Infotag ANSA/LS-OPT/META

Optimization with LS-OPT: Possibilities and new developments in LS-OPT 6.0

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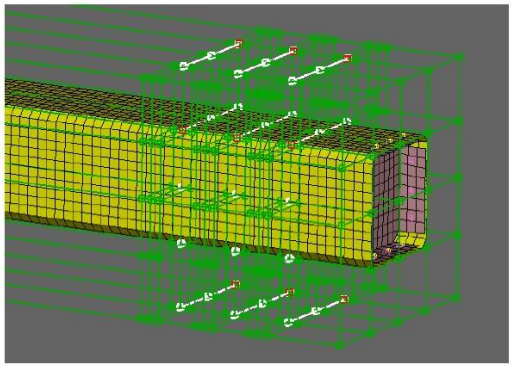
Outline

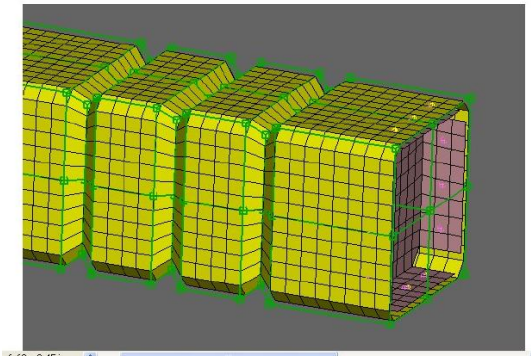
- About LS-OPT
- Methodologies
- Applications of LS-OPT
  - Optimization
  - Sensitivity Analysis
  - Robustness Analysis
- New developments in LS-OPT 6.0
  - DIC-based Parameter Identification
  - Interactive Tables
  - Efficient Global Optimization
  - Support Vector Classification
- Outlook

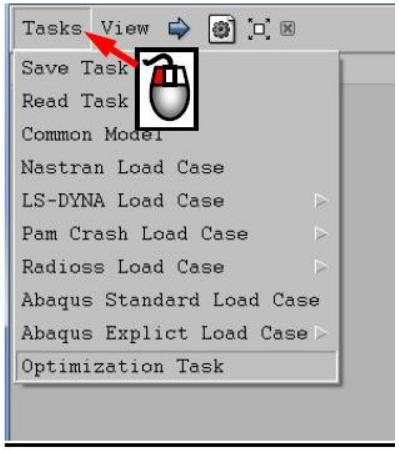
About LS-OPT

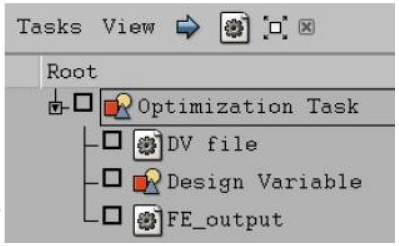
- LS-OPT is a stand alone optimization software
  - → can be linked to any (simulation) code –
    - Current production version is LS-OPT 5.2
    - Windows and Linux versions available
    - Interface to LS-DYNA, Excel, Matlab
    - Interface to LS-PrePost, ANSA, Hypermorph, …
      → **shape optimization**
    - Interface to META Post
      → **result extraction**
    - Interface to LS-OPT
      → **nested optimization**
    - User-defined interface
    - Interface to Queuing Systems
      - PBS, LSF, LoadLeveler, SLURM, AQS, User-defined, …

      → **LS-OPT as process manager**



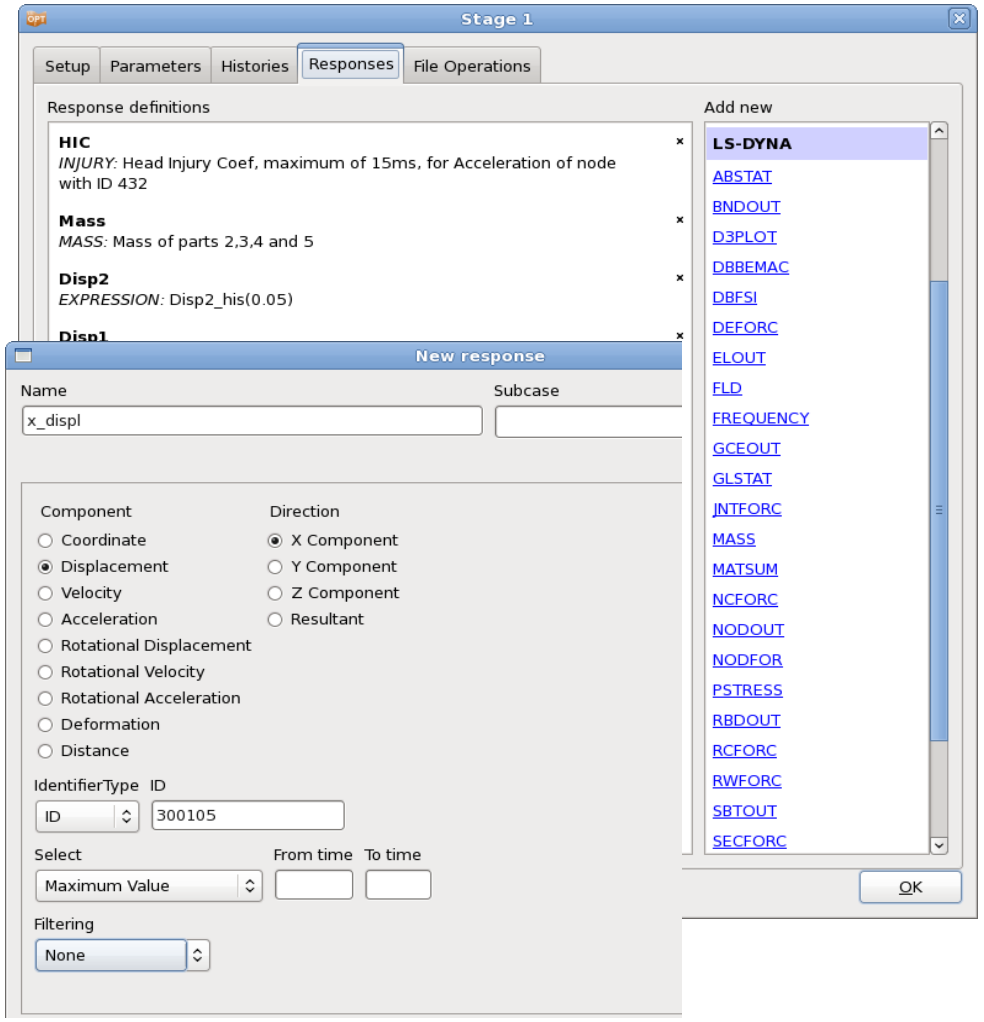






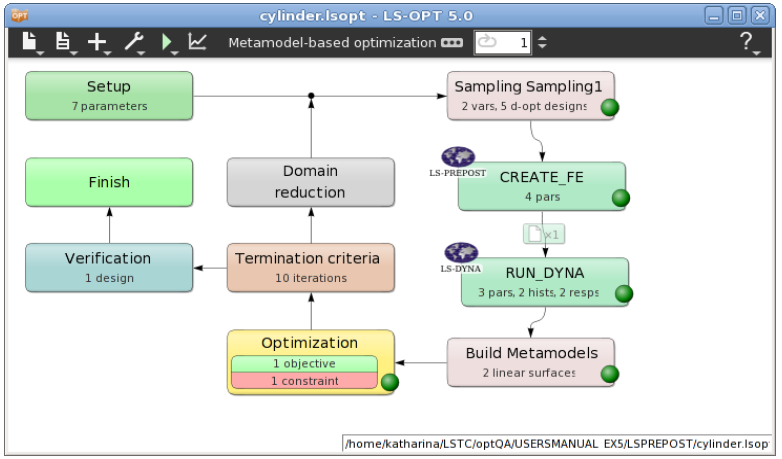
About LS-OPT

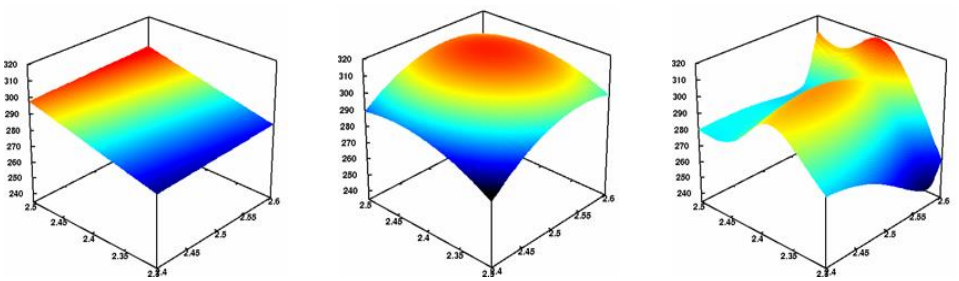
- LS-DYNA integration
  - Importation of design parameters from LS-DYNA keyword files (*PARAMETER)
  - Support of include files (*INCLUDE)
  - Result extraction of most LS-DYNA response types
  - Checking of LS-DYNA keyword files (*DATABASE_)
  - Monitoring of LS-DYNA progress
  - D3plot compression



Methodologies

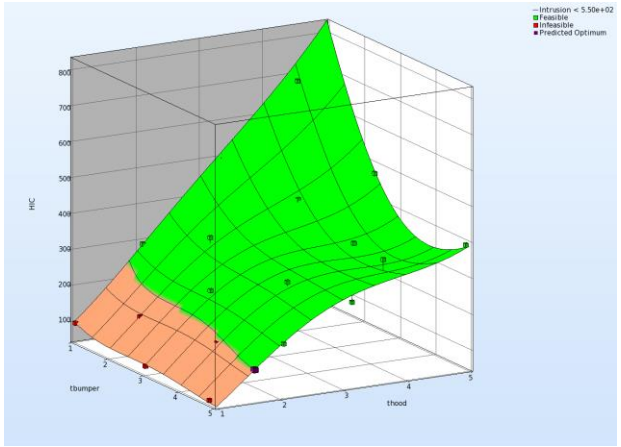
- (Sequential) Response Surface Method ((S)RSM)
  - → Metamodels
    - Polynomials
    - Radial Basis Functions (RBF)
    - Feedforward Neural Networks (FFNN)
- Genetic Algorithm (MOGA->NSGA-II)
  - → Multi-objective Optimization
    - Direct
    - Metamodel-based
- Monte Carlo Analysis
  - → Robustness Analysis
    - Direct
    - Metamodel-based

