Introduction to LS-OPT

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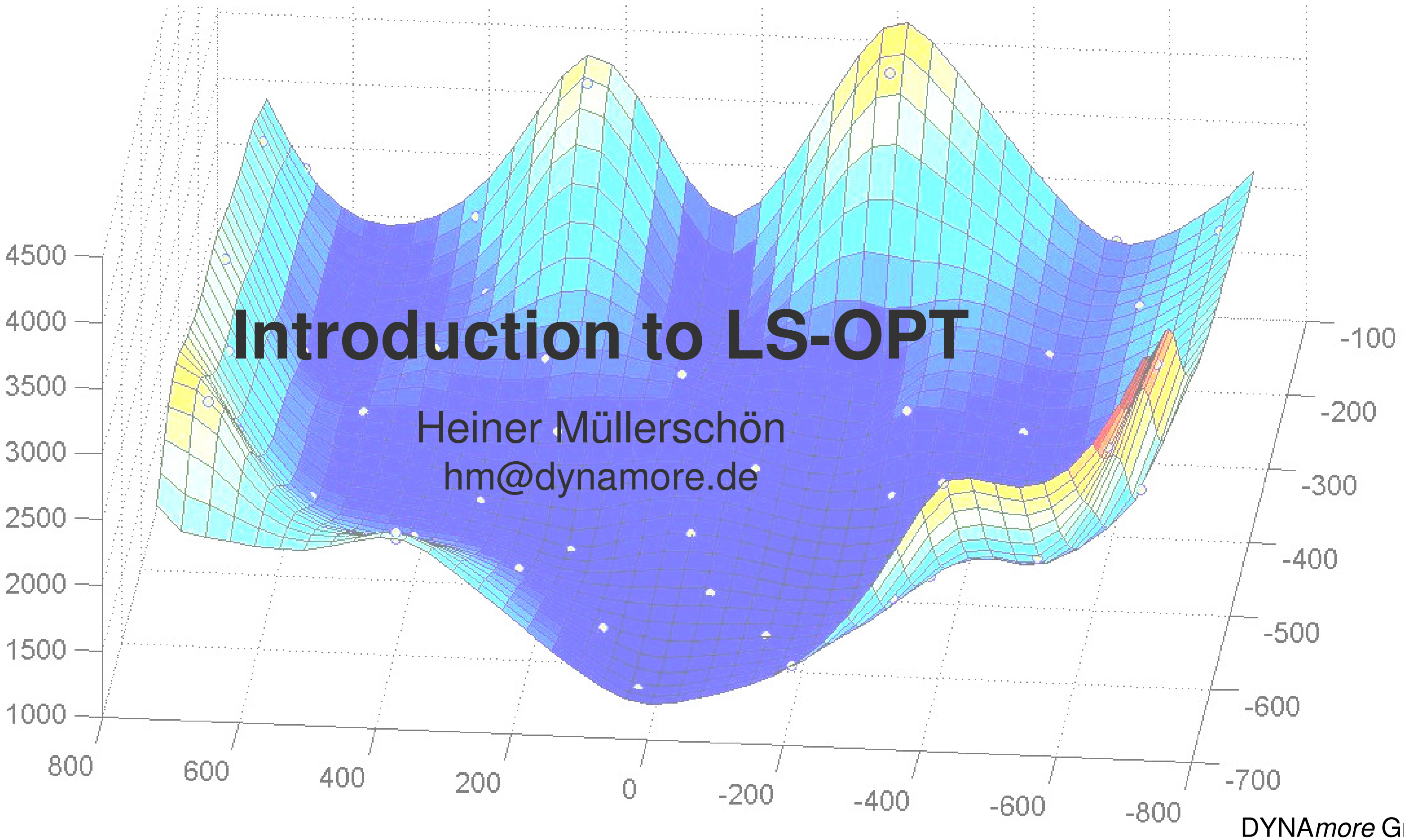

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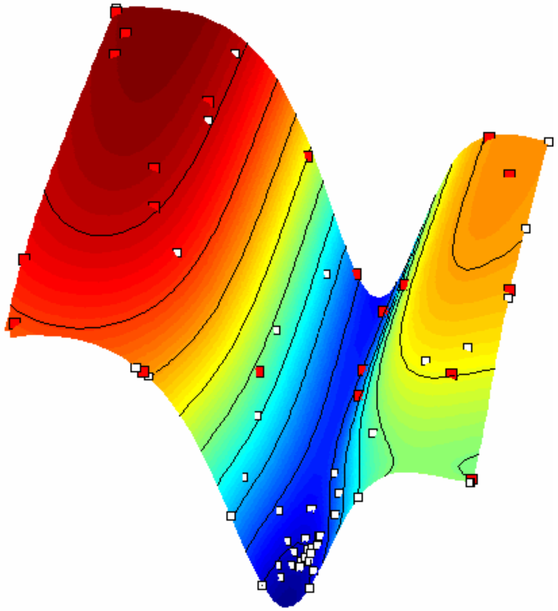
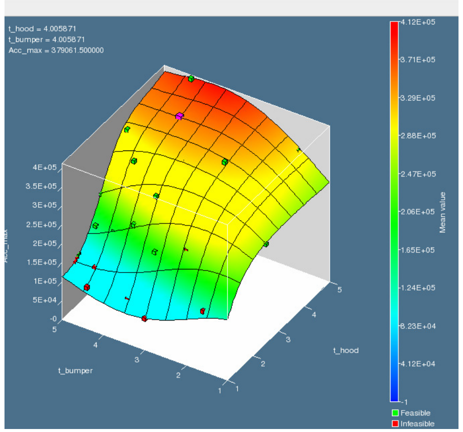
Overview

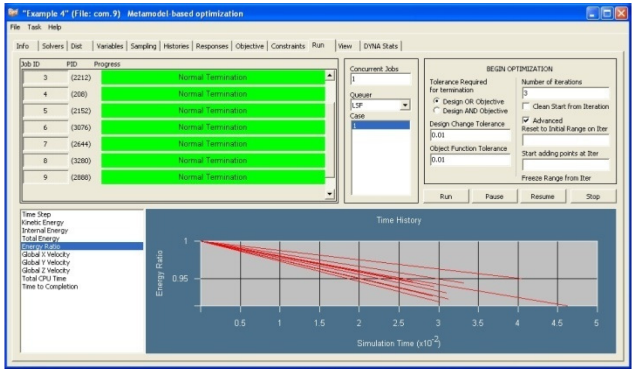
- Introduction/Features
- Methodologies – Optimization
- Methodologies - Robustness
- Examples - Optimization
- Examples - Robustness
- Version 3.3 / Outlook



About LS-OPT

- LS-OPT is a product of LSTC (Livermore Software Technology Corporation)
- LS-OPT can be linked to any simulation code – stand alone optimization software
- Methodologies/Features:
  - *Successive Response Surface Method (SRSM)*
  - *Genetic Algorithm (MOGA->NSGA-II)*
  - *Multidisciplinary optimization (MDO)*
  - *Multi-Objective optimization (Pareto)*
  - *numerical/analytical based sensitivities*
  - *Analysis of Variance (ANOVA)*
  - *Stochastic/Probabilistic Analysis*
  - *Monte Carlo Analysis using Metamodels*
  - *….*





Introduction / Features

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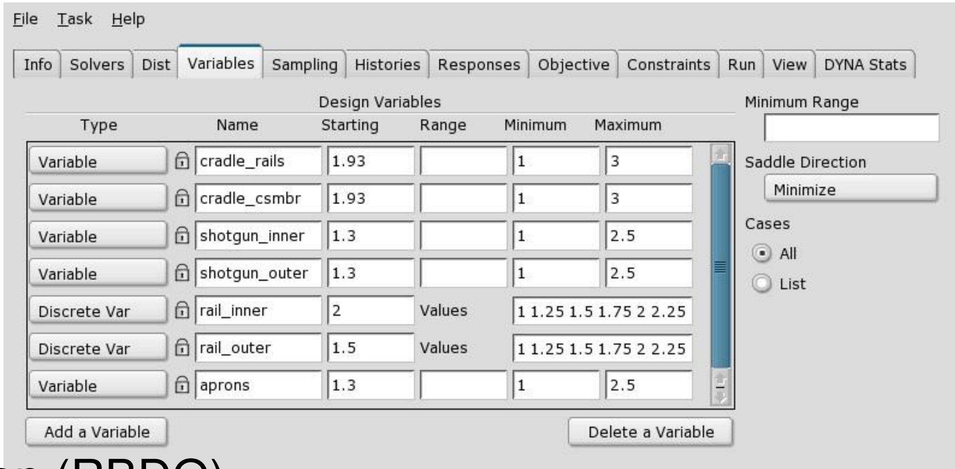
About LS-OPT

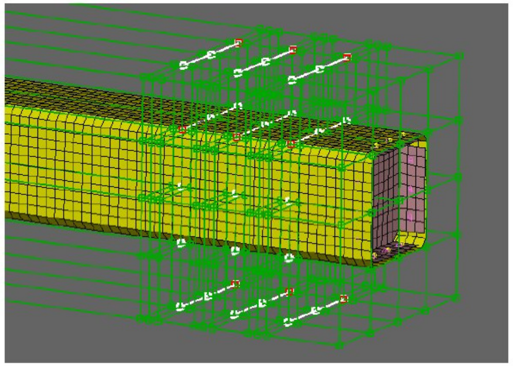
- Mixed Discrete-Continous Optimization
  - *Specify sets of discrete variables (e.g. sheet thicknesses)*

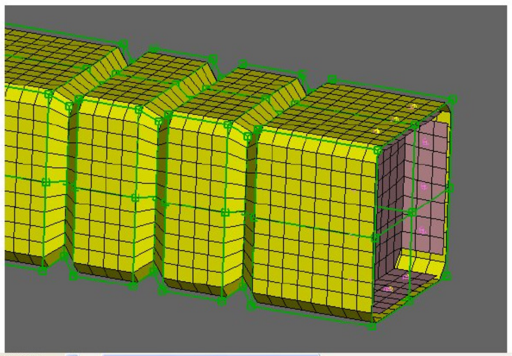


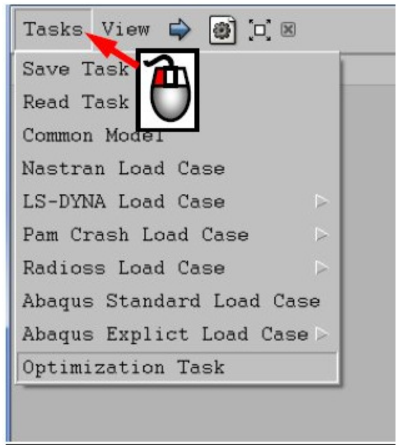
- Robust Parameter Design (RDO)
  - *Improve/Maximizing the robustness of the optimum*
- Reliability Based Design Optimization (RBDO)
  - *Improve failure probability of optimum*
- Visualization of Stochastic Results
  - *Confidence Intervals, reliability quantities*
  - *Fringe of statistic results on the FE-Model*

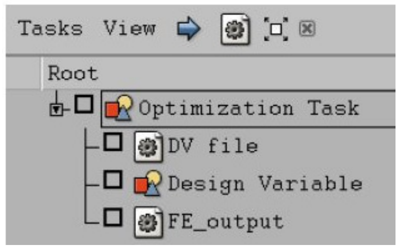
About LS-OPT

- Job Distribution - Interface to Queuing Systems
  - *PBS, LSF, LoadLeveler, SLURM, AQS, etc.*
  - *Retry of failed queuing (abnormal termination)*
- LS-OPT might be used as a "Process Manager"
- Shape Optimization
  - *Interface to* ***ANSA****, HyperMorph, DEP-Morpher, SFE-Concept*
  - *User-defined interface to any Pre-Processor*





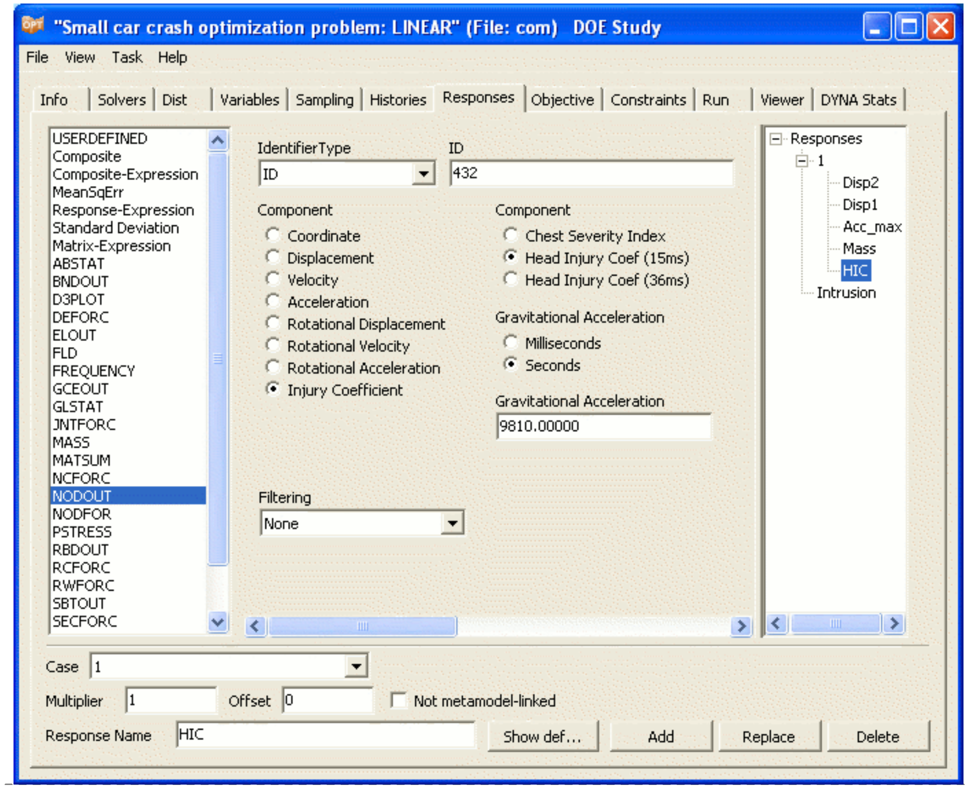




About LS-OPT

LS-DYNA Integration

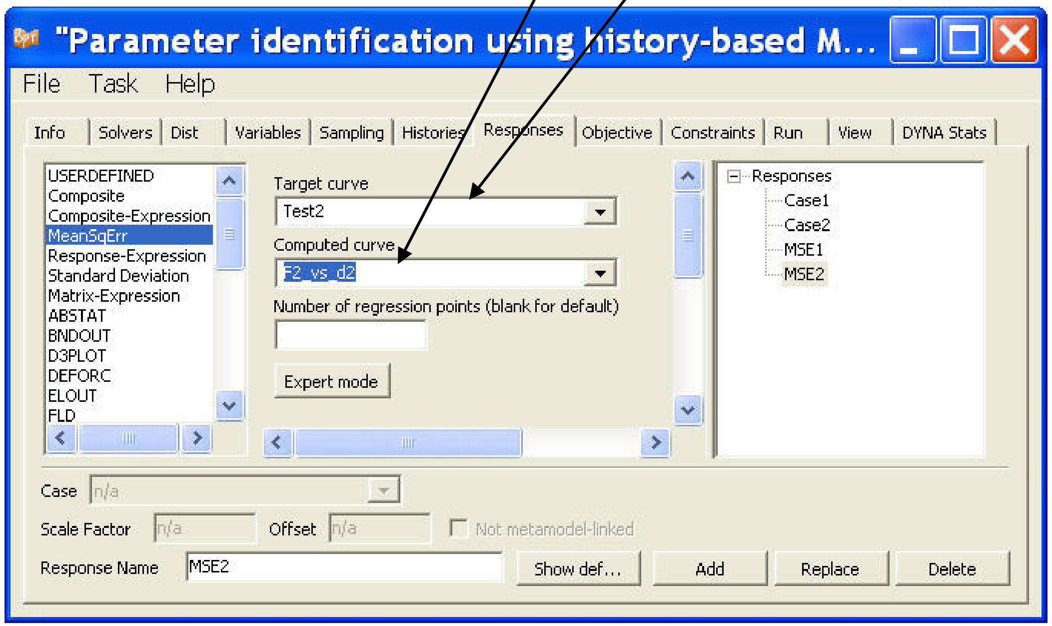
- *Checking of Dyna keyword files (*DATABASE_)*
- *Importation of design parameters from Dyna keyword files (*PARAMETER_)*
- *Monitoring of LS-DYNA progress*
- *Result extraction of most LS-DYNA response types*
- *D3plot compression (node and part selection)*



