Discover your design quicker as before with HPC

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Introduction
The ABS, in normal operation, engages and disengages rapidly (many times per second) as the control system senses and reacts to tire slippage. Some 2010 model year cars have reported experiencing inconsistent brake feel during slow and steady application of brakes on rough or slick road surfaces when the ABS is activated in an effort to maintain tire traction.

The cost of failure has never been so high, even for successful companies...
Variations in operating conditions, manufacturing processes and material properties create uncertainty in the overall success of a product design.
Need for HPC

Larger

- Assemblies
- CAD-to-mesh
- Capture fidelity

Faster

- Impact product design
- Enable large models
- Allow parametric studies

Extend

- Modal
- Nonlinear
- Multiphysics
- Dynamics

More

- Multiple design ideas
- Optimize the design
- Ensure product integrity
Summary

It’s all about getting better insight into product behavior quicker!

HPC enables high-fidelity
- Include details - for reliable results
- “Getting it right the first time”
- Innovate with confidence

HPC enables design exploration & optimization
- Consider multiple design ideas
- Optimize the design
- Ensure performance across range of conditions
Larger Simulations
Today’s multi-core / many-core hardware evolution makes HPC a software development imperative.
ANSYS Mechanical Scaling Achievement @ 13.0

6 Mio Degrees of Freedom
Plasticity, Contact
Bolt pretension
4 load steps
What about GPU Computing?

CPUs and GPUs work in a **collaborative** fashion

<table>
<thead>
<tr>
<th></th>
<th>CPU</th>
<th>GPU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multi-core processors</strong></td>
<td>Typically 4-6 cores</td>
<td>Typically hundreds of cores</td>
</tr>
<tr>
<td><strong>Powerful, general purpose</strong></td>
<td></td>
<td>Great for highly parallel code, within memory constraints</td>
</tr>
</tbody>
</table>

**PCI Express channel**
GPU Acceleration can be used with Distributed ANSYS to combine the advantage of GPU technology and the power of distributed ANSYS.
# ANSYS and NVIDIA Collaborations

<table>
<thead>
<tr>
<th>Release</th>
<th>ANSYS Mechanical</th>
<th>ANSYS Fluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.0 Dec 2010</td>
<td>SMP, Single GPU, Sparse and PCG/JCG Solvers</td>
<td></td>
</tr>
<tr>
<td>14.0 Dec 2011</td>
<td>+ Distributed ANSYS; + Multi-node Support</td>
<td>Radiation Heat Transfer (beta)</td>
</tr>
<tr>
<td>14.5 Oct 2012</td>
<td>+ Multi-GPU Support; + Hybrid PCG; + Kepler GPU Support</td>
<td>+ Radiation HT; + GPU AMG Solver (beta), Single GPU</td>
</tr>
</tbody>
</table>
Modal analysis of a radial impeller
- Block Lanczos Eigensolver
- Cyclic symmetry model with 2 million DOF:
  - 337916 nodes
  - 222725 elements
  - 10-node tetrahedral solid element

Results (baseline is 1 core):
- With GPU, ~6x speedup on 1 core
- ~8.5x speedup on 4 cores
- If 2 cores is taken as baseline instead, 2 cores with GPU Accelerator results in 3.7x speedup!

Windows workstation: Two Intel Xeon 5530 processors (2.4 GHz, 8 cores total), 48 GB RAM, NVIDIA Quadro 6000
Continuous performance improvements version over version
Parallel scalability near ideal (98%+!)
Demonstrable ability to solve large problems on large clusters very efficiently
Optimized Solver Performance
- ANSYS Fluent

Hybrid parallelism for best performance on multi-core chips within clusters

Fast Parallel I/O

Architecture-aware partitioning

Good scalability for simulations with monitors enabled

![Graph showing improved scaling with hybrid parallelism and R14 monitors](image-url)
Optimized Solver Performance
- ANSYS HFSS

Domain Decomposition Method (DDM), incl. support of finite antenna arrays (R14)

Increased memory efficiency for large and very large problems allows super-scaling!