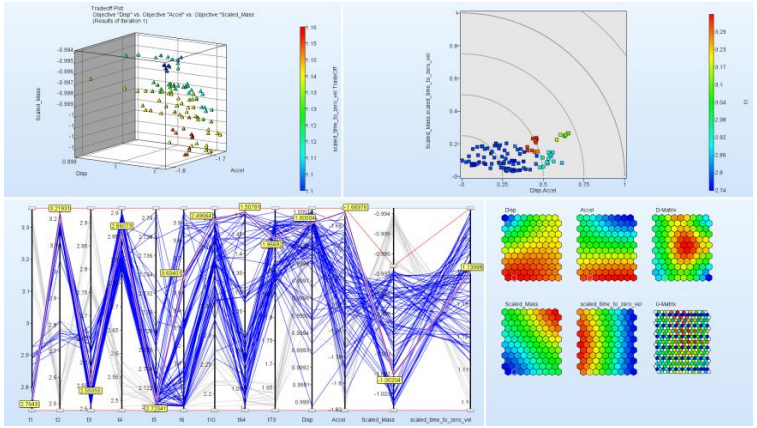




Applications of LS-OPT

- Optimization
  - Size-/Shape optimization
  - Mixed continuous/discrete variables
    - Specify sets of discrete variables (e.g. sheet thicknesses)
  - Parameter/System Identification
  - Multiple load cases
    - Multi-disciplinary Optimization (MDO)
  - Multi-objective optimization (Pareto Frontier)
  - Multi-level optimization
  - Reliability based design optimization
  - Robust parameter design
- Methodologies
  - Meta-model based approaches
  - Genetic Algorithms (MOGA->NSGA-II)

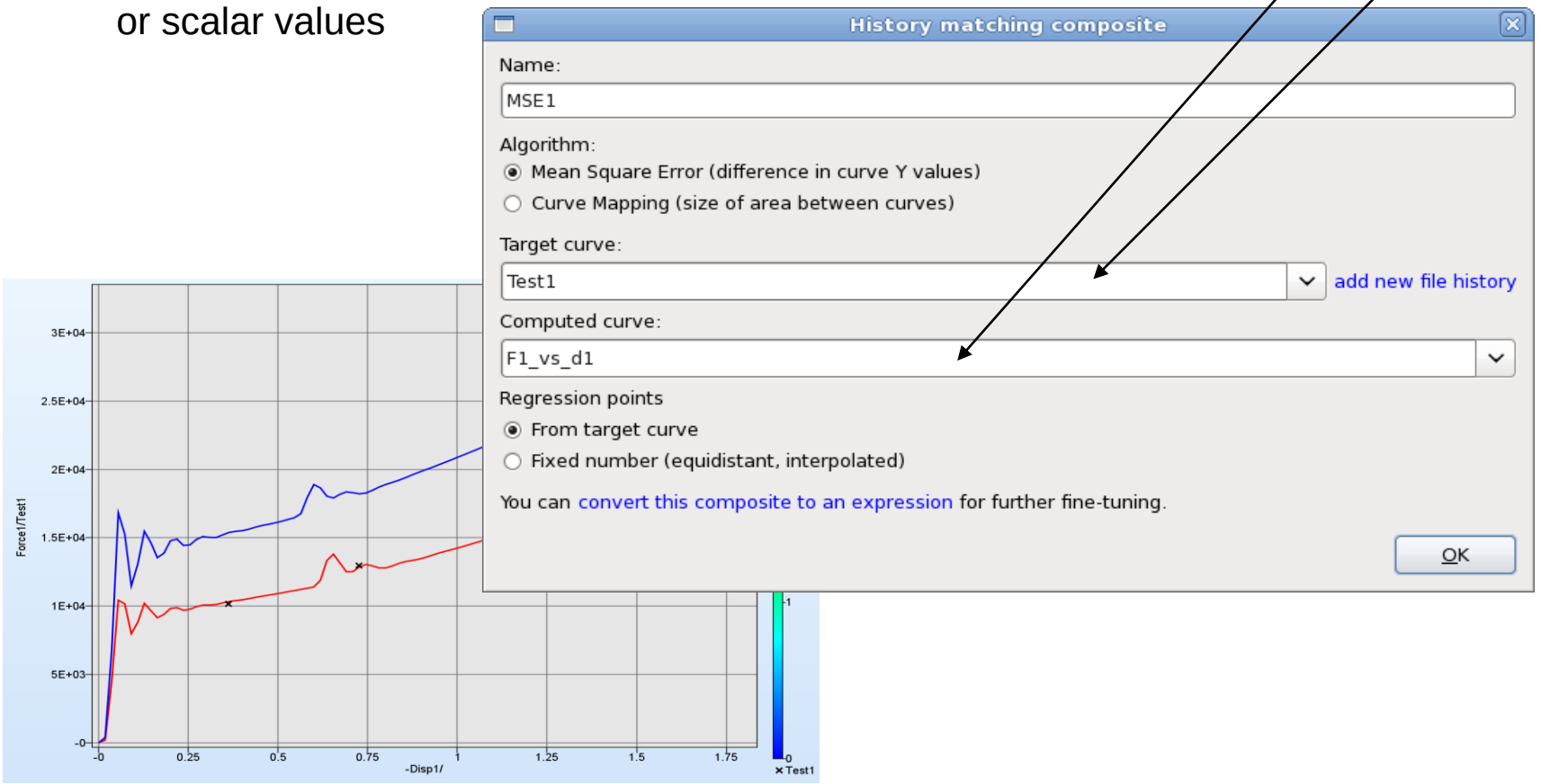




Applications of LS-OPT

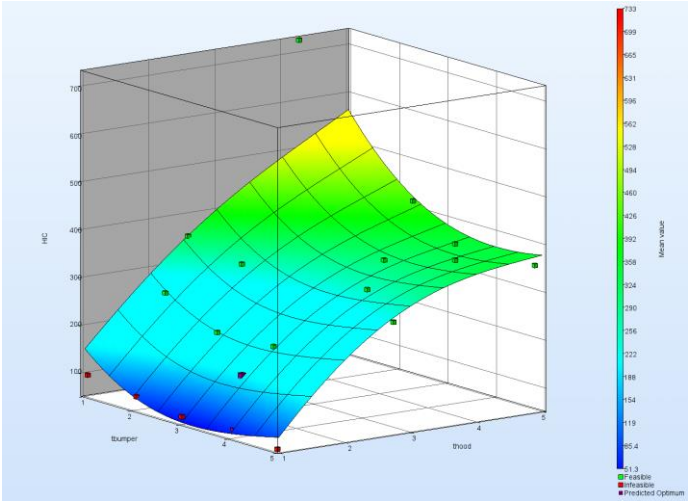
- Optimization
  - Parameter/System Identification Module: Calibration of test and simulation curves or scalar values

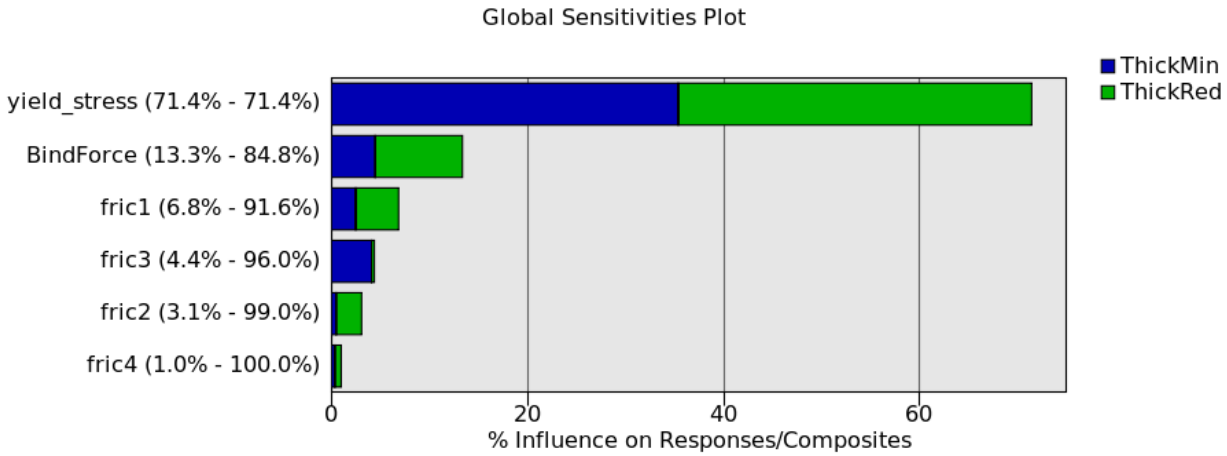
$$\frac{1}{P}\sum_{p=1}^{P} W_i \left(\frac{F_i(\boldsymbol{x}) - G_i}{s_i} \right)^2$$



Applications of LS-OPT

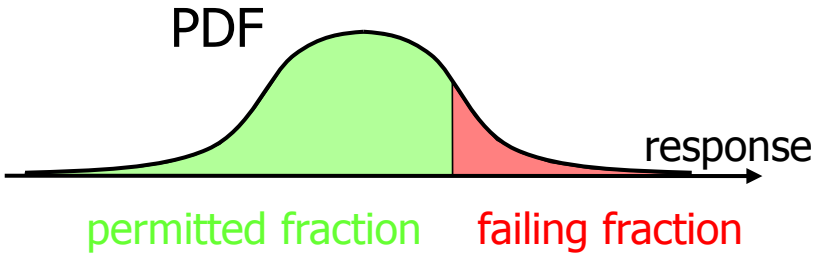
- Sensitivity Analysis
  - Design Exploration
  - DOE Studies for Variable Screening (ANOVA, Sobol)
    - *Contribution of variables to system performance*
    - *Identification of significant and insignificant variables*
    - *Ranking of importance*

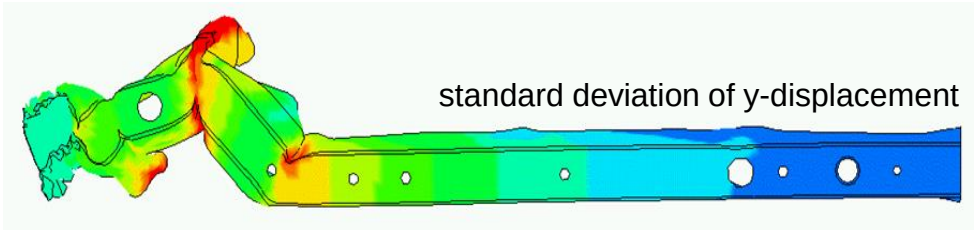


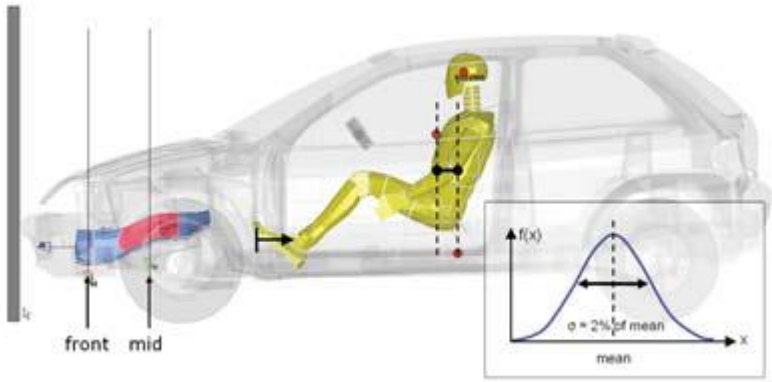


Applications of LS-OPT

- Stochastic/Probabilistic Analysis: Consideration of uncertainties
  - Test of Model Robustness
    - Statistics (mean, standard deviation)
    - Correlation Analysis
  - Reliability (Probability of Failure)
  - Outlier Detection
  - Fringe statistical results on FE model
- Methodology
  - Monte Carlo Analysis
    - Direct
    - Metamodel-based

