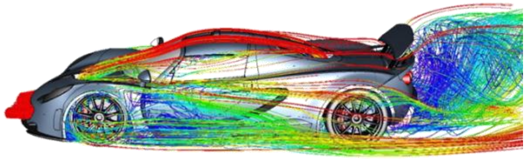
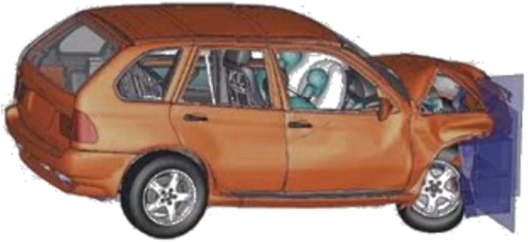
CAE Applications for HPC

Stephen Behling
Cray Inc
May, 2015





Short bio

- **Education in Nuclear Engineering**
- **Worked at U.S. National Laboratory in Idaho on reactor safety computer codes**
- **Joined Cray Research in 1986**
  - Vectors, micro-tasking, macro-tasking
  - CAE applications
- **IBM (1999 – 2008)**
  - CAE applications
- **Now back at Cray Inc. in Performance Team**
  - CAE applications: PowerFLOW, PAMCrash, AcuSolve, ANSYS Mechanical
  - Many other codes: SU3, GFS, NIM, …

CAE encompasses industries, national laboratories, and research

- **Aerospace**
  - Commercial; military; space
- **Automotive**
  - Commercial; sports
- **Other transportation**
  - Trains; ocean transport
- **Manufacturing**
- **Energy**
  - Fossil fuels
  - Nuclear
- **Hydrology; medical devices; architecture; insurance**

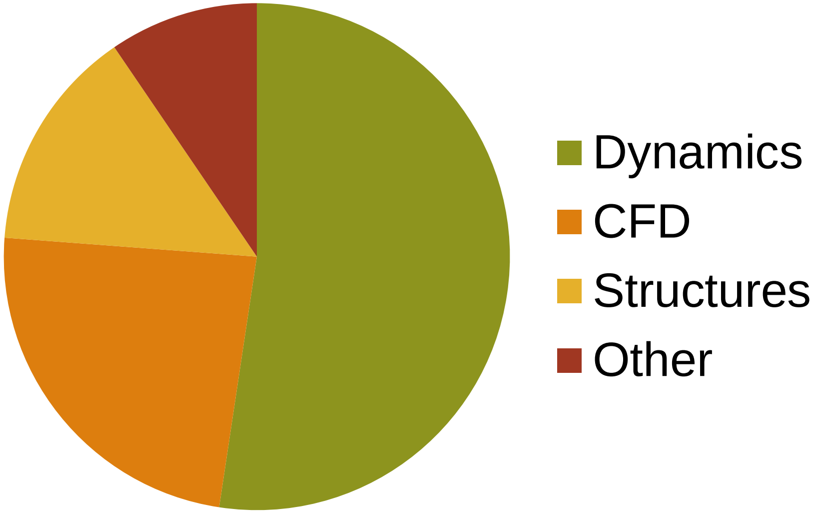
CAE is growing rapidly

- **Trends are:**
  - More accurate analyses
  - Bigger models
    - “1 billion cells”; “100 million elements”; “19 million degrees of freedom”
  - Bigger computers
    - More nodes; more cores; more memory; more parallel I/O

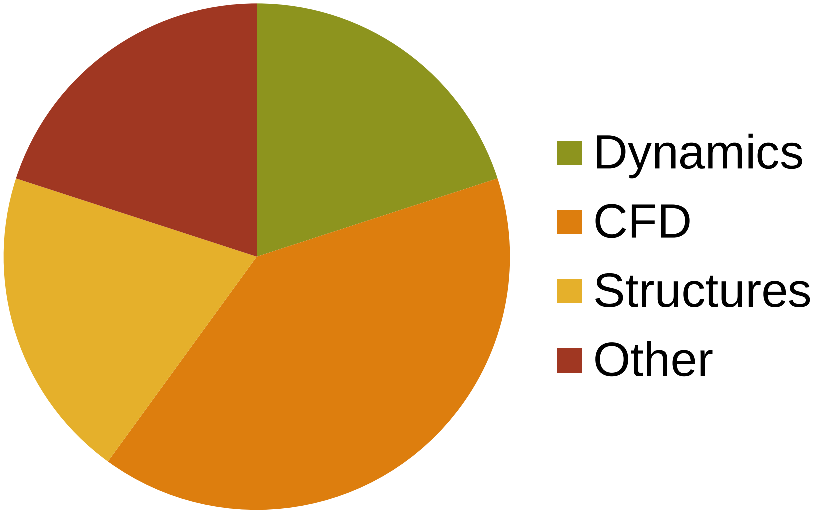
- **Much CAE work uses third-party Independent Software Vendors (ISVs) for financial reasons**
  - Engineers (cost the most)
    - Need to get answers quickly
  - Software licenses (second most costly)
    - Less costly than internal code development, maintenance, and support
  - Computer hardware (third most costly)

