Performance Benchmark of an Abaqus Problem - Utilising RAM, CPU, and a GPGPU on Different Hardware Platforms

(or one old man and his need for speed)

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Rolls-Royce Submarines Business

- Propulsor
- Thrust Block
- Turbo Generators
- Platform Management System Elements
- Flexible Coupling
- LV Switchboard Elements
- Reactor
HMS Vanguard
Operational Nuclear Submarines (Attack and Ballistic)

- United States of America (71)
- Soviet Union/Russia (42)
- United Kingdom (11)
- France (10)
- People’s Republic of China (8)
- India (1 leased from Russia, 1 undergoing sea trials)

- Currently only six countries in the world have nuclear submarines
- Iran, Israel, Australia and Pakistan would like to join the elite group and are developing their own capability
Aims - To Understand...

- What has the biggest effect on runtime?
- Is the analysis scalable?
- How effective are General-Purpose computing on Graphical Processing Units (GPGPUs) in workstations?
- How to identify bottlenecks

Note, looking at hardware performance, not hardware cost!!
Hardware

Three configurations of hardware platform were used:

- HP C3000 Mobile Blade Server
- IBM High Performance Compute Server
- HP xw8600 Workstation
Hewlett-Packard C3000 Hardware

**Standalone Analysis Server**

* HP C3000 Mobile Blade Server
  - One Head Node
  - Six Analysis Nodes
    - 2x Intel Xeon Dual Core E5260 3.30 GHz
    - 10 GB RAM
    - 2x73 GB RAID 0 15k SAS disk for scratch
  - One Data Node
    - 2.1 TB RAID 5 15k SAS storage
* RedHat Enterprise 6.2 64 Bit Edition
* 32 Bit Windows Clients
IBM High Performance Compute Hardware

- Server Room Rack Based Server
  - IBM HPC
    - Two Head Nodes
    - Sixty Four Analysis Nodes
      - 2x Intel Xeon Quad Core E5450 3.00 GHz
      - 32 GB RAM
      - 160 GB SATA disk for OS and scratch
    - Four Pre/Post Processing Nodes
      - 4x AMD Opteron Quad Core 8384 2.70 GHz
      - 128 GB RAM
      - 4x450 GB RAID 10 15k SAS disk for OS, data and scratch
    - General Parallel File System (GPFS)
      - Approx 90 TB storage (allocated)
    - RedHat Enterprise 6.2 64 Bit Edition
    - Windows 32 Bit Clients
Hewlett-Packard xw8600 Hardware

**Standalone Workstation**

- **HP xw8600 Desktop**
  - Technical Specification
    - 2x Intel Xeon Quad Core E5440 2.83 GHz
    - 16 GB RAM
    - 2x73 GB RAID 0 15k SAS disk storage for OS
    - 2x250 GB RAID 0 SATA (Hybrid) for scratch, COTS, data
    - NVIDIA Quadra 4000 Primary Graphics
    - NVIDIA Tesla C2075 GPGPU
    - Fusion-io ioDrive2 PCIe Card
  - **SUSE Linux 12.1 64 Bit Edition**
Quadro 4000 & Tesla C2075 (GPGPU) Hardware

NVIDIA TESLA C2075 TECHNICAL SPECIFICATIONS

- Form factor - PCIe x16 form factor
- 448 CUDA cores
- Frequency of CUDA cores - 1.15 GHz
- Double precision floating point performance (peak) - 515 Gflops
- Single precision floating point performance (peak) - 1.03 Tflops
- Total dedicated memory – 6 GB GDDR5*
- Memory speed - 1.5 GHz
- Memory interface - 384-bit
- Memory bandwidth - 144 GB/s
- Power consumption - 225W TDP
- System interface - PCIe x16 Gen2
- Thermal solution - Active Fansink
- Display support - Dual-Link DVI-I: 1
- Maximum Display Resolution 1600x1200
Data Processing Flow

1. Copy input data from CPU memory to GPGPU memory
2. Load GPGPU program and execute, caching data on chip for performance
3. Copy results from GPGPU memory to CPU memory
Fusion-io ioDrive2 TECHNICAL SPECIFICATIONS

- ioDrive2 Capacity 785 GB MLC
- Read Bandwidth (1 MB) 1.5 Gb/s
- Write Bandwidth (1 MB) 1.1 Gb/s
- Sequential Read IOPS (512B) 443,000
- Sequential Write IOPS (512B) 535,000
- Random Read IOPS (512B) 141,000
- Random Write IOPS (512B) 535,000
- Read Access Latency 68 µs
- Write Access Latency 15 µs
- Bus Interface PCI-Express 2.0 x4
- Warranty 5 years or maximum endurance used
Benchmarking

The following were used in the tests:

- 13 analysis input decks
- 13 different analysis configuration setups
- 135 analysis runs
- 1054 compute cores
- 5896 GB of RAM
- 3048 hours 12 minutes and 26 seconds elapsed wall clock time
- 1 Tesla C2075 and 8 Tesla M2090
- 1 ioDrive2
Simple Models (1)

- **LS-RigFullLength**
  - Simple linear analysis (hollow tube)
  - Point force loading
  - Combining analytical rigid components
  - 36520 C3D8R hexahedral elements
  - 1828 S3 elements