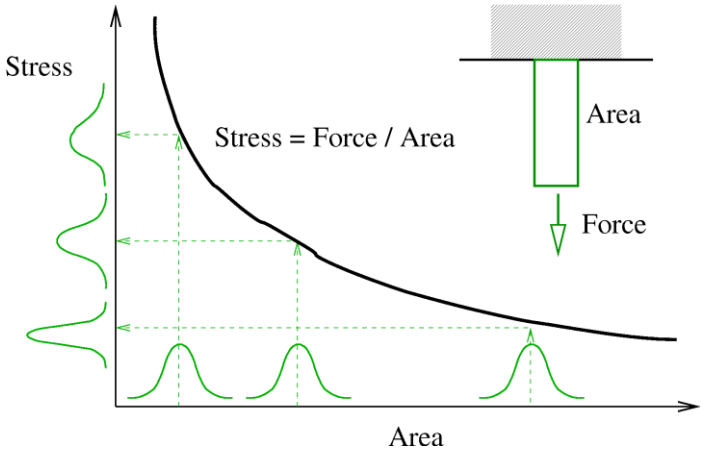


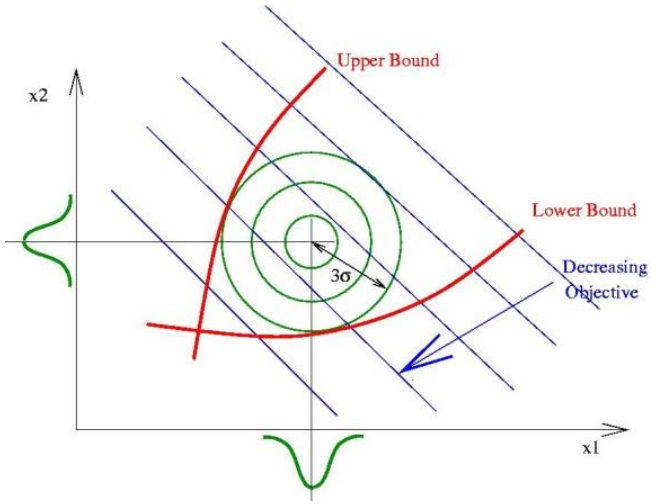




Applications of LS-OPT

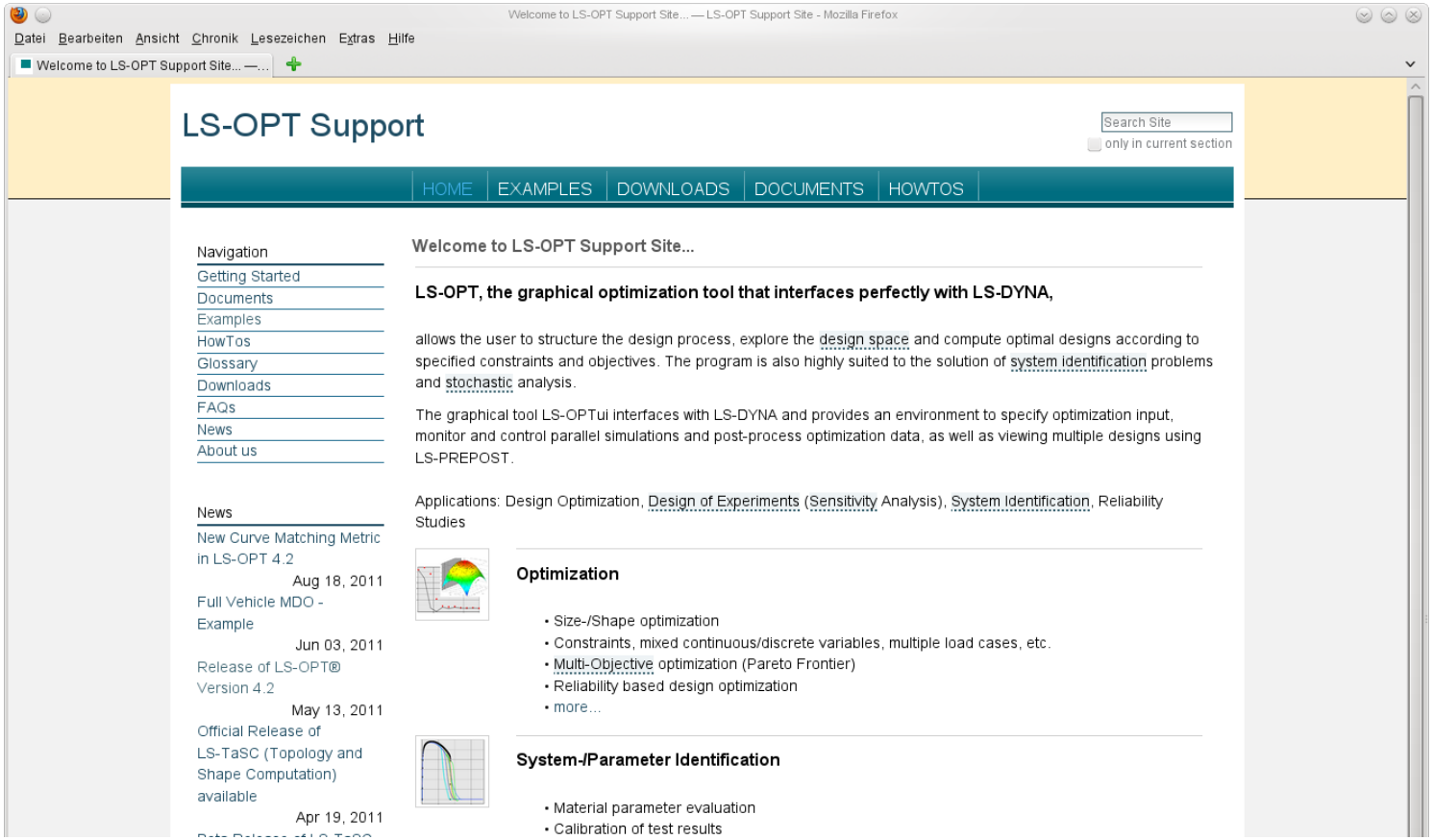
- Optimization incorporating uncertainties
  - Robust Parameter Design (RDO)
    - Improve/Maximize the robustness of the optimum
  - Reliability Based Design Optimization (RBDO)
    - Improve failure probability of optimum





LS-OPT Support webpage

- www.lsoptsupport.com
  - Many examples, tutorials, FAQs, HowTos…
  - Download LS-OPT



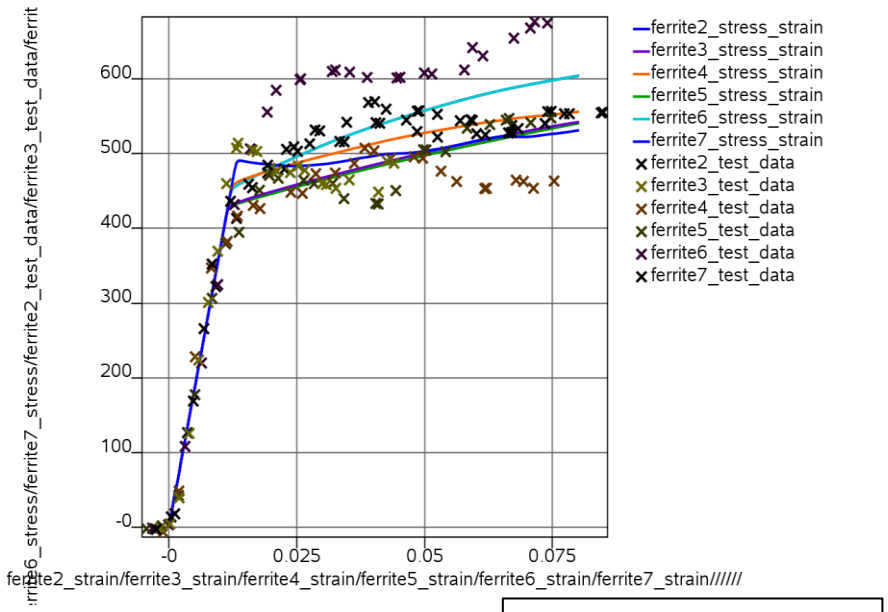
New features in LS-OPT 6.0

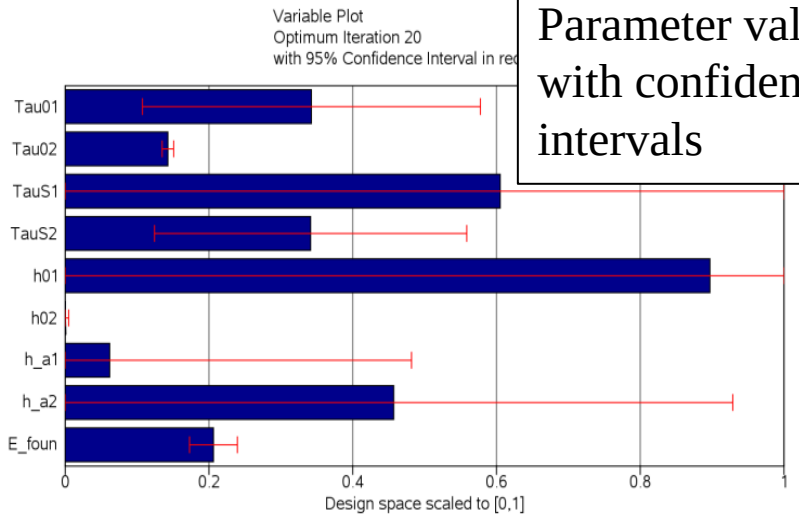
Overview

- New features for LS-OPT 6
  - DIC-based parameter identification
  - Interactive tables
  - Efficient Global Optimization (EGO)
  - Support Vector Classification
- Other new features
- Outlook

DIC-based Parameter Identification

- Uniaxial experiments do not necessarily predict non-uniform deformations
- Local phenomena such as coupon necking/barreling missed
- Instability is typical in inverse problems of this nature
- Spatially distributed (full field) data can provide more information than values at individual points
- See e.g. work by Mahnken and Stein, U. Hannover (1997-2001)



