LS-OPT®: Status and Outlook

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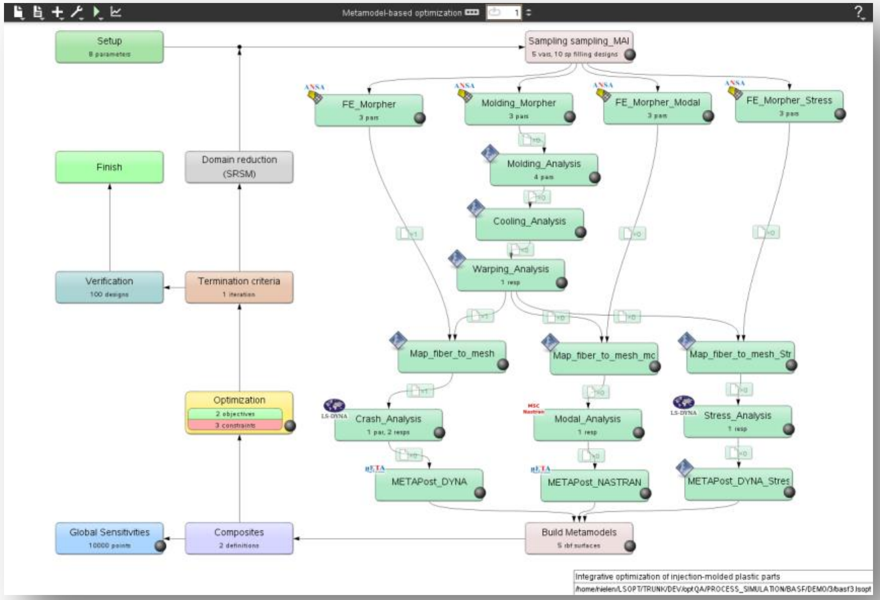
Contents

LS-OPT: Brief overview

- Optimization
  - Direct and Metamodel-based
- Reliability and Robustness (RBDO)
- Process Optimization
- Multiple solvers,
  pre-, post-
  processors
- *Network-based*
  - *Job scheduling*
  - *Monitoring*
  - *Control*



- Parameter Identification (Materials, Systems)

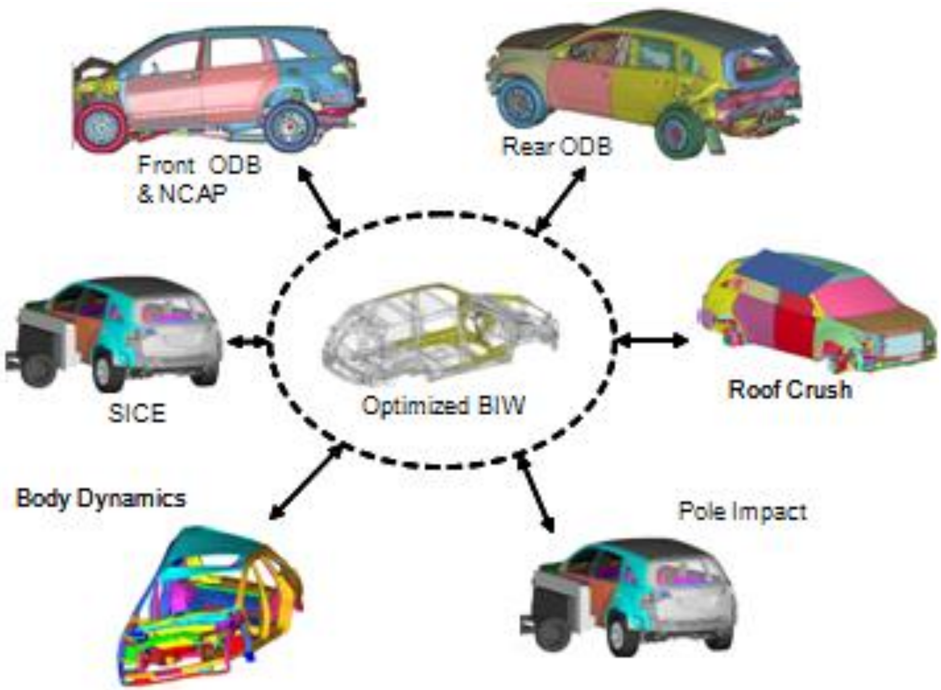
LS-OPT Methodology

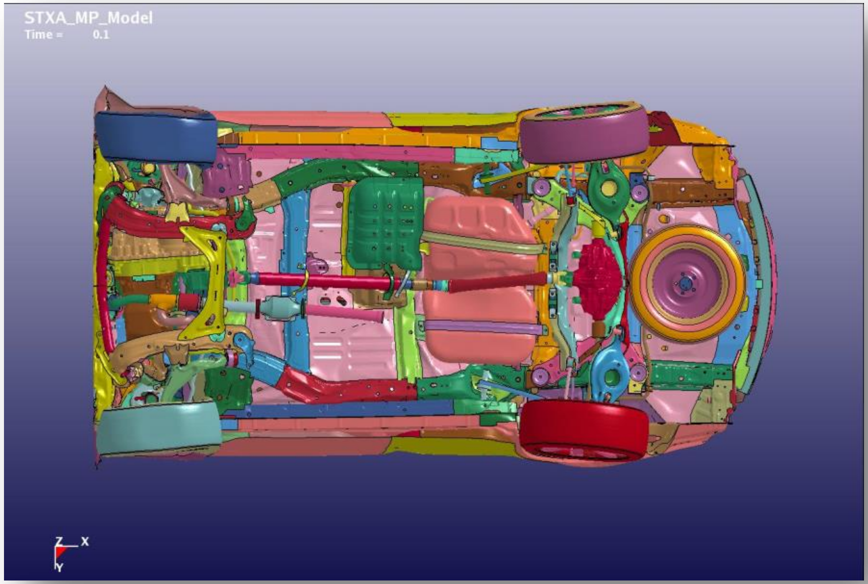
- Metamodel-based Optimization/Reliability
  - Discrete-Continuous problems (Sizing/Shape)
  - Benefits derived from metamodels
    - Build a global model of the design for graphical exploration
    - Stochastic methods inexpensively applied
      - Reliability and Robustness Analysis/Optimization
      - Global Sensitivity Analysis
      - Outlier Analysis
      - Tolerance Optimization

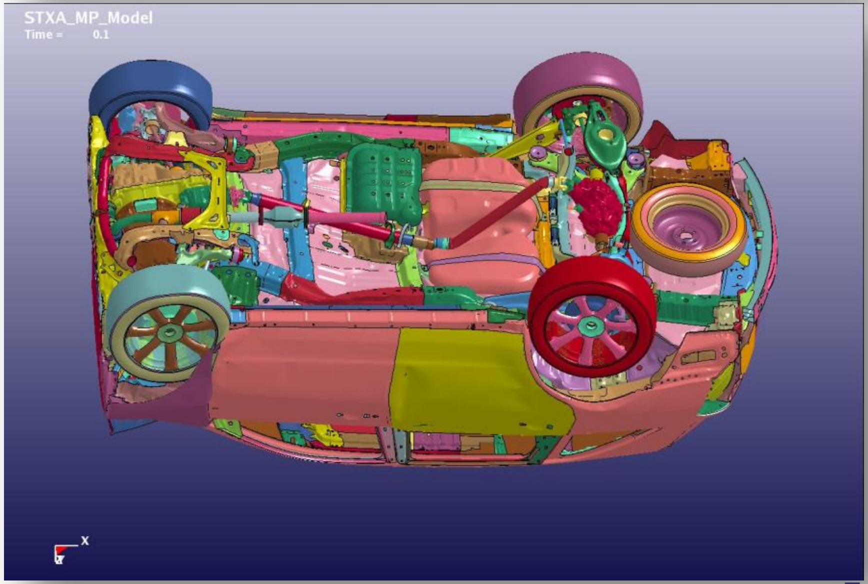
- Direct Optimization
  - Global Optimization
  - Integer (category, material), Discrete-Continuous, Multi-Objective

Vehicle Crash Example: MDO Model detail

6 Crash Modes + Body Dynamics Mode:
- approximately **3 million element** models



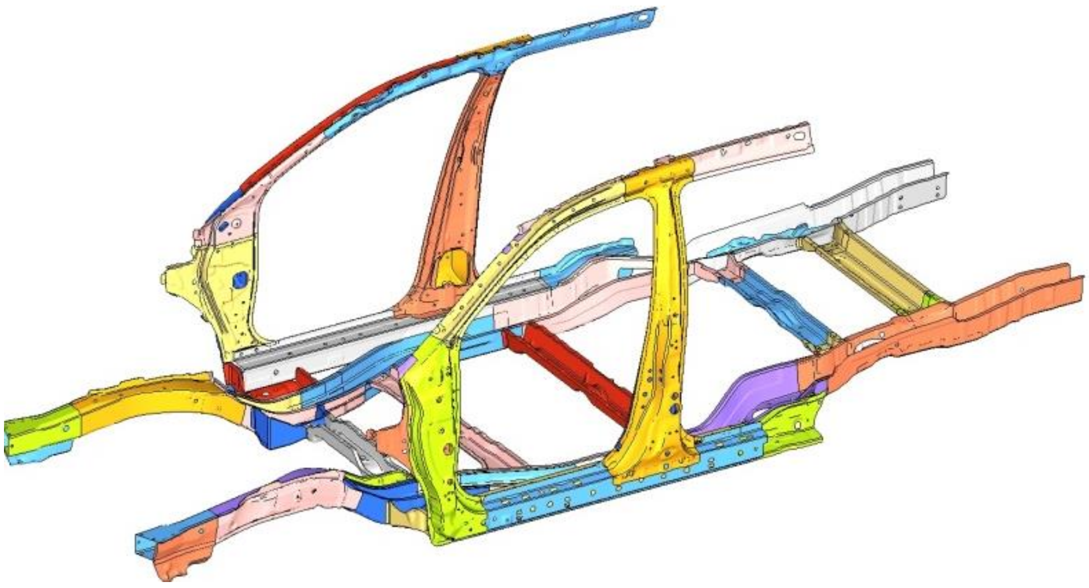




Allen Sheldon, Ed Helwig (Honda R&D)