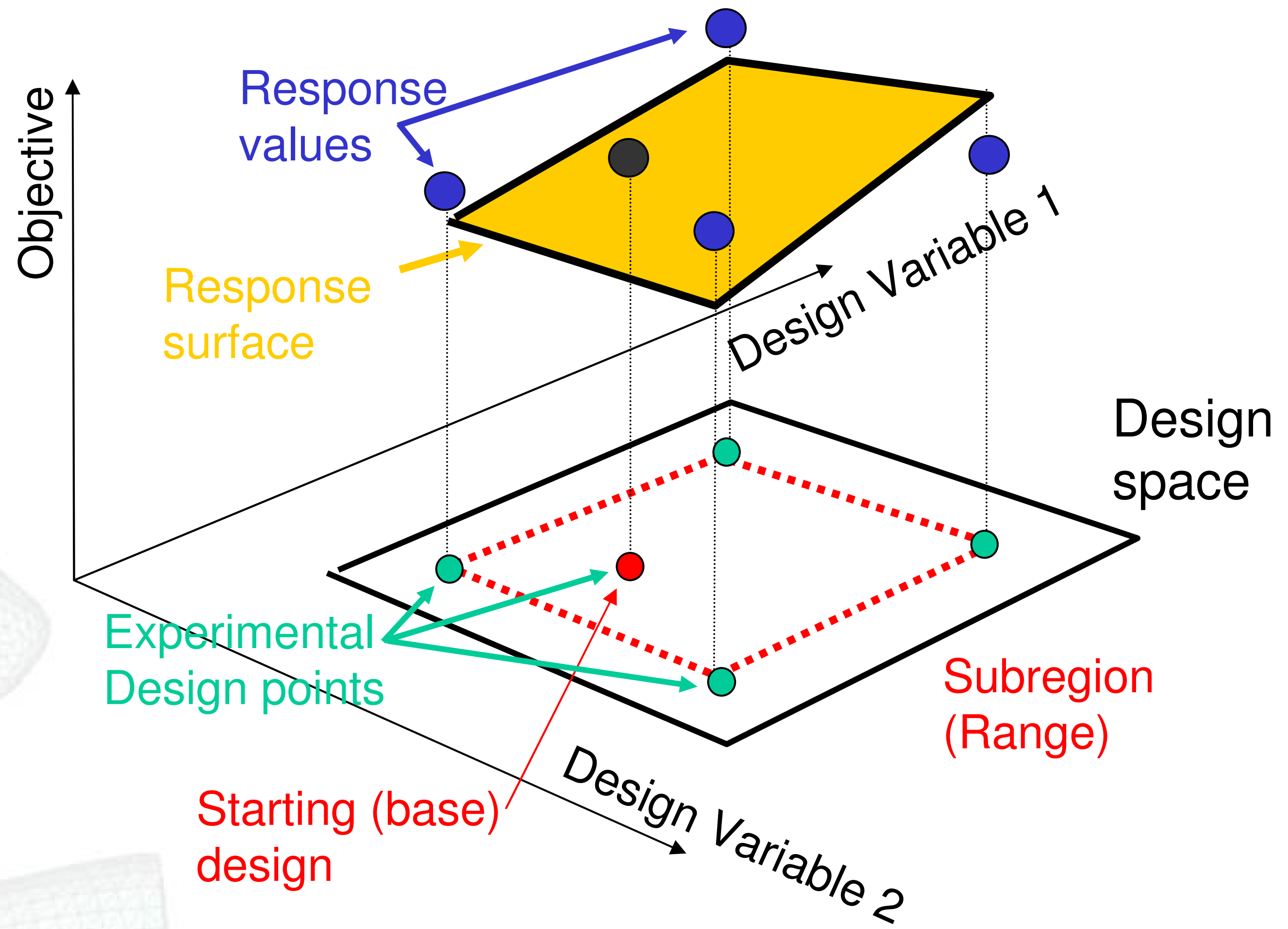
About LS-OPT

- Parameter Identification Module
  - *Handles "continuous" test curves*
  - *Automated use of test results to calibrate materials/systems*
  - *Simplify input for system identification applications*
  - *Visualization of test and simulation curve to compare*
  - *Confidence intervals for individual parameters in parameter identification*

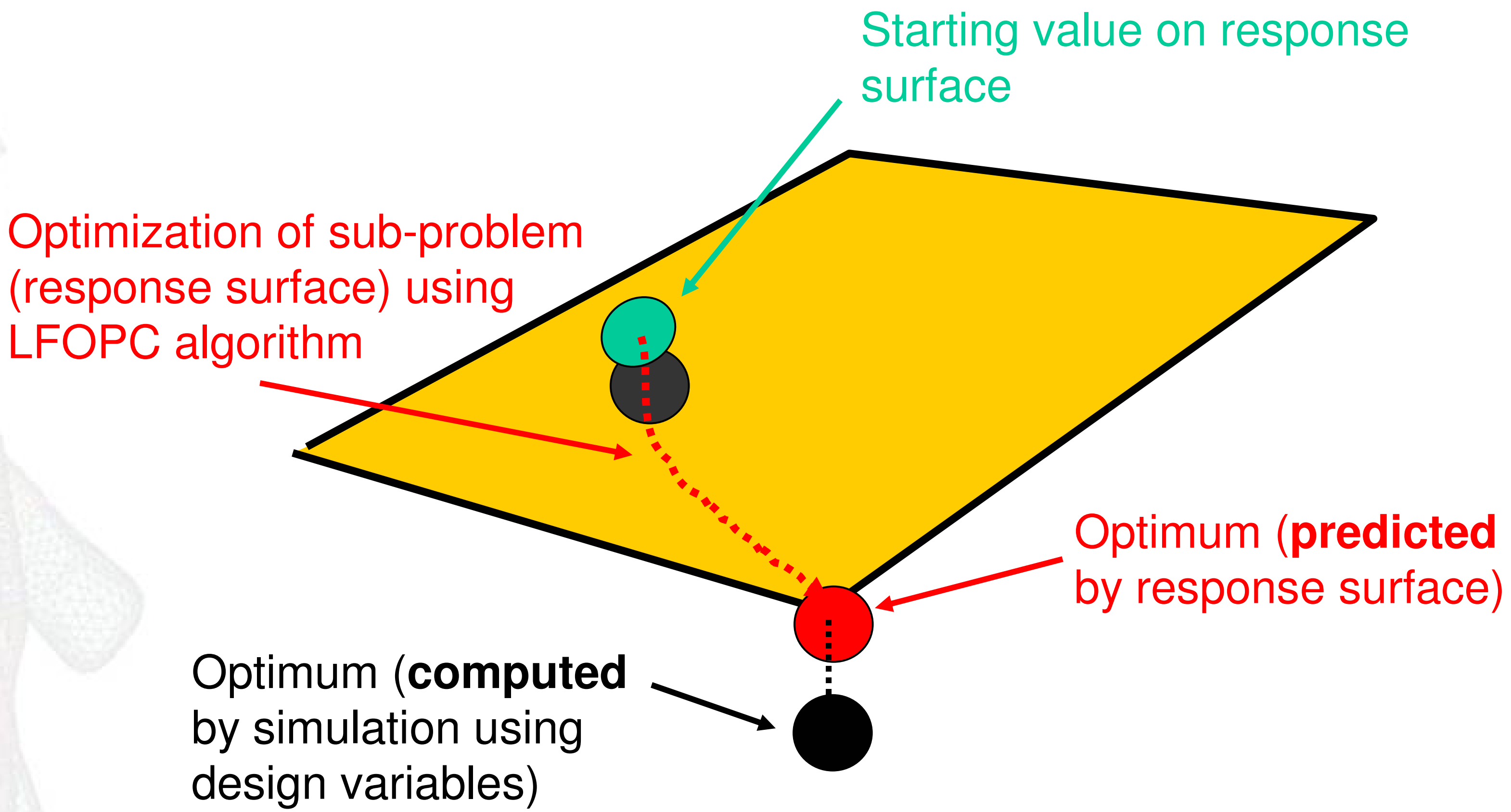
$$\frac{1}{P}\sum_{p=1}^{P} W_i\left(\frac{F_i(\boldsymbol{x})-G_i}{s_i}\right)^2$$



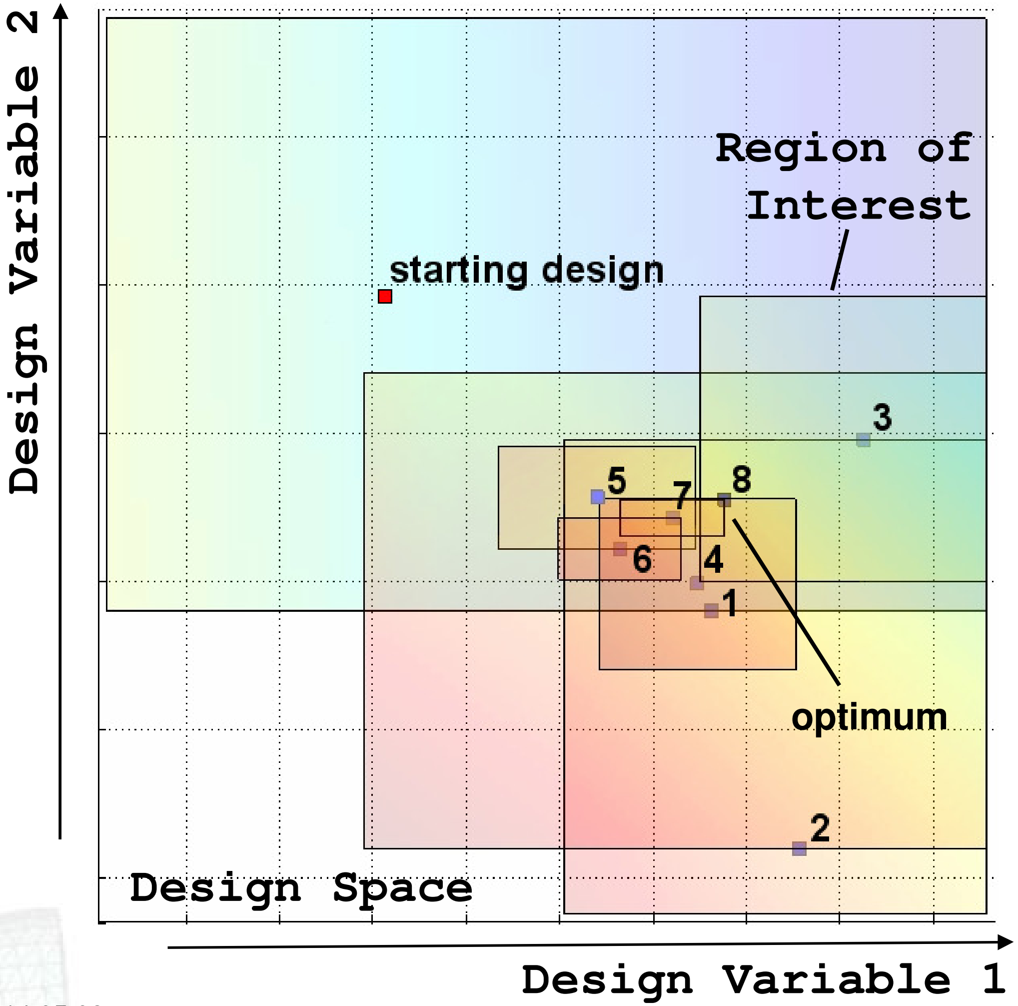
Response Surface Methodology - Optimization Process



Find an Optimum on the Response Surface (one iteration)



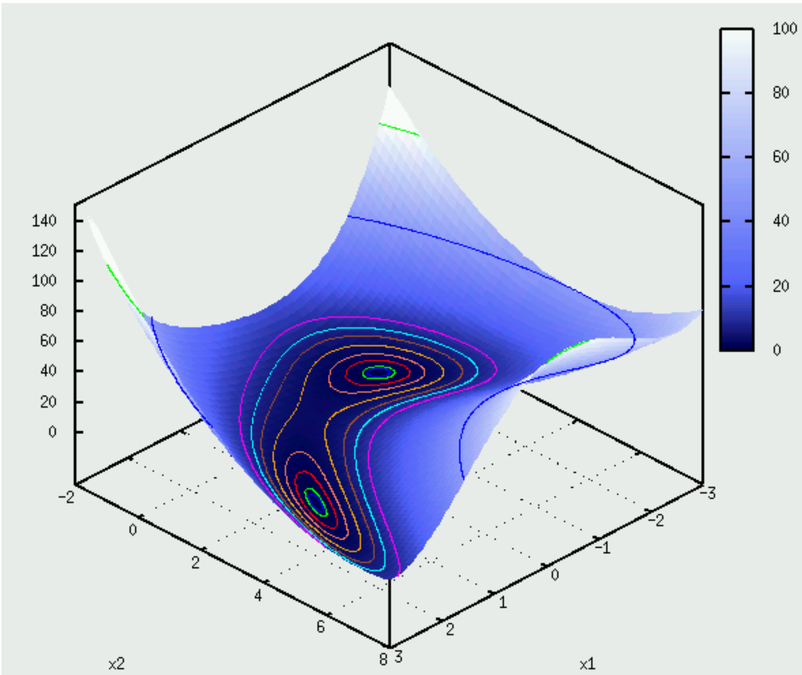
Successive Response Surface Methodology



Successive Response Surface Methodology

- Example - 4th order polynomial

$$g(\mathbf{x}) = 4 + \frac{9}{2}x_1 - 4x_2 + x_1^2 + 2x_2^2 - 2x_1x_2 + x_1^4 - 2x_1^2x_2$$



movie

Methods - Optimization

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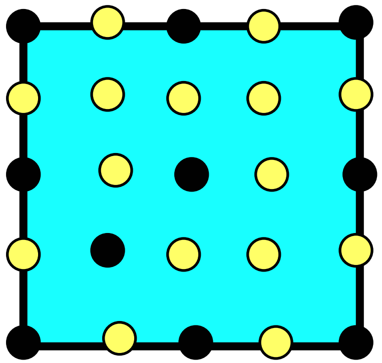
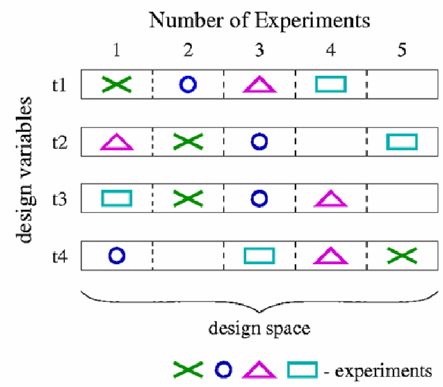
Design of Experiments (DOE) - Sampling Point Selection