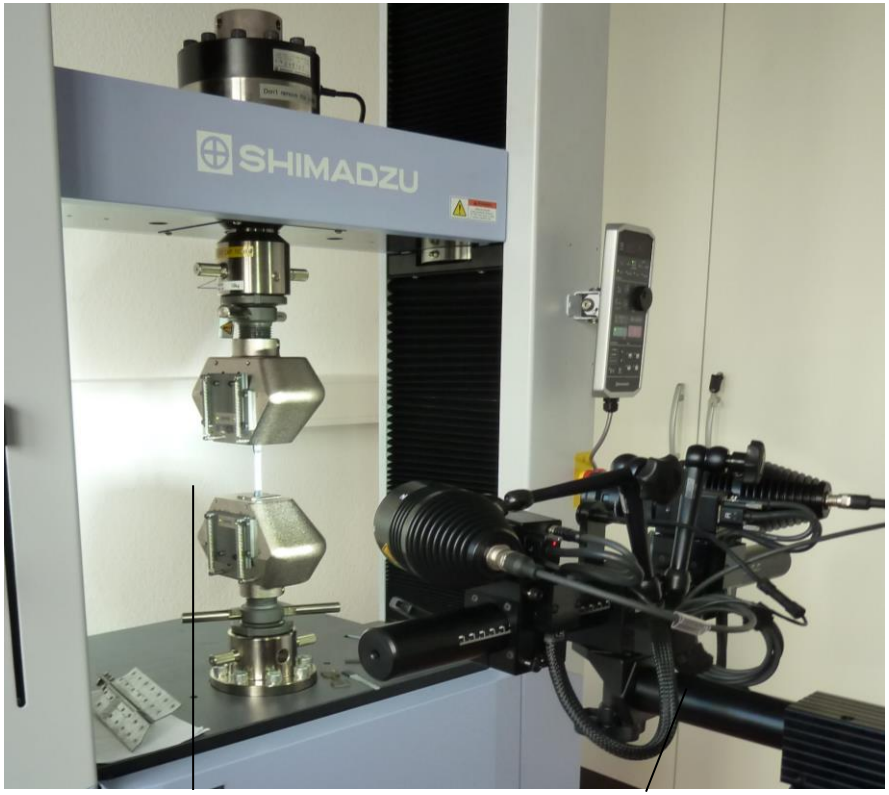


Parameter values with confidence intervals

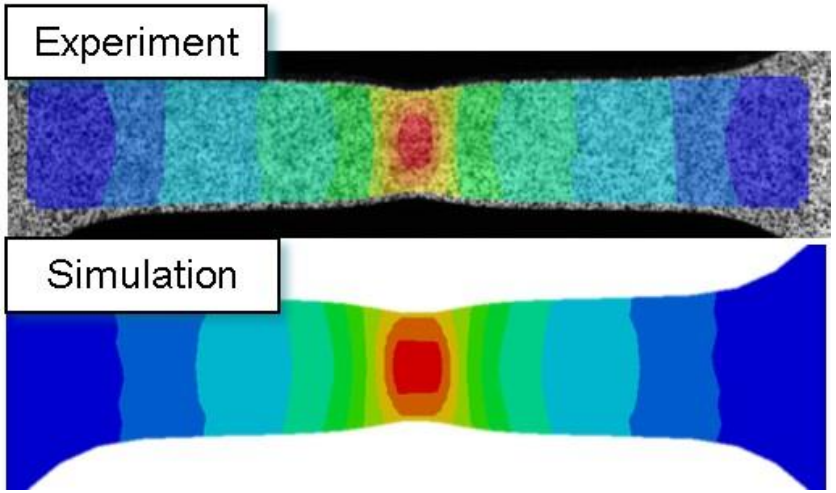
Ferrite single crystal calibration

DIC-based Parameter Identification

- Digital Image Correlation - Optical method for tracking changes in images



Tensile testing equipment

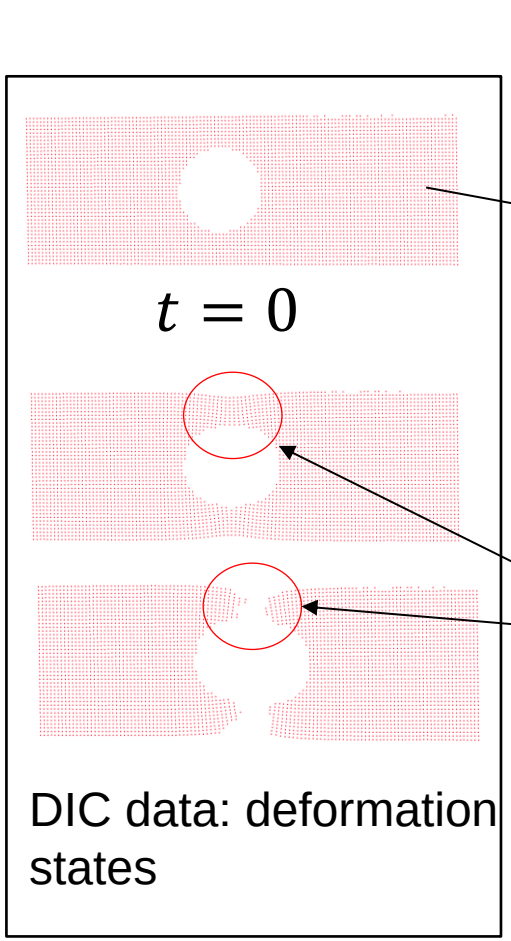


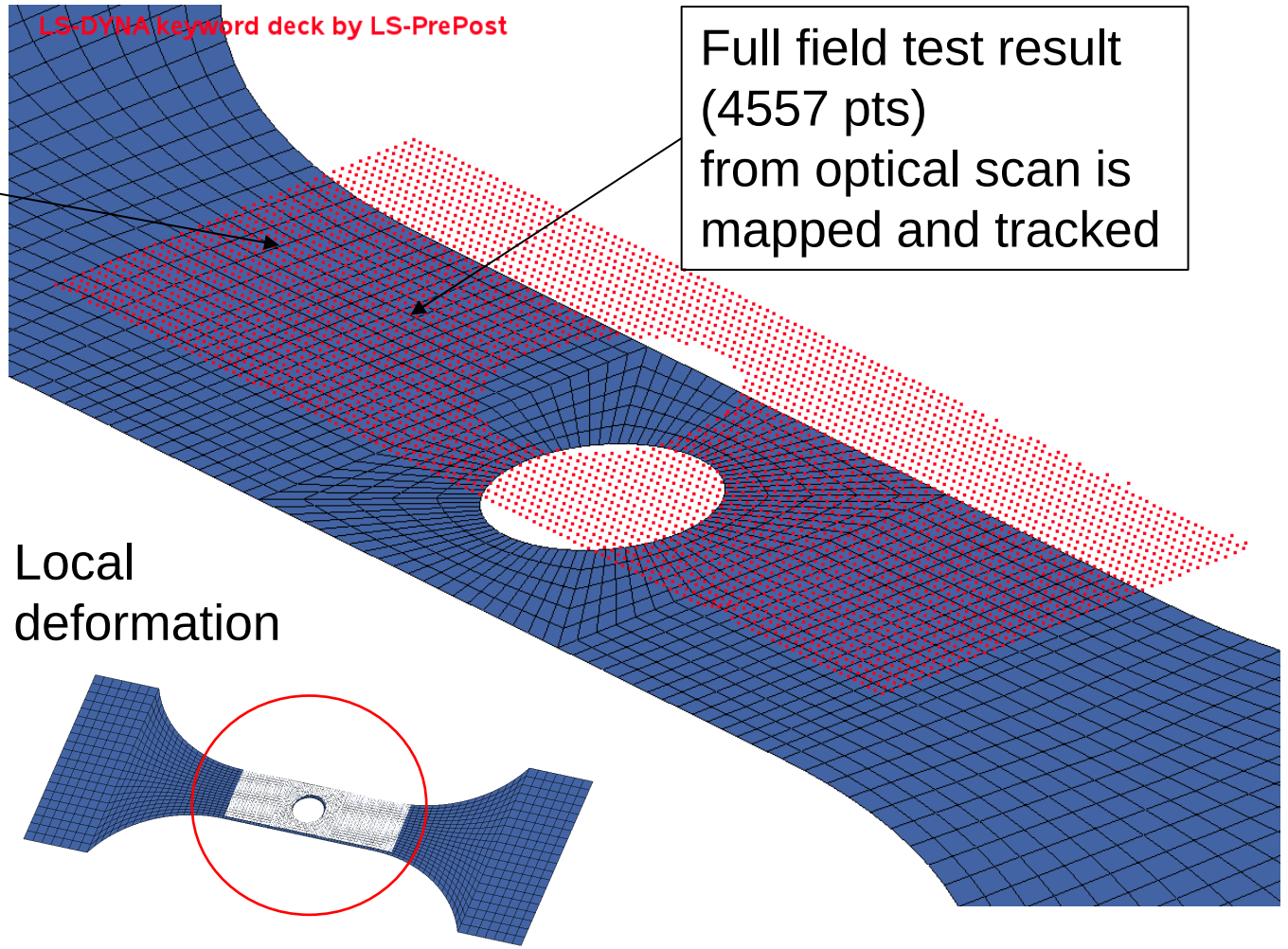
Measurement system

gom/ARAMIS setup at DYNAmore GmbH

DIC-based Parameter Identification

- Matching in time and space: Example (tensile)

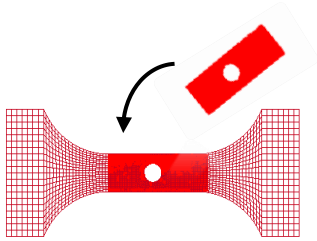




DIC-based Parameter Identification

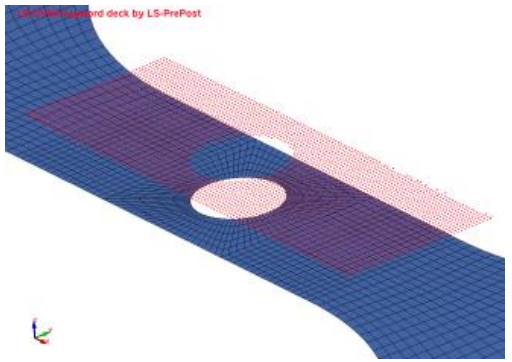
- **Transform:** Align test to FE model. Least Squares solution:

$$\min_{\boldsymbol{T},\hat{s}} \|\hat{s}\boldsymbol{X}_1\boldsymbol{T} - \boldsymbol{X}_2\|$$



