New Developments in LS-OPT Version 4

Nielen Stander, Willem Roux, Tushar Goel
LSTC, Livermore, CA

David Björkevik, Christoffer Belestam
ERAB, Linköping, Sweden

Katharina Witowski
DYNAmore GmbH, Stuttgart, Germany

April, 2009
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

Thickness design variables
Design criteria

Minimize

- Mass
- Acceleration

Maximize

- Intrusion
- Time to zero velocity

9 thickness variables of main crash members

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

- 640-core HP XC cluster (Intel Xeon 5365 80 nodes of 2 quad-core)
- *Queueing* through LSF
- 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
Stochastic input

- Truncated normal
- Uniform

Copyright © 2008 Livermore Software Technology Corporation
### Variables and distributions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Name</th>
<th>Starting</th>
<th>Init. Range</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>11</td>
<td>3.137</td>
<td>2.5</td>
<td>3.706</td>
<td>Uniform</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>12</td>
<td>3.112</td>
<td>2.48</td>
<td>3.75</td>
<td>Uniform</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>13</td>
<td>2.997</td>
<td>2.4</td>
<td>3.6</td>
<td>Uniform</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>14</td>
<td>3.072</td>
<td>2.4</td>
<td>3.6</td>
<td>Uniform</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>15</td>
<td>3.4</td>
<td>2.72</td>
<td>4.08</td>
<td>Uniform</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>16</td>
<td>3.861</td>
<td>2.85</td>
<td>4.27</td>
<td>Truncated</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>17</td>
<td>2.7</td>
<td>2.16</td>
<td>3.24</td>
<td>Truncated</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>164</td>
<td>1.262</td>
<td>1</td>
<td>1.51</td>
<td>Truncated</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>173</td>
<td>1.99</td>
<td>1.6</td>
<td>2.4</td>
<td>Truncated</td>
<td></td>
</tr>
</tbody>
</table>

Copyright © 2008 Livermore Software Technology Corporation
Scatterplot of intrusion: feasibility level
Metamodel Accuracy

Objective Functions
Metamodel Accuracy

Constraint Functions
Sensitivity: Objectives

![Sensitivity Plots](image)

- Sensitivities Plot for $N_1_{\text{disp}}$ with 90% Confidence Interval
- Sensitivities Plot for $N_1_{\text{accel}}$ with 90% Confidence Interval
- Sensitivities Plot for MASS with 90% Confidence Interval
- Sensitivities Plot for $t_{\text{to}_-\text{zero}_-\text{vel}}$ with 90% Confidence Interval

Copyright © 2008 Livermore Software Technology Corporation
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)

Copyright © 2008 Livermore Software Technology Corporation
Pareto Optimal Frontier
Hyper Radial Visualization (variable $t5$ in color)

Indifference curves (Utopian level)

Mapped Pareto Frontier
All points are Pareto optimal

“Best” design for Selected weighting

Utopian point (origin)