Vehicle Crash Example: Design Formulation

35 Continuous Thickness Variables:
33% of BIW mass



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Objective:
Minimize Mass

Constraints:
Front NCAP:
- Decelerations
- Intrusions

Front Offset:
- Intrusions
- Cabin Integrity

SICE:
- Intrusions

Side Pole
- Intrusions

Roof Crush:
- Force

Rear ODB
- Intrusions
- Fuel System Clearance

NVH:
- Body Stiffness
- Body Frequency

Vehicle Crash Example: Setup and results

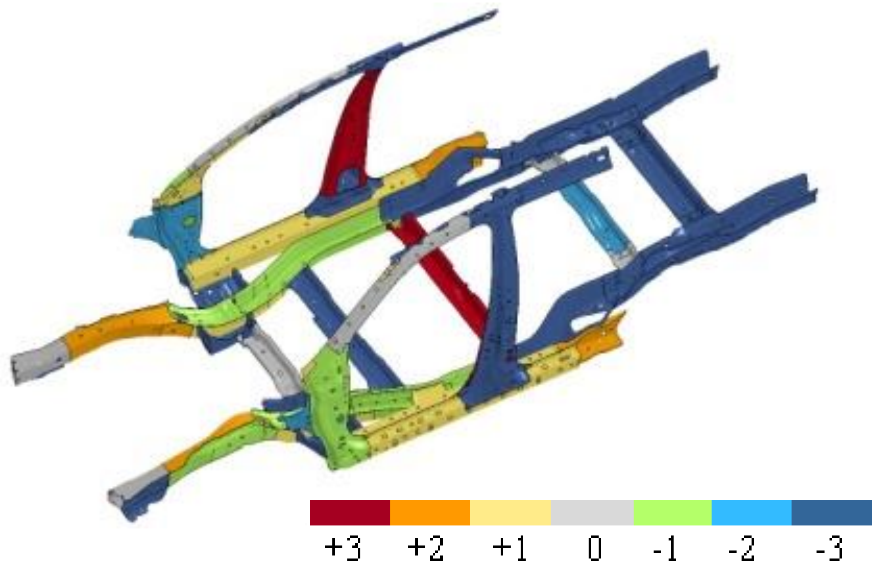
LS-OPT SRSM Settings:

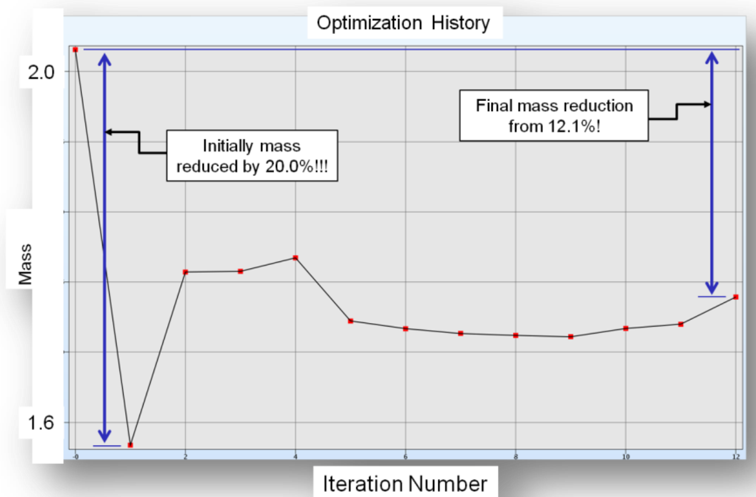
• **Optimization Strategy**
SRSM (Domain Reduction)

•**Metamodel**
Radial Basis Function Network (global)

• **Point Selection**
Adaptive Space Filling
54 points per iteration

Gauge Changes





- Optimization was aggressive with a significant initial mass reduction.
- Then optimization converges as constraints are satisfied.
- Final step shows some increase in mass as variables are switched to discrete values.

- Gauge changes are non-intuitive.
- Some parts have significant gauge up values.
- Rear portion of structure saw significant gauge down.

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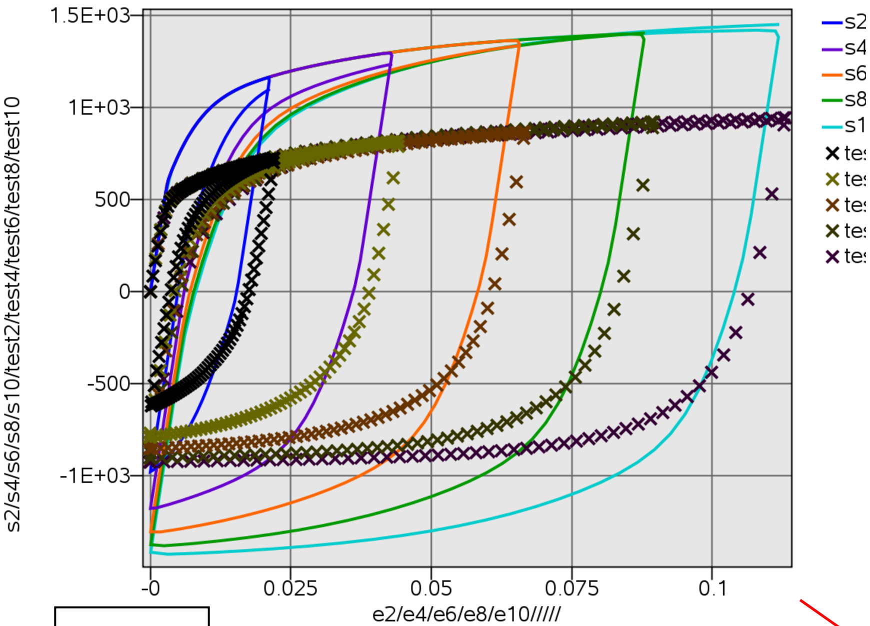
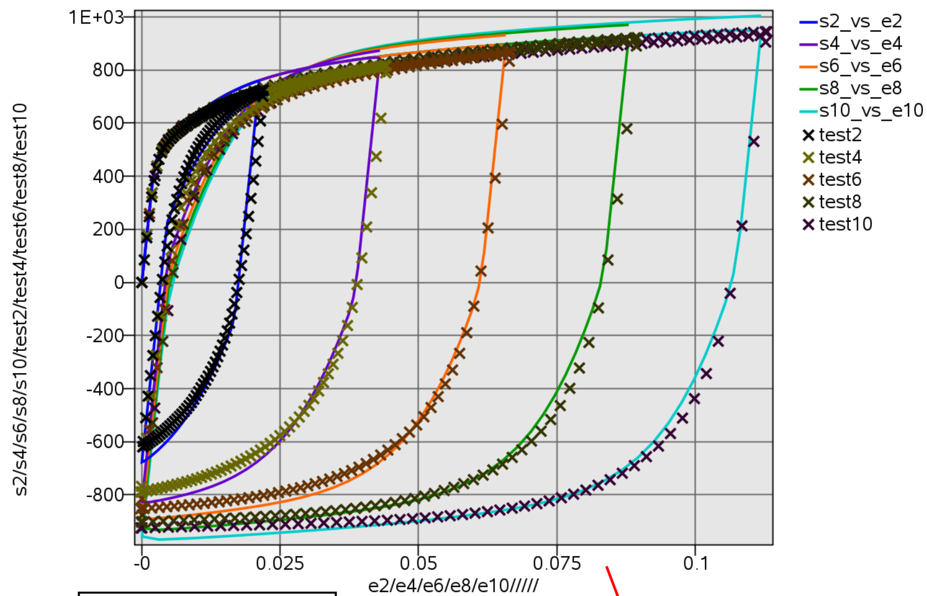
Example: Calibration of material 125