- Koshal, Central Composite, Full Factorial
- D-Optimality Criterion - Gives maximal confidence in the model

$$\max \left| X^T X \right|$$

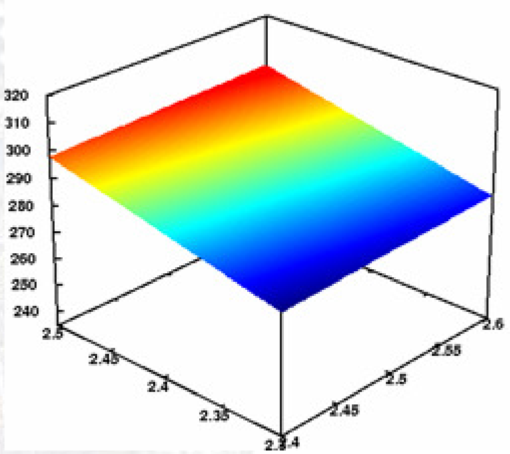


- Monte Carlo Sampling
- Latin Hypercube Sampling (stratified Monte Carlo)
- Space Filling Designs
- User Defined Experiments

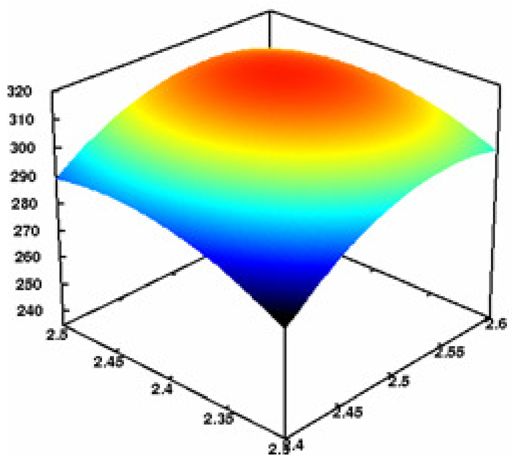


Response Surfaces (Meta Models)

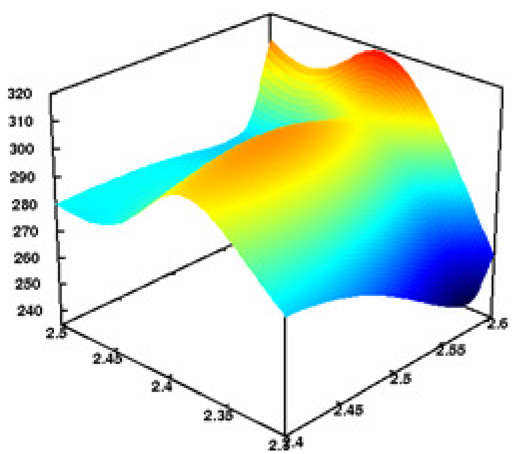
- Linear, Quadratic and Mixed polynomial based
- Neural Network and Kriging for Nonlinear Regression



linear polynomial



quadratic polynomial

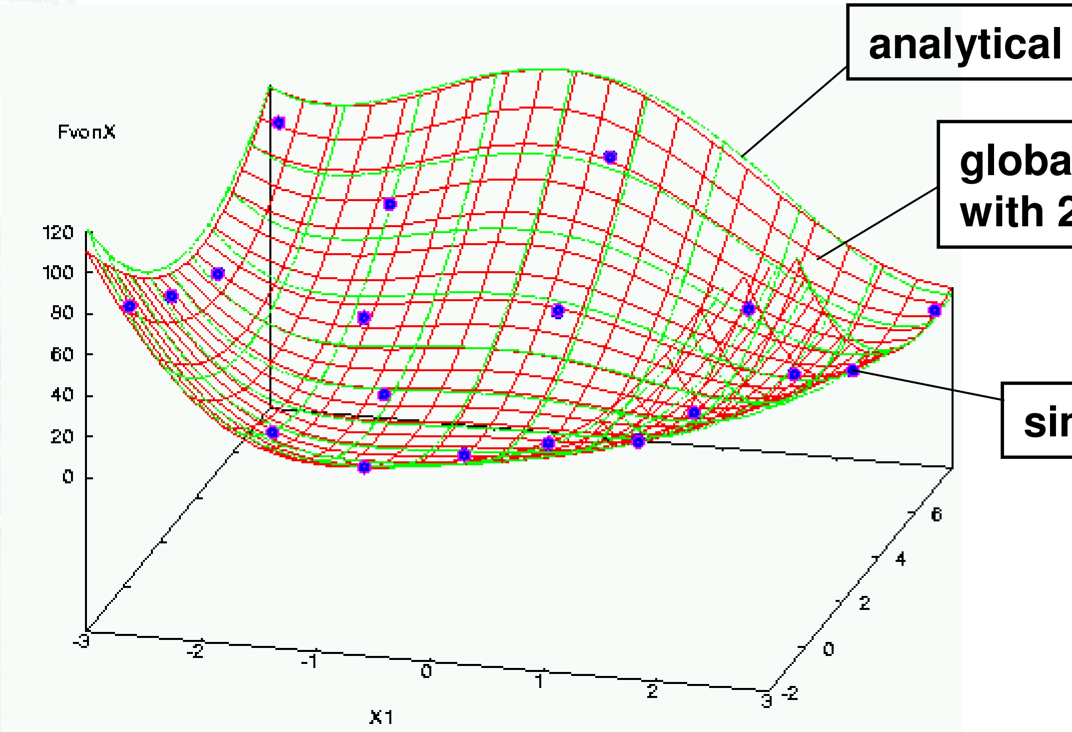


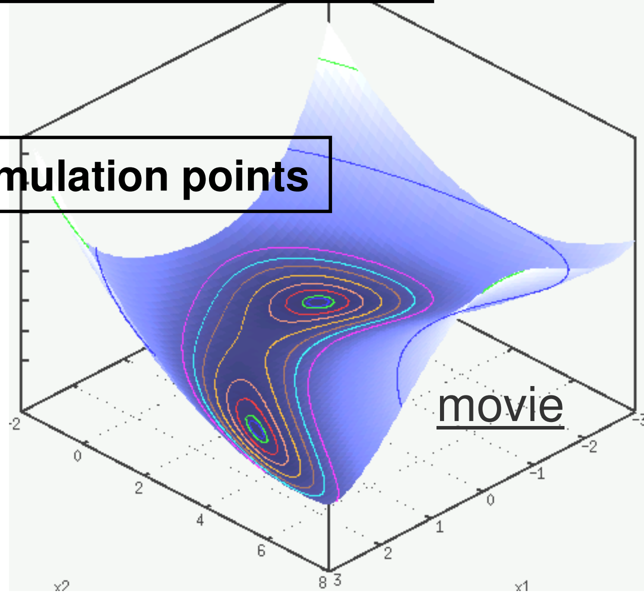
neural network

Neural Network Regression

- Example - 4th order polynomial

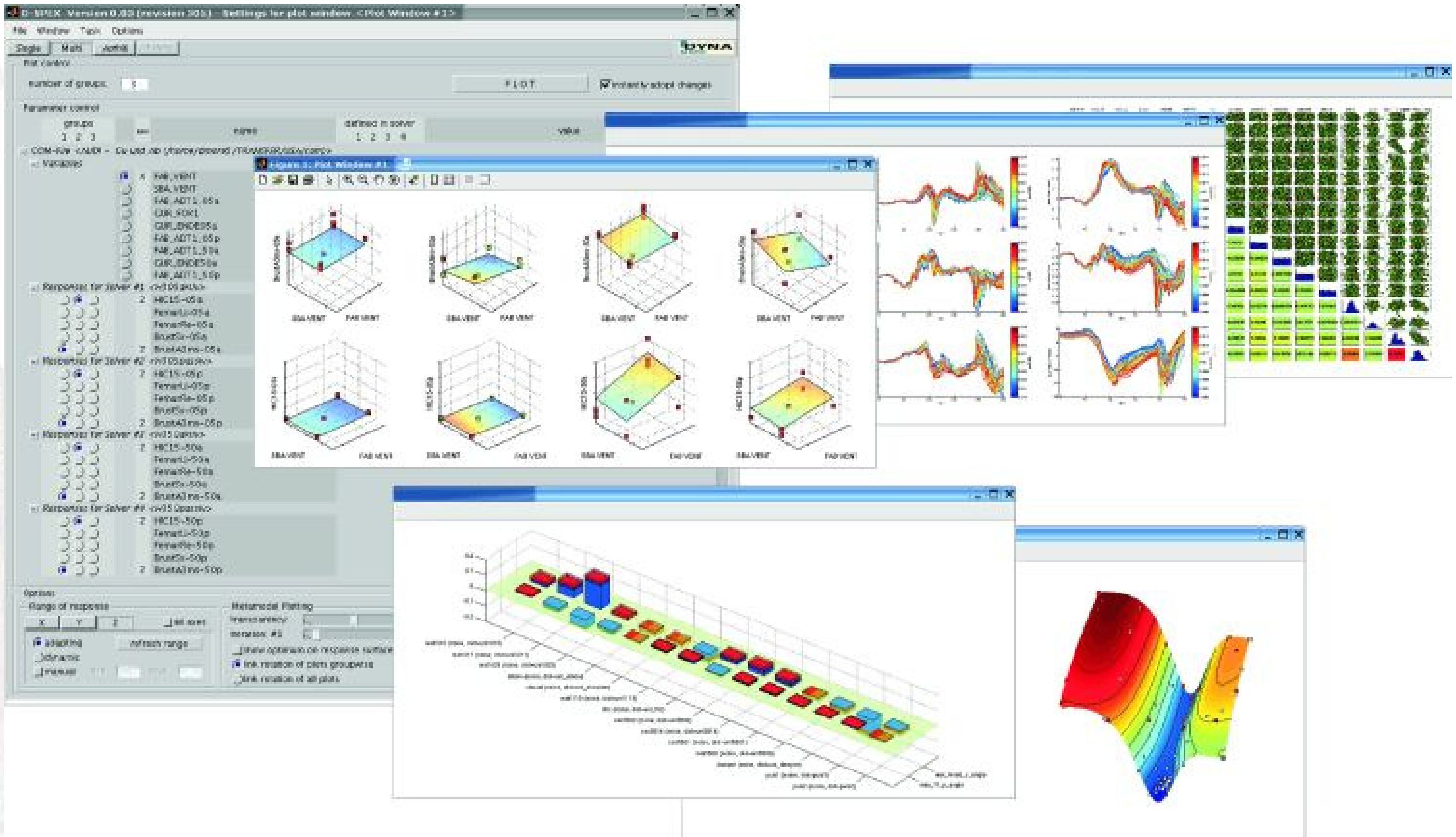
$$g(\mathbf{x}) = 4 + \frac{9}{2}x_1 - 4x_2 + x_1^2 + 2x_2^2 - 2x_1x_2 + x_1^4 - 2x_1^2x_2$$





Meta-Model Viewer - Exploration of Design Space

- Compare responses, histories or even different optimization projects



D-SPEX
DESIGN SPACE EXPLORER
FOR OPTIMIZATION AND STOCHASTIC ANALYSIS

D-SPEX by DYNA*more* GmbH
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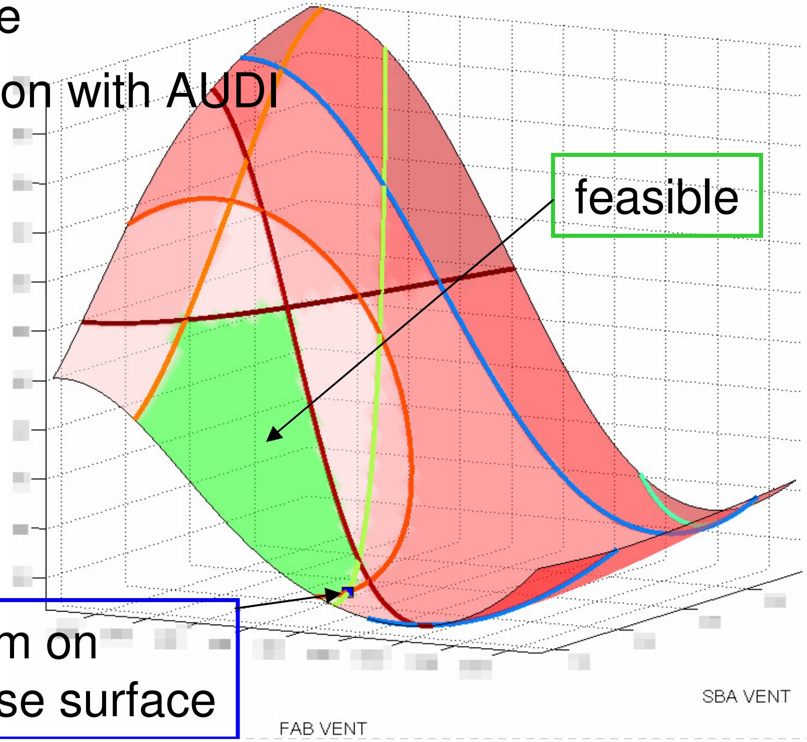
www.dynamore.de

About D-SPEX

- D-SPEX – **D**esign **SP**ace **EX**plorer
- D-SPEX is a software tool for the visualization of Meta-Models and results of optimization or stochastic analysis
- Versions Windows 32/64bit and Linux 32/64bit
- Complete interface to LS-OPT database
- Developed by DYNA*more* in collaboration with AUDI (property of DYNAmore)
- Methodologies/Features:
  - *Meta-Model viewer*
  - *Curve statistics*
  - *Feasible/Infeasible design*
  - *Ant-Hill plots*
  - *Statistic evaluations*