HPC workload

Automotive



Aerospace

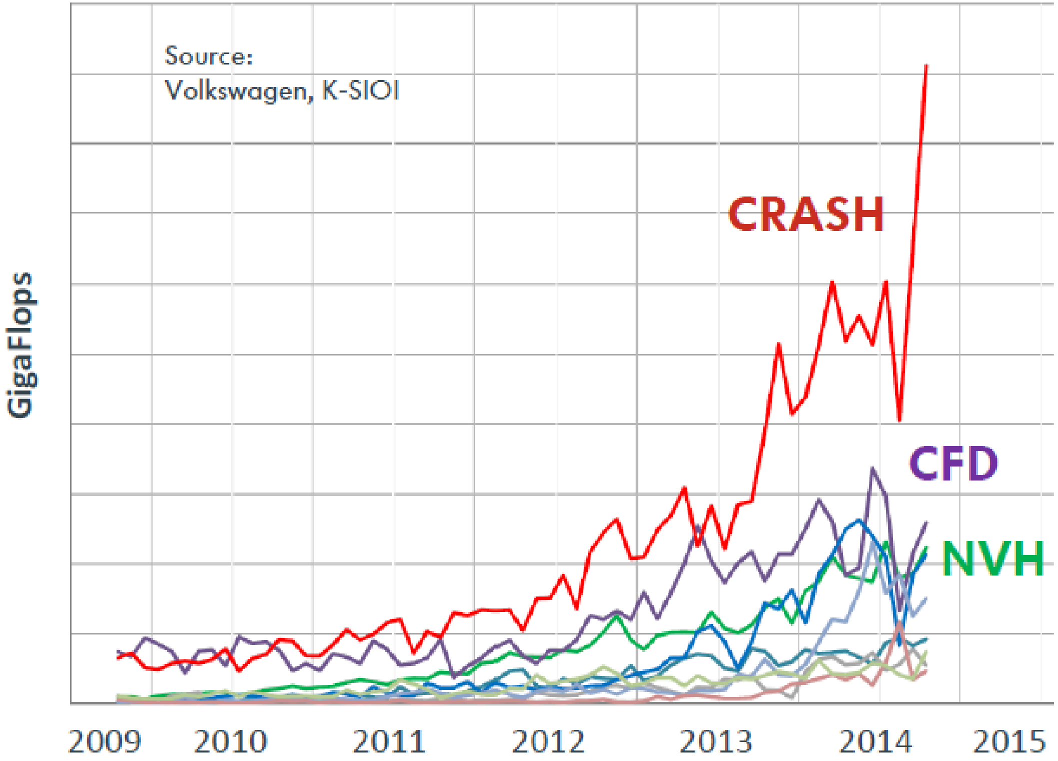


Growth in CAE HPC usage

Automotive and aerospace companies saw a huge growth in CAE HPC power from 2000-2015

and

CAE simulation is growing at an increasing rate in recent years



Ref:
Industrial High Performance Computing:
Michael Taeschner, Volkswagen AG

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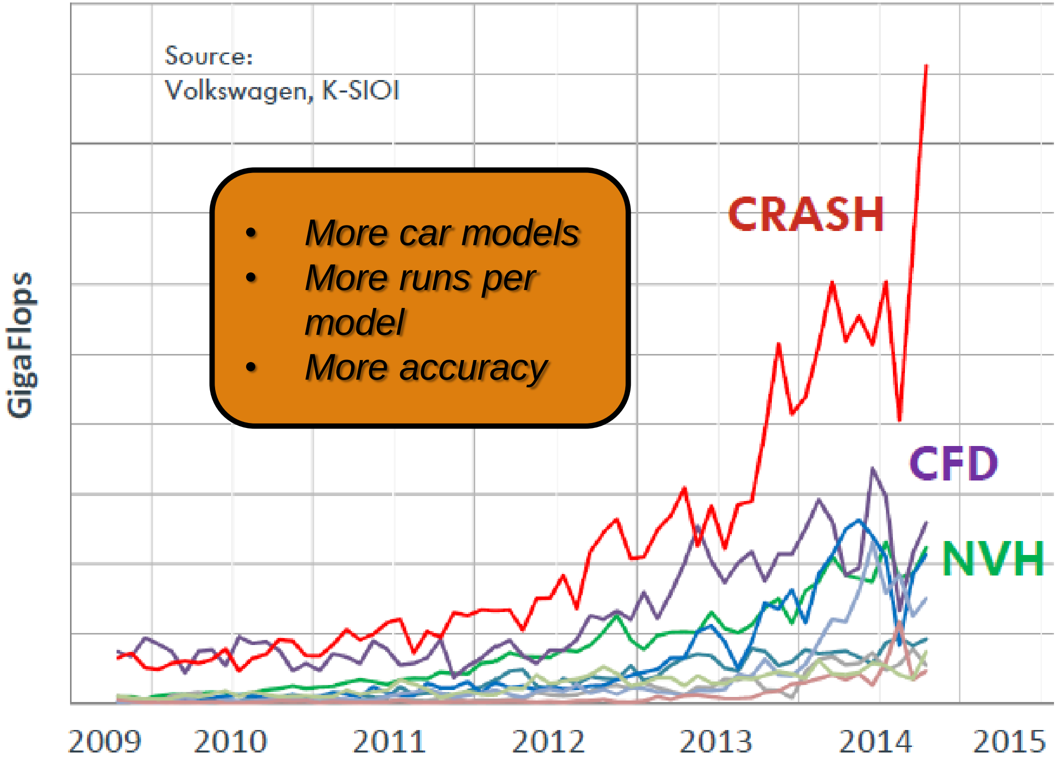

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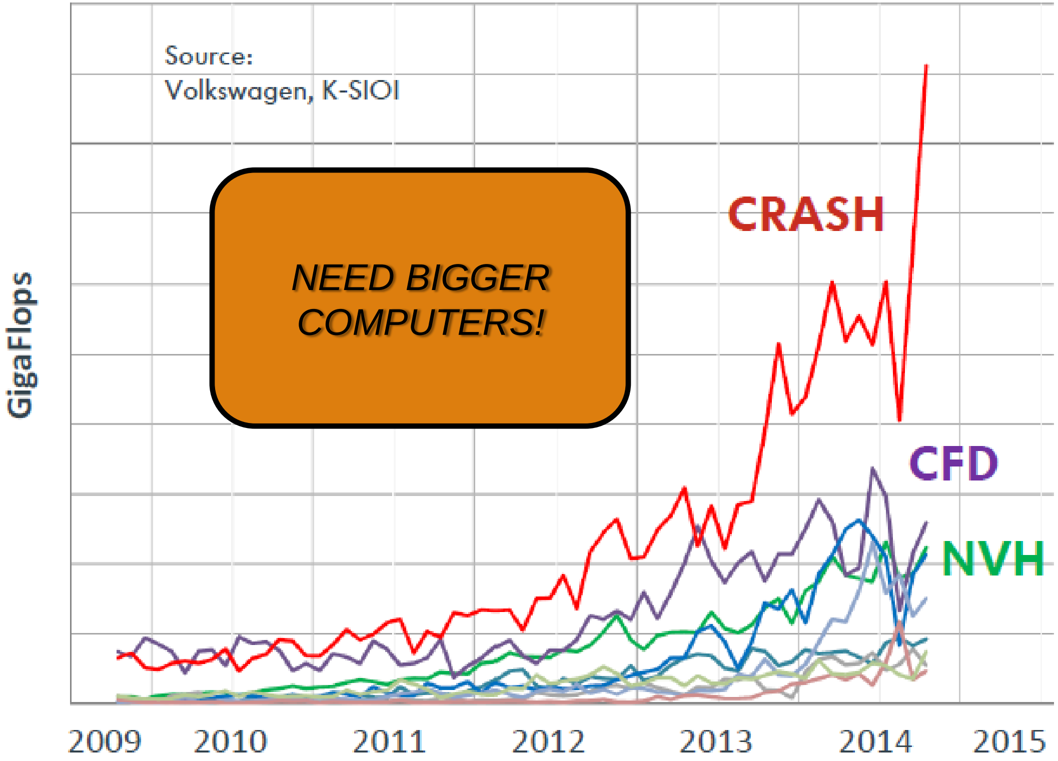