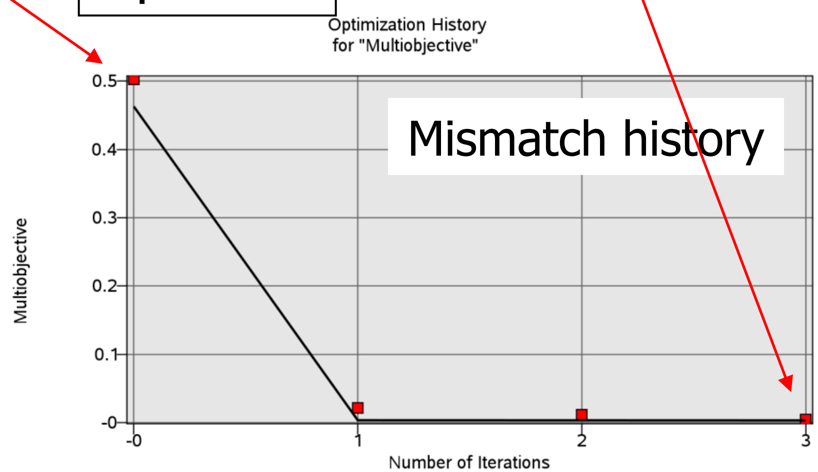
Start



Optimum

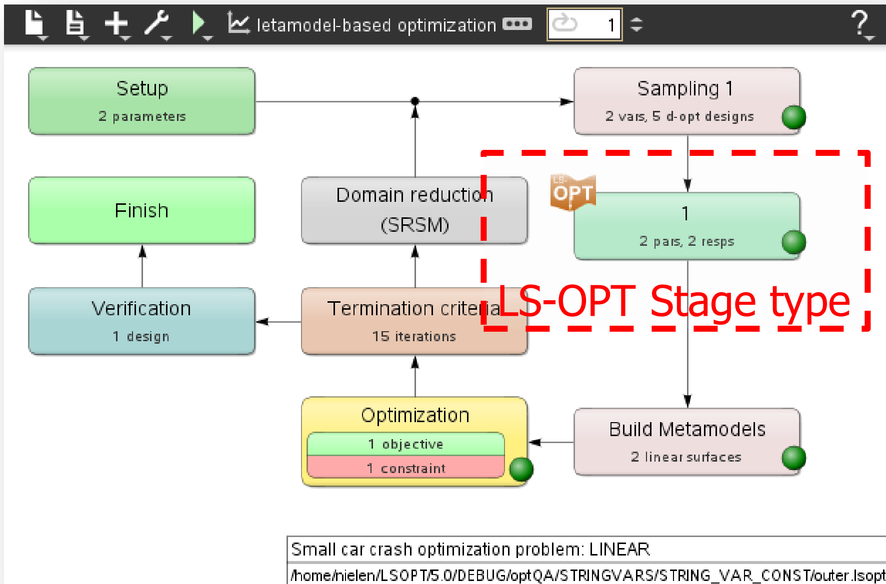
9 parameters

5 tension/compression cases

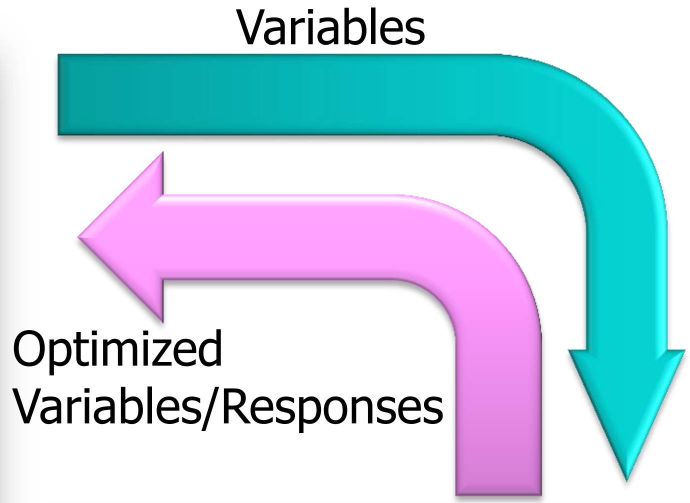


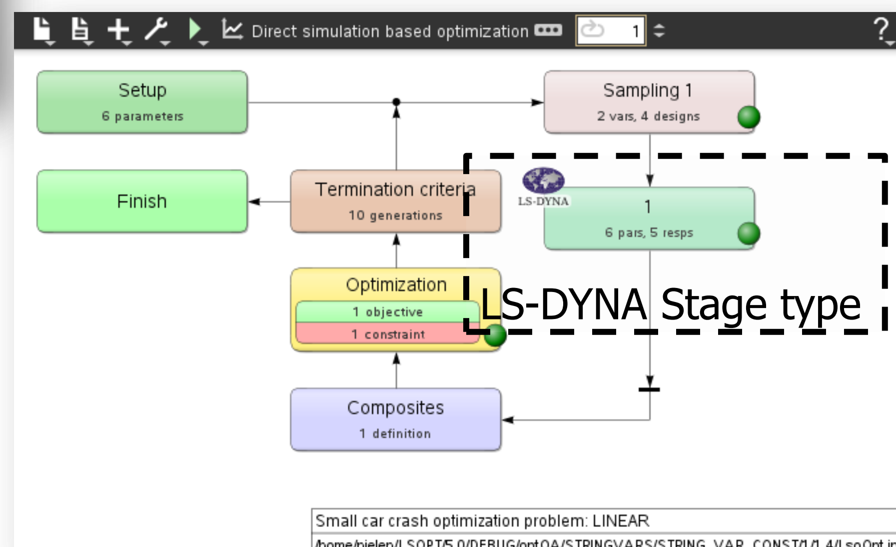
New Features

Multi-level Optimization



OUTER





INNER

- Subdivision of problem into levels
- *Nesting* the optimization problem
- *Variables* and *responses* are transferred between levels
- Inner level optimization is done for each outer level sample

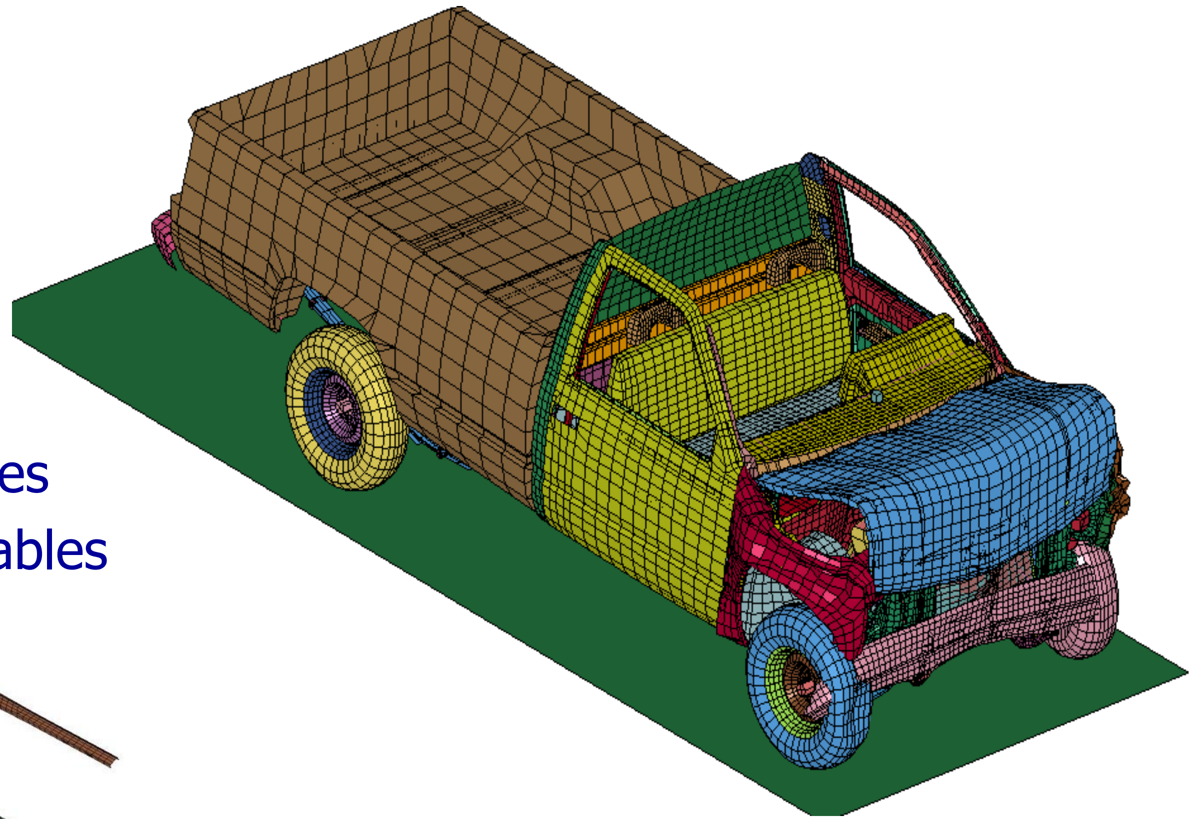
Multi-level Optimization: Why?

- *Organization*. Easier to organize the problem as a collection of subsystems
- *Efficiency.* Solution algorithm takes advantage of the subproblem type
  - Can match optimization methods with variable types, e.g. materials (categorical), sizing/shape (continuous).
- *Robustness and accuracy.* Smaller sub-problems are typically solved in a relatively low-dimensional space
- Critical framework for rational decomposition methods: *Analytical Target Cascading*
  - Iterative method which resolves *inconsistencies* between individual processes with *shared* variables

Multi-level Optimization: Applications

- Applications:
  - System Optimization (component sublevels)
  - Design of Product families
  - Tolerance optimization
    - *(Basudhar, A. and Stander, N. Tolerance Optimization using LS-OPT, Proceedings of the LS-DYNA Forum, Bamberg, October, 2014)*
  - Robust design using Random Fields
    - (*Craig, K.-J. and Stander, N. Optimization of shell buckling incorporating Karhunen-Loève-based geometrical imperfections, Structural and Multidisciplinary Optimization, 2008, 37:185:194)*
  - Integrated Design and Materials Engineering (e.g. ICME project)
    - Engineer materials at various levels
    - Integrate materials with Forming design