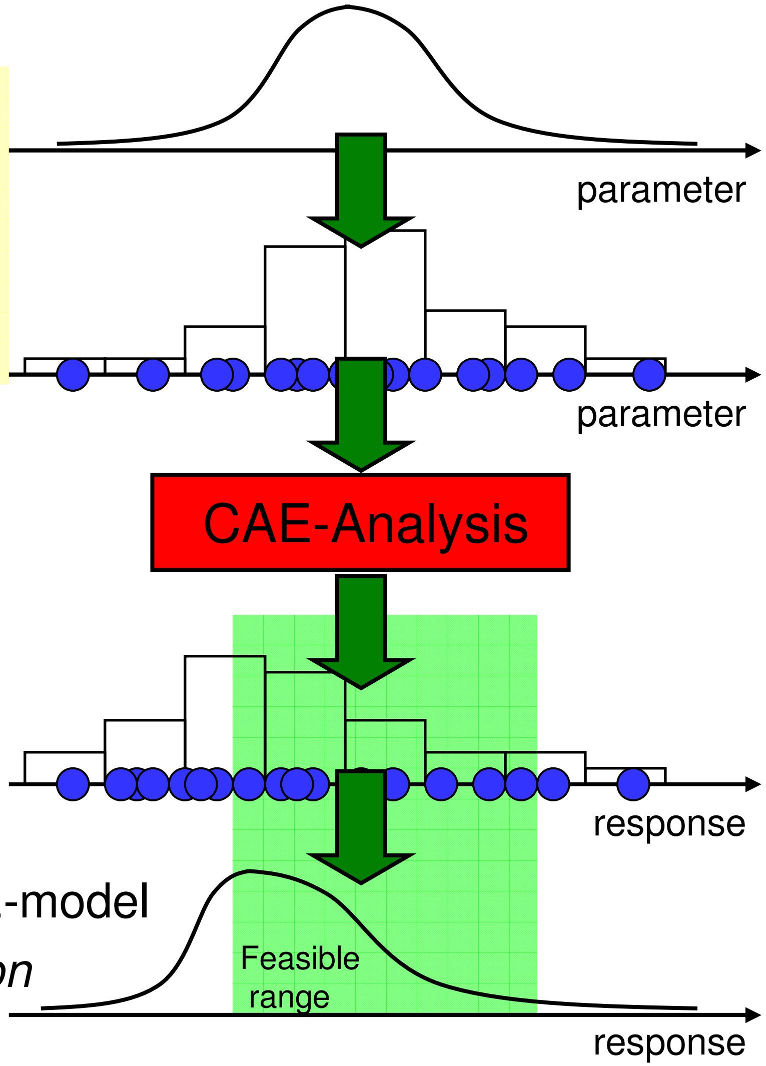


Overview – Optimization Methodologies for highly nonlinear Applications

	Gradient Based Methods	*Random Search*	*Genetic Algorithms*	*RSM / SRSM*
	§ accuracy of solution § number of solver calls	§ very robust, can not diverge § easy to apply	§ good for problems with many local minimas	§ very effective, particularly SRSM § trade-off studies on RS § filter out noise, smoothing of results
	§ can diverge § can stuck in local minimas § step-size dilemma for numerical gradients	§ bad convergence, not effective § Chooses best observation – may not be representative of a good (robust) design	§ many solver calls, only suitable for fast solver runs § Chooses best observation – may not be representative of a good (robust) design	§ approximation error § verification run might be infeasible § number of variables control minimum number of required runs

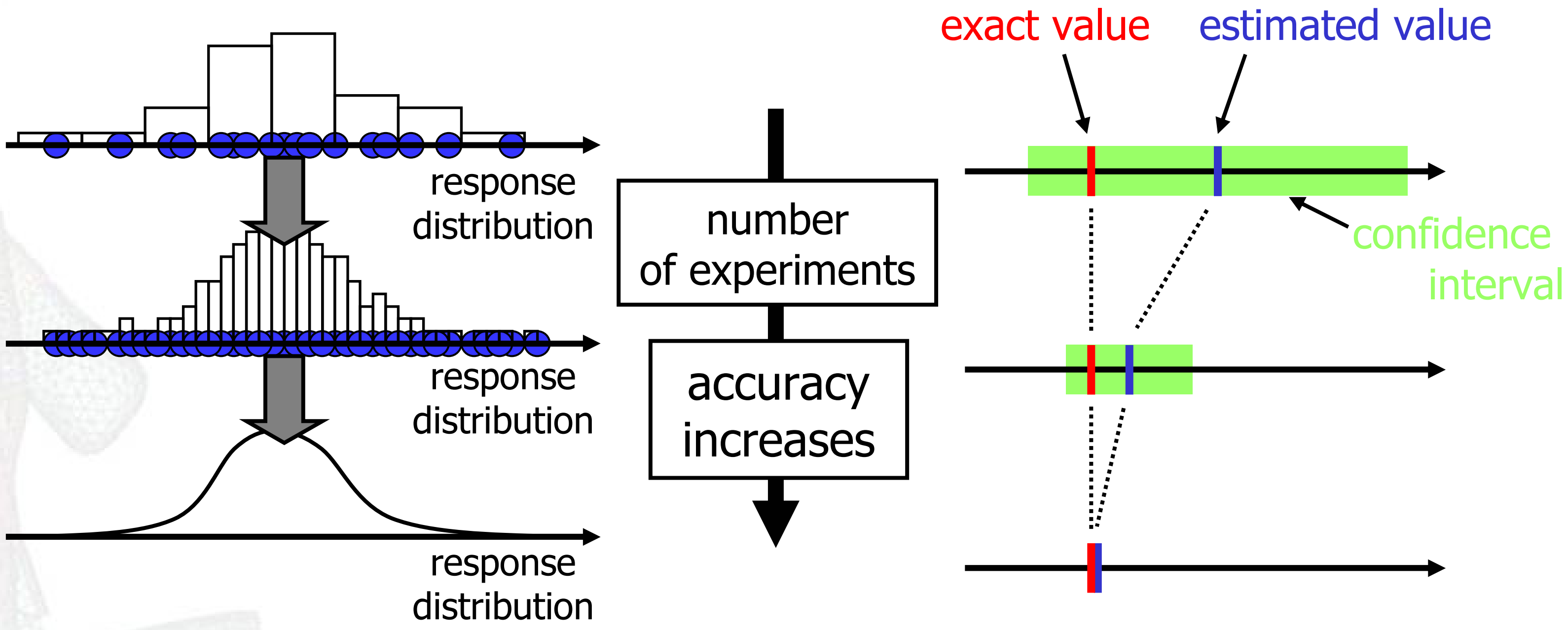
Stochastic Analysis - Goals

- Statistical Quantities of Output (Response) due to Variation of Input (Parameter)
  - *Mean*
  - *Standard deviation*
  - *Distribution function*
- Significance of Parameter with respect to Responses
  - *Correlation analysis*
  - *Stochastic contributions*
  - *ANOVA – analysis of variance*
- Reliability Issues
  - *Probability of failure*
- Visualization of statistical quantities on FE-model
  - *Spatial detection of variation/correlation*



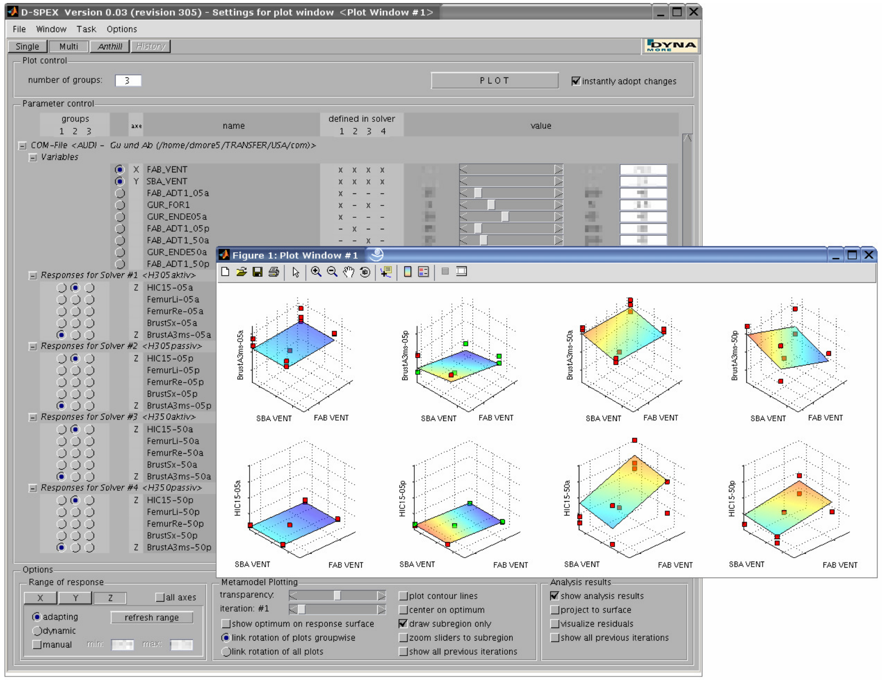
Statistical Quantities of Output due to Variation of Input

- Direct Monte Carlo Sampling
  - *Latin Hypercube sampling*
  - *Large number of FE runs (100+)*
  - *Consideration of confidence intervals for mean, std. dev., correlation coeff.*



Statistical Quantities of Output due to Variation of Input

- Monte Carlo using Meta-Models
  - *Response Surface / Neural Network*
  - *Medium number of FE runs (10 – 30+)*
  - *Number of runs depend on the dimension of the problem (number of variables) and the type of the response surface*
  - *Identify design variable contributions clearly*
  - *Exploration of parameter space ->D-SPEX*



Multi Meta-Model exploration with D-SPEX

Stochastic Analysis - Goals

- Statistical Quantities of Output (Response) due to Variation of Input (Parameter)
  - *mean*
  - *standard deviation*
  - *distribution function*
- Significance of Parameter with respect to Responses
  - *correlation analysis*
  - *stochastic contributions*
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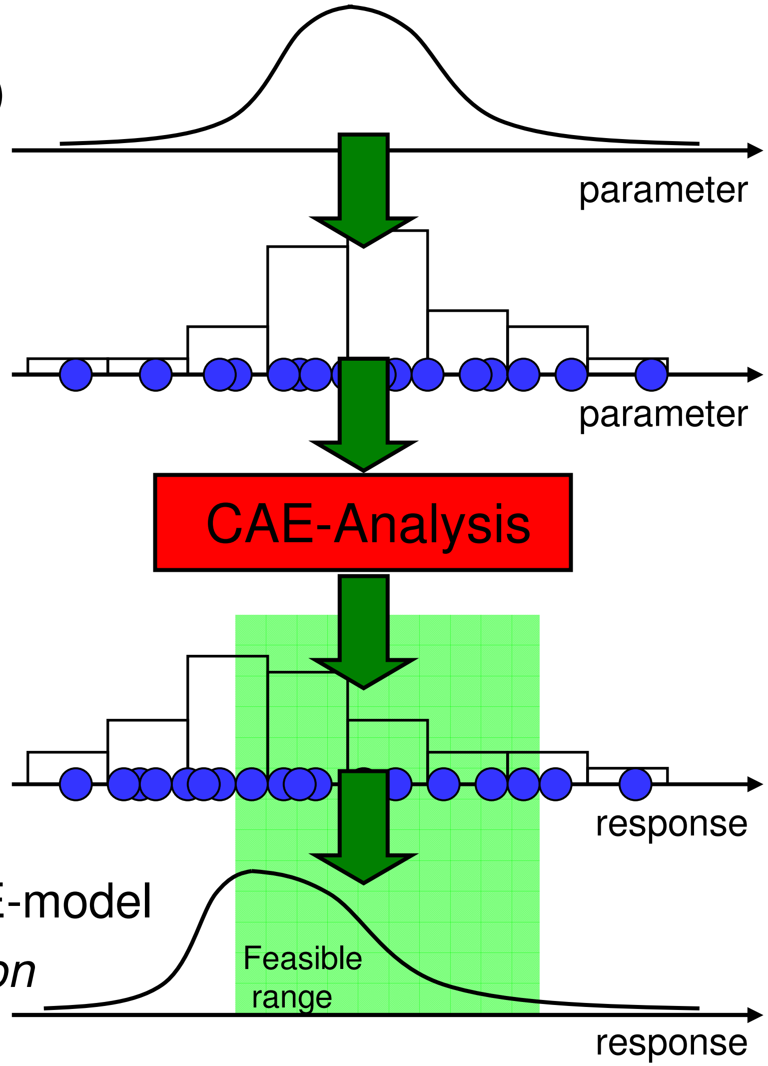
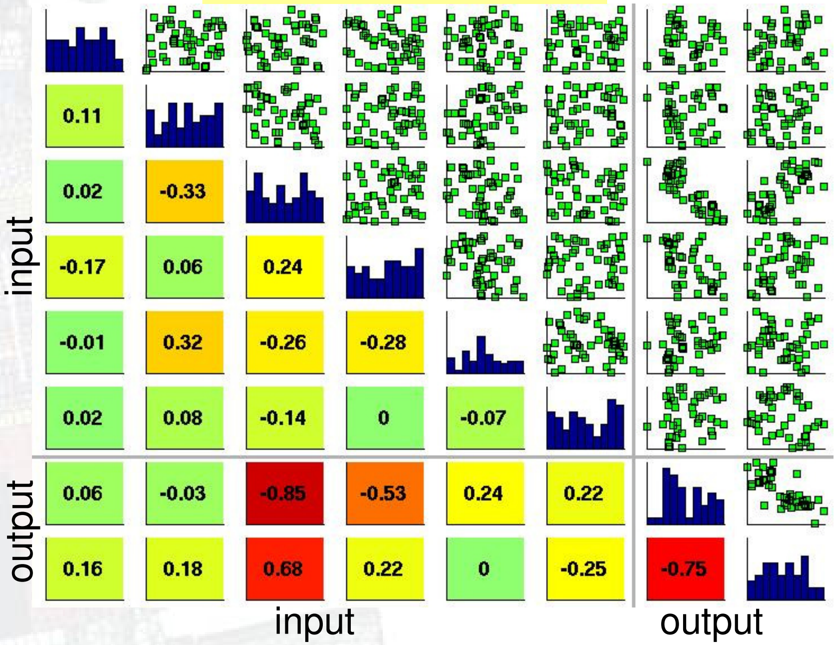
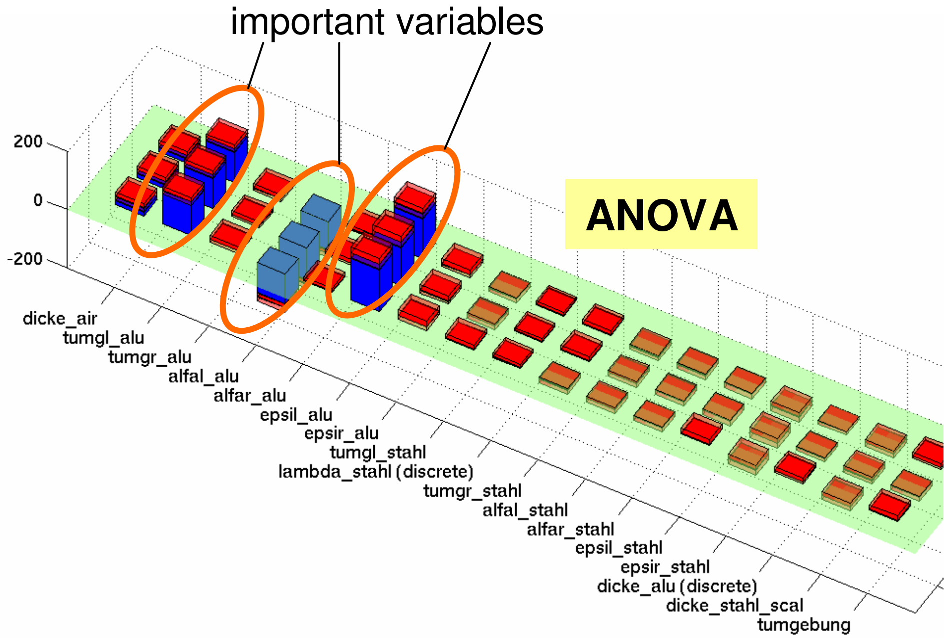