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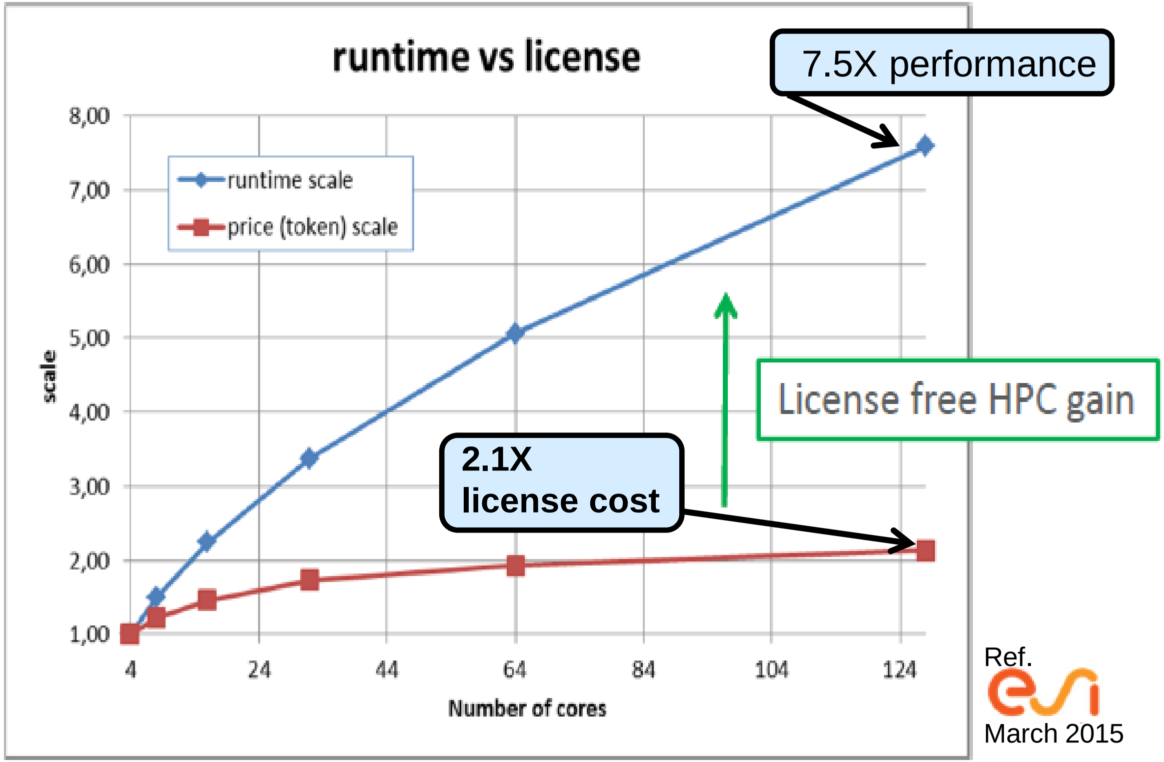
ISV license pricing favors parallel computing

- Most ISVs have a pricing system the encourages running in parallel
- It is typically cheaper per simulation to use more cores
- Graph shows PAM-CRASH example with "very conservative" estimate for parallel performance

PAM-CRASH performance vs. License cost



Ref. esi March 2015

CAE and parallel computers

- **Computational Fluid Dynamics (CFD)**
  - Most scalable of the CAE applications
  - All codes are MPI parallel
  - Some have threading
- **Structural Dynamics**
  - Moderate scaling; contact as parts buckle is difficult
  - All codes are MPI parallel
  - Some have threading
- **Structural NVH (Noise, Vibration, Harshness)**
  - Low scaling; large memory or large I/O requirements
  - All codes are MPI parallel and may be threaded

CAE Workflow

1. **Recognize problem to be solved**
   - Meet safety requirements?
   - Reduce drag?
   - Minimize weight/noise/cost?
   - Maximize efficiency/reliability/profit/safety?
2. **Represent system via a CAD model**
   - Multiple use: both for manufacturing and for various analyses
3. **Translate CAD description into computational mesh**
   - Each discipline needs its own mesh
4. **Decompose mesh into computational domains**
   - First pick number of computational nodes/cores and then run decomposition tool
5. **Solve**
   - Main computational task in CAE
6. **Analyze**
   - Graphics; statistics