Multi-level Optimization: Example -- Truck

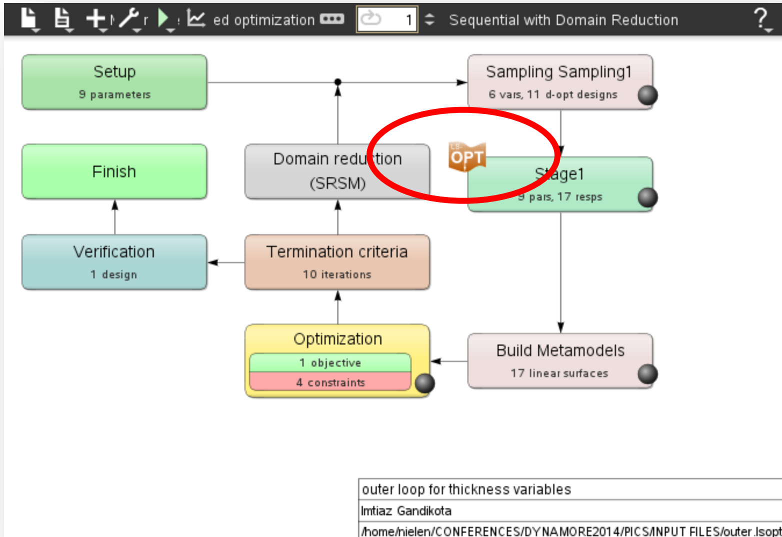


6 Thickness design variables

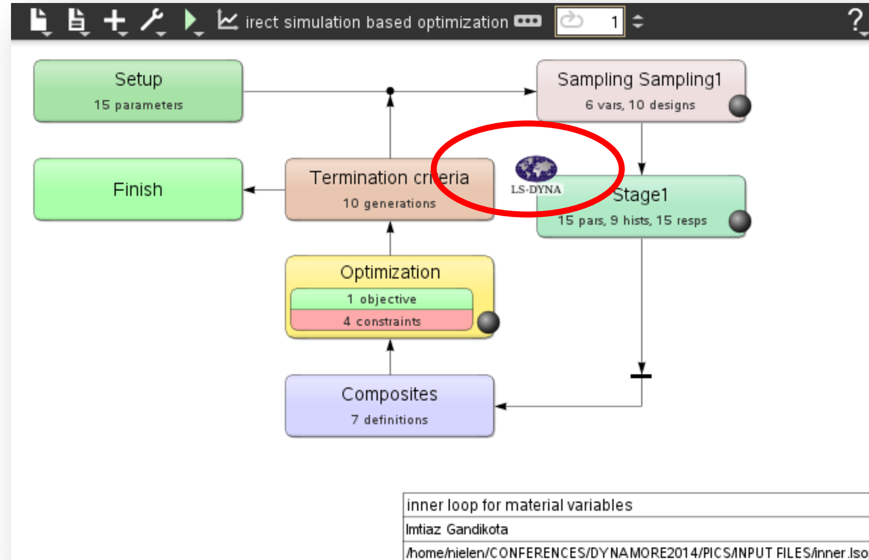
6 Material categorical variables

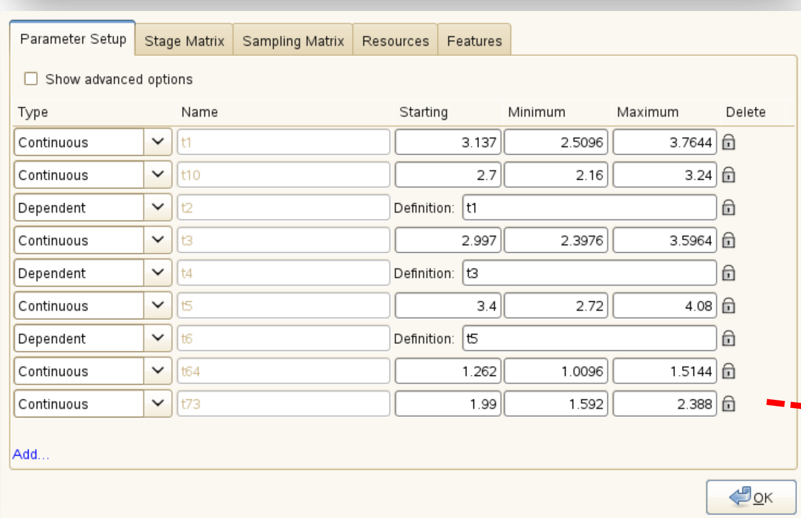
Multi-level Optimization: Example

Outer level: Continuous



Inner level: Discrete/Categorical

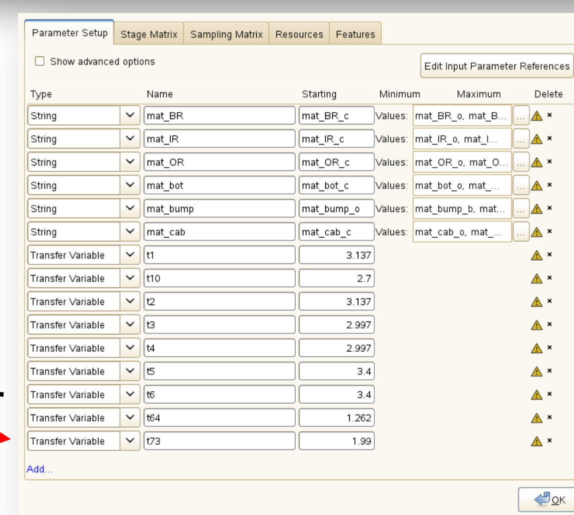




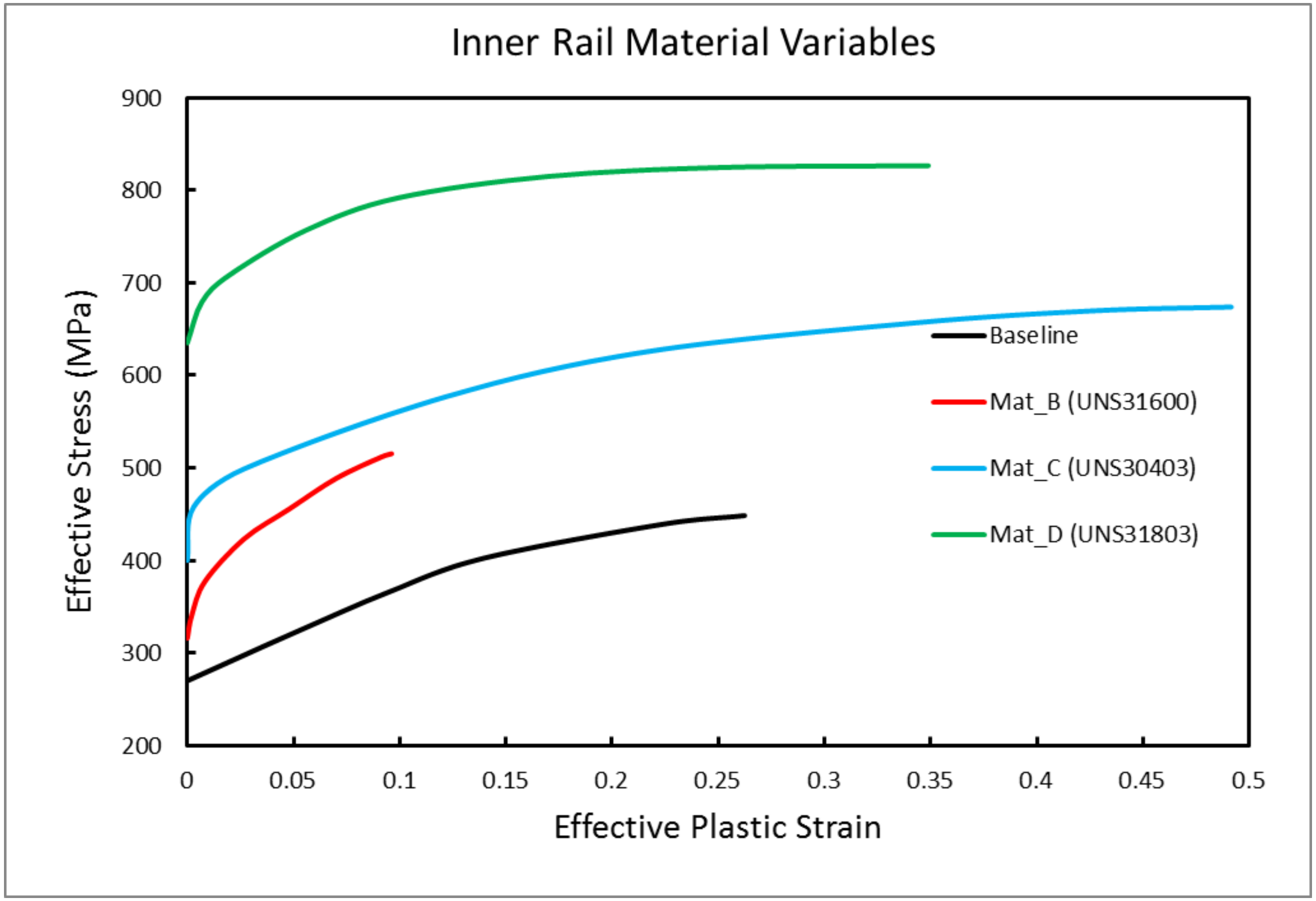
Variable setup

Material categories

thickness transfer



Multi-level Optimization
Categorical variables: Material levels



Multi-level Optimization: Design Criteria

Variables

- Outer level: 6 thickness variables of main crash members
- Inner level: 4 material types (levels) for 6 main crash members

Minimize

- Mass

Criteria

Intrusion	<	721
Stage 1 pulse	<	7.5g
Stage 2 pulse	<	20.2g
Stage 3 pulse	<	24.5g

Multi-level Optimization: *SRSM/GA* vs. *GA* only

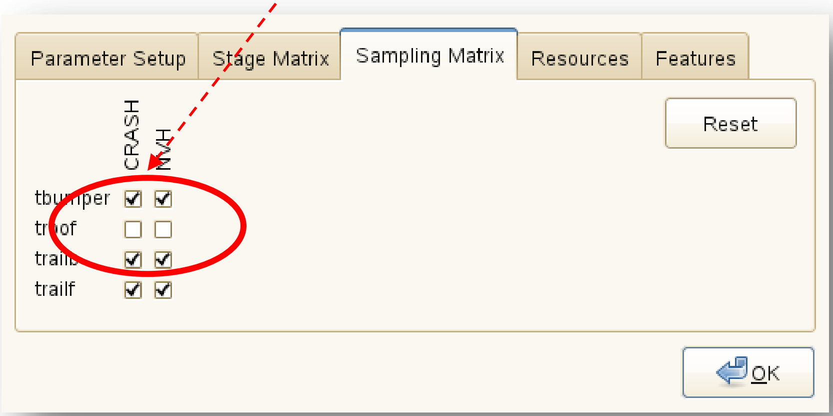
Analysis Type	No. of DVs	Mass (Kg) Baseline	Mass (Kg) Optimum	Reduction (%)	Cost (LS-DYNA runs)
Multilevel Optimization with thickness and discrete material variables	6 (thickness) + 6 part materials (4 discrete levels) = 12	138.1	122.2	11.6	**9340**
Direct optimization with both thickness and material variables (population size: 30)	6 (thickness) + 6 part materials (4 discrete levels) = 12	138.1	130.5	**5.5**	3000
Direct GA with thickness and discrete material variables (population size: 100)	6 (thickness) + 6 part materials (4 discrete levels) = 12	138.1	121.9	**11.8**	5000

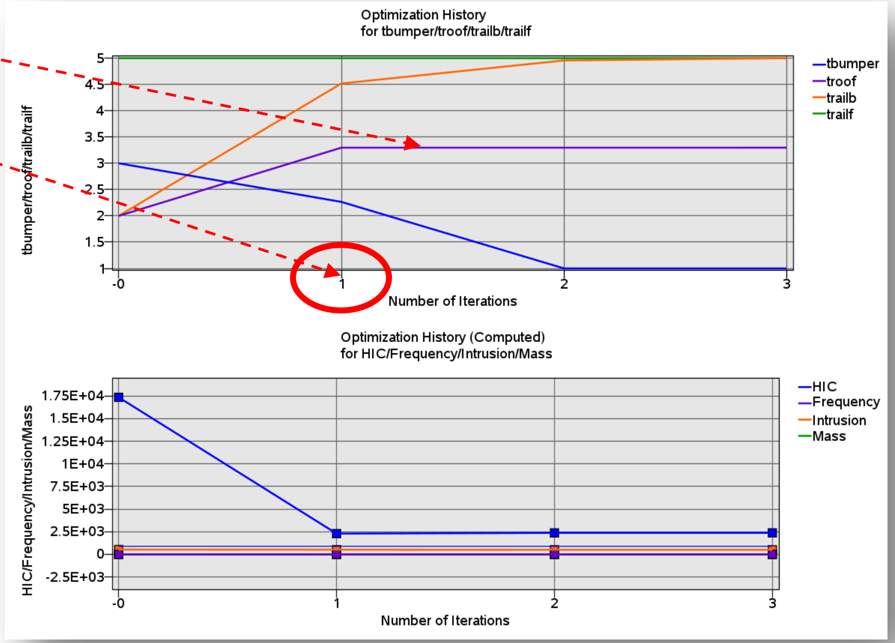
Multilevel Optimization: Observations

- Multilevel more robust (possibly).
  - GA population size can significantly influence global optimality
- Multilevel allows metamodel creation for continuous variables
  - E.g. can apply robustness, tolerance optimization etc.
- Disadvantage: Multilevel more expensive.
  - Optimization could be streamlined, e.g. by adapting starting points for sublevel optimization. Hybridization of optimizer.
- Multilevel useful in other applications such as tolerance optimization: *Tolerance Optimization Using LS-OPT (Basudhar). Proceedings of this forum*
  - Also, Collaborative Design Optimization, Design of Product Families

Variable deactivation (iterative methods)

- Optimization: large number of function evaluations, especially in multi-level setup
- Variables can be manually de-activated
  - Save computational effort (variable screening)
  - Variable is frozen
  - Seamless restart