Significance of Variables

- Correlation Analysis
- ANOVA - Meta-Model based
- Stochastic Contributions – Meta-Model based

Correlation Matrix





Stochastic Analysis - Goals

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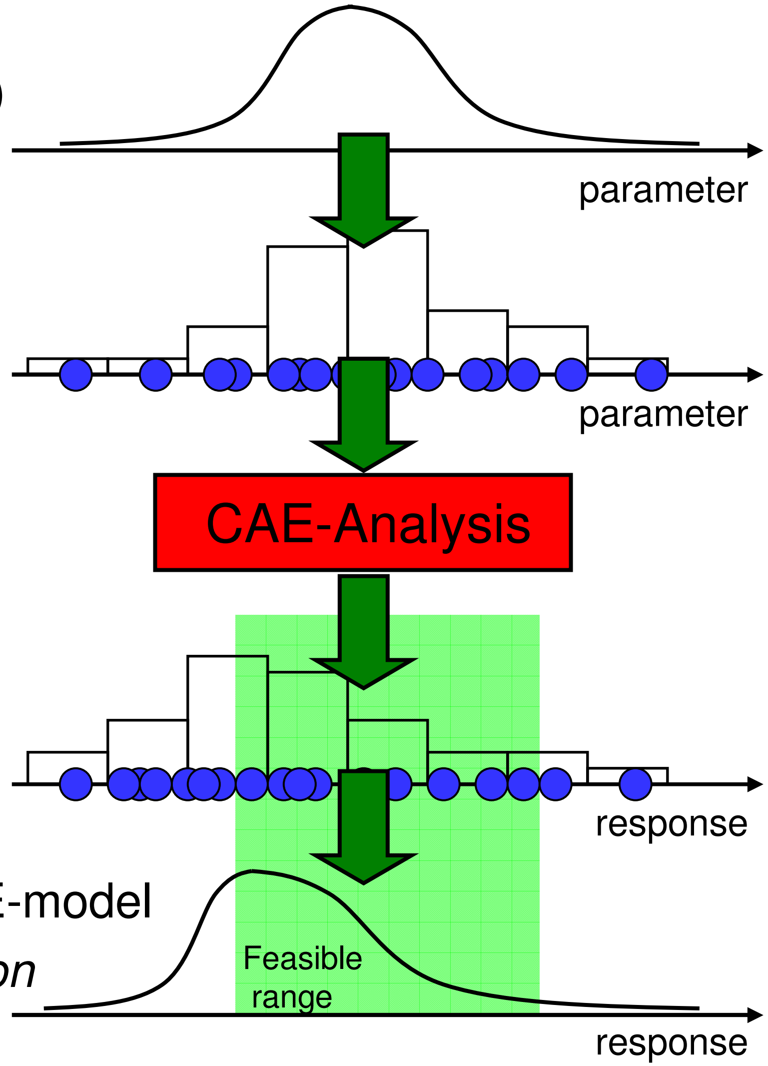
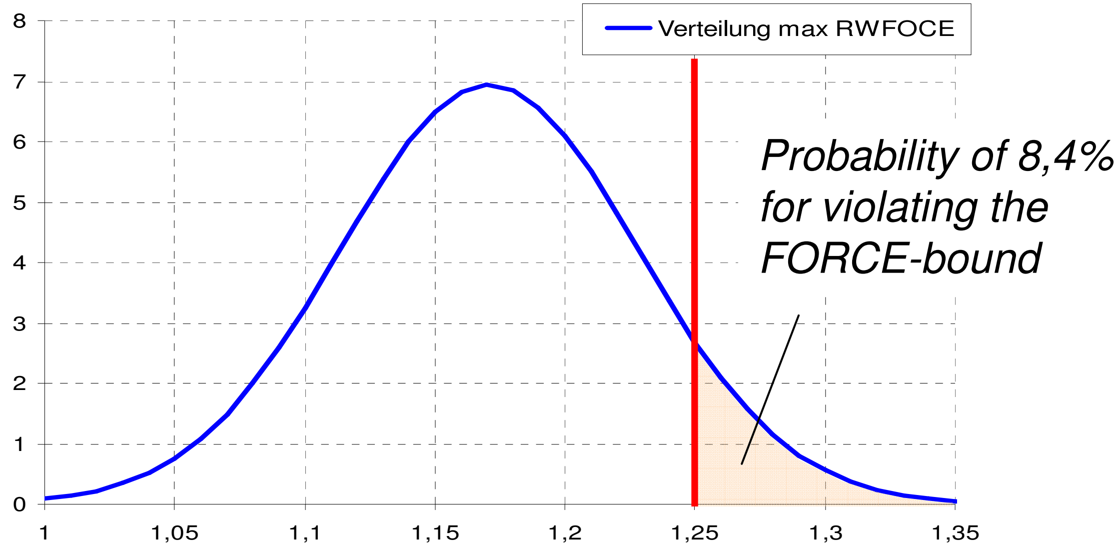


Reliability Analysis

- Probability of failure
- Evaluation of confidence interval
- Prediction error (confidence interval) depends
  - *on the number of runs*
  - *on the probability of event*
  - *not on the dimension of the problem (number of design variables)*



Stochastic Analysis - Goals

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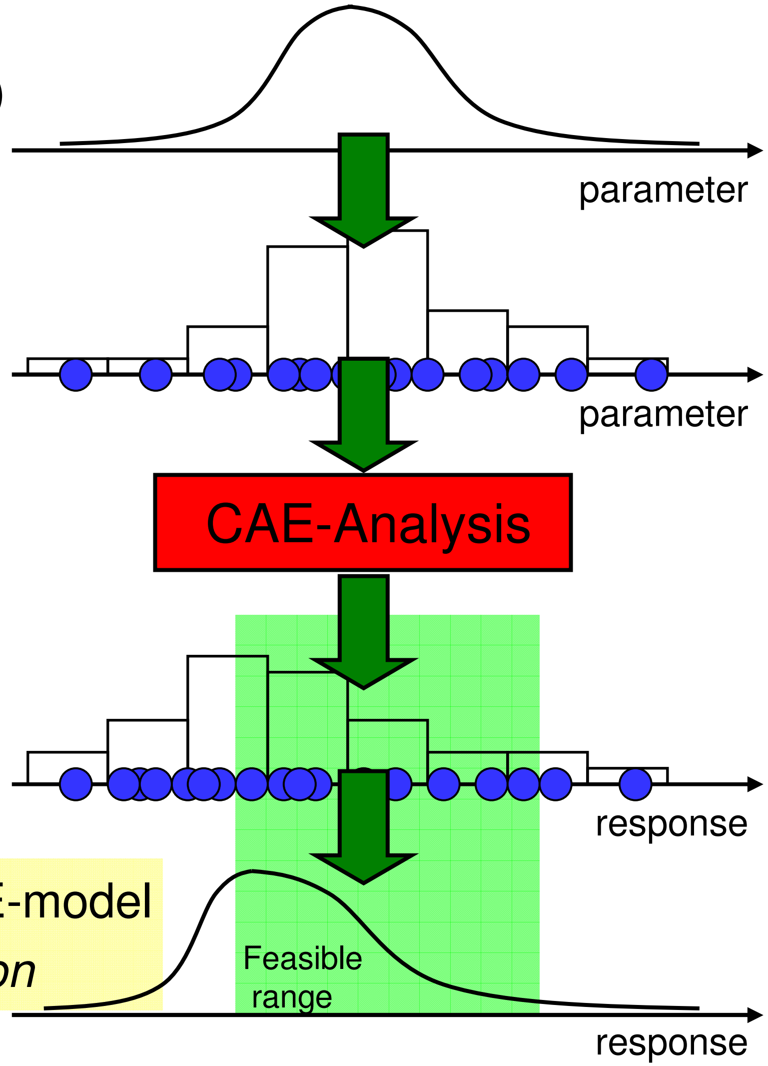
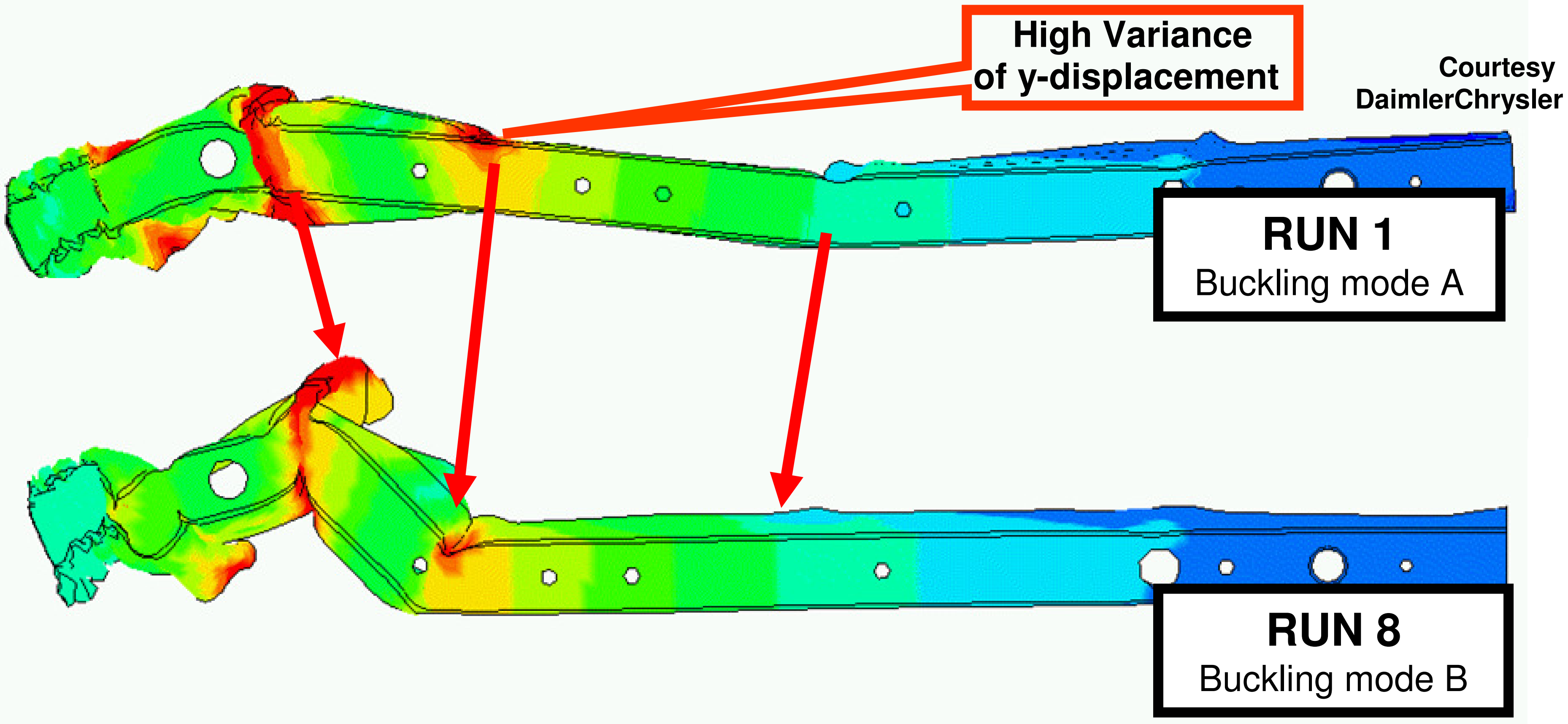


Visualization of Statistical Quantities on FE-model

- Standard deviation of y-displacements of each node (40 runs)

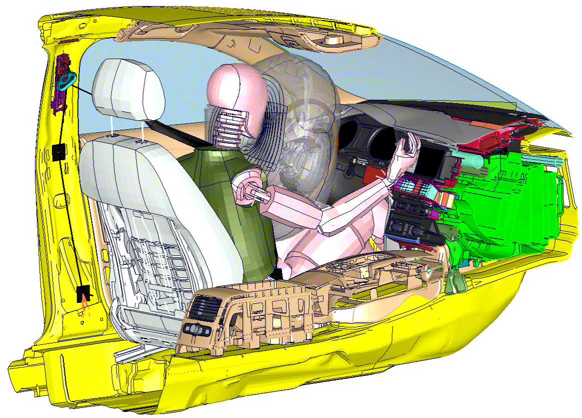


Optimization of an Adaptive Restraint System

- Four Different Front-Crash Load Cases (FMVSS 208)

Dummy	56 km/h – belted	40 km/h – not belted
Hybrid III 5th Female	**H305a**(ktiv)	**H305p**(assiv)
Hybrid III 50th Male	**H350a**(ktiv)	**H350p**(assiv)

- PAM-Crash Model
  - *about 500000 elements*
  - *wall clock simulation time ~19 h, 4 cpus, distributed memory*

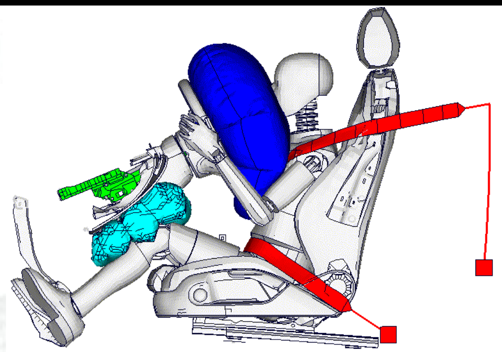


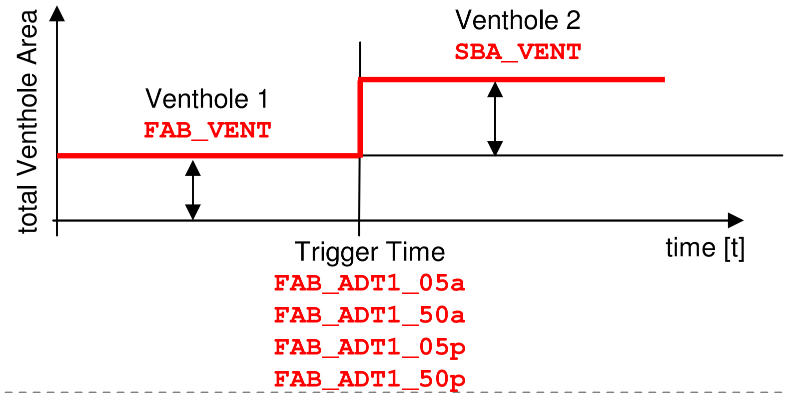
- Load Case Detection available
  - *Differentiation of the loadcases* ***belted*** */* ***not belted*** *and* ***"Hybrid III 5th Female"*** */* ***„Hybrid III 50th Male"*** *possible*
  - *Trigger time for seatbelt, airbag and steering column might be different*