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Repeat

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If needed, Repeat

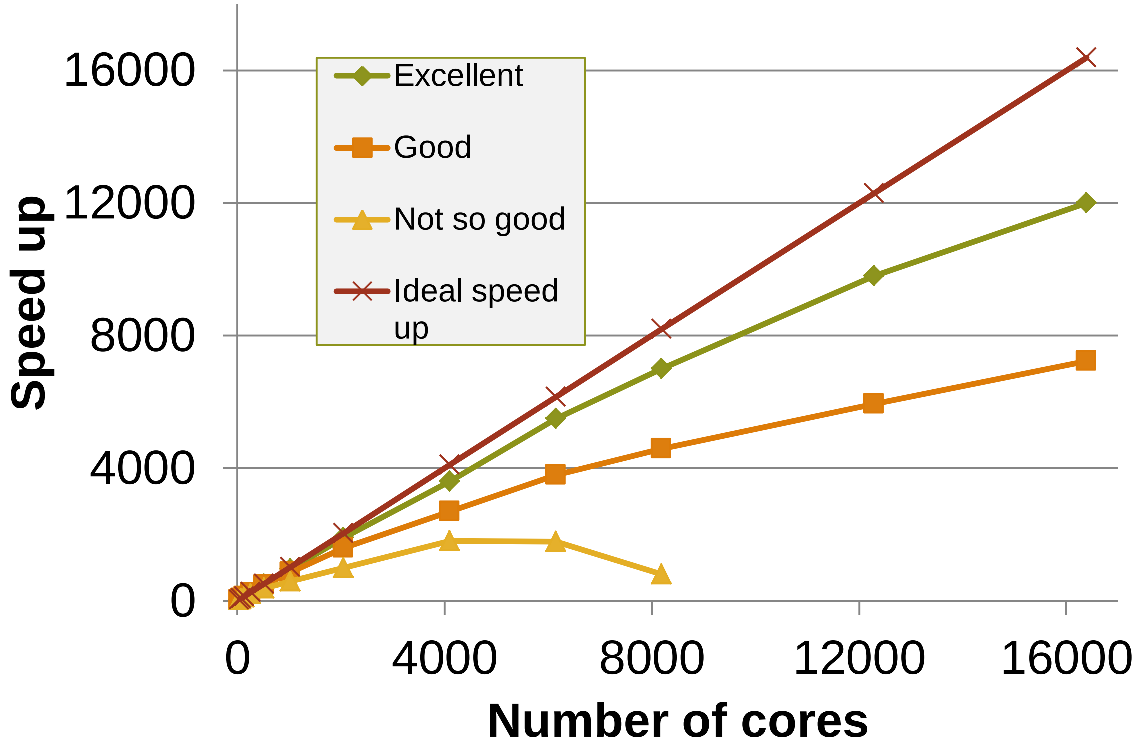
CAE Workflow requirements

- **CAD**
  - Days to weeks
- **Translate CAD to mesh**
  - Hours to day
  - Usually single processor
- **Domain decomposition**
  - Minutes to hours; can be single workstation
  - May use parallel processing and may be part of solve step
  - Examples: Metis (serial), pMetis (parallel)
- **Solve**
  - Hours to days to weeks to … unsolvable
  - The most benefit for engineers is to have **one or more results per day**
  - **Need a supercomputer for this**
- **Analyze**
  - Days or more
  - Need powerful graphics

CAE simulation characteristics for solve step

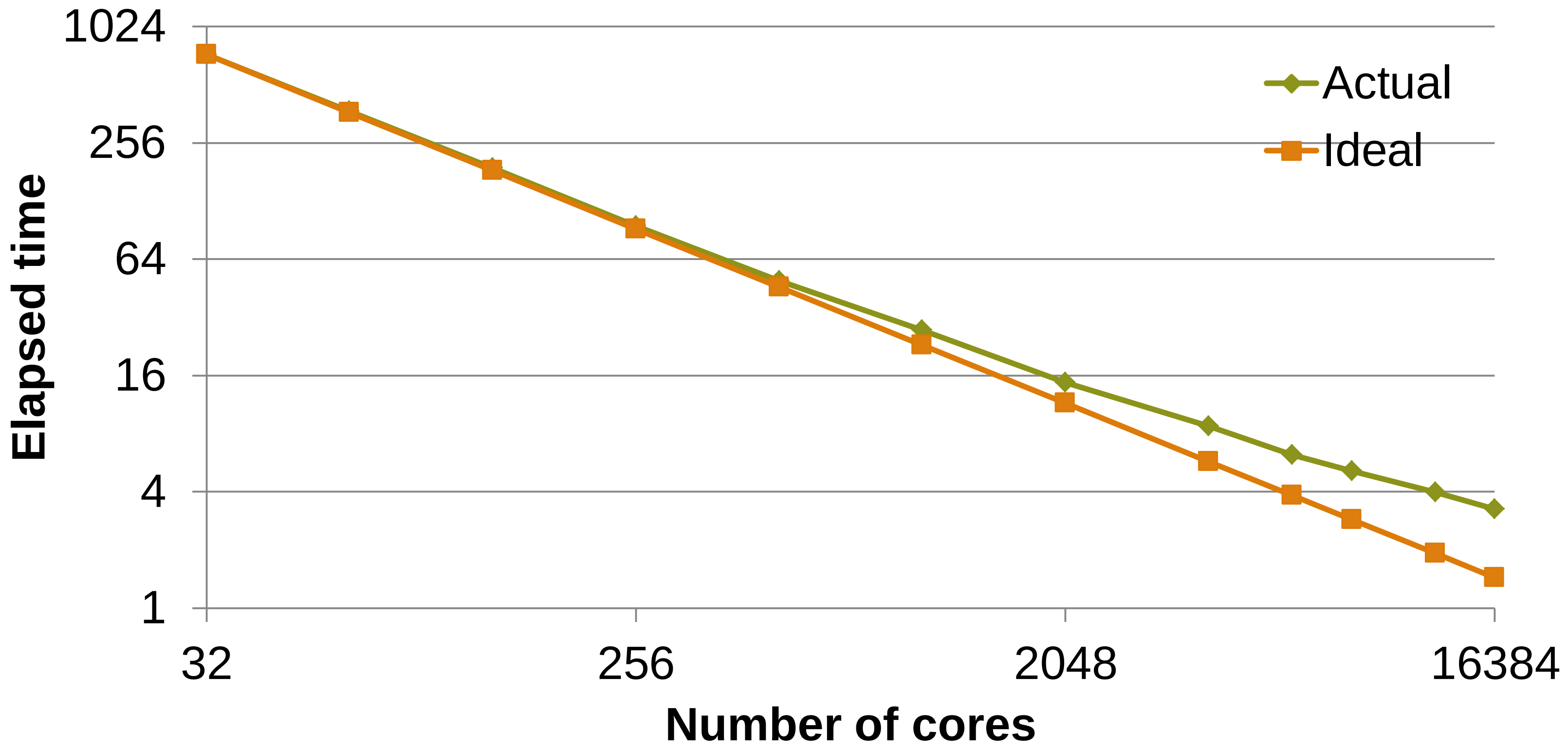
- **Computational Fluid Dynamics (CFD)**
  - Often highly scalable (16000+ cores)
  - I/O requirements low to moderate for typical analyses; big data for LES
  - Seldom use math libraries; HDF5
  - Typical runs 100 -1000 cores
- **Dynamics: Impact Simulation; Crash/Safety Simulation**
  - Can be moderately scalable (2000+ cores)
  - Low I/O requirements
  - Seldom use math libraries; HDF5
  - Typical runs: 20 – 200 cores
- **Structures and NVH**
  - Low Scaling (200+) cores
  - Large memory; good I/O; often have GPU option
  - BLAS2, BLAS3
  - Typical runs: 1 to 10% of the HPC environment
- **Other/Multi-Physics**
  - Fluid-Structure interaction
    - Ships and waves; Blood flow; Oil pipe riser (sub-sea well to shore)

