

New Developments in LS-OPT Version 4

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LS-OPT Capabilities

- Design of Experiments
 - D-Optimality, Latin Hypercube, Space Filling
- Metamodels
 - Polynomials, Radial Basis Function networks, Feedforward Neural networks, Kriging, User-defined metamodels
 - Used for variable screening, optimization, prediction, reliability and outlier analysis
- Pre/Post-processor interfaces
 - ANSA, META-Post, Truegrid, User-defined
- Job distribution
 - PBS, SLURM, NQE, NQS, LSF, User-defined, Blackbox, Honda, LoadLeveler

LS-OPT Optimization Capabilities

- Optimization solvers
 - NSGA-II (Non-dominated sorting Genetic Algorithm)
 - Multi-Objective global optimization
 - Adaptive simulated annealing
 - Single objective global optimization. Very fast
 - LFOPC
 - Original algorithm, highly accurate for single objective
- Reliability-based Design Optimization
- Topology optimization
 - LS-DYNA explicit and implicit (linear + nonlinear)
 - Multi-case design
 - Large number of elements (1e6 tested)
 - General and extruded geometries
 - Non-cuboidal design domains

LS-OPT development: 4.0

Next Generation Postprocessor (Viewer)

- New architecture
 - Split windows, vertically/horizontally
 - Detachable windows
 - Spreadsheet type point listing
- Correlation Matrix
 - Scatter plots, Histograms and Correlation values
 - Interactive: Display histograms or correlation bars
- Visualization of Pareto Optimal Front
 - 4D plotting (already in Version 3.4)
 - Multi-axis plot for higher dimensions
 - Hyper-Radial Visualization
 - Self Organizing Maps (Version 4.1)
- Virtual histories
 - Plot history at any point in the design space (Version 4.1)

Outlook: LS-OPT development: 4.0

♦ META Post interface

 Allows extraction of results from any package (Abaqus, NASTRAN, ...) supported by META Post (ANSA package)

♦ LS-OPT/Topology

- Nonlinear topology optimization
- LS-DYNA based
- Multiple load cases
- Linear as well as non-linear
- Design part selection
- Job distribution (queuing) as in LS-OPT

Multi-Objective Optimization: Example



Design criteria

Minimize

- Mass
- Acceleration

Maximize

- Intrusion
- Time to zero velocity

9 thickness variables of main crash members

- ♦ Intrusion < 721</p>
- ♦ Stage 1 pulse < 7.5g</p>
- ♦ Stage 2 pulse < 20.2g</p>
- ♦ Stage 3 pulse < 24.5g</p>

Simulation statistics

- 640-core HP XC cluster (Intel Xeon 5365 80 nodes of 2 quad-core)
- ♦ Queuing through LSF
- \Leftrightarrow Elapsed time per generation ~ 6 hours
- ♦ Total of 1,000 crash runs
- ♦ Strategy: Single stage run
- Sampling scheme: Space Filling (MinMax distance) using 1000 points
- ♦ Surrogate model: Radial Basis Function Network
- Optimization solver: NSGA-II to find Pareto Optimal Frontier

Correlation Matrix of 1000 simulation points

Variables				Variables									Composites						
												/	/		Mass	time_to_ze	stage1_pu	stage2_pu	stage3_pulse
		1	12	13	14	15	16	110	164	173		Disp	Accel	Scaler	scaled	scaled	scaleo	scaled	»-
	t1	(second	-0.01	0.01	-0.01	0.01	0.03	0.00	0.00	0.02		0.50	-0.07	-0.22	-0.29	0.05	0.57	0.21	5
	t2			-0.01	0.01	0.06	0.04	0.01	0.03	-0.01		0.41	-0.02	-0.21	-0.25	0.03	0.47	0.17	
	t3			الحياة	0.03	0.03	-0.00	-0.00	-0.00	0.03		0.52	-0.12	-0.21	-0.45	0.04	0.31	0.48	
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uriable	t5						-0.01	0.02	0.03	0.01		0.08	-0.14	-0.46	0.04	-0.04	-0.00	-0.10	
Va	t6							-0.04	-0.02	-0.01	- 2	0.07	0.08	-0.45	0.10	-0.14	0.05	-0.10	
	t10								0.01	0.06		0.03	-0.00	-0.33	0.16	0.97	-0.28	0.02	
	t64									0.00		0.07	0.01	-0.07	-0.05	-0.01	0.11	0.01	
	t73											0.04	-0.06	-0.60	-0.05	-0.12	-0.10	0.18	
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	scaled_stage2_pulse						NAME					No.					A	0.37	
	scaled_stage3_pulse		es man								N				Marine Marine			A	