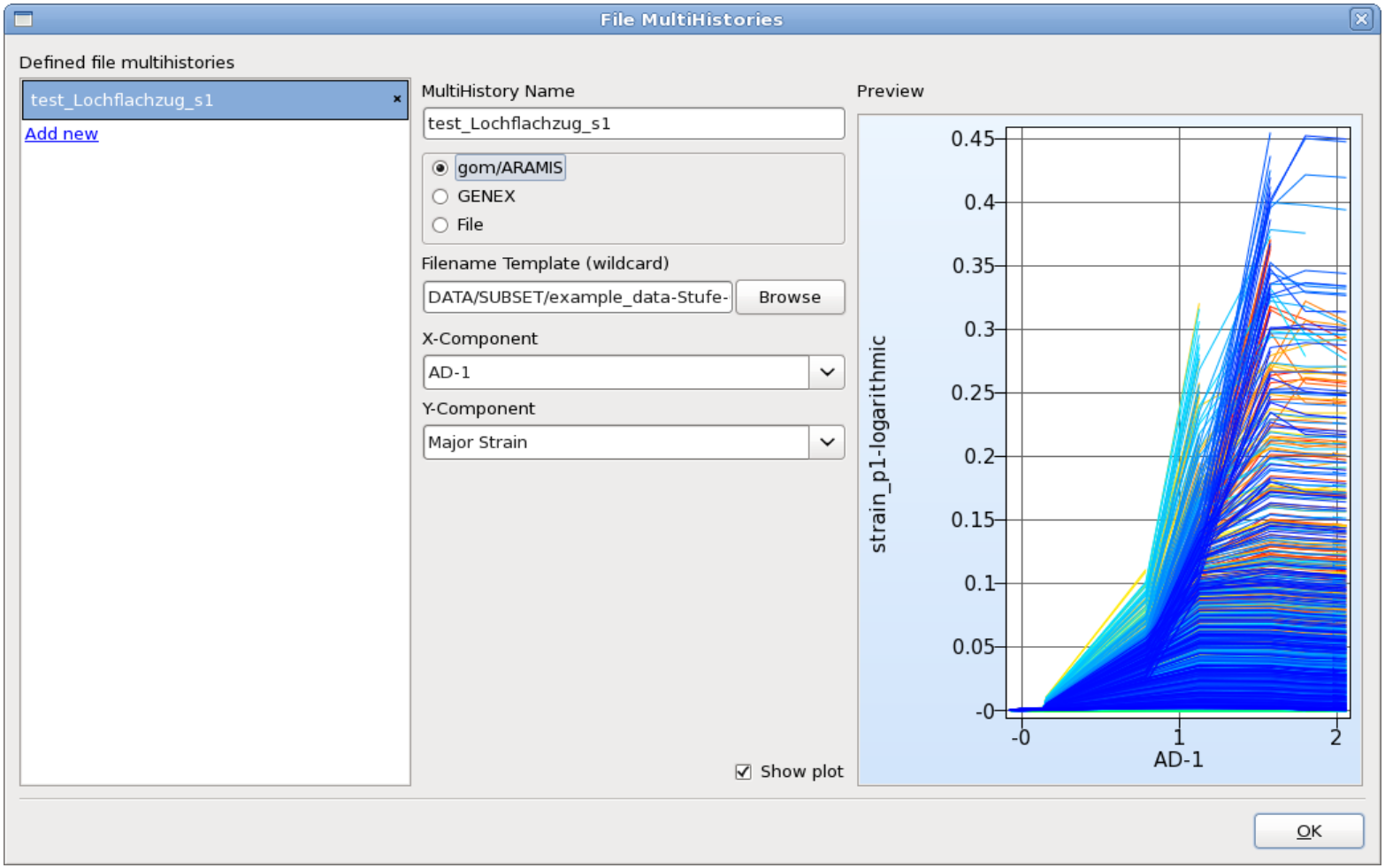
  - $\boldsymbol{X}_1$: Test pts (subset), $\boldsymbol{X}_2$: FE model pts, $\boldsymbol{T}$: transform, $\hat{s}$: Isotropic scaling
  - Linear system (using SVD) if $\hat{s}$ = constant
  - *Alternative:* Pre-processor (e.g. LS-PrePost) to translate, rotate and scale test points
- **Map:** Test → FE mesh: Exact Nearest Neighbor search and element interpolation (10^7 → 10^7 pts)
- **Optimization:** Minimize MSE residual

$$\min_{\boldsymbol{x}} \sum_{j=1}^{n} \|(\boldsymbol{\varphi}_j(\boldsymbol{x}) - \tilde{\boldsymbol{\varphi}}_j\|^2$$



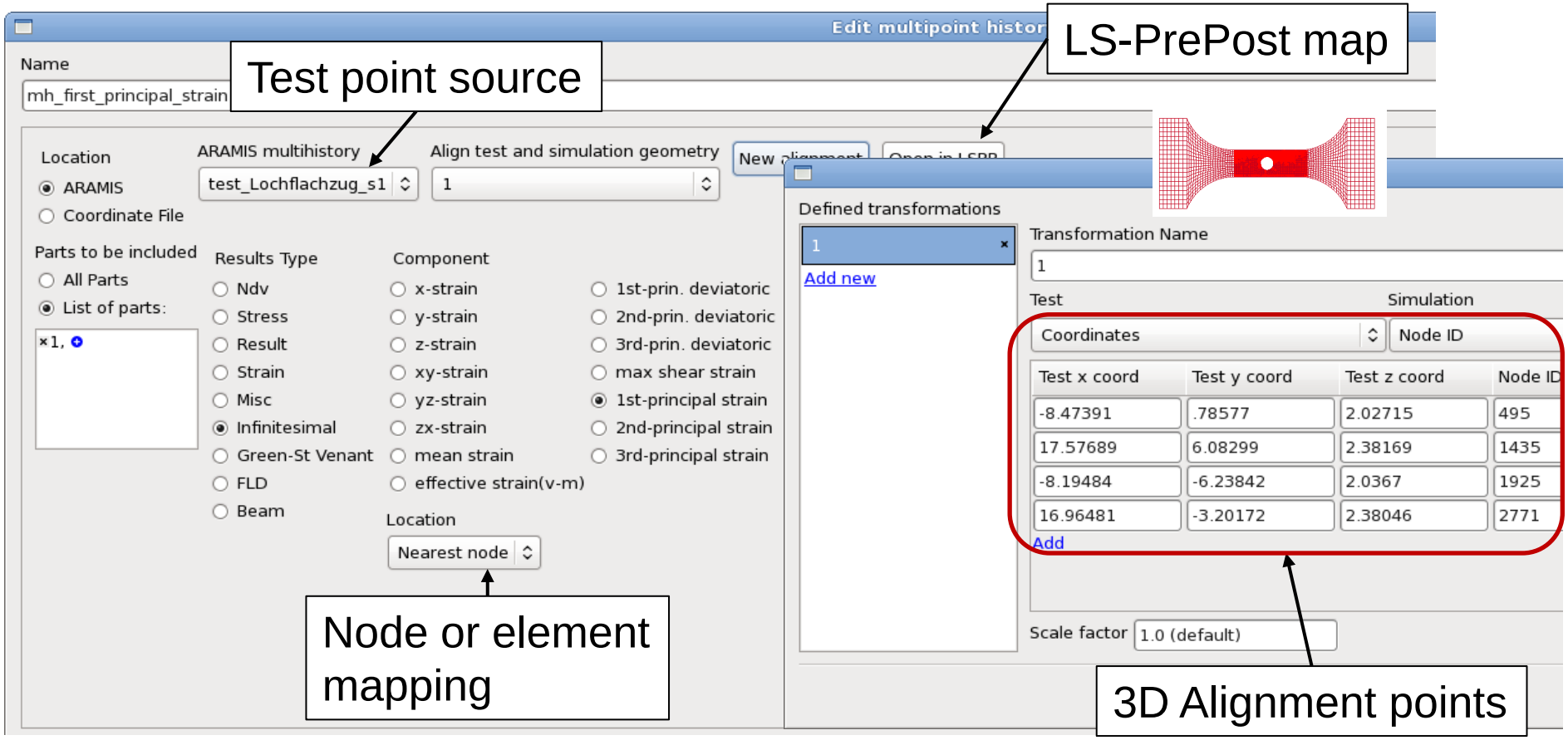
DIC-based Parameter Identification

- Interface to import DIC data



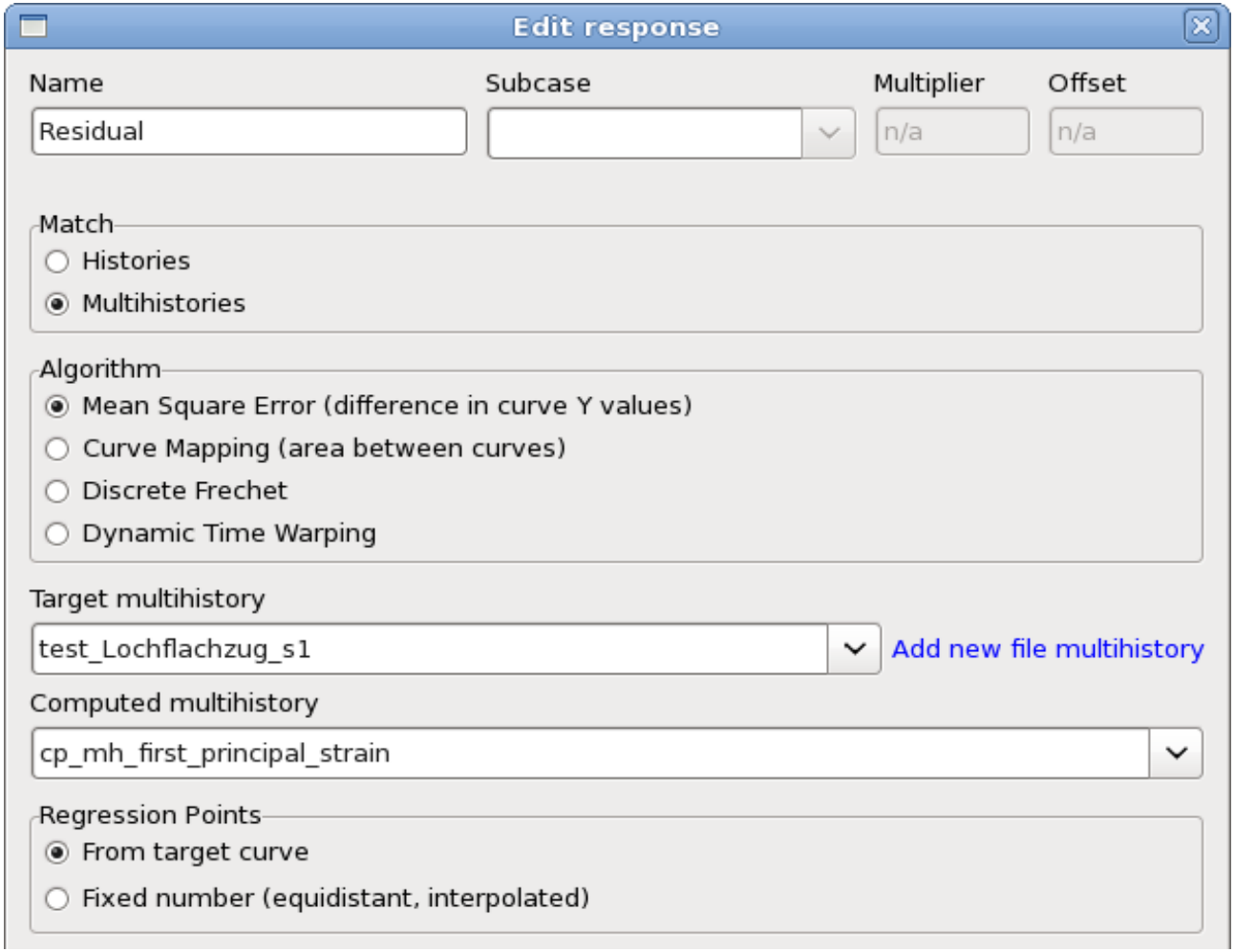
DIC-based Parameter Identification

- Extraction from Simulation: Multipoint histories
  - D3plot interface
  - Crossplots, Expressions