Design Variables

- Adaptive Airbag Deployment (6 Variables)

	H305a 5%-dummy, belted	H305p 5%-dummy, not belted	H350a 50%-dummy, belted	H350p 50%-dummy, not belted
Area Venthole1 Lower – Upper B.	FAB_VENT	FAB_VENT	FAB_VENT	FAB_VENT
Area Venthole2 Lower – Upper B.	SBA_VENT	SBA_VENT	SBA_VENT	SBA_VENT
Trigger Time Lower – Upper B.	FAB_ADT1_05a	FAB_ADT1_05p	FAB_ADT1_50a	FAB_ADT1_50p

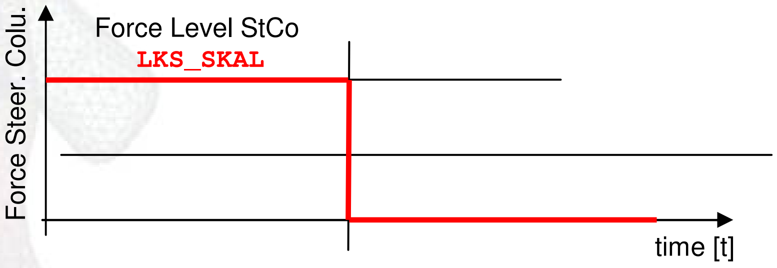


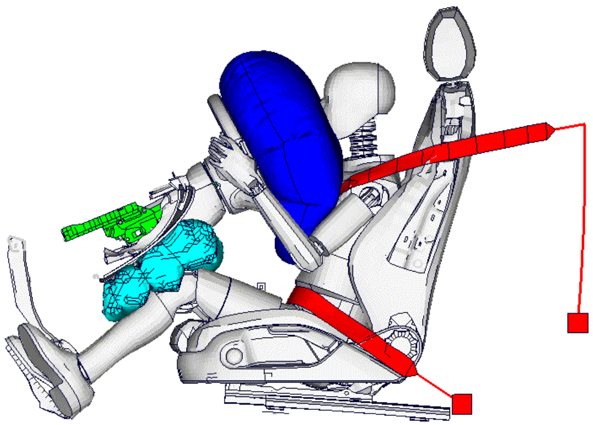


Design Variables

- Adaptive Steering Column (5 Variables)

	H305a 5%-dummy, belted	H305p 5%-dummy, not belted	H350a 50%-dummy, belted	H350p 50%-dummy, not belted
Force Level StCo	LKS_SKAL	LKS_SKAL	LKS_SKAL	LKS_SKAL
Lower – Upper Bound				
Trigger Time	LKS_DOWN05a	LKS_DOWN50a	LKS_DOWN05p	LKS_DOWN50p
Lower – Upper Bound				

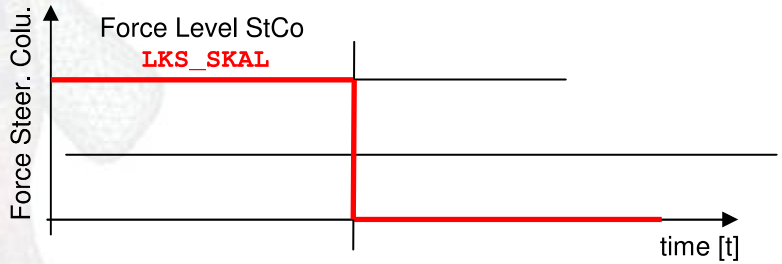


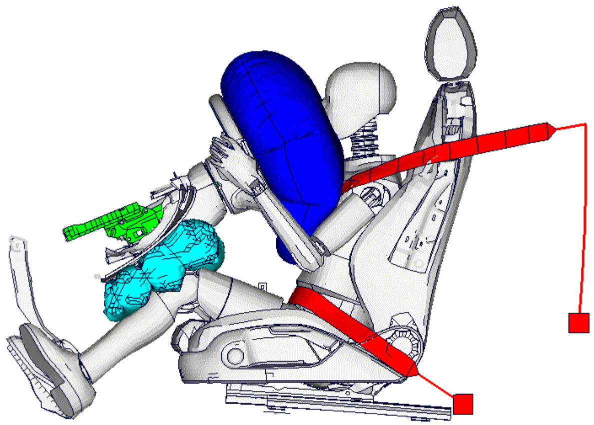


Design Variables

- Adaptive Steering Column (5 Variables)

	H305a 5%-dummy, belted	H305p 5%-dummy, not belted	H350a 50%-dummy, belted	H350p 50%-dummy, not belted
Force Level StCo	LKS_SKAL	LKS_SKAL	LKS_SKAL	LKS_SKAL
Lower – Upper Bound				
Trigger Time	LKS_DOWN05a	LKS_DOWN50a	LKS_DOWN05p	LKS_DOWN50p
Lower – Upper Bound				



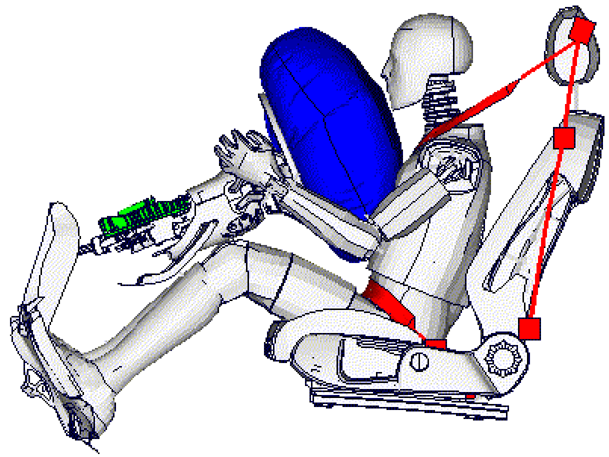


Example I - Optimization

Optimization Problem

- Objective
  - *Minimize Thorax Acceleration*

    -> min BrustA3ms-05a
    -> min BrustA3ms-50a
    -> min BrustA3ms-05p
    -> min BrustA3ms-50p



- Constraints < 80% of regulation requirements
  - *Head Injury Coefficient (15ms)*

    -> HIC15-05a
    -> HIC15-50a
    -> HIC15-05p
    -> HIC15-50p
  - *Thorax Intrusion*

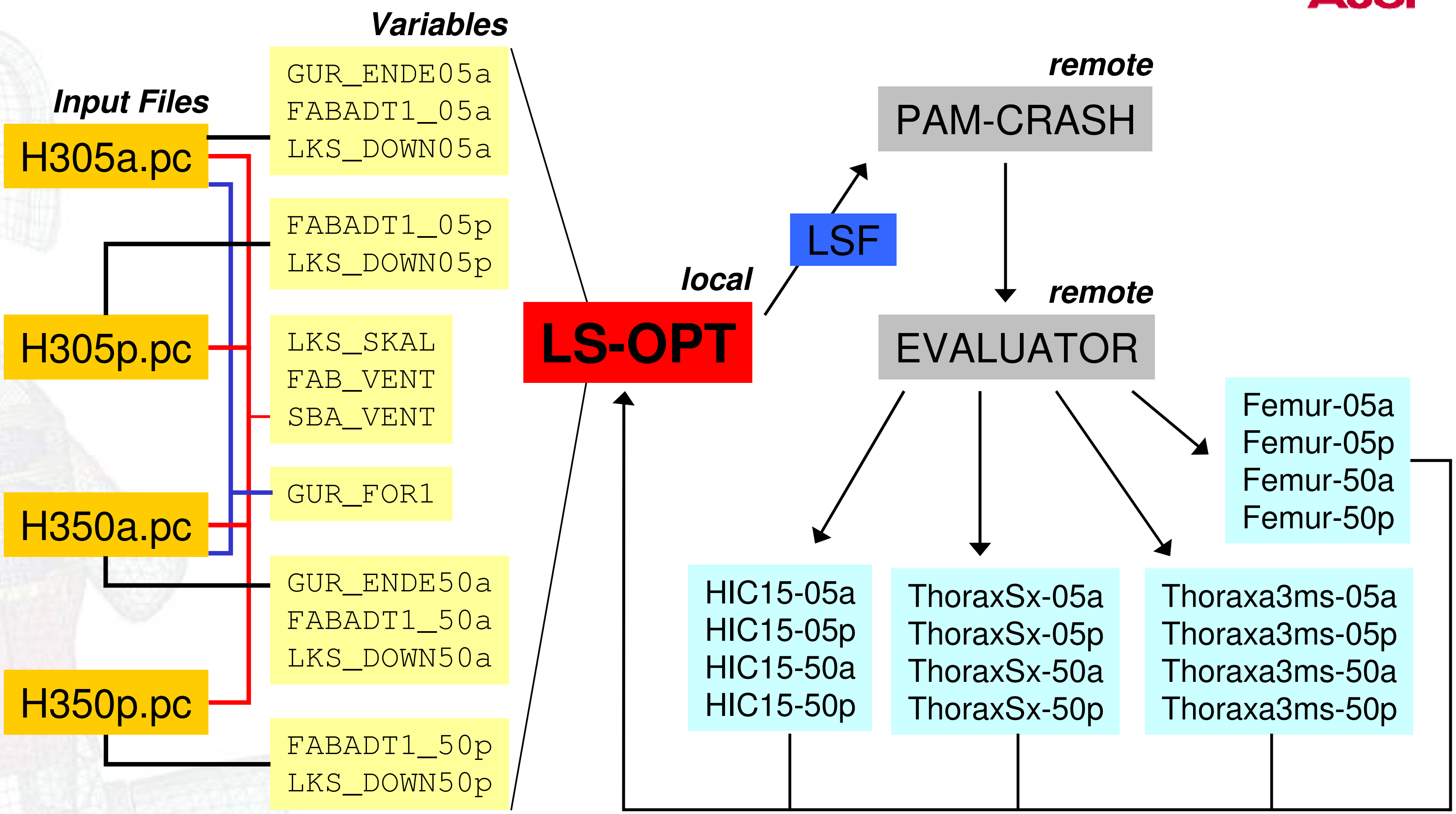
    -> BrustSx-05a
    -> BrustSx-50a
    -> BrustSx-05p
    -> BrustSx-50p
  - *Femur Forces (left/right)*

    -> FemurLi-05a
    -> FemurLi-50a
    -> FemurLi-05p
    -> FemurLi-50p
  - *Thorax Acceleration*

    -> BrustA3ms-05a
    -> BrustA3ms-50a
    -> BrustA3ms-05p
    -> BrustA3ms-50p

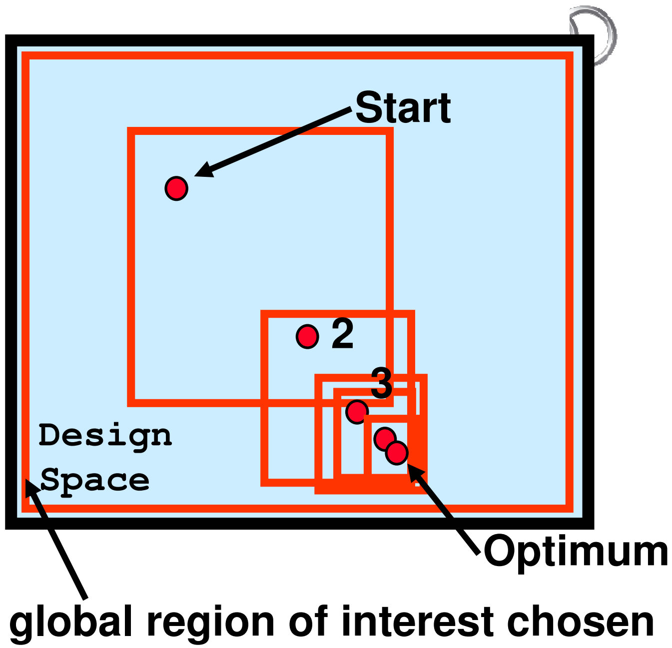
Example I - Optimization

Process Work Flow



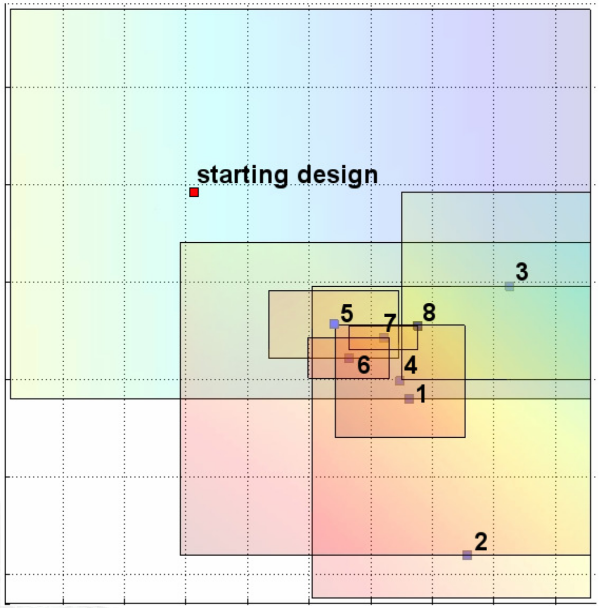
Application of Optimization

- Preferred Configuration at AUDI
  - *Adaptive Restraint System only for Airbag and Seatbelt*
  - *Reduction to 9 Variables in total (active=6, passive=3)*
- LS-OPT Approach: Successive Response Surface Methodology (SRSM) using linear polynomial approximations
  - *34 runs per iteration*
  - *D-optimal Design of Experiments (DOE)*
- Results
  - *8 iterations - total runs: 276*
  - *all constraints are fulfilled*
  - *minimization of multi-objective (second step) not applied*