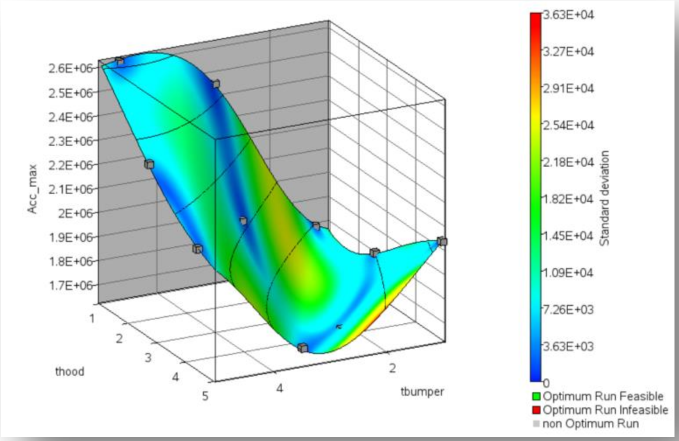


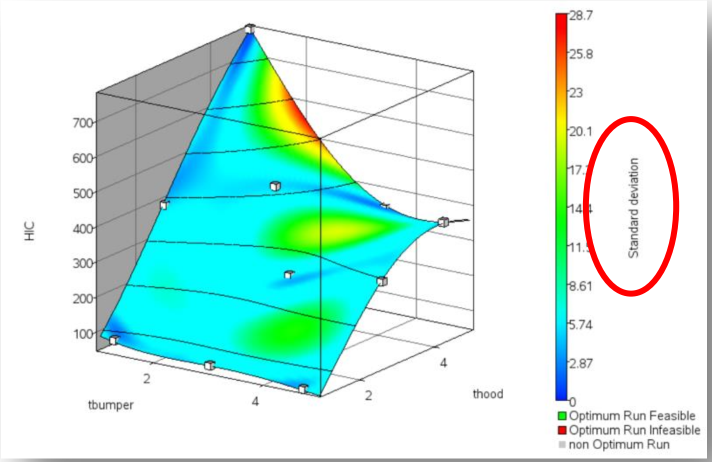


Multiple entity plot

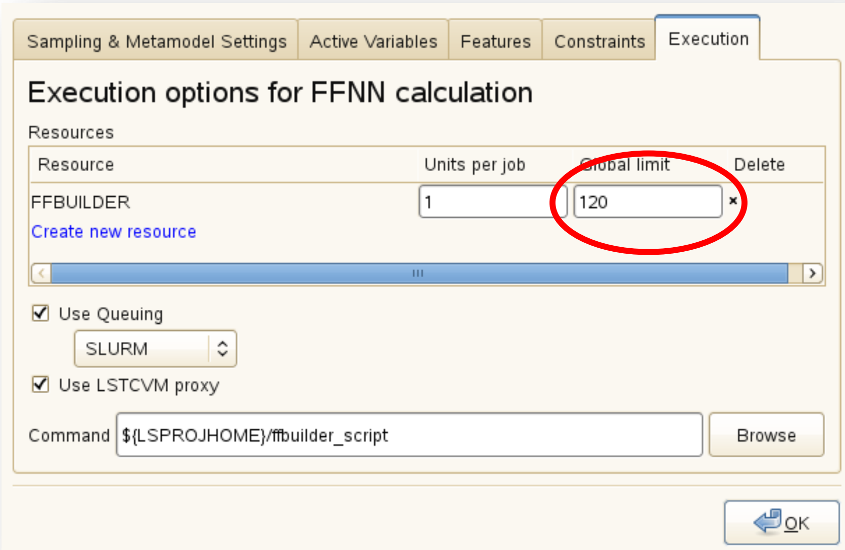
Parallel Neural Networks: Motivation

- High metamodel accuracy required. Even with screening, appropriate metamodeling tools needed
- Feedforward Neural Networks
  - High accuracy global approximation. Good bias-variance compromise. Variance information available (illustrated below)
  - Expensive. Vehicle crash often 100+ responses. Solved independently due to nonlinearity. Reduction (as when linear) not possible.
    - *Ensembles* (sorting through hidden nodes to get the right order)
      - *Committees* (Monte Carlo method to improve prediction)
  - Ensembles and Committees are suitable for parallelization

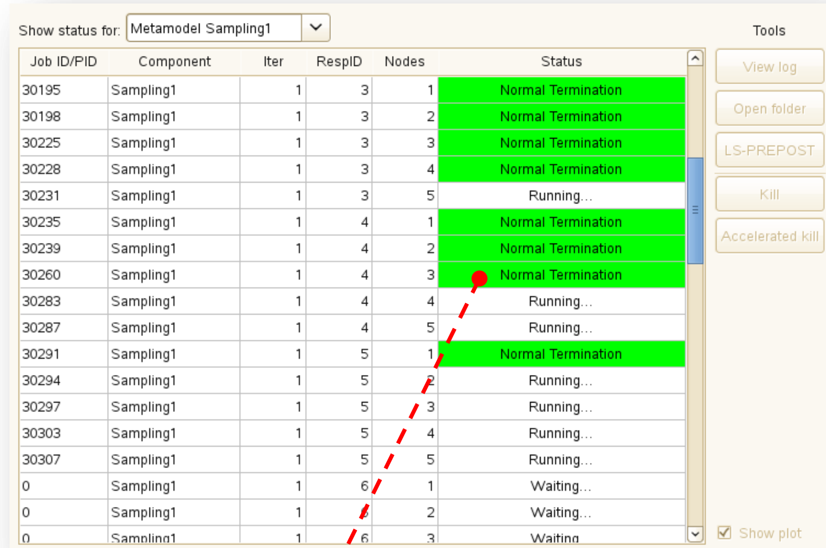




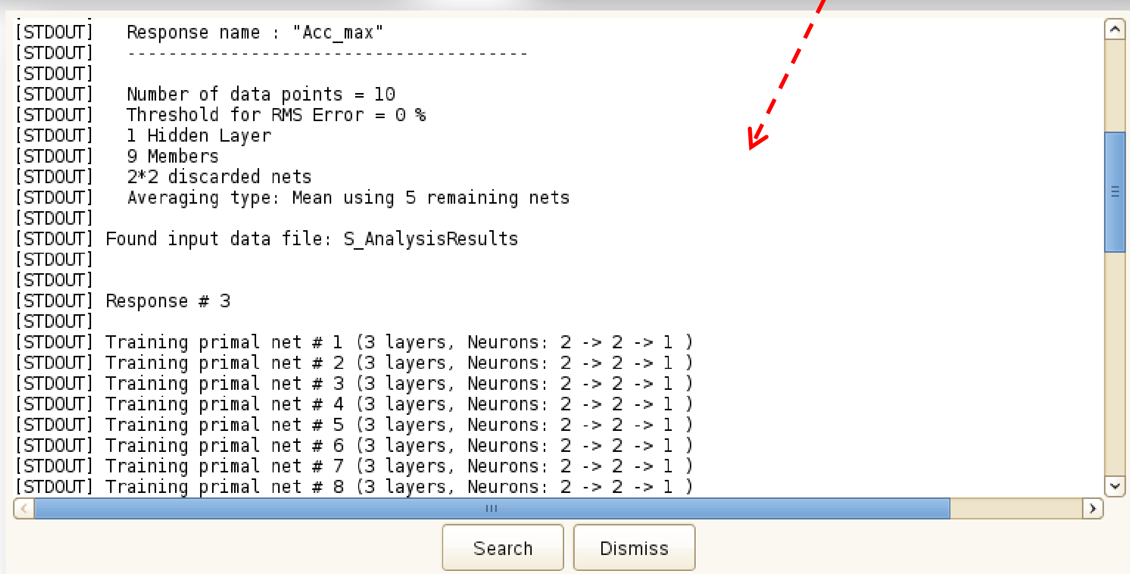
Parallel Neural Networks: Interface



Dialog



Progress

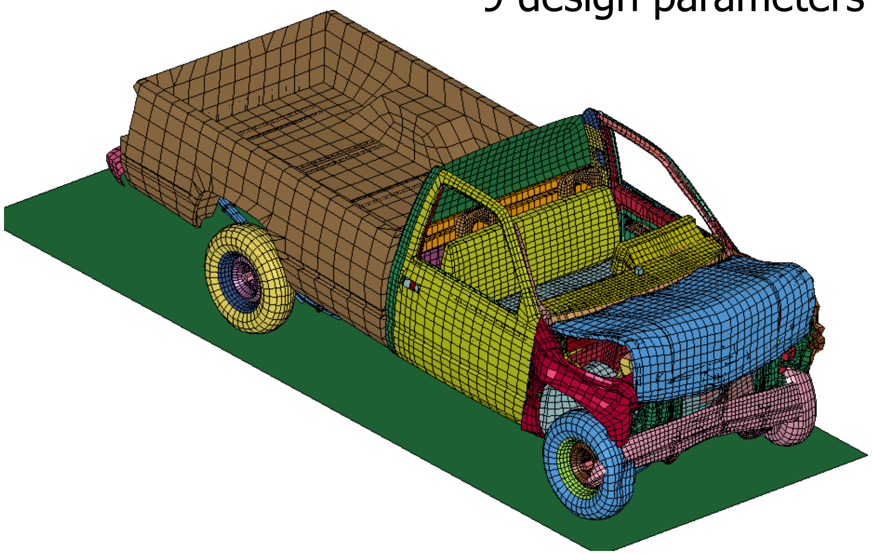


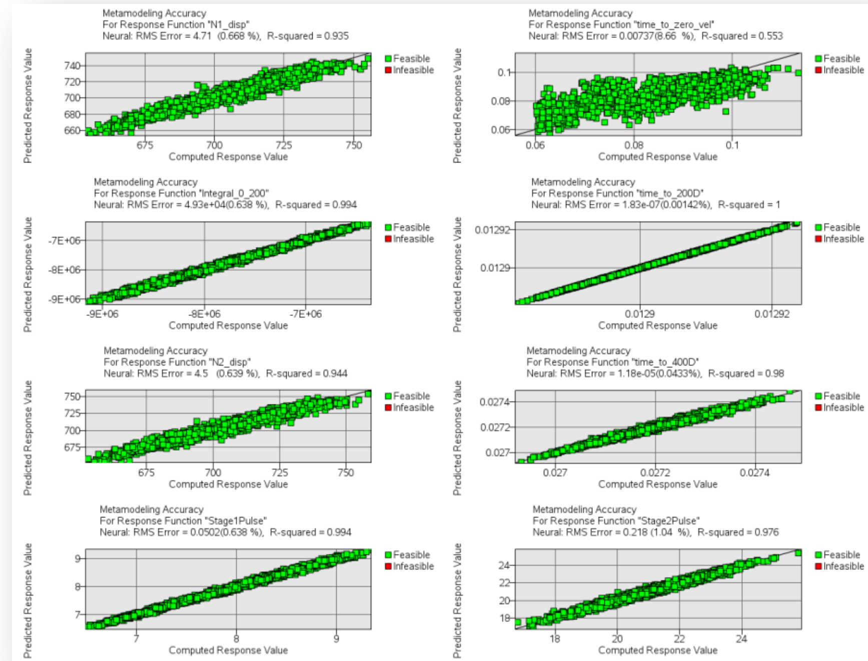
- Functionality similar to solver job monitoring.
- Jobs can be distributed