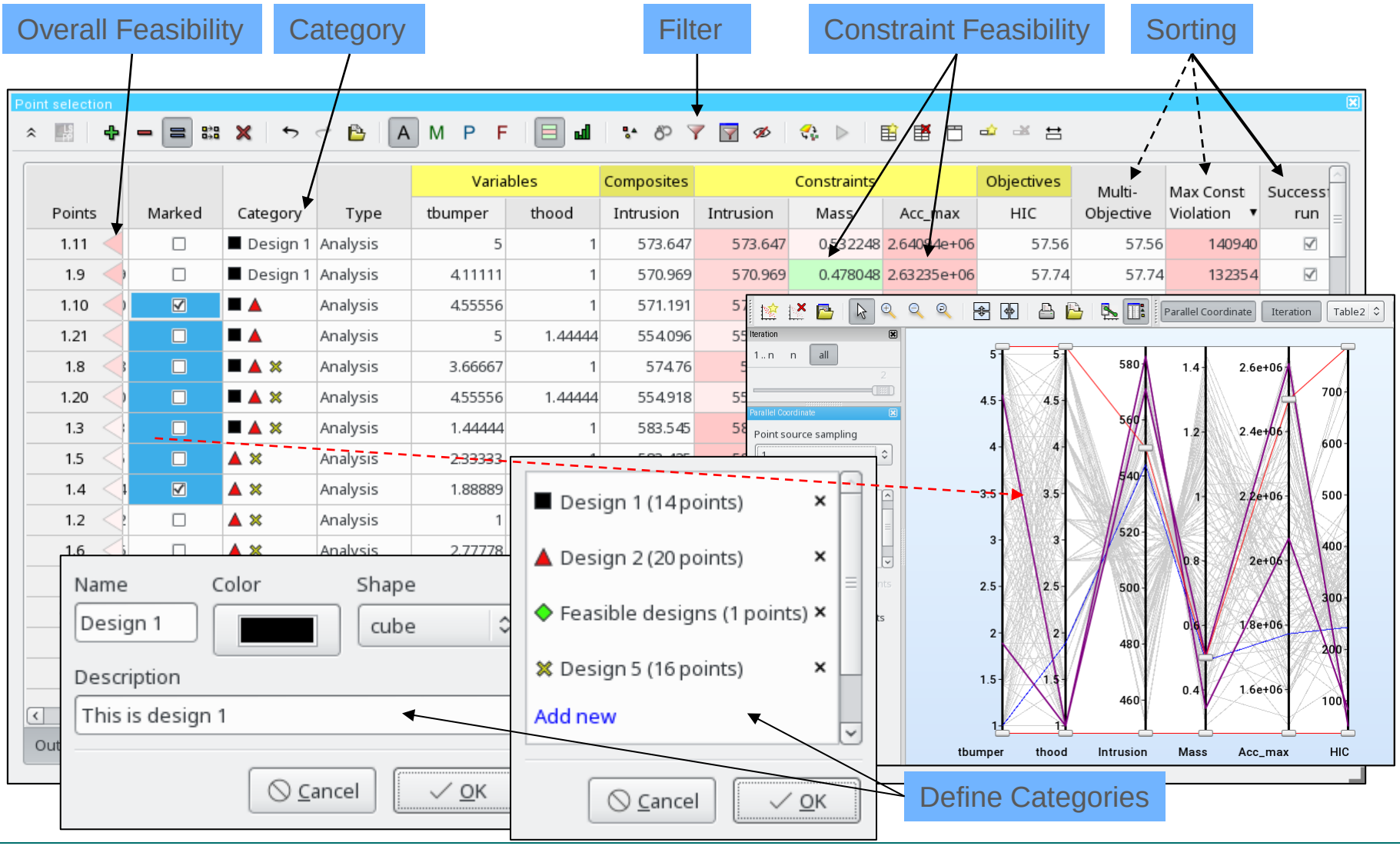


DIC-based Parameter Identification

- Multihistory matching

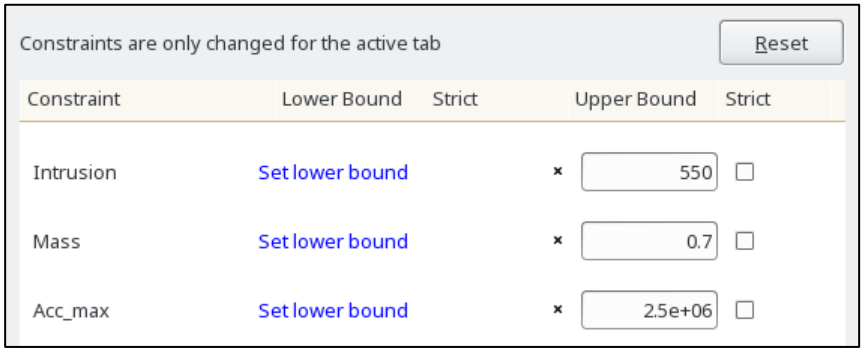


Interactive Tables



Interactive Tables

- Interactive Constraint management

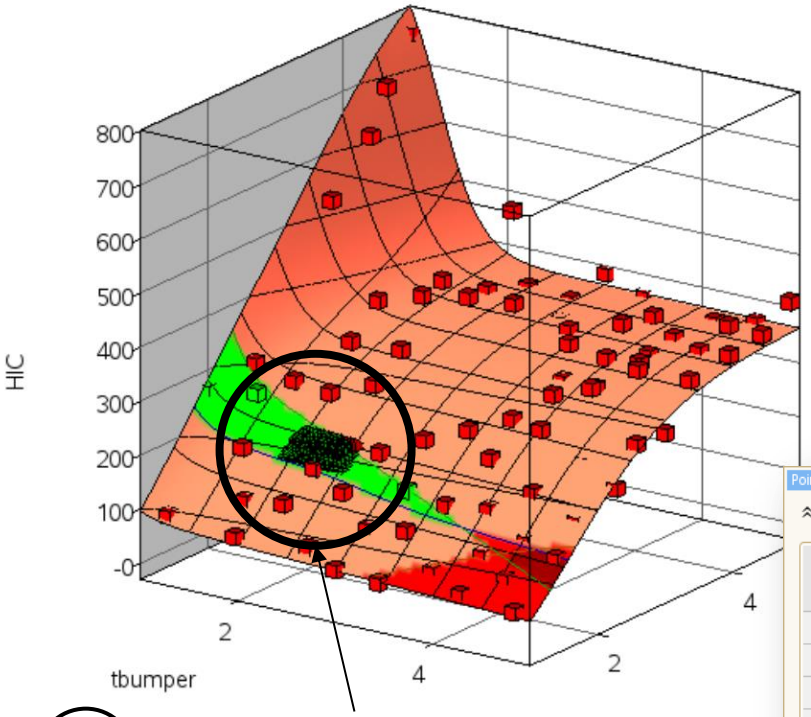


- Statistics of selected point

	Variables		Composites	Constraints			Objectives	Multi-Objective	Max Constr. Violation
Points	tbumper	thood	Intrusion	Intrusion	Mass	Acc_max	HIC		
Nominal	0	0	0	0	0	0	0	0	0
Mean	2.97523	2.93732	521.056	521.056	0.849357	1.99565e+06	286.893	286.893	5503.76
StdDev	1.27034	1.29872	33.3185	33.3185	0.306708	288499	143.974	143.974	23963.3
SS	1086.83	1071.02	2.83503e+07	2.83503e+07	84.7155	4.22765e+14	1.0695e+07	1.0695e+07	6.2297e+10
Min	1	1	450.81	450.81	0.288374	1.4871e+06	51.52	51.52	0
Max	5	5	583.545	583.545	1.44187	2.64094e+06	773.8	773.8	140940
Lower Constraint	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lower Exceeded	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Prob. Exceed Lower	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Upper Constraint	N/A	N/A	N/A	550	0.5	2.5e+06	N/A	N/A	N/A
Upper Exceeded	N/A	N/A	N/A	24	88	6	N/A	N/A	N/A
Prob. Exceed Upper	N/A	N/A	N/A	0.230769	0.846154	0.0576923	N/A	N/A	N/A
Num. Values	104	104	104	104	104	104	104	104	104

