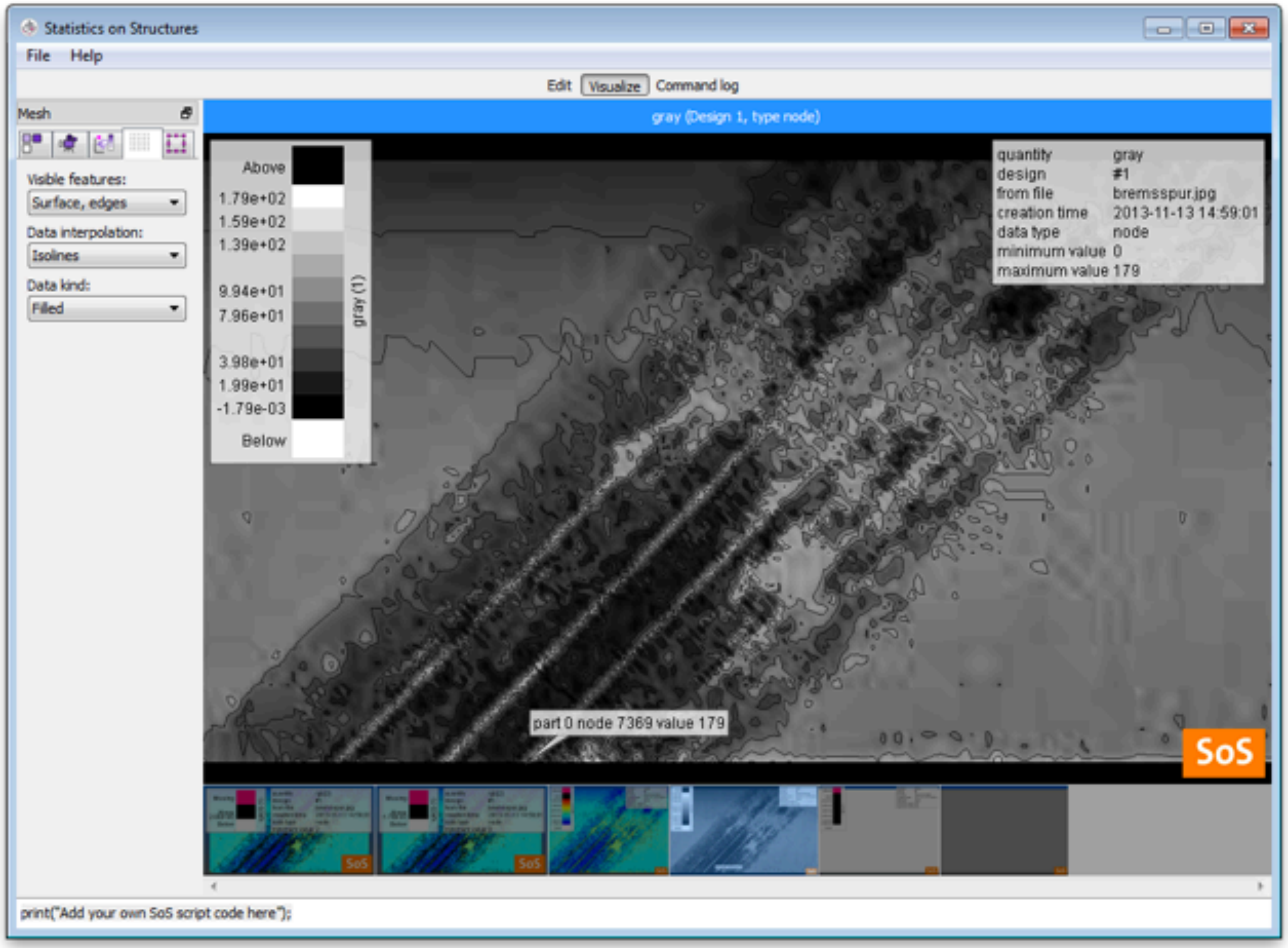
- Operating systems: Windows 7 64 Bit, Linux 64 Bit (Redhat 6, SLES 11)
- Mesh coarsening: Not existing anymore
- Relaxed limitations on FEM mesh sizes (tested up to 500.000 elements)
- Improved numerical efficiency and memory consumption
- Full use of multi-core workstations by shared memory parallelization
- Portable binary format
- Embedded scripting (Lua)
- Batch processing on Linux servers (incl. graphics)

File formats

format	import	export
Native binary data base, script	yes	yes
scalar parameters **optiSLang, CSV**	yes	yes
FEM mesh **STL**	yes	
FEM mesh + data **LS-Dyna, NASTRAN, PNG**	yes	yes
AutoForm through **LS-Dyna**		

Image processing

- Import photos (from measurements)



Summary

Statistics on Structures is the tool to answer the questions:

Where?

Locate hot spots of highest variation and/or extreme values, which may cause lack of performance or quality.

Why?

Find the input parameters which cause scatter of the results, by analyzing correlation/CoD between random inputs and spatially distributed results, export to optiSLang for MoP/CoP analysis, improve

Further it is the tool to

Generate random designs