Log

Parallel Neural Networks: Results

9 design parameters





Predicted vs. Computed

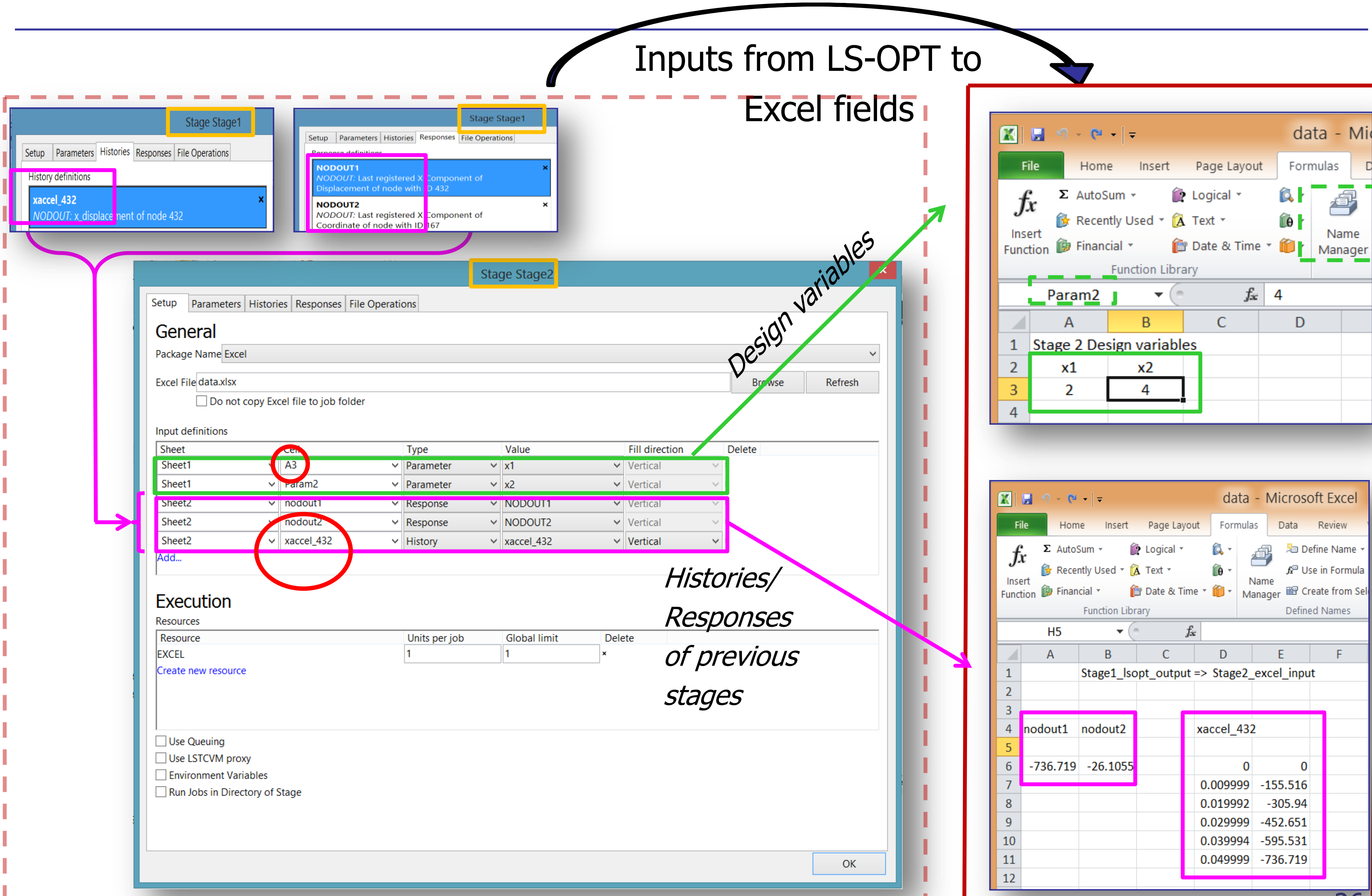
Statistics

Parameters	9
Simulations	1997
Responses	15
Processors	8

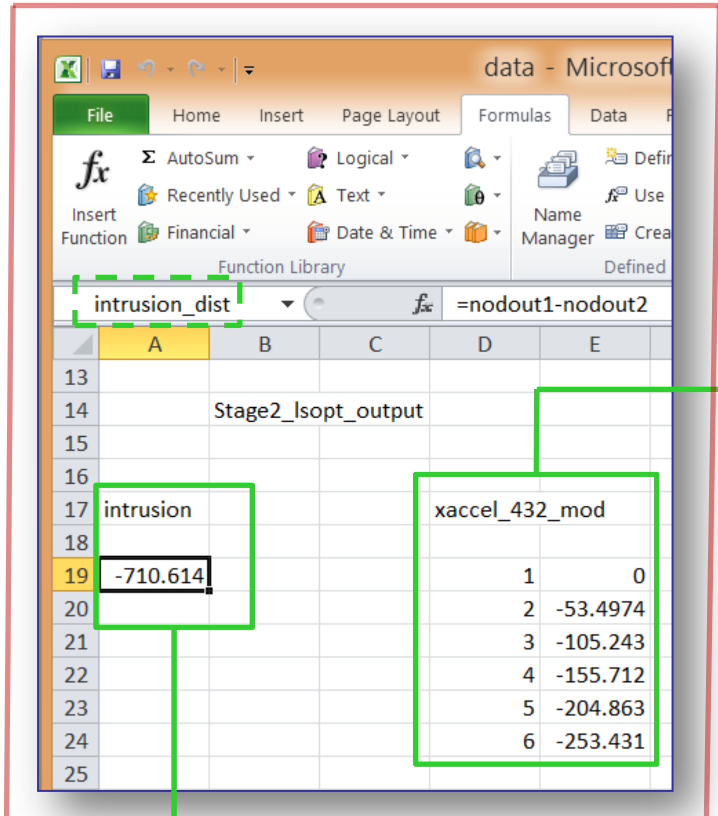
Calculation times

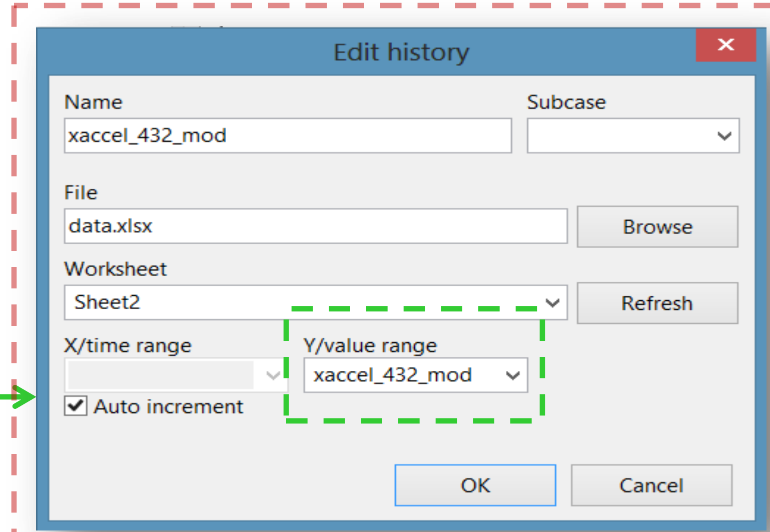
Type	Order	MC	Time (min.)
Min	3	*9*	2.8
Default	***5****	***9****	10.6
Max	10	19	99.6

Excel stage type (substitution)

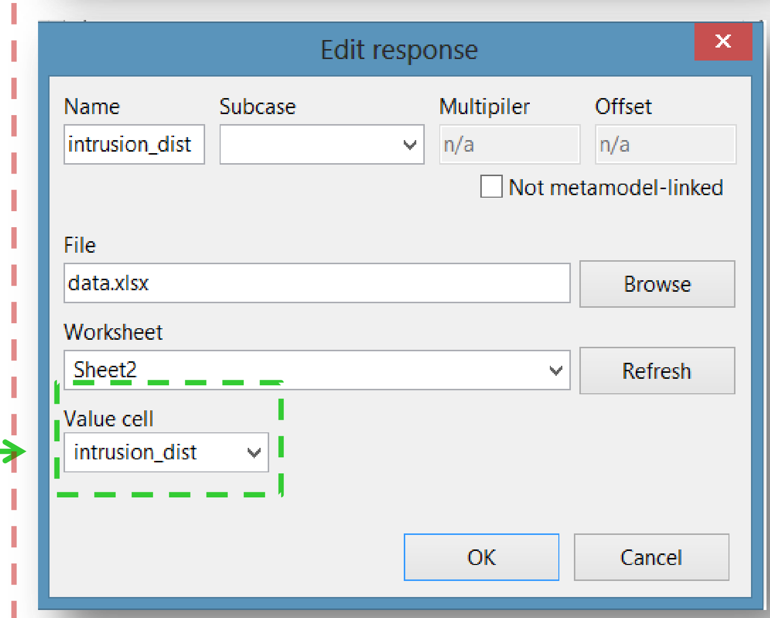


Excel stage type (extraction)



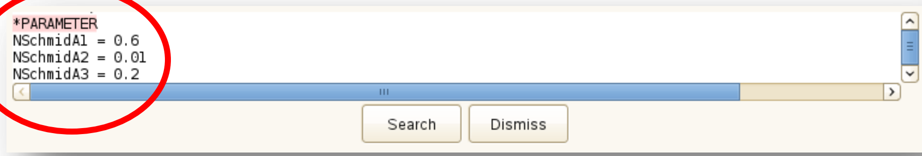


Excel fields as LS-OPT histories/responses



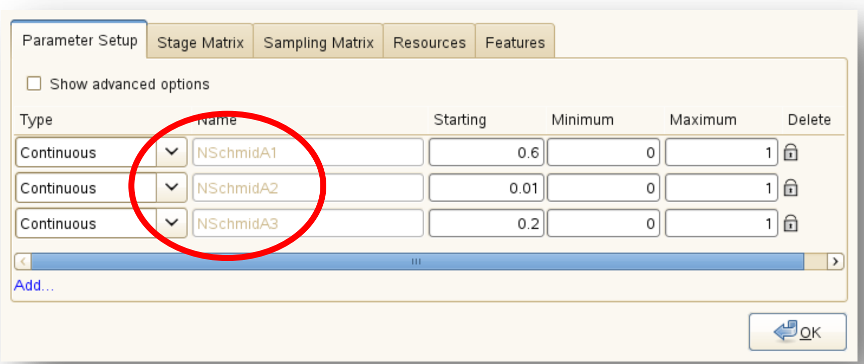
Third Party solvers: Example

Courtesy: Aboozar Mapar, MSU

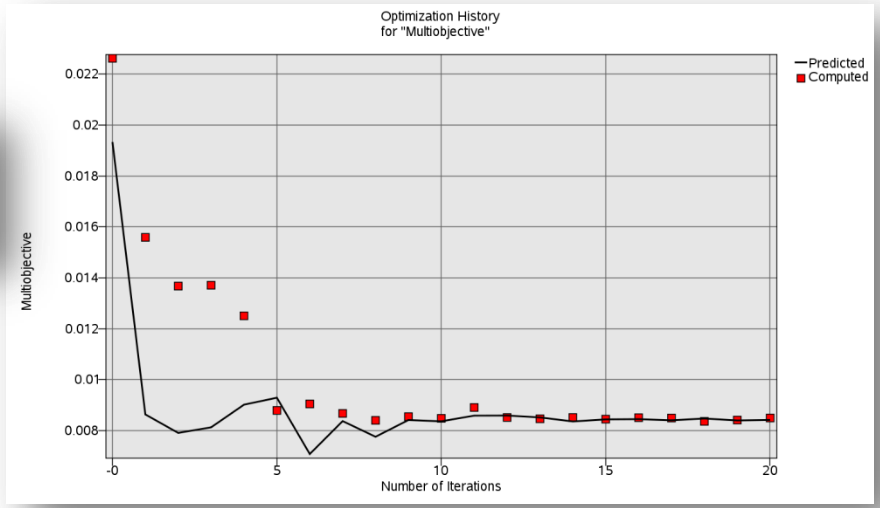


Parameter definition
(solver input file)