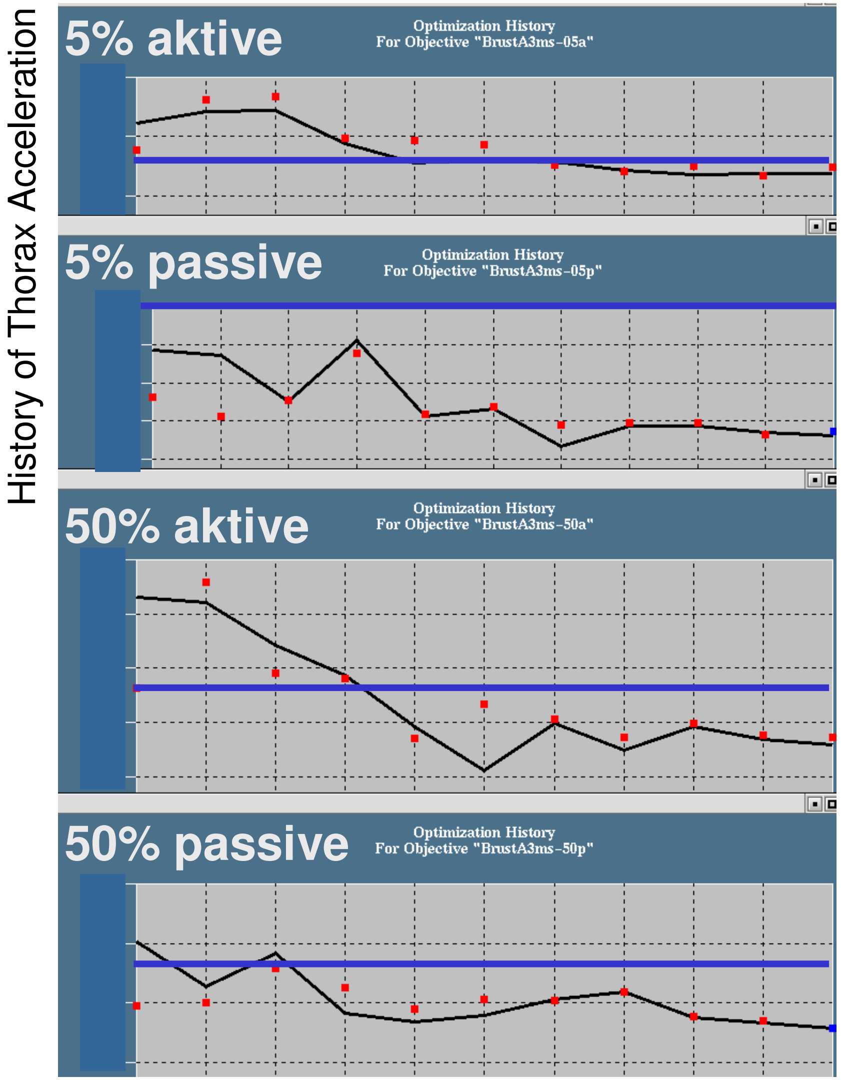


Example I - Optimization

- **Optimization Progress**



a result which meets all requirements is gained in 8 iterations, each with 34 shots



Example I - Optimization

Parameter Identification of Plastic Material

- Material properties: nonlinear visco-elastic behaviour
- LS-DYNA hyperelastic/viscoelastic formulation - *MAT_OGDEN_RUBBER (#77)
- Hyperelasticity

$$W = \sum_{i=1}^{3} \sum_{j=1}^{n} \frac{\mu_j}{\alpha_j}\left(\lambda_i^{\alpha_j} - 1\right) + \frac{1}{2}K(J-1)^2$$

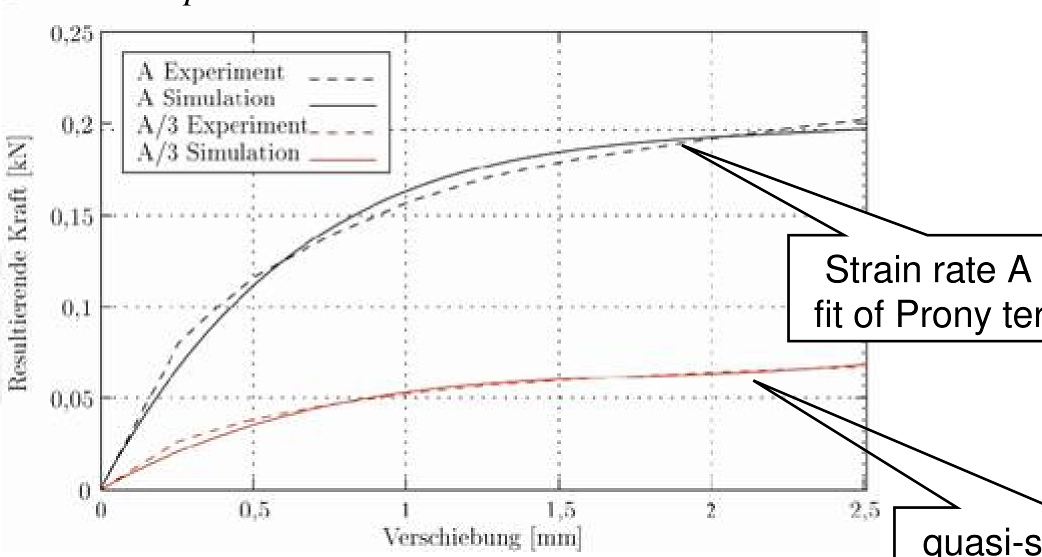
- Prony series representing the viscos-elastic part (Maxwell elements):

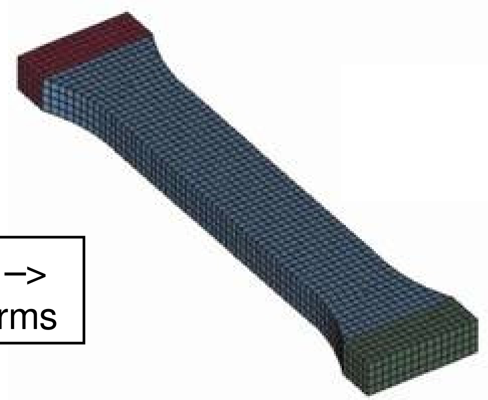
$$g(t) = \sum_{m=1}^{N} G_m e^{-\beta_m t} \quad ; \; \text{N=1, 2, 3, 4, 5, 6} \quad ; \; \sigma_{ij} = \int_0^t g_{ijkl}(t-\tau)\frac{\partial \varepsilon_{kl}}{\partial \tau} d\tau$$

Parameter Identification of Plastic Material

- Minimize the distance between experimental curve and simulation curve
- Least-Squares Objective Function

$$F(\mathbf{x}) = \sum_{p=1}^{P} \{[y(\mathbf{x}) - f(\mathbf{x})]^2\} \rightarrow \min F(\mathbf{x})$$

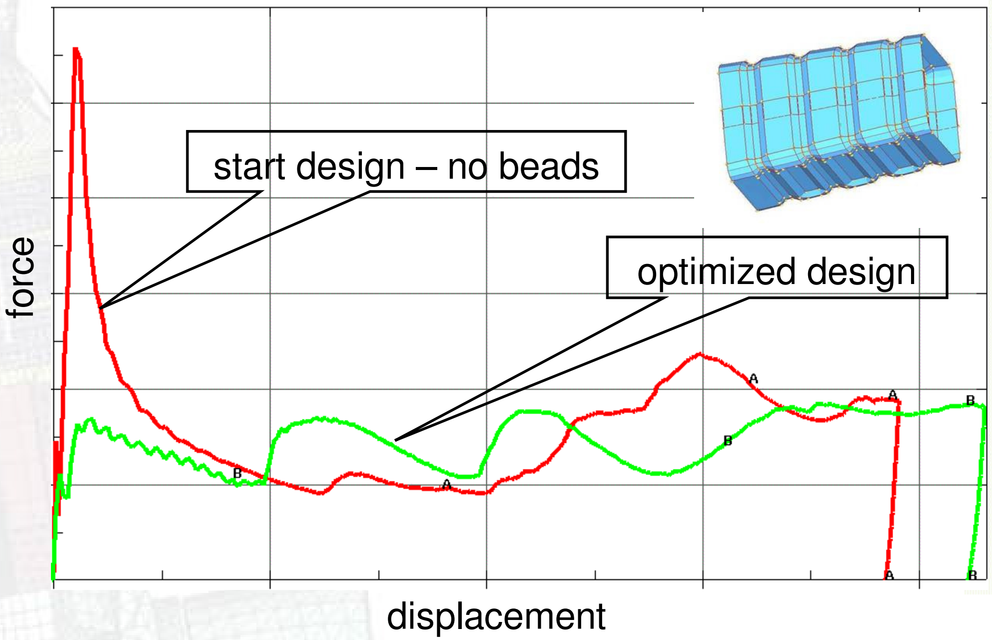


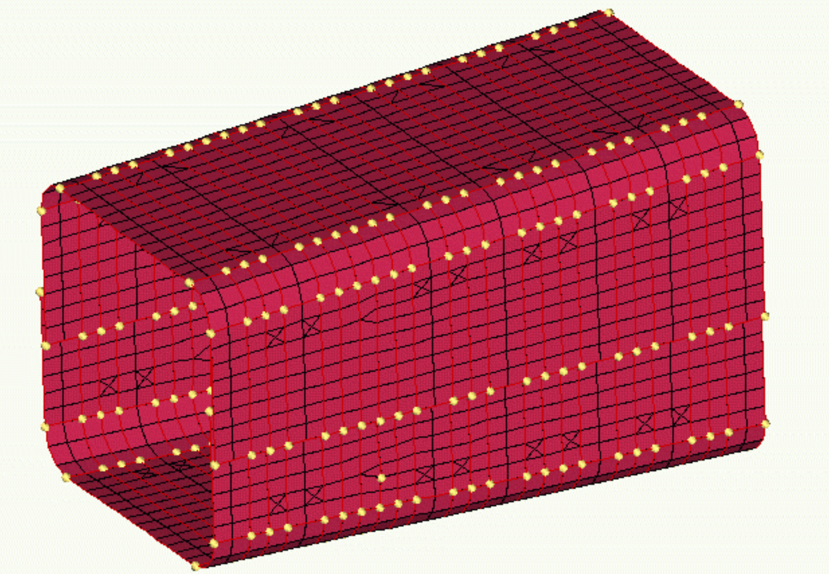


Example III – Optimization

Shape Optimization of a Crash Box

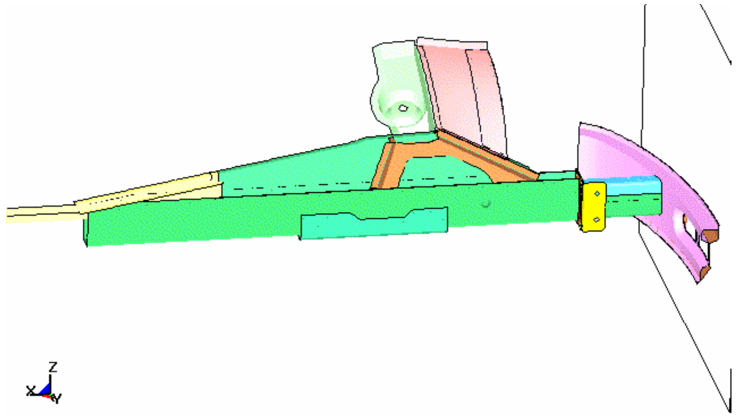
- Scope of optimization:
  - *minimize the maximum crash force*
  - *steady-going force progression*
- Shape variation by using Hypermorph and LS-OPT (20 design variables)





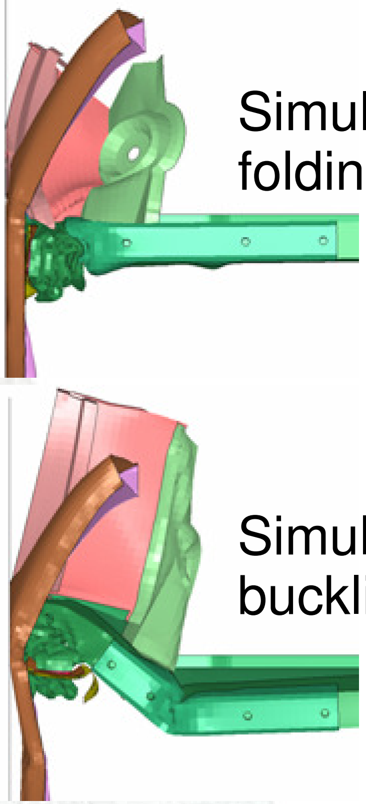
Robustness Investigations – Monte Carlo Analysis

- Variation of sheet thicknesses and yield stress of significant parts in order to consider uncertainties
- Normal distribution is assumed
  - *T_1134 (Longitudinal Member)* *mean = 2.5mm;* *σ = 0.05mm*
  - *T_1139 (Closing Panel)* *mean = 2.4mm;* *σ = 0.05mm*
  - *T_1210 (Absorbing Box)* *mean = 0.8mm;* *σ = 0.05mm*
  - *T_1221 (Absorbing Box)* *mean = 1.0mm;* *σ = 0.05mm*
  - *SF_1134 (Longitudinal Member)* *mean = 1.0 ;* *σ = 0.05*
- Monte Carlo analysis using 182 points (Latin Hypercube)