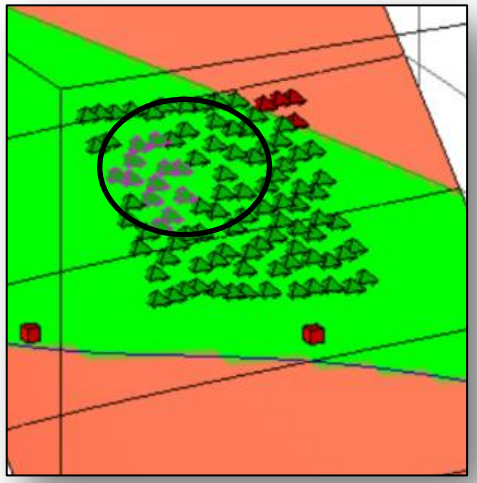
Interactive Tables

- Virtual points



1 Generate in Viewer

2 Select



Virtual points Run simulations

Point selection

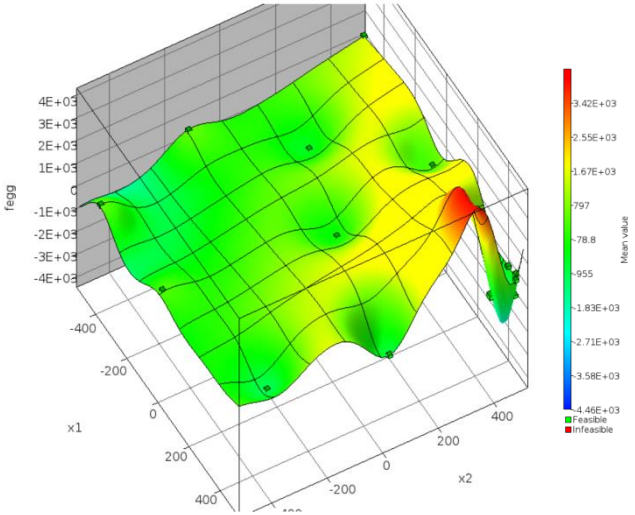
Points	Marked	Type	Variables		Constraints			Objectives	Ma
			tbumper	thood	Intrusion	Mass	Acc_max	HIC ▲	V
vo1.109	☑	Virtual	2.25259	1.86465	544.755	0.561377	1.88095e+06	200.142	
vo1.144	☑	Virtual	2.19286	1.87575	544.488	0.560259	1.85526e+06	202.227	
vo1.149	☑	Virtual	2.23566	1.9226	542.64	0.573522	1.85635e+06	208.534	
vo1.167	☑	Virtual	2.16694	1.93914	542.235	0.573095	1.82604e+06	211.42	
vo1.182	☑	Virtual	2.3141	1.89203	543.545	0.571354	1.89467e+06	203.571	
vo1.196	☑	Virtual	2.12216	1.88888	544.171	0.558934	1.82481e+06	204.703	
vo1.200	☑	Virtual	2.3527	1.84454	545.248	0.562909	1.92413e+06	196.428	

Output Table1

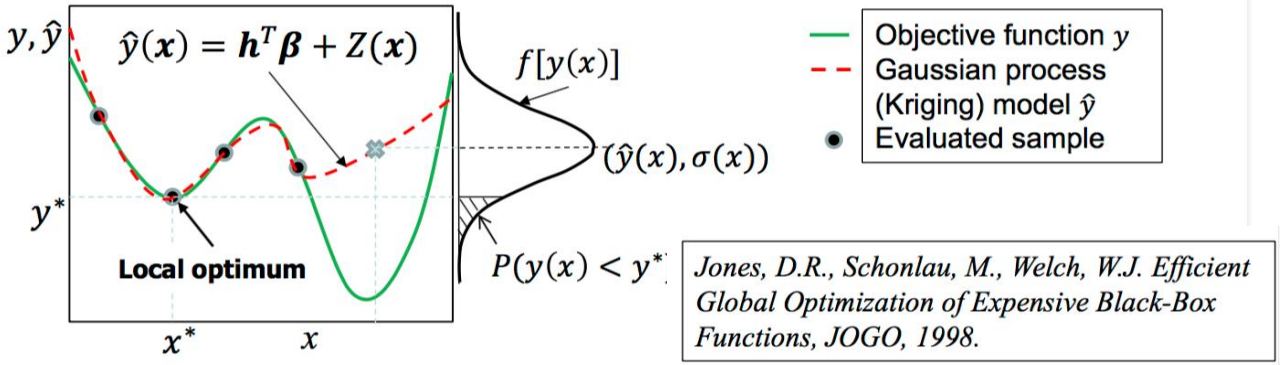
3 Evaluate & Simulate

Efficient Global Optimization (EGO)

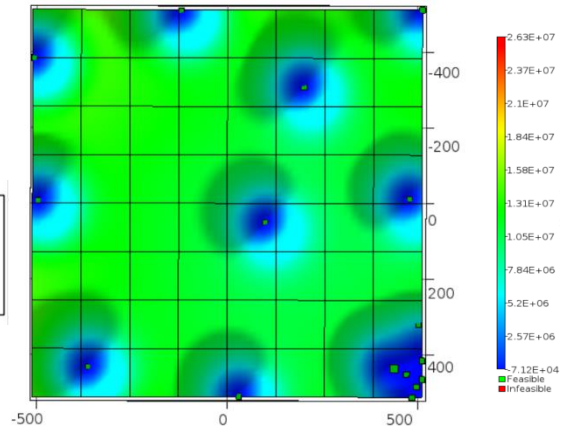
- Basic Idea
  - Balances local and global search through compromise between good objective function value and high prediction uncertainty
  - Needs Kriging metamodel for objective function
  - Limited to small variable sets (e.g. 10)
  - Useful for parameter identification



Minimize mean function value (exploitation)



Jones, D.R., Schonlau, M., Welch, W.J. Efficient Global Optimization of Expensive Black-Box Functions, JOGO, 1998.



Maximize standard deviation (exploration)

Expected improvement of the objective function:

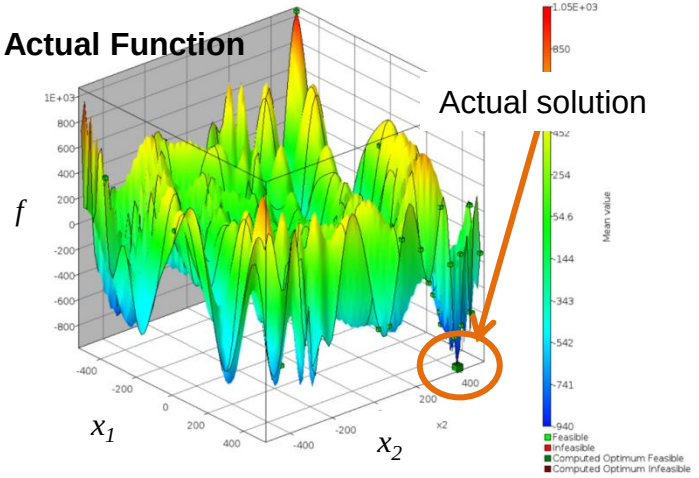
$$E[I(\boldsymbol{x})] = \int_{-\infty}^{y^*} (y^* - y(\boldsymbol{x}))f[y(\boldsymbol{x})]\,\mathrm{d}y = (y^* - \hat{y})\Phi\left(\frac{y^* - \hat{y}}{\sigma}\right) + \sigma\phi\left(\frac{y^* - \hat{y}}{\sigma}\right) \rightarrow \max_{\boldsymbol{x}}$$

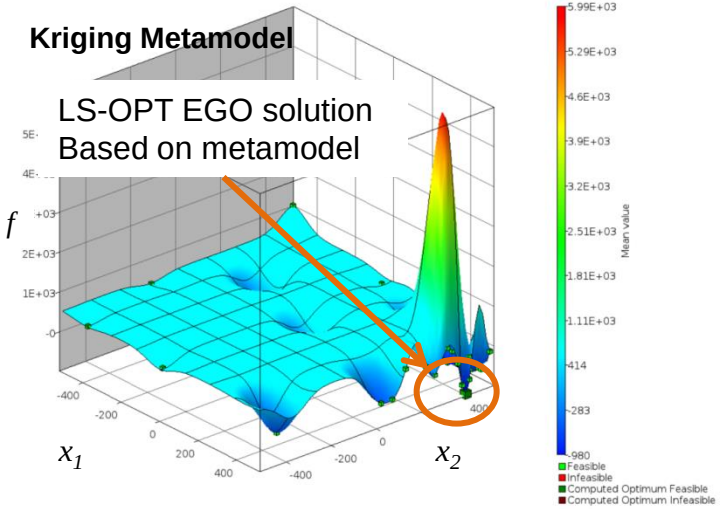
Efficient Global Optimization (EGO)

- Example and comparison to GA

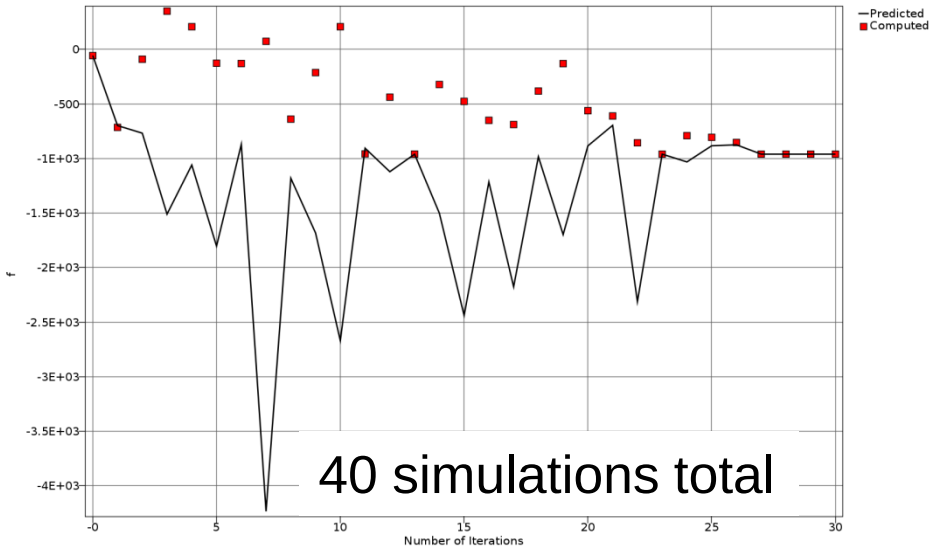
$$f(x_1, x_2) = -(x_2 + 47)\sin\left(\sqrt{\left|\frac{x_1}{2} + (x_2 + 47)\right|}\right) - x_1 \sin\left(\sqrt{|x_1 - (x_2 + 47)|}\right)$$