Import



Variable setup



Minimization of residual

Third Party solvers: Example

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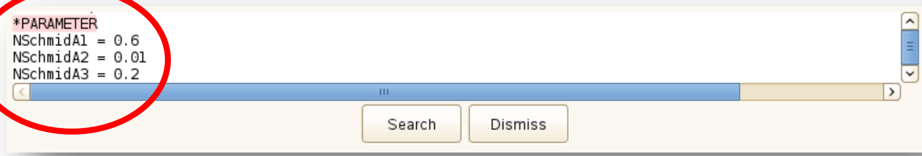
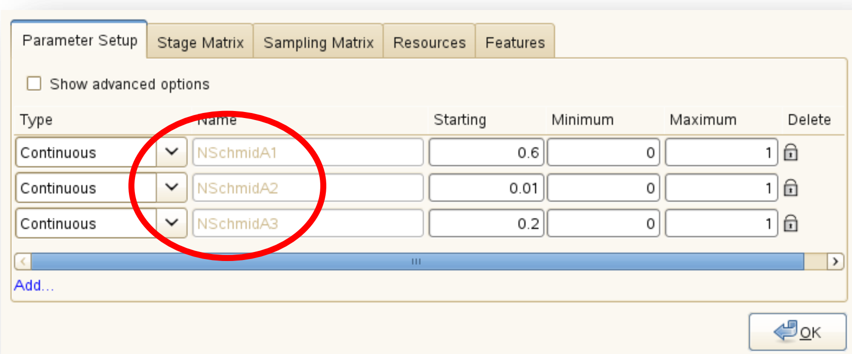
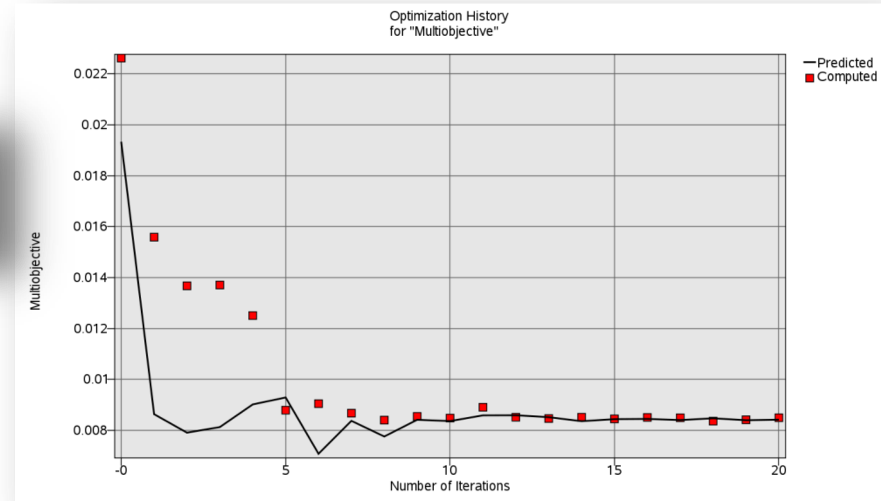


Parameter definition
(solver input file)

Import



Variable setup

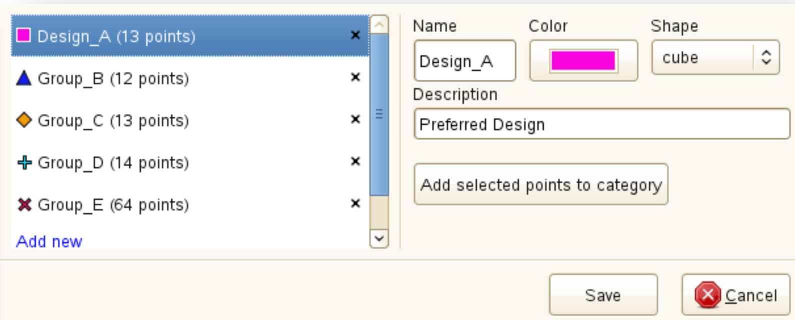


Minimization of residual

Graphical Features
(Viewer)

Design Point Categories

◈ Picking, displaying and saving designs of interest



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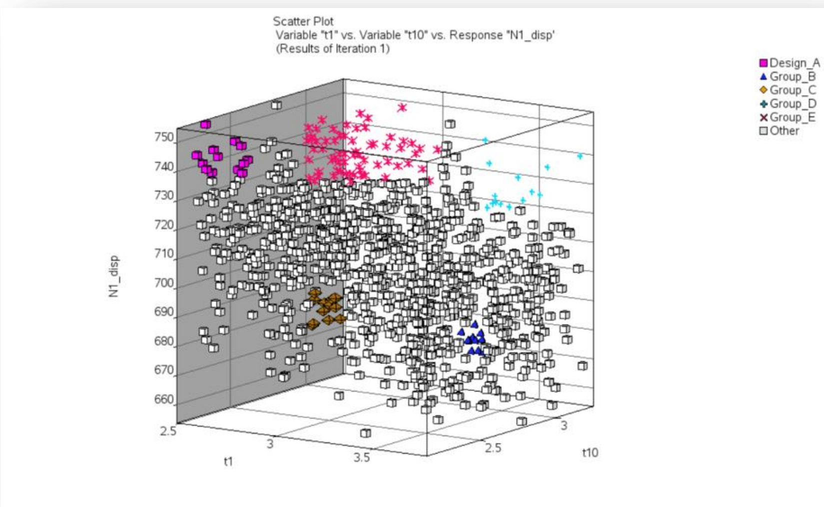
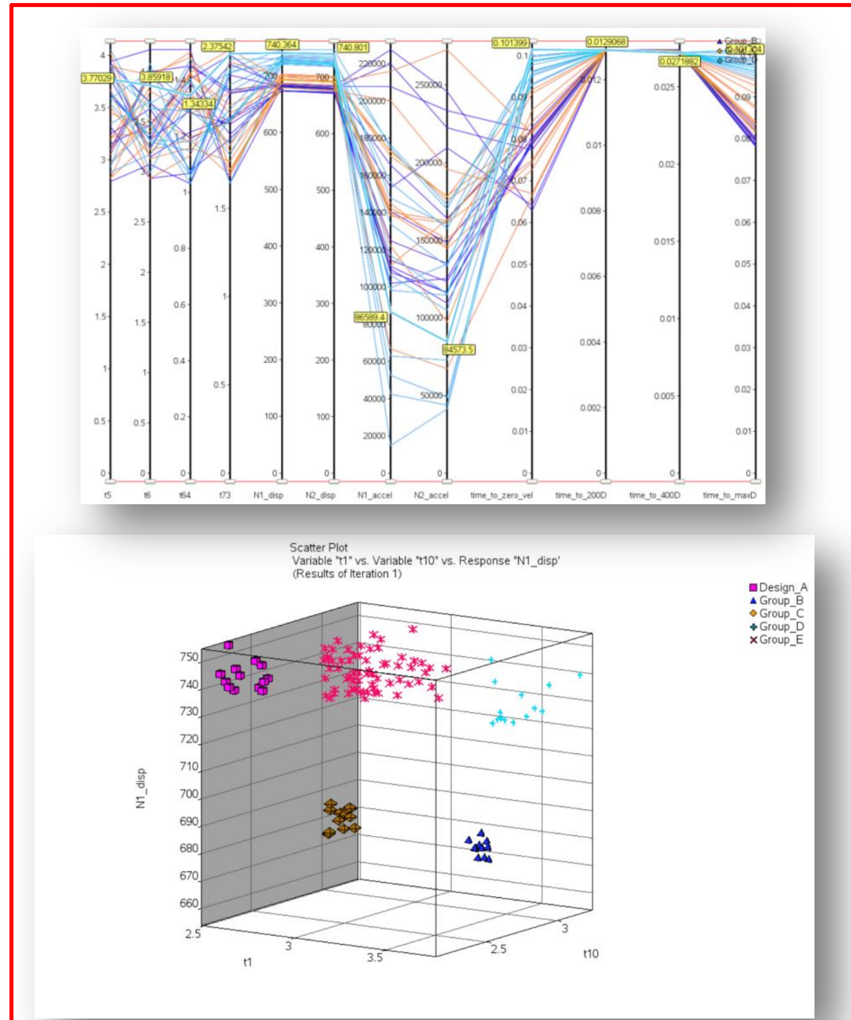


Categories + Other



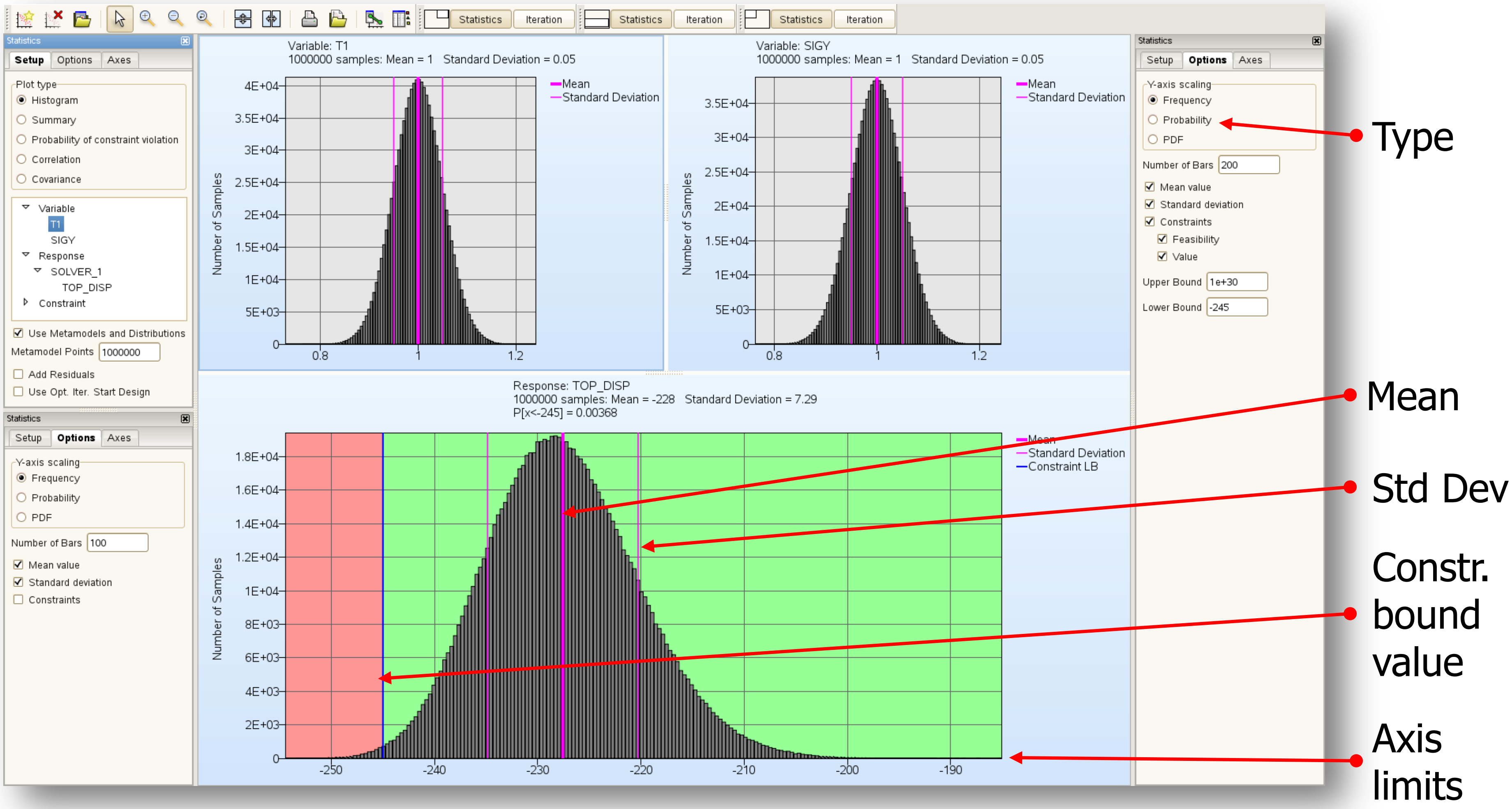
“Other” points hidden

Histogram visualization

- Manual axis control of the region of interest
  - Range, step size
- Graphical visualization of properties (mean, std dev, feasibility range)
- Additional histogram types
  - Frequency
  - Probability / Relative Frequency = $\dfrac{\text{Frequency}}{\text{Sample size}}$
  - Probability Density Function (PDF) / Relative Frequency per Unit Width = $\dfrac{\text{Probability}}{\text{Bin width}}$