Faster solutions across multiple processors
More Simulations
Introduction
- Levels of Parametric Simulation

- Single Design Point
- Parametric Studies - What If?
- Design of Experiments
- Goal Driven Optimization
- Six-Sigma Analysis
- RDO + Uncertainty Optimization
- Quality Engineer
- Designer & Engineer
Introduction
- Evolution of Parametric Simulation

Single Design Point
- Solves a single simulation involving single or multiple physics
- Users are interested in solution robustness, speed, accuracy, ease of use and engineering results
- And the ease and power of the physics coupling

Isn’t this design optimal? How can I improve performance? Can I reduce weight or cost? What is limiting performance? Is this a robust design?
Introduction
- Evolution of Parametric Simulation

“What If” Study
- User adjusts inputs and investigates results
- Builds on previous expectations, adds requirement of easy and robust parametric updates and comparative reports

Need a more scientific and automated way to decide which points to solve
Need a way to interpolate between these points
Introduction
- Evolution of Parametric Simulation

Difficult to optimize a design with many inputs and goals

Design Exploration
- Scientific methods to explore the design space fully
- Amplifies the importance of the previous technology
- Adds requirements for: robust efficient & affordable distributed solve, sensitivity and correlation, DOE and response surface technology, mesh morphing, charting and reporting

Response Surface
Provides design understanding, but optimization is not automated
Introduction
- Evolution of Parametric Simulation

Optimization
- Searches the design space for optimal candidates, given user-defined goals and priorities
- Amplifies the importance of the previous technology
- Adds requirements for: advanced optimization algorithms to efficiently search for candidates, comparative reporting

Real-world inputs typically have some variation and may require a more “robust design” goal
Introduction
- Evolution of Parametric Simulation

Robust Design
- Taking the variation of inputs into account, and seeking a design with a probabilistic goal

- RDO => Min standard deviation of the results
- Six Sigma => Optimal design within a safe domain
- There are other Robust Design methods/goals...

- Amplifies the importance of the underlying Workbench and solver technologies
- Adds requirements for: probabilistic parameters, specific probabilistic optimization algorithms
Our Solution
- From Single Physics to Robust Design

Robust Design is an ANSYS Advantage

Single Physics Solution
- Accuracy, robustness, speed...

Multiphysics Solution
- Integration Platform

“What if” Study
- Parametric Platform
- Simultaneous Solve

Design Exploration
- DOE, Response Surfaces, Correlation, Sensitivity, Unified reporting, etc.

Optimization
- Algorithms
- Published API

Robust Design
- Six Sigma Analysis
- Probabilistic Algorithms
- Adjoint solver methods

Increasing understanding, innovation, ROI
Until ANSYS 14.0, design points had to be solved sequentially. That is run dp0 through to dp \( n \). With potentially hundreds of long-running design points, this can be *time* prohibitive.
R14.0 supports updating *design points* simultaneously via RSM.

With several design points running simultaneously, the time to the overall result can be greatly lessened.

14.5 included a lot of work to improve the robustness, speed and usability of RSM.
ANSYS Workbench Enables...

RSM with 3rd Party Scheduler

RSM has two modes:
- It can be used as a scheduler for local jobs, or
- It can be used as a mechanism to access 3rd party schedulers for more advanced distributed solves...

RSM as a scheduler (Unit: Jobs)

You setup the compute servers and how many jobs run on each, the queues and which have priority

RSM as a transport mechanism to a 3rd party scheduler such as LSF or PBS (Unit: Cores)

Third party tools break up the jobs and can distribute them across a network
License Usage

- ANSYS products “grab” licenses as each software component is executed.
- To update n design points simultaneously you need \( n \) * the licenses.
- This makes running simultaneous design points cost prohibitive.
- It can also make design points prone to failure if not enough licenses were available during the update process.
Scalable, like ANSYS HPC Packs
- Enhances the customer’s ability to include many design points as part of a single study

Amplifies complete workflow
- Allow users to run n design points simultaneously, multiplying the “base” license(s)
- Design points can include execution of multiple products (pre, meshing, solve, HPC, post)

Requirements
- Parameters need to be in ANSYS Workbench
- Sequential execution of geometry updates
ANSYS Workbench Enables...
“Game Changing” Time to Design Insight

Time to Insight
Example: simulation of 4 design points
License Costs

sequential execution

Need Time!

simultaneous execution

Shorten Time to Design Insight at Lower Costs!