Scaling is affected by load imbalance and network communication



It can be a lot of work to move from “good” to “excellent” scaling.

Elapsed time (on log-log plot) is another way to look at scaling



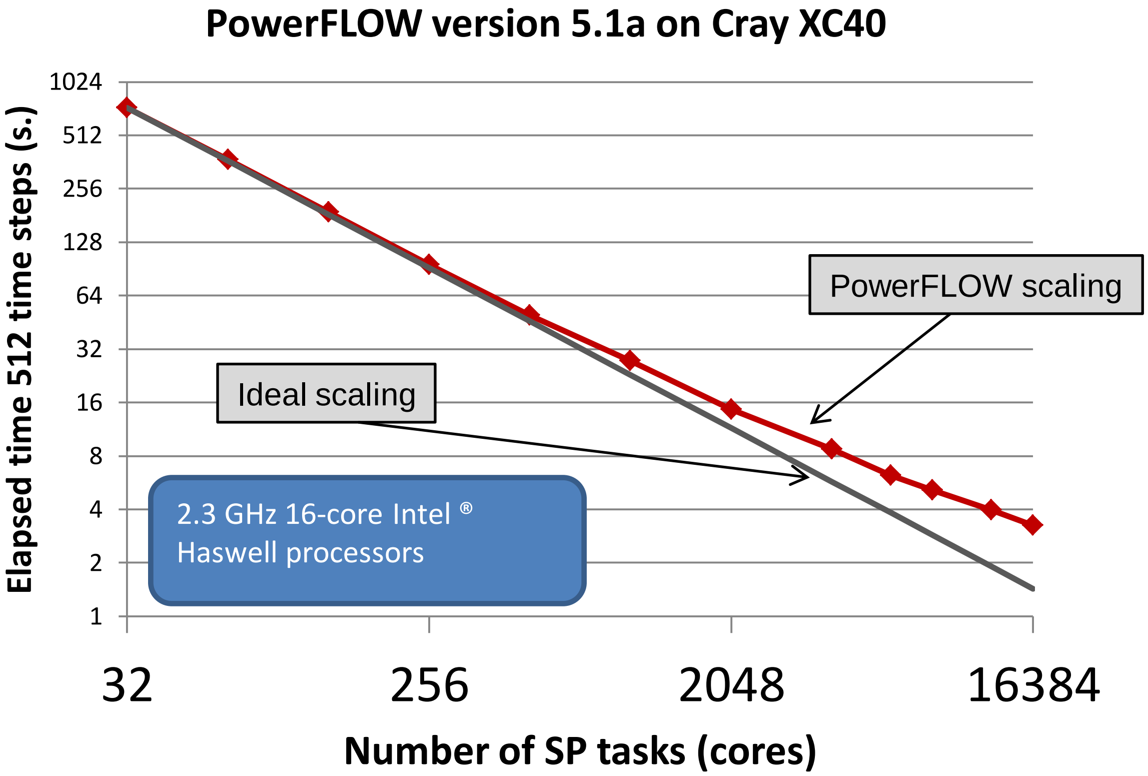
CFD ISV examples: all are unstructured grids

- **OpenFOAM by OpenCFD Ltd at ESI Group**
  - Open source under GNU General Public License
  - Finite volume discretization for typical CFD; MPI parallelization
- **ANSYS Fluent by ANSYS Inc.**
  - Finite volume discretization; MPI parallelization
- **STAR-CCM+ by CD-adapco Inc.**
  - Finite volume discretization; MPI parallelization
- **AcuSolve by Altair**
  - Finite element; hybrid MPI and OpenMP parallelization
- **PowerFLOW by Exa Corporation**
  - Lattice Boltzmann; MPI parallelization with some threading
- **HiFUN by Sandl**
  - MPI parallelization