Stochastic input



Variables and distributions

<u>F</u>ile <u>V</u>iew <u>T</u>ask <u>H</u>elp

Info Strategy	Solv	vers Dist Varia	bles Sampling	Histories R	esponses O	bjective Constra	aints Algorithms	Run Viewer	DYNA Stats		
Туре		Name	Starting Init	t. Range	Desig Minimum	n Variables Maximum	Distribution				
Variable	-	t1	3.137		2.5	3.765	Uniform 🔻			_	Saddle Direction
Variable	-	t2	3.112		2.48	3.75	Uniform 👻				Minimize
Variable	-	t3	2.997		2.4	3.6	Uniform 👻				Cases
Variable	-	t4	3.072		2.4	3.6	Uniform 👻				⊖ List
Variable	-	t5	3.4		2.72	4.08	Uniform 👻				
Variable	-	t6	3.561		2.85	4.27	Truncatec 👻				
Variable	-	t10	2.7		2.16	3.24	Truncatec 👻				
Variable	-	t64	1.262		1	1.51	Truncatec 👻				
Variable	-	t73	1.99		1.6	2.4	Truncatec 👻				
Add a Variabl	e									Delete a Variable	J

Scatterplot of intrusion: feasibility level



Metamodel Accuracy

Objective Functions



Metamodel Accuracy

Constraint Functions



Sensitivity: Objectives



Pareto Optimal Frontier

- A hyper-surface of optimal designs for multiple objectives
- Visualization is complicated, hence 4 tools are provided
 - 4D Spatial plot
 - Traditional
 - Parallel Coordinate plot
 - Pans and zooms in hyperspace
 - Hyper-Radial Visualization
 - Weighting of objectives
 - Self-Organizing Maps (Ver. 4.1)
 - Continuous mapping of objective space
 - "Hole" detection

Pareto Optimal Frontier Spatial plot: t_5 in color



Pareto Optimal Frontier Parallel Coordinate Plot: Variables and Objectives (Full/Reduced databases)



Pareto Optimal Frontier Hyper Radial Visualization (variable *t5* in color)



Sliders for adjusting weights

Hyper Radial Visualization

- Hyper Radial Visualization (HRV) maps any number of objectives to 2D
- Objectives are placed in X and Y groups
- Grouping does not matter as "best" point (closest to Utopian point) is always the same
- Points on the same contour have the same "value"
- Objectives can be weighted by moving sliders

Cross-display of selected points



Spreadsheet of selected points

tion													
/	~ 🗗 🗕 🗕												
•	Point					Variables							
	ID	t1	t2	t3	t4	t5	t6	t1 0	t64	t73	N1_disp	N2_disp	N1
	t1.61	2.97461	2.48845	2.63813	3.0794	2.81527	2.94545	2.34648	1.00323	2.03686	717.13	718.566	1
	t1.314	2.97028	2.50838	2.68088	3.01328	2.73141	2.94295	2.34327	1.01036	1.93423	717.33	718.472	1
	t1.339	2.97033	2.48855	2.6456	3.07694	2.72019	2.85593	2.34345	1.00244	1.92001	717.046	718.437	1
	t1.360	2.97461	2.49834	2.64825	3.08183	2.81396	2.94505	2.35213	1.20886	2.0356	718.167	718.057	1
	t1.381	2.98462	2.4904	2.68054	3.00873	2.72048	3.00838	2.34825	1.01035	2.04238	716.999	718.375	1
	t1.388	3.2071	2.52048	2.68494	2.6768	2.72071	2.92279	2.36076	1.00453	2.05429	717.589	718.2	1
	t1.395	3.18645	2.49159	2.68559	2.69227	2.72118	2.86564	2.34113	1.00694	2.01281	717.287	718.296	1
	t1.510	3.20129	2.48092	2.73607	2.64129	2.76148	2.86426	2.3466	1.02748	1.94592	717.561	718.189	1