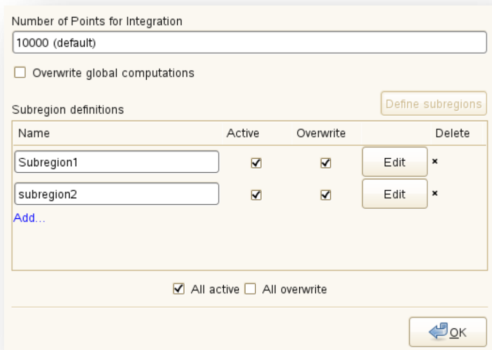
(standard representation)

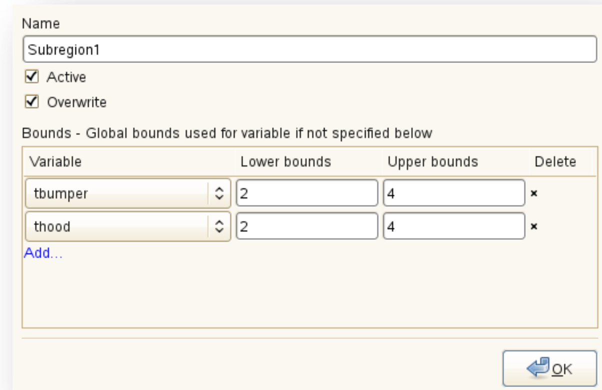
Histogram visualization – attributes

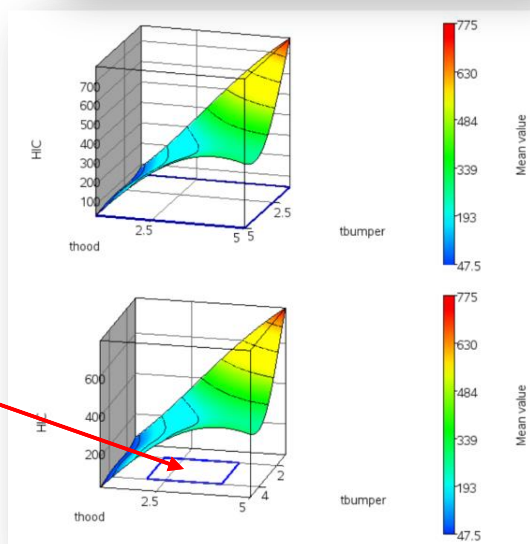


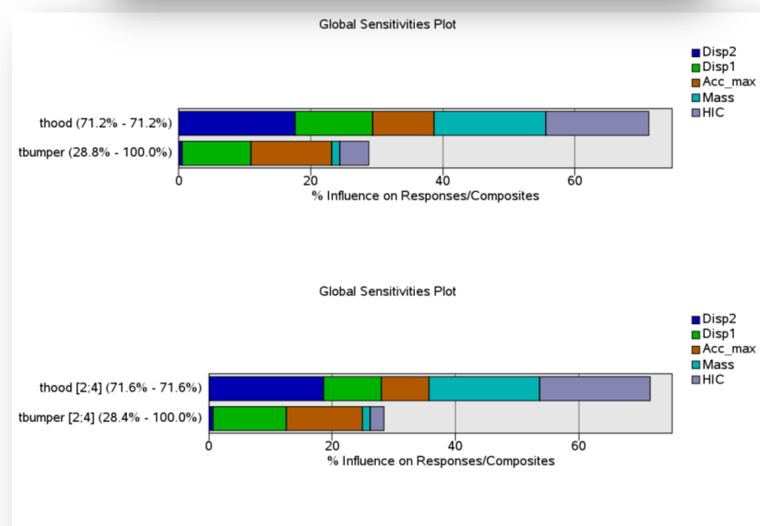
Global Sensitivity Analysis (subregion)

- Sensitivities within specific design *proximity*
- Can set up *multiple* sub-regions interactively





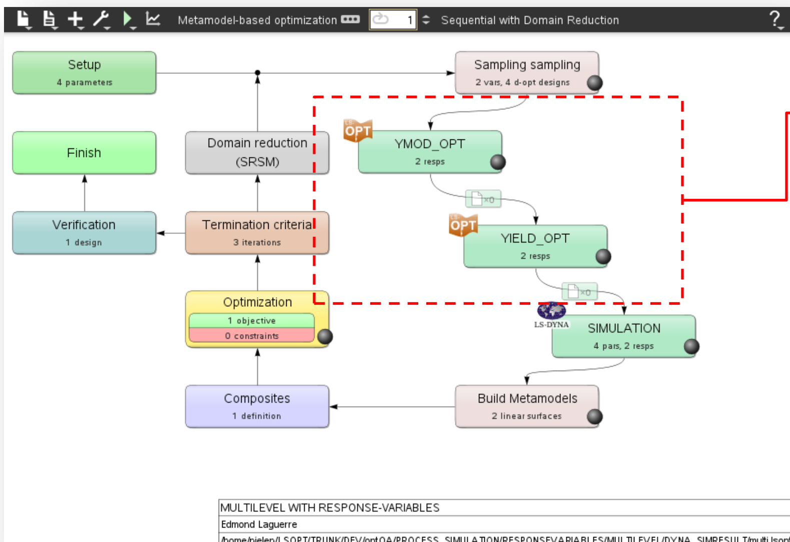


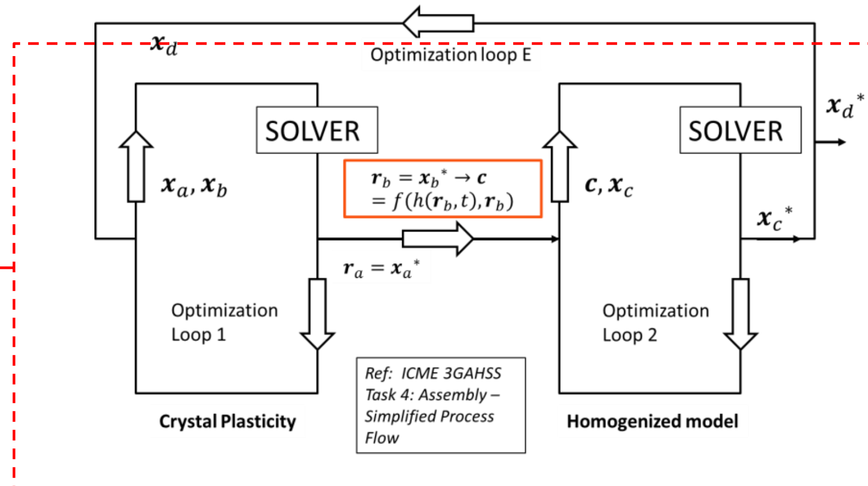


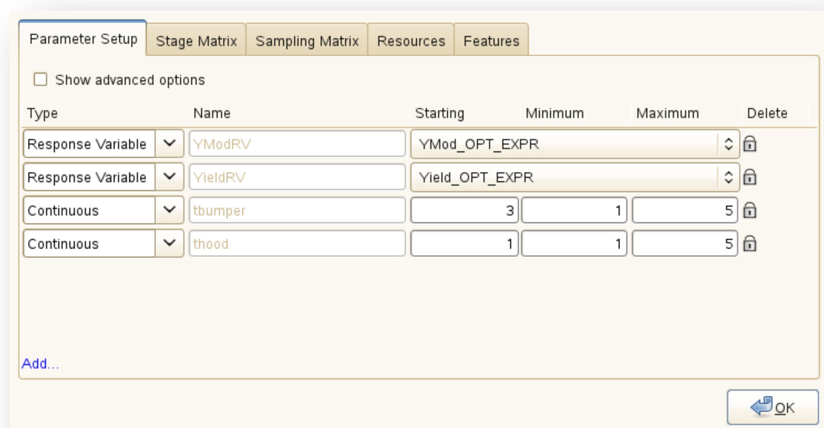
Sub-region

Response-variables (development version)

- Transfer variables between design stages
- Responses are substituted in successor stage input







Outlook

Outlook

- Multi-level Optimization
  - Funded by US Department of Energy
  - *Analytical Target Cascading* as a logical development path to provide a collaborative capability
- Viewer (post-processing, data mining)
  - Result table manipulation: integration of *categories* into tables, etc.
  - Speed improvements to Viewer displays
  - Virtual design displays: generate cluster of surrogate results
- Reliability
  - Probability Density Function approximation from empirical data
    - Kernel density approximation
  - Sequential reliability analysis
    - Convergence of probability of failure value
    - Adaptive sampling
  - Tolerance-based optimization – See paper by *Anirban Basudhar*

Outlook

- New applications for approximations
  - Domain reduction approaches for multi-objective optimization (MOO)
    - Extend work done for User's Conference 2012
    - Classification-based Decision Boundaries
      - Support Vector Machines
      - Application in domain definition for binary and discontinuous responses
  - Multi-response metamodels
    - Spatial distribution of response locations
    - Biomechanical applications, e.g. using MRI spatial data for heart muscle calibration
- Metamodels: performance and usability
  - Multiple metamodel type displays: comparison of metamodels

Outlook

- Job scheduler
  - LS-OPT job scheduler handles/monitors ~330 jobs in parallel (Linux limitation).
  - With MPP (e.g. 64 nodes/job) ~ 21,000 but capacity is now typically ~20,000 nodes
- More solver types
  - Matlab
  - *LS-TaSC*

Other papers at this conference

- Tolerance Optimization Using LS-OPT (Basudhar)
- LS-OPT Current development: A perspective on multilevel optimization, MOO and classification methods (Stander, Basudhar) (Developers Forum, Sweden)