EXA/PowerFLOW scaling on the Cray XC40

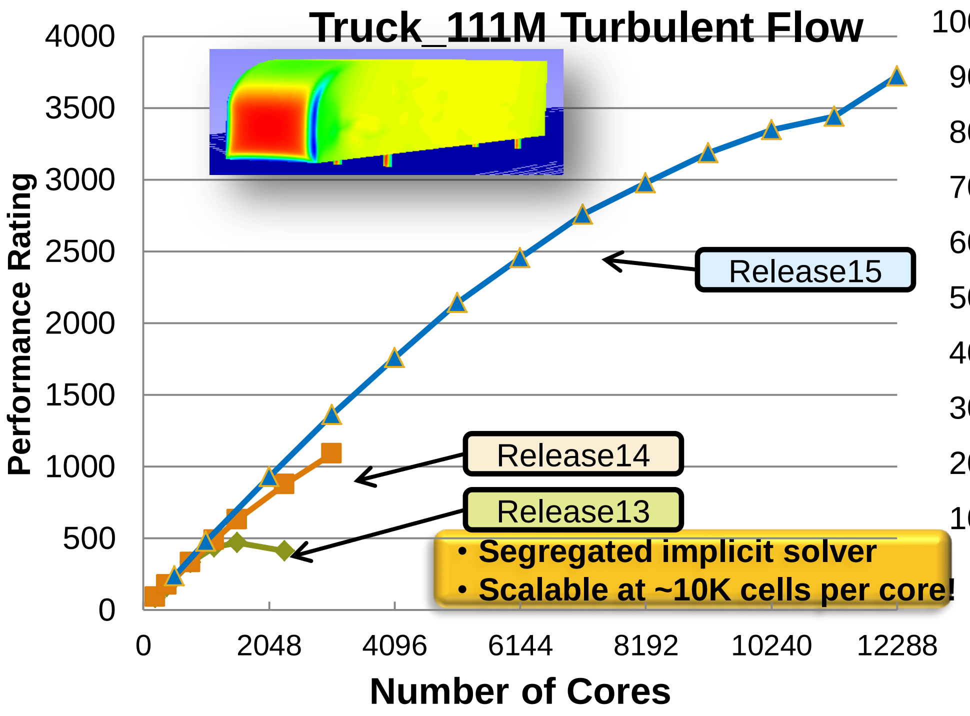
PowerFLOW CFD simulation scaling to over 16,000 cores

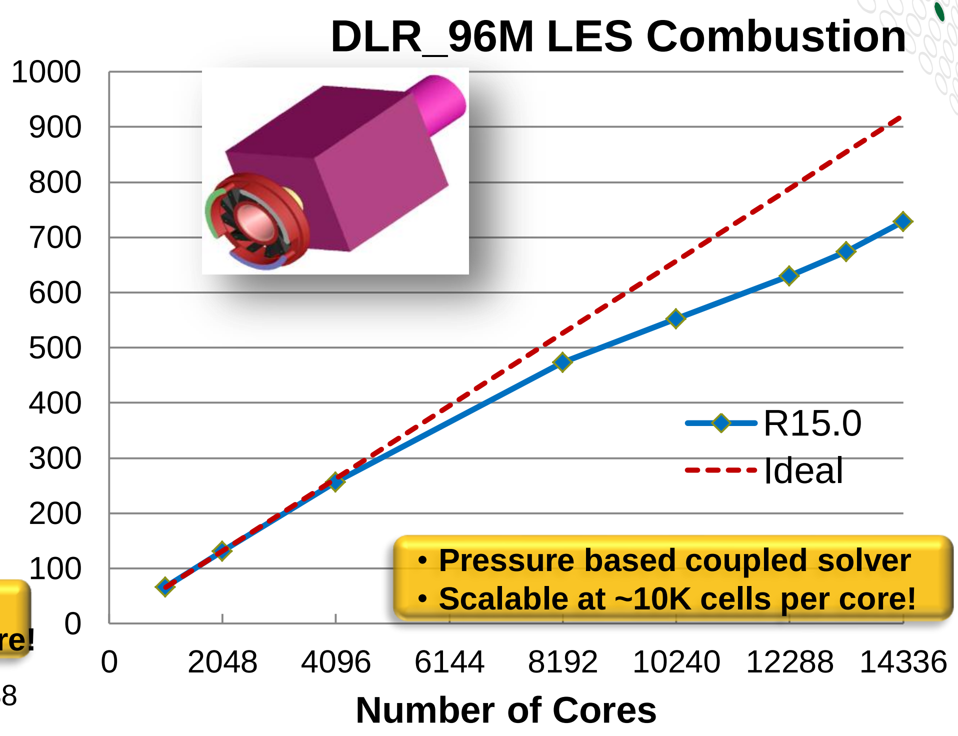
Lattice Boltzmann code
88 million voxels
“large-performance-test”



Cray and ANSYS/Fluent work together to add value

On-going development effort to improve HPC scaling in Fluent

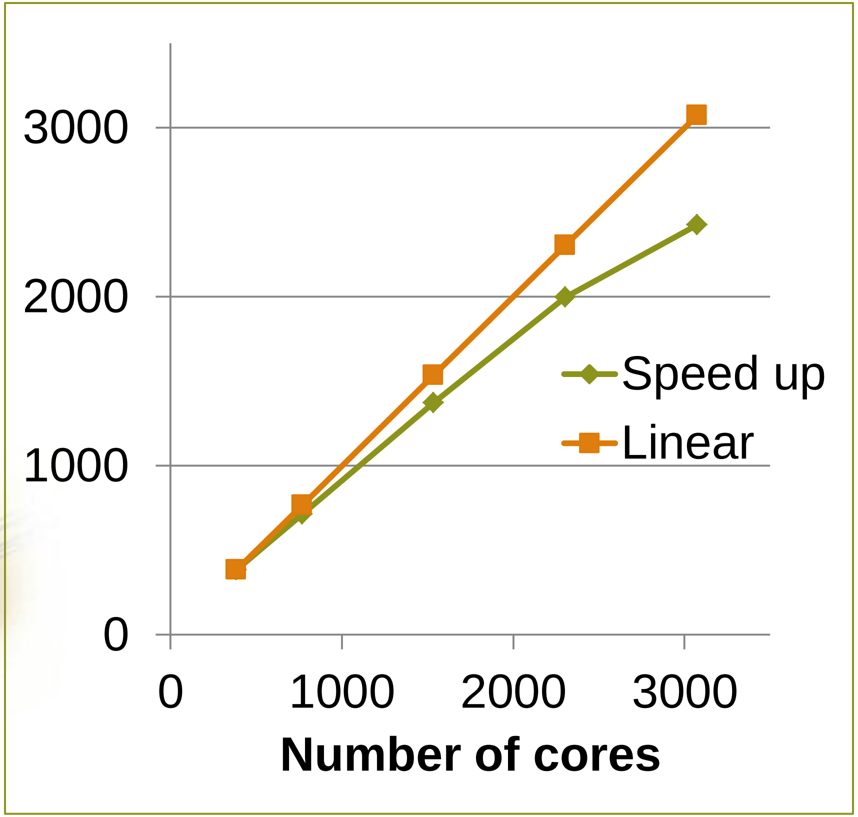




Rating is jobs per day. A higher rating means faster performance.