1 serial license
4 serial licenses
2 serial licenses
1 serial license + 1 HPC Parametric Pack

1 serial license
4 serial licenses
2 serial licenses
1 serial license + 1 HPC Parametric Pack
ANSYS Workbench Enables…
“Game Changing” Time to Design Insight

Time to Insight

Example: simulation of 4 design points

License Costs

Sequential execution

Add HPC and Reduce Time to Design Insight Even More, at Lower Costs!

1 serial license

4 serial licenses

2 serial licenses

1 serial license + HPC + 1 HPC Parametric Pack
Optimization Partners

ANSYS simulation software has been effectively used in concert with many optimization partners:

- MATLAB (Mathworks)
- modeFRONTIER (Esteco)
- optiSLang (Dynardo)
- eArtius
- Optimus (Noesis)
- RBF-Morph
- Sculptor (Optimal)
- Sigma Technology (IOSO)
- TOSCA (FE-DESIGN)
- iSight (Dassault)
- Qfin (Qfinsoft)
- and more...
HPC Parametric Pack Example Applications
Rear Axle Model
- Evaluating Material Properties

Problem Description
- Large deflection non-linear static model investigating design sensitivity to material properties
- Input parameter: material property (8 design points)
- Detail:
  - Sparse matrix solver running incore; 4 load steps
  - 1,393,811 nodes, 829,701 elements (4,151,766 DOF)
  - Hardware: Dell workstation with dual Intel Xeon E5-2690 (2.90 GHz, 16 cores), 256 GB memory, all jobs running 2 cores

Licensing Solution
- 1 ANSYS Mechanical
- 2 ANSYS HPC Parametric Packs

Result/Benefit
- 5x speedup over sequential execution
- Easier and fully automated workflow!
Static Analysis of Semi-submersible
- Evaluating Shell Thicknesses

Problem
- Static Analysis of semi-submersible using beam & shell elements, subjected to hydrostatic pressure and gravity loading
- Design objective: minimize both total mass and equivalent stress
- Input parameters: pontoon thickness, base column thickness (16 design points)
- Detail:
  - 232,583 nodes, 230,770 elements
  - Hardware: Dell workstation with dual Intel® Xeon® E5-2690 (2.90 GHz, 16 cores), 256 GB memory, all jobs running 2 cores

Licensing Solution
- 1 ANSYS Mechanical
- 2 ANSYS HPC Parametric Packs

Result/Benefit
- ~6x speedup over sequential execution
- Easier and fully automated workflow

Acknowledgment: Paul Schofield and Jiaping Zhang, ANSYS Houston
Fatigue Analysis of Shaft
- Evaluating Geometries

Problem
Å Fatigue Analysis of steel shaft subjected to shear cyclic loading on top surface while being fixed on the bottom end
Å Input parameters: base height, base thickness, groove height (15 design points)
Å Detail:
  – Strain-life fatigue analysis of shaft subject to cyclic loading on the top surface
  – 364,959 nodes, 82,863 elements
  – Hardware: Dell workstation with dual Intel Xeon E5-2690 (2.90 GHz, 16 cores), 256 GB memory, all jobs running 2 cores

Licensing Solution
Å 1 ANSYS Mechanical, 1 Fatigue Module, 1 ANSYS Design Modeler
Å 2 ANSYS HPC Parametric Packs

Result/Benefit
Å 3.2x speedup over sequential execution
Å Easier and fully automated workflow

Acknowledgment: Paul Schofield and Jiaping Zhang, ANSYS Houston
Response Spectrum of Pressure Vessel - Evaluating Geometries

Problem

- Pressure Vessel subjected to high internal pressure and subjected to acceleration in supports during earthquake
- Input parameters: vessel thickness, vessel radius, vessel height (16 design points)
- Detail:
  - “Static Structural” + “Modal Analysis” + “Response Spectrum”
  - 62,439 nodes, 150,169 elements
  - Hardware: Dell workstation with dual Intel Xeon E5-2690 (2.90 GHz, 16 cores), 256 GB memory, all jobs running 2 cores