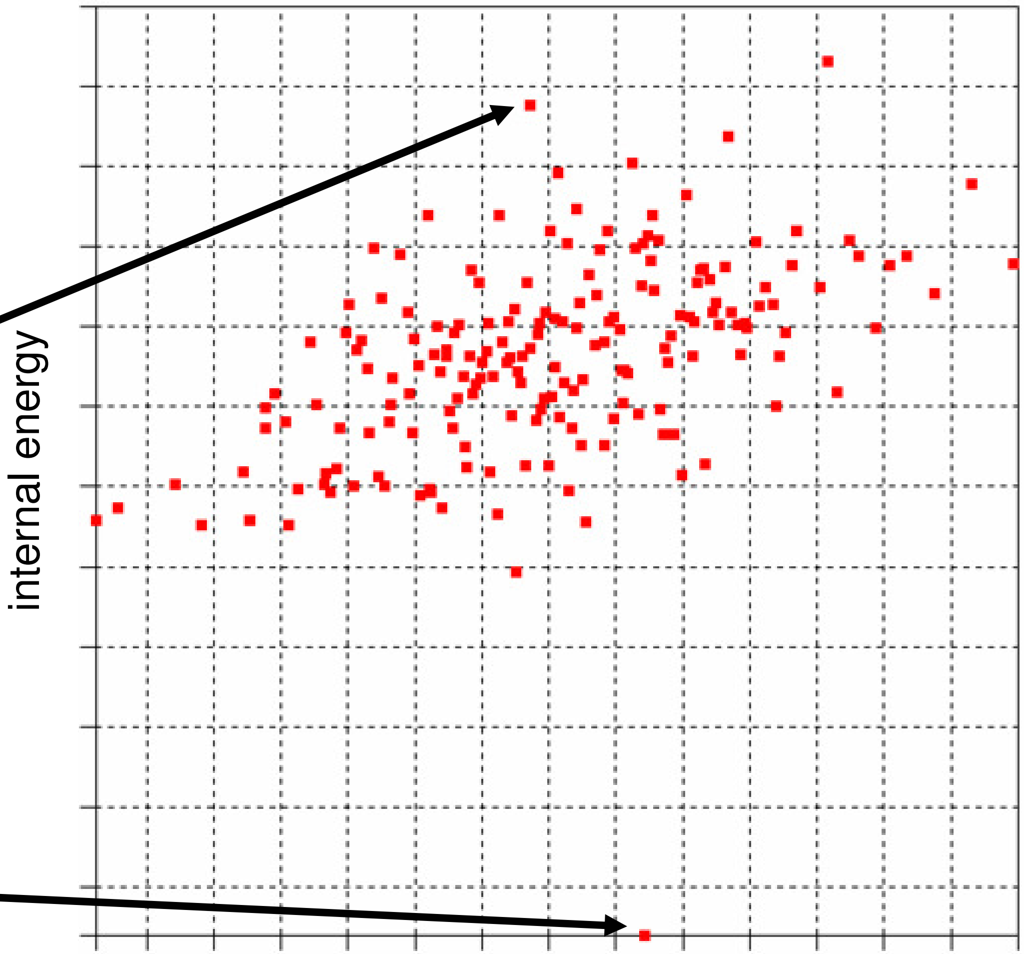
Tradeoff Plot

- Monte Carlo Simulation
- Identification of Clustering



Simulation 185
folding

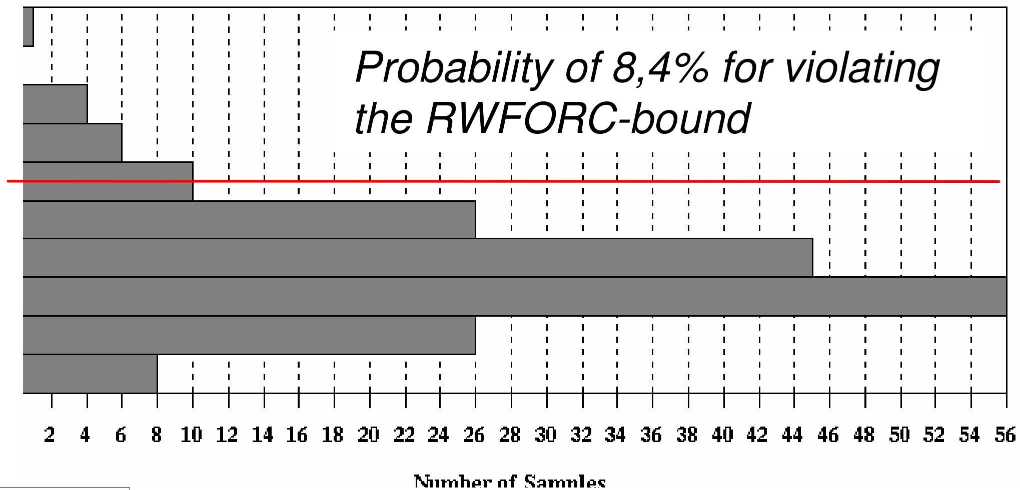
Simulation 47
buckling



Example I – Robustness

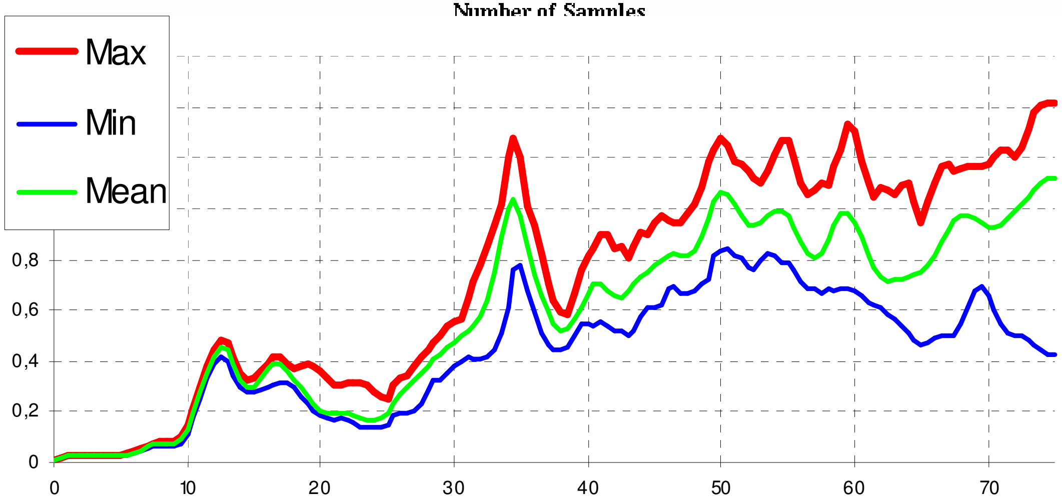
Reliability Analysis

- Histogram of distribution
- Probability of exceeding a constraint-bound

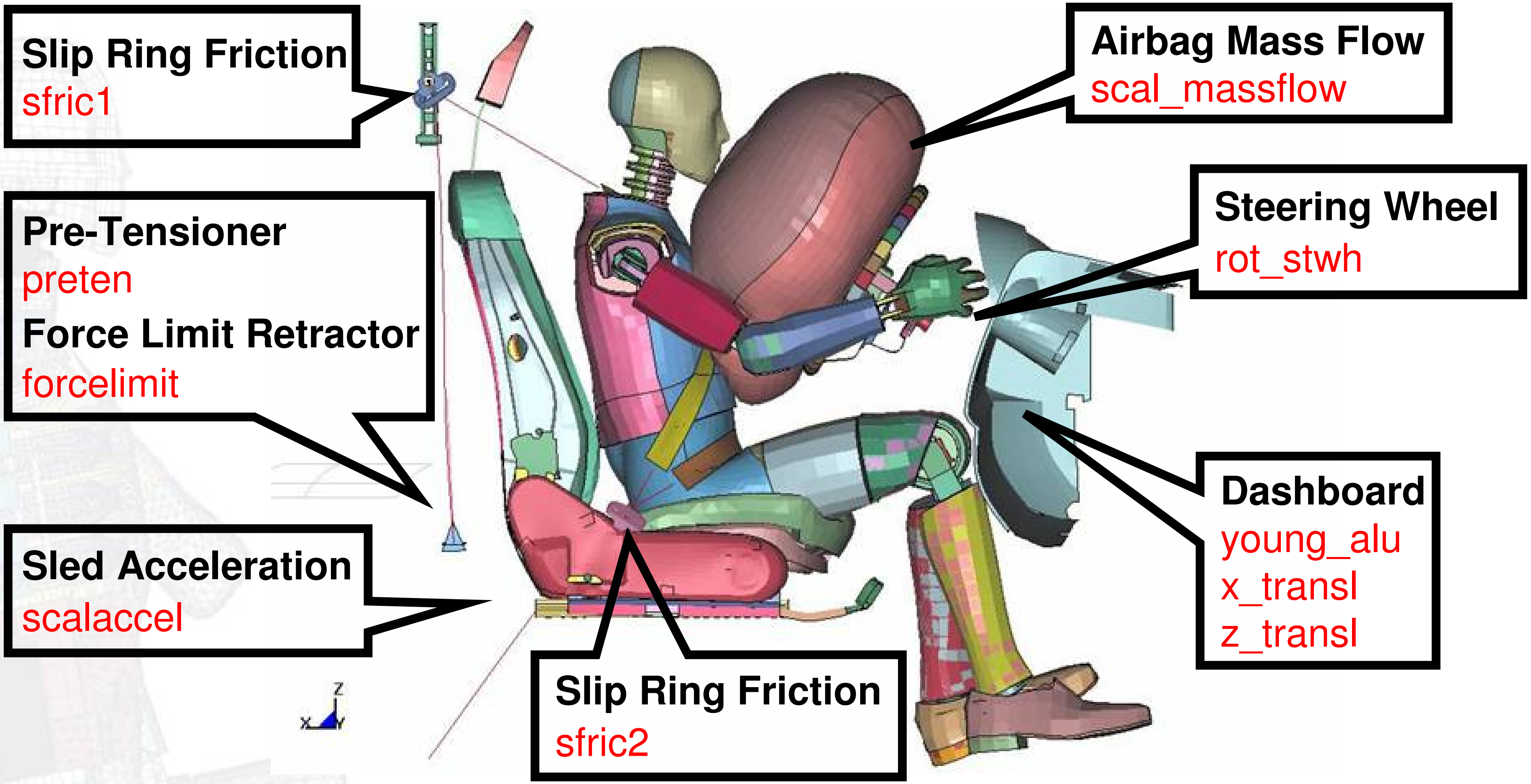


Min-Max Curves

- Plot of minimum, maximum and mean history values
- Gives a confidence interval of history values



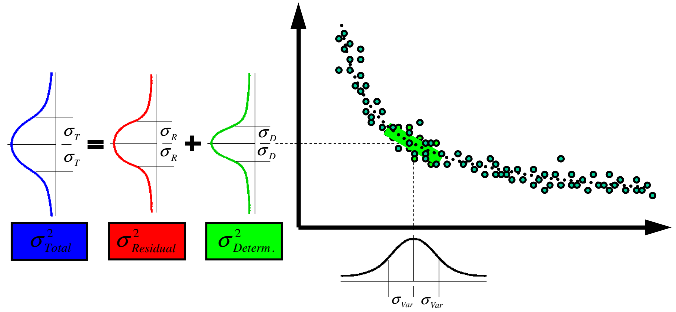
Design Variables - Uncertainties in Test Set-Up



Example II – Robustness

Stochastic Contribution - Results of 30 Experiments

Design Variable	Standard Deviation of Design Variable	Standard Deviation Contribution: HIC36	max_chest_intru	max_b_f_shoulder	max_bf_pelvis	max_chest	max_pelvis
scalaccel	2,5%	3,1%	1,5%	0,1%	2,3%	1,9%	2,9%
sfric1	25,0%	1,3%	0,6%	4,1%	1,8%	0,7%	0,7%
sfric2	25,0%	0,5%	0,6%	0,1%	3,7%	0,1%	0,1%
preten	4,4%	0,0%	0,5%	0,0%	1,1%	0,3%	0,2%
forcelimit	5,6%	1,3%	0,4%	4,4%	0,6%	1,4%	0,2%
rot_stwh	4,8%	0,5%	0,1%	0,1%	0,0%	0,1%	0,1%
transl_x	50,0%	0,1%	0,1%	0,7%	4,5%	0,5%	0,8%
transl_z	50,0%	1,2%	1,0%	0,3%	1,6%	0,2%	0,9%
scalmassflow	5,0%	1,8%	1,8%	0,6%	2,2%	0,6%	0,9%
young_alu	5,0%	0,3%	0,3%	0,0%	0,5%	0,1%	0,1%
all variables		4,3%	2,8%	6,1%	7,2%	2,6%	3,4%
residuals		4,7%	1,9%	1,8%	6,0%	3,5%	2,3%
Total		**6,4%**	**3,4%**	**6,3%**	**9,4%**	**4,3%**	**4,1%**



Contribution of variation of design variables to variation of results

Meta-model space

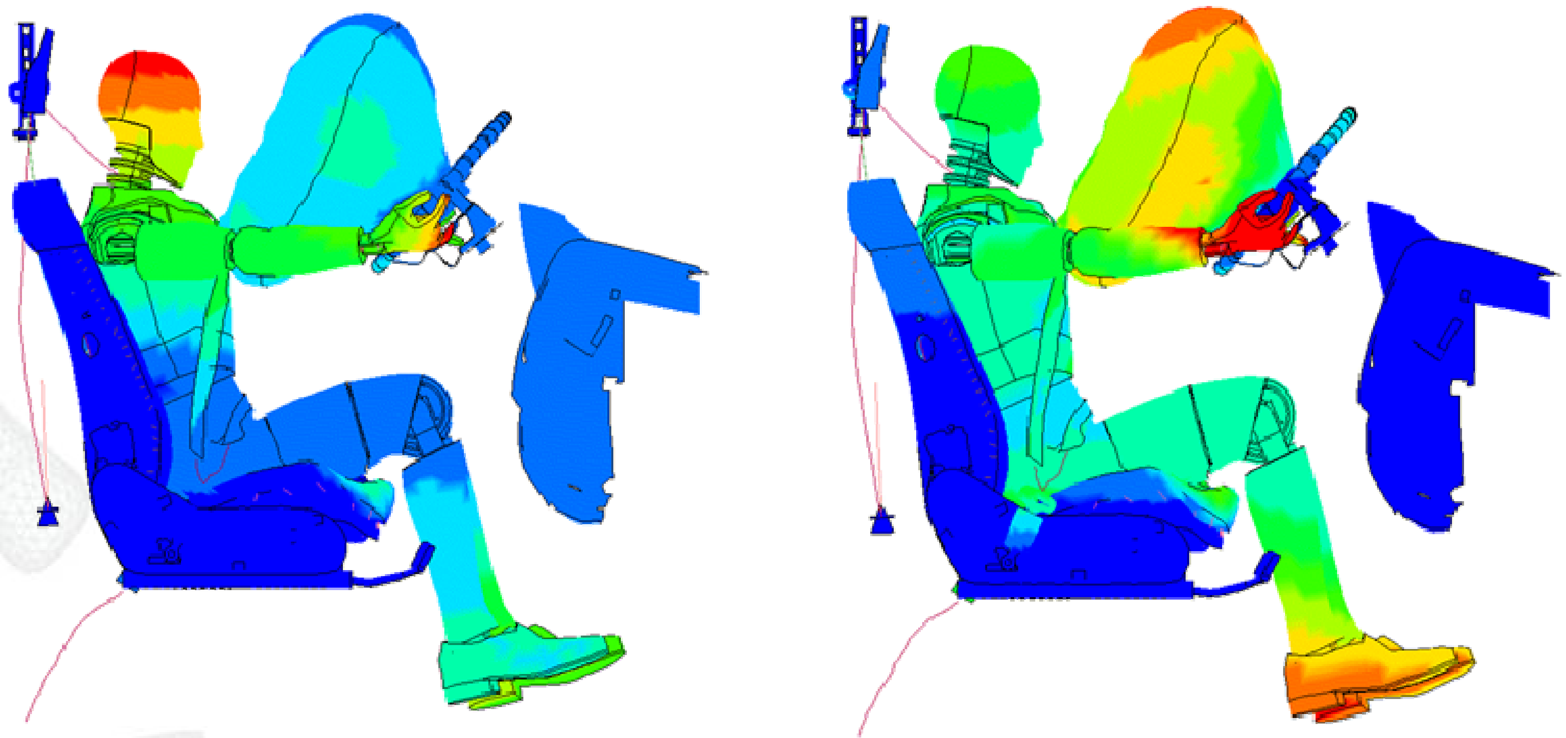
Residual space

Total Variation

- Standard deviation of x-displacements of each node (120 runs)

(a) Deterministic (Meta-Model)

(b) Residual (Outliers)



Version 3.3

- Improvements of Meta-Models
  - *Implementation of Radial Basis Functions*
  - *Speed/Performance enhancements of Neural Networks*
- Genetic Algorithm (MOGA – NSGA-II)
  - *Improve of Multi-Objective Optimization (Pareto Fronts)*
  - *Direct GA available*
- Tied ANSA Interface
  - *User friendly coupling of ANSA*
- Extra Input Files
  - *Additional Input Files containing Variables can be specified*
  - *For other solvers than LS-DYNA*

Version 3.3

- DYNAstats for Metal Forming
  - *Available for adaptive meshing*
  - *Mapping of nodal/element results onto reference mesh*
- 3-D metamodel plot enhancements
  - *Activate Post-Processor on point selection*
  - *Add value list display on point selection (similar to 2D)*
- ANOVA chart enhancements
  - *Positive/negative correlation*
- DOE-Task for Sensitivities and Variable Screening
  - *Dedicated task for DOE-Study (no optimization)*

DYNA MORE

Version 3.3

- Interface for User-defined Meta Models
- Summary Report File
- Import of Check Points
  - *Calculation of predicted values for user-defined points*

Outlook

- Generic File extractor
  - *Extraction of values from any ASCII input file*
- Visualization of “Pareto Fronts” for Multi-Objective Optimization (MOO)
  - *Difficult for more than 3 objectives*
- *Correlated Input Variables for Stochastic Investigations*
- Additional injury criteria (DYNA extraction)
  - *IIHS, neck/tibia indices,…*

Thanks for your attention!