1 billion element AcuSolve Formula 1 external flow simulation

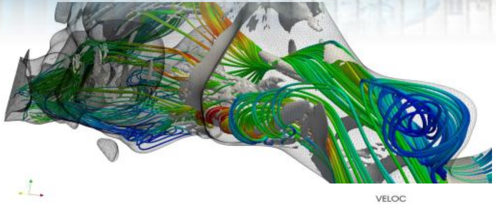
- Date = Fri Nov 8 15:49:22 2013
- Problem = F1
- Title = AcuSolve Problem
- Platform = Linux 3.0.80-0.5.1_1.0501.7664-cray_ari_c x86_64
- Machine = linux64
- No. of threads = 24
- No. of nodes = 169984316
- No. of elements = 1007704126



CFD Results from NCSA "Blue Waters" system
ALYA CFD code: 3 Real-World Cases

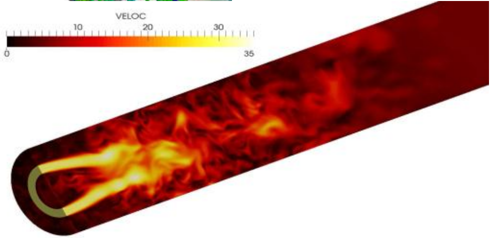
Human Respiratory System

Transient incompressible turbulent flow
360M elements, scaled to 25,000 cores



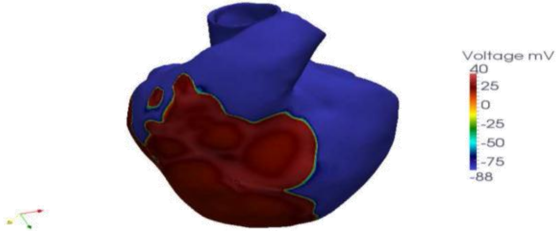
Kiln Furnace

Transient incompressible turbulent flow
Coupled with energy and combustion
4.22 billion elements, scaled to 100,000 cores



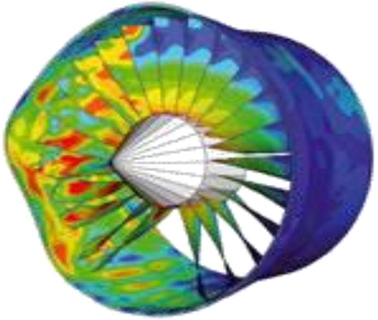
Human Heart

Non-linear solid mechanics
Coupled with electrical propagation
3.4 billion elements, scaled to 100,000 cores



Ref: "Growth of HPC Industrial Partnership", Merle Giles NCSA, Oct. 2014

Impact/Crash Simulation
Dynamic Structural Analysis



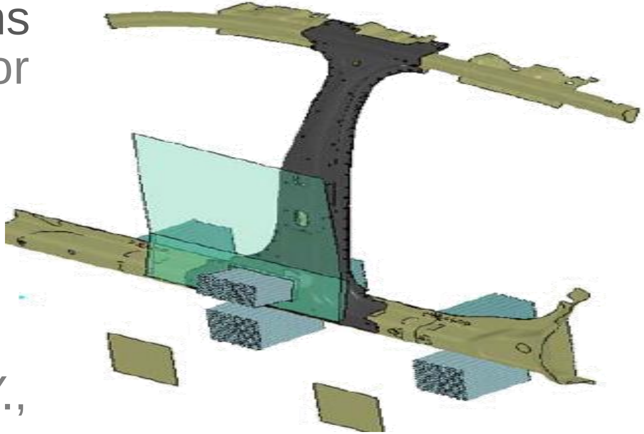
Examples:
- LS-DYNA by LSTC
- RADIOSS by Altair
- PAMCrash by ESI Group
- Abaqus explicit by Dassault Systèmes