Licensing Solution

- 1 ANSYS Mechanical, 1 ANSYS DesignModeler
- 2 ANSYS HPC Parametric Packs

Result/Benefit

- ~3x speedup over sequential execution
- Easier and fully automated workflow

Acknowledgment: Paul Schofield and Jiaping Zhang, ANSYS Houston
Intake Manifold Fluid Analysis
- Evaluating Geometries

Problem Description
- Non-homogenous air flow in intake manifold through the 4 outlets
- Design objectives:
  - Equal fresh and exhaust gas mass flow distribution to each cylinder
  - To minimize the overall pressure drop
- Input Parameters: radii of 3 fillets near inlet (16 design points)
- Detail:
  - Steady state pressure based solver, realizable k-epsilon model
  - 57,790 nodes, 208,740 elements
  - Hardware: Dell workstation with dual Intel Xeon E5-2690 (2.90 GHz, 16 cores), 256 GB memory

Licensing Solution
- 1 ANSYS CFX, 1 ANSYS DesignModeler
- 2 ANSYS HPC Parametric Packs

Result/Benefit
- ~2.2x speedup over sequential execution
- Easier and fully automated workflow

Acknowledgment: Paul Schofield and Jiaping Zhang, ANSYS Houston
Other Example Applications
Design Objective:
To determine the optimal parameters for maximum fatigue life of a blade root.

**Input Parameters**
- ds_xtilt
- ds_ytill
- ds_rootrad

**Output Parameter:** Minimum Life
Turbine Blade Root

Objective is to maximize fatigue life

Design point for best candidate

| Optimization | Initial Design | Optimized Design |
Design Objective:
- To optimize the implant for minimum human discomfort
- Constraint: the relative sliding between bone marrow and implant should be less than 120 μm but greater than 30 μm
Hip Joint Implant

Response Surface

Sensitivity curve indicates sliding distance is more sensitive to stem width

Optimization

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2 - Frictional - Implant Stem - Friction Coefficient</td>
<td>P5 - stem_width</td>
<td>P7 - Friction - Implant Stem - Friction Coefficient</td>
<td>P3 - Sliding Distance Maximum (m)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Optimization Study</td>
<td>No Objective</td>
<td>No Objective</td>
<td>No Objective</td>
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<tr>
<td>2</td>
<td>Objective</td>
<td>No Objective</td>
<td>No Objective</td>
<td>No Objective</td>
</tr>
<tr>
<td>3</td>
<td>Target Value</td>
<td>P5: 0.5</td>
<td>P5: 0.5</td>
<td>P5: 0.5</td>
</tr>
<tr>
<td>4</td>
<td>Importance</td>
<td>Default</td>
<td>Default</td>
<td>Default</td>
</tr>
<tr>
<td>5</td>
<td>GEO Sample Set 1</td>
<td>Candidate A</td>
<td>0.51900</td>
<td>0.0053988</td>
</tr>
<tr>
<td>6</td>
<td>Candidate B</td>
<td>0.21236</td>
<td>0.0050125</td>
<td>-473.75</td>
</tr>
<tr>
<td>7</td>
<td>Candidate C</td>
<td>0.48288</td>
<td>0.0052399</td>
<td>-615.17</td>
</tr>
</tbody>
</table>

Optimized Geometry

Stem width changed by 18 %
Design objective:
- Maximize amplification ratio for a given size and power consumption
- 3 main design parameters, i.e. gap in annular ring, internal profile of ring, profile of external ramp

Customer benefits include:
- Explored 10-fold of design variations than would otherwise have been possible (each day 10 instead of 1)
- Improved performance 250% over original design
Design Objective:

Maximize Effective Flow Area of a gasoline engine within a specified range of input design parameters

Parametric CAD model created in CATIA

Imported geometry in WB

Tetrahedral meshing using AMP:
- Mesh Count = 800K
- Curvature and Proximity based sizing functions

Custom DOE generated with 13 design points for 3 input parameters
IC Engine Intake Port