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

<table>
<thead>
<tr>
<th>Point ID</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
<th>t5</th>
<th>t6</th>
<th>t10</th>
<th>t14</th>
<th>N1_disp</th>
<th>N2_disp</th>
<th>N1_n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.61</td>
<td>2.9746</td>
<td>2.48845</td>
<td>2.63813</td>
<td>3.0794</td>
<td>2.81527</td>
<td>2.96545</td>
<td>2.74848</td>
<td>1.00323</td>
<td>2.03686</td>
<td>717.13</td>
<td>718.558</td>
</tr>
<tr>
<td>1.71</td>
<td>2.97028</td>
<td>2.50838</td>
<td>2.08086</td>
<td>3.01328</td>
<td>2.73141</td>
<td>2.49286</td>
<td>2.34327</td>
<td>1.01036</td>
<td>1.93423</td>
<td>717.33</td>
<td>718.472</td>
</tr>
<tr>
<td>1.80</td>
<td>2.97028</td>
<td>2.50838</td>
<td>2.08086</td>
<td>3.01328</td>
<td>2.73141</td>
<td>2.49286</td>
<td>2.34327</td>
<td>1.01036</td>
<td>1.93423</td>
<td>717.33</td>
<td>718.472</td>
</tr>
<tr>
<td>1.99</td>
<td>2.97028</td>
<td>2.50838</td>
<td>2.08086</td>
<td>3.01328</td>
<td>2.73141</td>
<td>2.49286</td>
<td>2.34327</td>
<td>1.01036</td>
<td>1.93423</td>
<td>717.33</td>
<td>718.472</td>
</tr>
<tr>
<td>1.118</td>
<td>2.9746</td>
<td>2.49634</td>
<td>2.64625</td>
<td>3.01663</td>
<td>2.61596</td>
<td>2.94505</td>
<td>2.35213</td>
<td>1.20866</td>
<td>2.0556</td>
<td>718.167</td>
<td>718.057</td>
</tr>
<tr>
<td>1.126</td>
<td>2.9746</td>
<td>2.49634</td>
<td>2.64625</td>
<td>3.01663</td>
<td>2.61596</td>
<td>2.94505</td>
<td>2.35213</td>
<td>1.20866</td>
<td>2.0556</td>
<td>718.167</td>
<td>718.057</td>
</tr>
<tr>
<td>1.137</td>
<td>2.9746</td>
<td>2.49634</td>
<td>2.64625</td>
<td>3.01663</td>
<td>2.61596</td>
<td>2.94505</td>
<td>2.35213</td>
<td>1.20866</td>
<td>2.0556</td>
<td>718.167</td>
<td>718.057</td>
</tr>
<tr>
<td>1.144</td>
<td>2.9746</td>
<td>2.49634</td>
<td>2.64625</td>
<td>3.01663</td>
<td>2.61596</td>
<td>2.94505</td>
<td>2.35213</td>
<td>1.20866</td>
<td>2.0556</td>
<td>718.167</td>
<td>718.057</td>
</tr>
<tr>
<td>1.151</td>
<td>2.9746</td>
<td>2.49634</td>
<td>2.64625</td>
<td>3.01663</td>
<td>2.61596</td>
<td>2.94505</td>
<td>2.35213</td>
<td>1.20866</td>
<td>2.0556</td>
<td>718.167</td>
<td>718.057</td>
</tr>
<tr>
<td>1.156</td>
<td>2.9746</td>
<td>2.49634</td>
<td>2.64625</td>
<td>3.01663</td>
<td>2.61596</td>
<td>2.94505</td>
<td>2.35213</td>
<td>1.20866</td>
<td>2.0556</td>
<td>718.167</td>
<td>718.057</td>
</tr>
</tbody>
</table>

Copyright © 2008 Livermore Software Technology Corporation
Starting Design

Probability distributions of constraint values
Probability distributions of constraint values

Optimal Design (equal weights)
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 strain energy \( U^e \) generated during loading.

\[
\text{target (S) } \rightarrow \text{strain energy density}
\]

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

\[
\text{target (S) } \rightarrow \text{internal energy density}
\]
Example problem: short beam

$M_f^*=0.2$

$v_0=40 \text{ m/s}$

$80 \times 20 \times 20$ elements*

*~7 minutes/FEA (DYNA) evaluation
Effects of model simplifications

\[ M_i^* = 0.2 \]

Nonlinear-dynamic

Linear-static

Nonlinear-static

Courtesy Neal Patel
Short beam: extrusion results

Conventional topology
(no extrusion)

Extruded topology

$M_f^* = 0.2$

Conventional topology

$d_{\text{max}} = 40.1 \text{ mm}$

Extruded topology

$d_{\text{max}} = 47.6 \text{ mm}$

$v_0 = 20 \text{ m/s}$

Courtesy Neal Patel
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 – 10mm$^3$, 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