$$-512 \le x_1, x_2 \le 512$$





Optimization History of objective function

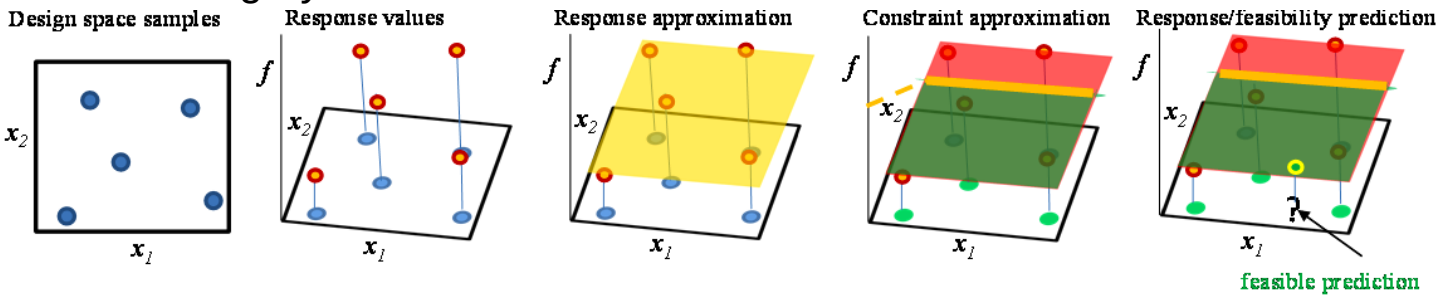


Algorithm	Cost	Objective
GA	300	-718
GA	600	-889
EGO	40	-960

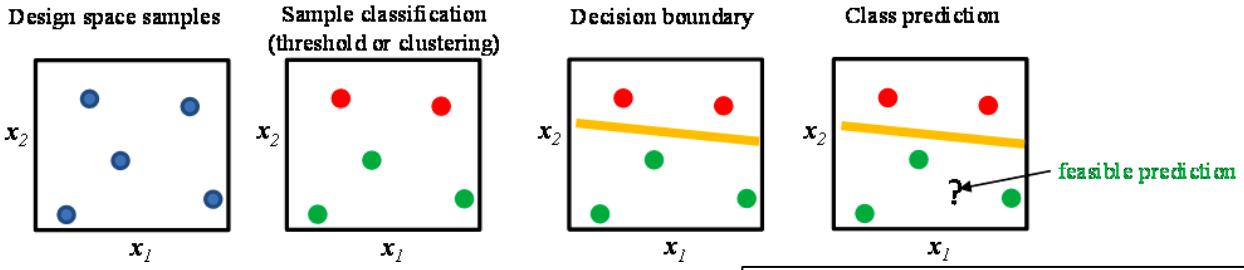
Support Vector Classification

- Discontinuous and binary responses
  - Map input data to category

Metamodeling



Basic classification method



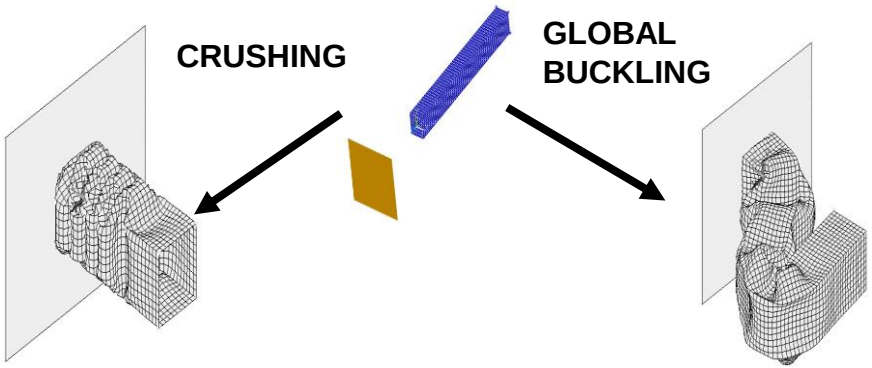
- Adaptive multi-objective optimization
  - classifier defines the boundary of the Pareto optimal designs

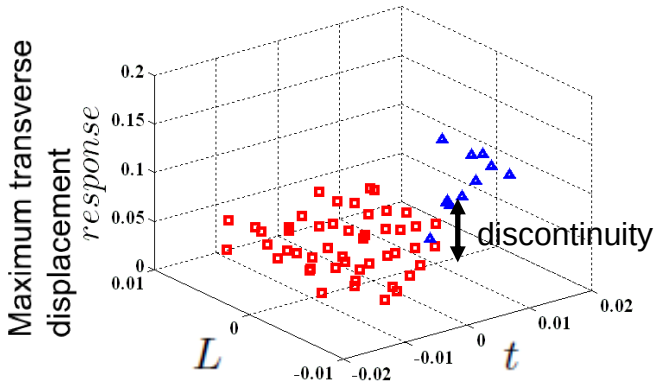
Basudhar, A. (2015). Multi-objective Optimization Using Adaptive Explicit Non-Dominated Region Sampling. In 11th World Congress on Structural and Multidisciplinary Optimization.

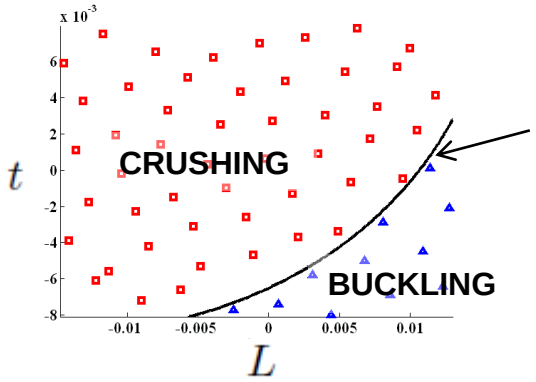
- Statistical Classification together with established features (e.g. multi-layer Feedforward Neural Networks is progression towards building a Statistical Learning tool based on the current Viewer

Support Vector Classification

- Example: Tube impact





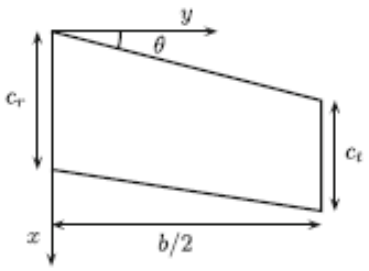


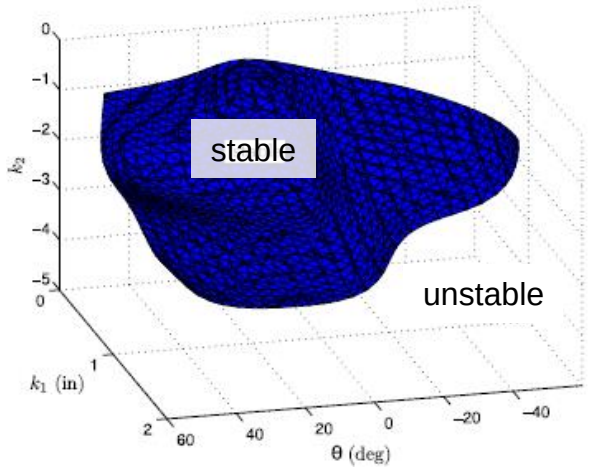
Design Space (length and thickness)

Support Vector Classification

- Example: Wing Aeroelasticity
- Binary constraints
  - **Divergence instability**
    - Zero vs Non-zero Modal Frequency
  - **Flutter instability**
    - Positive vs Negative damping coefficient

***Basudhar**, Anirban, et al. "Constrained efficient global optimization with support vector machines." Structural and Multidisciplinary Optimization 46.2 (2012): 201-221.*

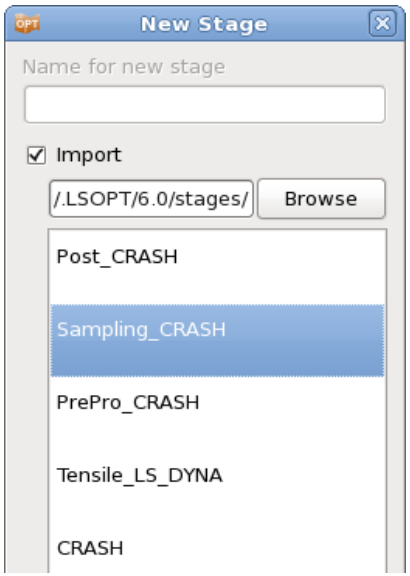


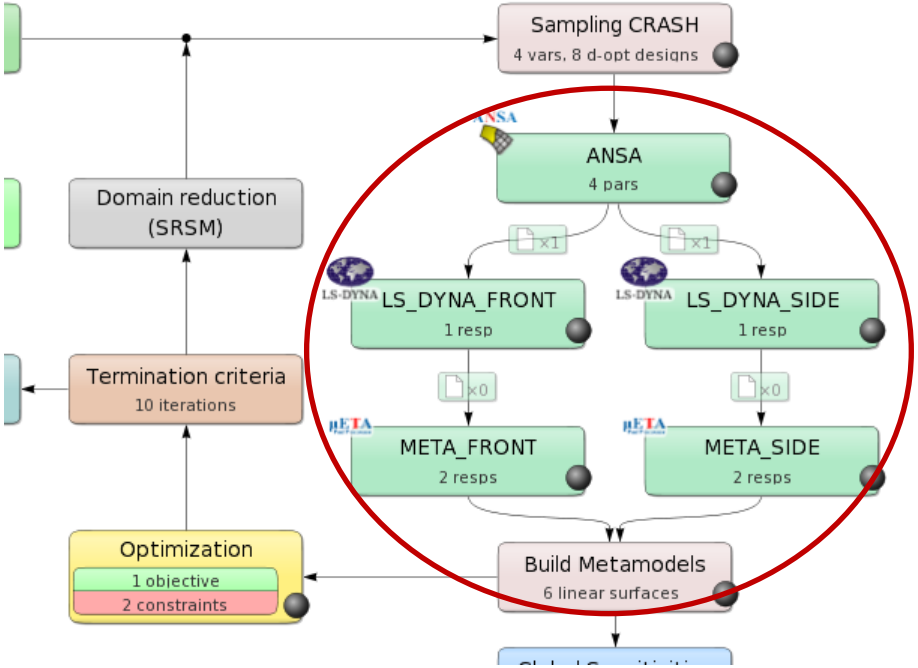


Decision Surface in Design Space

Other new Feature

- Taguchi method
  - Classical robust design approach using Orthogonal Arrays
- Export and import of stages
  - Individually
  - Full case-based process
    - E.g. Frontal Crash including its pre- and post-processing could be imported/exported as a unit with a given name





Outlook

- Full-Field Calibration (DIC)
  - Pre-viewing, editing and Pre-processing tools
    - Edit test data using filtering, truncation, reduction, etc.
    - Includes editing of full-field data
  - Curve similarity criteria
    - Others in addition to MSE, PCM, DF, DTW
- Statistical Learning Tools
  - Incorporation of metamodeling into Viewer so it becomes an independent Statistical Learning Tool
  - Tools: Classification, Neural Networks, Principle Component Analysis (existing or under development)
- Job distribution
  - Graphical Interface for Blackbox option

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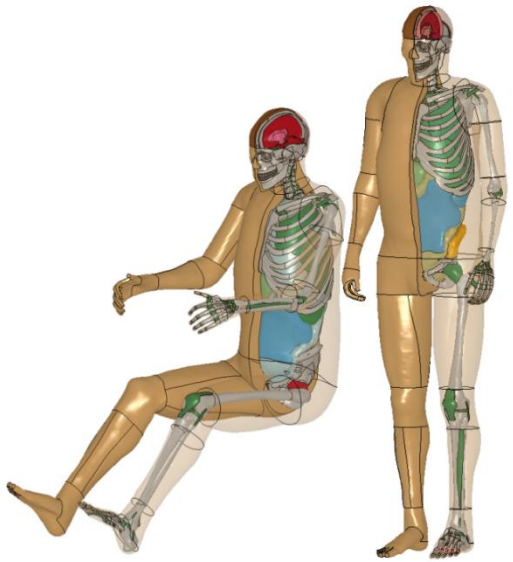

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