Response Surface and Sensitivity Chart

Statistical Analysis using 10000 points:
(A) Trade-off plot
(B) Multiple Goal Driven Optimization

Baseline Design

Optimized Design

<table>
<thead>
<tr>
<th></th>
<th>Guide Curve Angle (Deg)</th>
<th>Guide Curve Radius (mm)</th>
<th>Section-1-Length (mm)</th>
<th>EFA (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>63</td>
<td>41</td>
<td>51</td>
<td>1100.2</td>
</tr>
<tr>
<td>Optimized</td>
<td>50</td>
<td>30</td>
<td>60.5</td>
<td>1180.4</td>
</tr>
</tbody>
</table>

Customer Benefits:

- Able to quickly identify the key parameters the design is most sensitive to
- Considerable reduction of labor time and chances of human error by automating the whole process
**Fan-Heat Sink**

**Design Objective:**
Optimize the fan-heat sink geometry such that the temperature on the 2 chips is lower than the baseline design (with fixed fan design).

![Diagram showing fan, shroud diameter, and chip placement]

- **Fan RPM = 2000**
- **Chip 1 = 35000 W/m²**
- **Chip 2 = 40000 W/m²**

<table>
<thead>
<tr>
<th>Parameter Manager</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shroud_HS_gap = 1</td>
</tr>
<tr>
<td>Fin_Angle = 30</td>
</tr>
<tr>
<td>Fin_front_length = 25</td>
</tr>
<tr>
<td>Shroud_Diameter = 120</td>
</tr>
<tr>
<td>Number_of_Fins = 12</td>
</tr>
</tbody>
</table>

| Input Geometric Parameters |

| Design Parameters | Parameter/Dimension Assignments | Check |

<table>
<thead>
<tr>
<th>Output Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>P14</td>
</tr>
<tr>
<td>P15</td>
</tr>
<tr>
<td>P17</td>
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<td>P18</td>
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<tr>
<td>P19</td>
</tr>
<tr>
<td>P21</td>
</tr>
<tr>
<td>P22</td>
</tr>
</tbody>
</table>
Fan-Heat Sink

Chip temperature vs. (Shroud Diameter & Fan Heat Sink gap)

Customer Benefits:
Â Quick understanding of relationship between many design variables and performance
Â Easy exploration of a large number of ‘optimal’ designs (by using trade-off charts)

Blue dots shows the designs most suitable to the desired goals

Dots in the extreme left of the chart gives designs where both chips have minimum temperature

Tradeoff chart between Temperature of Chip1 and Chip2
Ongoing HPC Initiatives

ANSYS focus on HPC is ongoing…

- Ongoing optimization and performance tuning
  - Dynamic load balancing; optimized resource mapping, compiler evaluation
- Architecting for next level scalability
  - Performance at 10,000 cores or more; increased core density and GP-GPUs
  - Innovative mechanical solvers: Multilevel PCG, 2D parallel DSPARSE fronts
  - Hybrid distributed/shared memory and vector processing paradigms
- Scalability across all components and full simulation process
  - Meshing, setup, solver, I/O, visualization, optimization…
  - Parallel for linear dynamics, including mode superposition-based analyses
  - Distributed domain solver, especially for contact nonlinearities
  - Partial factorization (in-core substructuring) for localized nonlinearities
- Usability
  - Multi-component parallel execution environment, job scheduler support
  - Hardware fault tolerance, system performance tracking and debugging

All to achieve next-generation capability / performance!
ANSYS maintains close technical collaboration with the leaders in HPC

This mutual commitment ensures that you get the most possible value from your overall HPC investment

Some current examples:

- Optimized performance on multicore processors from Intel, with R&D focused on Intel’s Many Integrated Core (MIC)
  - Over 60% performance boost for the latest Intel® Xeon® E5-2600 processor (Sandy Bridge) family compared to previous Intel (Westmere) generation

- GPU computing accelerates ANSYS Mechanical today, with very active R&D engagement with NVIDIA across full portfolio

- ANSYS and IBM – Optimized cluster and storage architectures for ANSYS

- ANSYS and Cray – Support for extreme scalability of ANSYS CFD on the Cray XE, up to 1000’s of cores
THANK YOU

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