2014 IDC award for scaling LS-DYNA

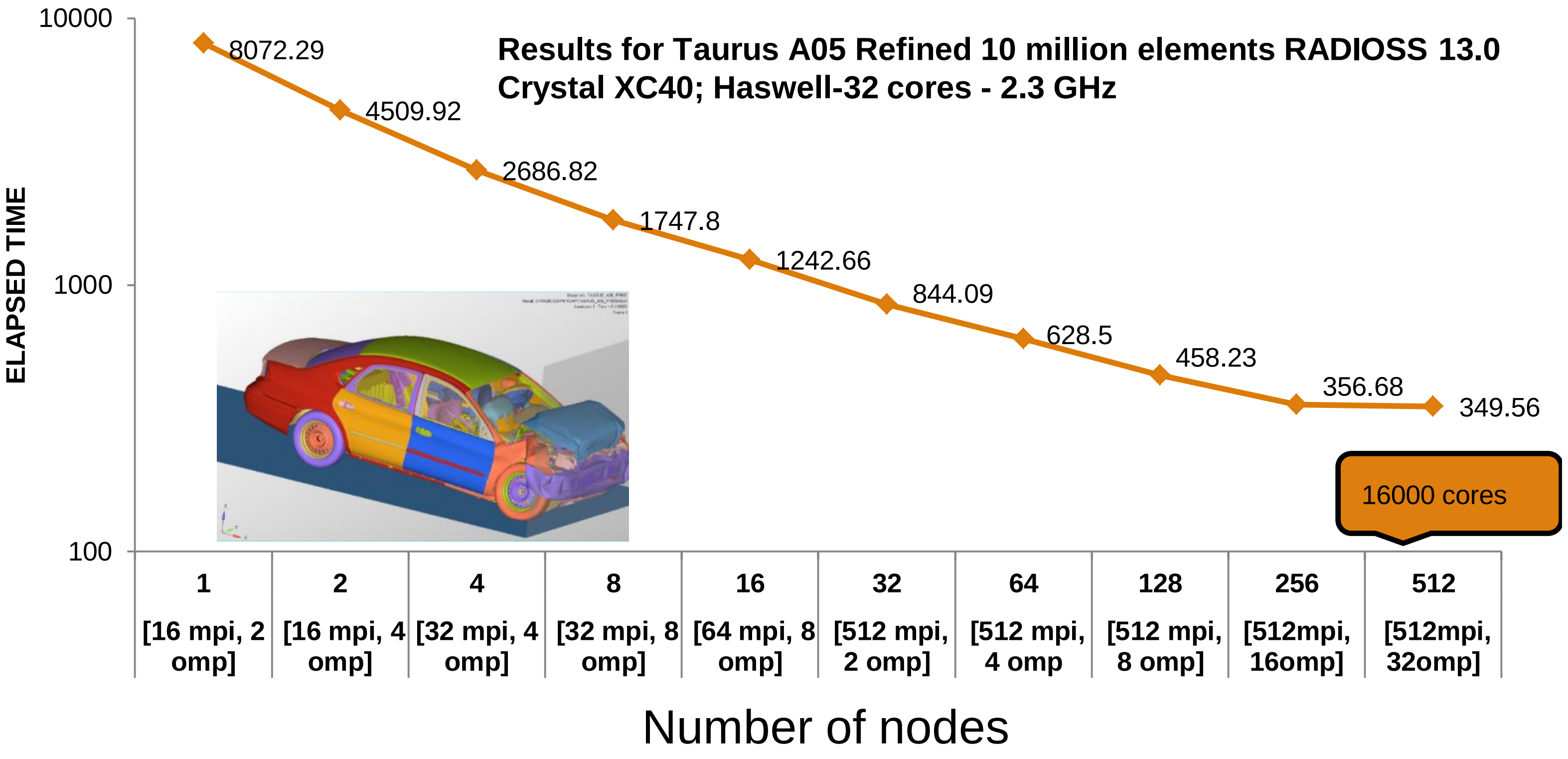
Rolls-Royce, Procter and Gamble, National Center for Supercomputing Applications, Cray Inc., Livermore Software Technology Corporation (U.S.). Researchers from NCSA, Rolls Royce, Proctor and Gamble, Cray Inc, and Livermore Software Technology Corporation were able to **scale the commercial explicit finite element code, LS-DYNA, to 15,000 cores…**

Ford: 100M Element Model of "B pillar"

- **Three papers at the 2014 LS-DYNA conference using 100M element model**
  - "LS-DYNA performance in Side Impact Simulations with 100M element Models" El Fadl, B., Ford Motor Company
    - **2048 cores: 2.5 days**
    - 1024 cores: 4.5 days
  - "Meso-Scale FEA Modeling to Simulate Crack Initiation and Propagation in Boron Steel" Chen, Y., Ford Motor Company
  - "Fracture Prediction and Correlation of ALSi Host Stamped Steels with Difference Models in LS-DYNA" by Zhu, H.



Example using RADIOSS



Noise, Vibration & Harshness (NVH) Implicit Structural Analysis

Examples:

- MSC-Nastran by MSC Software
- Abaqus Implicit by Dassault Systèmes
- ANSYS Mechanical by Ansys Inc.

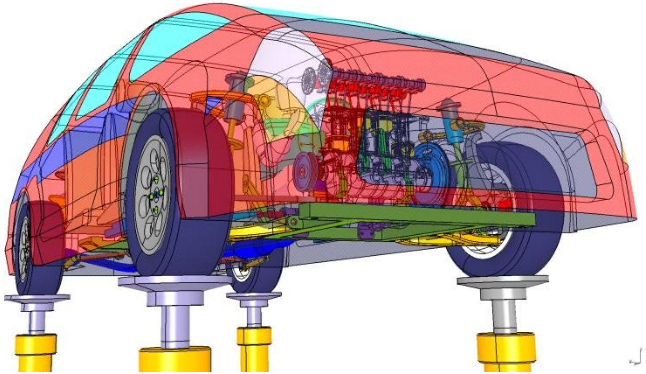


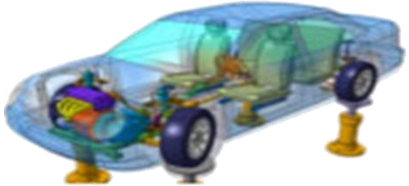
Image courtesy of MSC Software

MSC Nastran NVH performance on Cray CS400

Implicit, structural eigenvalue solutions require a balance of processor speed, memory and IO performance

Large Structure Nodes

- Two Xeon E5-2667-v3 (Haswell, 8 core, **3.2 GHz**)
- **758 GB RAM** – Twenty four (24) 32GB DIMMs
- **4 x 1.6TB PCIe SSDs** (Striped)



Recent MSC Nastran benchmarks posted:

http://web.mscsoftware.com/support/prod_support/nastran/performance/msc20140.cfm

- **Largest NVH model size increased to 19 million DOF**
- **This NVH model is 5X the version largest version 2013 example**
- **Cray CS400 "NVH configuration" 1.6X faster than best version 2013 results**

Summary

Scalability of select ISV applications in CLE

ISV Application	Primary segment	Demonstrated scalability *
ANSYS Fluent	Commercial CFD	>36,000 cores
LS-DYNA	Impact/crash analysis	>15,000 cores
CFD++	Aerospace CFD	>10,000 cores
STAR-CCM+	Commercial CFD	>100,000 cores
PowerFLOW	External CFD	>16,000 cores
AcuSolve	Commercial CFD	> 6,000 cores
Abaqus/standard	Structural analysis	>300 cores

* Demonstrated scalability typically limited by the simulation model available

CAE is growing rapidly

- **Trends are:**
  - More accurate analyses
  - Bigger models
    - “1 billion cells”; “100 million elements”; “19 million degrees of freedom”
  - Bigger computers
    - More nodes; more cores; more memory; more parallel I/O

- **Cray Inc is proud to be a key vendor in this discipline**

Questions