Probability distributions of constraint values

Starting Design







Composite: scaled_stage2_pulse 10000 samples: Mean = 1.05 Standard Deviation = 0.0123 95% confidence interval in red



Composite: scaled_stage2_pulse 10000 samples: Mean = 1.05 Standard Deviation = 0.0123



Composite: scaled_stage1_pulse 10000 samples: Mean = 1.05 Standard Deviation = 0.0178 95% confidence interval in red

Composite: Disp



Composite: scaled_stage1_pulse 10000 samples: Mean = 1.05 Standard Deviation = 0.0178



Composite: scaled stage3 pulse 10000 samples: Mean = 1 Standard Deviation = 0.00476 95% confidence interval in red



Composite: scaled_stage3_pulse 10000 samples: Mean = 1 Standard Deviation = 0.00475



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of Samples

Number (

Probability distributions of constraint values

Optimal Design (equal weights)

Composite: Disp

Composite: Disp 10000 samples: Mean = 0.996 Standard Deviation = 0.00365 95% confidence interval in red





Composite: scaled stage1 pulse

Composite: scaled_stage2_pulse 10000 samples: Mean = 0.962 Standard Deviation = 0.0113 95% confidence interval in red



Composite: scaled_stage2_pulse 10000 samples: Mean = 0.962 Standard Deviation = 0.0112



Composite: scaled_stage1_pulse 10000 samples: Mean = 0.982 Standard Deviation = 0.0159 95% confidence interval in red





Composite: scaled_stage3_pulse 10000 samples: Mean = 0.985 Standard Deviation = 0.00475 95% confidence interval in red

05

P[x<0] = 0 P[x>1] = 0.0006

P[x>1]

P[x<0]

Composite: scaled_stage3_pulse 10000 samples: Mean = 0.985 Standard Deviation = 0.00473



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Number of Samples

Self-Organizing Maps



Self-Organizing Maps

- In prototype stage (*D-SPEX* by *DYNAmore* GmbH shown)
- ♦ Released in Version 4.1, Fall 2009

Hybrid Cellular Automata (HCA) algorithm

In traditional elastic-static problems, material is distributed based on the <u>strain energy</u> (U^e) generated during loading

target (*S*) \rightarrow strain energy density

♦ For elastic-plastic problems, every finite element must contribute to absorb <u>internal energy</u> (U) which includes both elastic strain energy and plastic work during loading.



Example problem: short beam



 $^{00 \}times 20 \times 20$ elements

^{*~7} minutes/FEA (DYNA) evaluation

Effects of model simplifications



Short beam: extrusion results



Problem Definition



- Three poles hit the fixed-fixed beam with an initial velocity of 40m/s, one at a time (three load cases)
- Get the optimal structure with 30% mass, equal importance of each load case
- ♦ Mesh size 10mm³, Material: Bi-linear Aluminum
- ♦ MPP LS-DYNA simulations with 8 processors per case

Final Results

- 37 iterations to obtain optimal topology
- The initial shape was evolved within 20 iterations
- Tabular structure with two legs was evolved as optima
- Uniform distribution of material



Estimated beta release

- ♦ Version 4.0: April, 2009
- Version 4.1: September, 2009
- ♦ Topology Optimization, April, 2009