- **LS-EPP-Blank-C3D8R**
  - Simple non-linear analysis (hollow tube)
  - Point force loading
  - Combining analytical rigid components
  - 36520 C3D8R hexahedral elements
  - 1828 S3 elements

- **LS-EPP-Blank-C3D8R-Mod**
  - Non-linear analysis (solid bar)
  - Point force loading
  - Combining analytical rigid components
  - 238680 C3D8R hexahedral elements
  - 1828 S3 elements
Simple Models (2)

Simple model, simple tube, (analytical rigid supports)
36520 hexahedral elements

Reaction points – RP1 and RP2
Rotation around the Z axis

Applied force

Rolls-Royce data
Simple Models (3)

Low model complexity, runs in RAM, number of cores improves overall performance (IBM PP with 16 cores is faster than when it is run on 5 cores)

Memory Requirements to Minimise I/O
- LS-RigFullLength = 727 MB
- LS-EPP-Blank-C3D8R = 728 MB
- LS-EPP-Blank-C3D8R-Mod = 7.9 GB
Intermediate Models (1)

- **LS-EP-C3D8R**
  - Non-linear analysis (threaded hollow tube)
  - Small distribution over three threads
  - 1396290 C3D8R hexahedral elements

- **LS-EPP-C3D8R**
  - Non-linear analysis (threaded hollow tube)
  - Small distribution over three threads
  - 1396290 C3D8R hexahedral elements

- **LS-EPP-C3D8R-WC**
  - Non-linear analysis (threaded hollow tube)
  - Small distribution over three threads
  - 1396290 C3D8R hexahedral elements
Intermediate Models (2)

Intermediate model - Full thread form
1396290 Hexahedral Elements
As model complexity increases, hardware effects are starting to become more evident on the overall time. IBM HPC slowed by GPFS access.

Memory Requirements to Minimise I/O
LS-EP-C3D8R = 47.6 GB
LS-EPP-C3D8R = 47.6 GB
LS-EPP-C3D8R-WC = 47.6 GB
Intermediate Models (4)

Memory requirement is the same for all three models, therefore the run time is consistent.

Rolls-Royce data
Complex Models (1)

- **LS-EPP-Combined-DistributedLoad**
  - Non-linear analysis
  - Threaded hollow tube
  - Small distributed load over three threads
  - 80688 C3D8R hexahedral elements
  - 336294 C3D20R quadrilateral elements
  - Complexity level 1

- **LS-EPP-Combined-WC-Mk1**
  - Non-linear analysis
  - Threaded hollow tube
  - Small distributed load over three threads
  - 80688 C3D8R hexahedral elements
  - 336294 C3D20R quadrilateral elements
  - Complexity level 2

- **LS-EPP-Combined-WC-Mk2**
  - Non-linear analysis
  - Threaded hollow tube
  - Small distributed load over three threads
  - 80688 C3D8R hexahedral elements
  - 336294 C3D20R quadrilateral elements
  - Complexity level 3

- **LS-EPP-Combined-WC-Mk3**
  - Non-linear analysis
  - Threaded hollow tube
  - Small distributed load over three threads
  - 80688 C3D8R hexahedral elements
  - 336294 C3D20R quadrilateral elements
  - Complexity level 4

- **LS-EPP-Combined-WC-Mk4**
  - Non-linear analysis
  - Threaded hollow tube
  - Small distributed load over three threads
  - 80688 C3D8R hexahedral elements
  - 336294 C3D20R quadrilateral elements
  - Complexity level 5

- **LS-EPP-Combined-EC-Mk1**
  - Non-linear analysis
  - Threaded hollow tube
  - Extended distributed load over threads
  - 875784 C3D8R hexahedral elements
  - 336294 C3D20R quadrilateral elements
  - Complexity level 6

- **LS-EPP-Global**
  - Non-linear analysis
  - Threaded hollow tube
  - Extended distributed load over threads
  - 875784 C3D8R hexahedral elements
  - 336294 C3D20R quadrilateral elements
  - Complexity level 7

*NB The complexity level of the model is related to the run time, number of elements and load distribution pattern. This is duplicated in the X axis of the graph overleaf (Complex Models (4)).*
Complex Models (2)

C3D20R Elements

C3D8R Elements
Rolls-Royce data

Memory Requirements to Minimise I/O
- LS-EPP-Combined-DistributedLoad = 93.7 GB
- LS-EPP-Combined-WC-Mk1 = 92.8 GB
- LS-EPP-Combined-WC-Mk2 = 92.8 GB
- LS-EPP-Combined-WC-Mk3 = 92.8 GB
- LS-EPP-Combined-WC-Mk4 = 92.8 GB
- LS-EPP-Combined-EC-Mk1 = 117.5 GB
- LS-EPP-Global = 120.8 GB
Complex Models (4)

High model complexity, hardware has big effect on the overall time, RAM, I/O, disk

IBM PP runs out of allocated RAM for model 6 and 7, forcing data to scratch – hence the upturn in wallclock time
GPU Workstation Performance (1)

- First run set
  - 5 cores
  - 16 Gb RAM
  - SATA RAID for scratch

- Second run set
  - 5 cores
  - 16 Gb RAM
  - SATA RAID for scratch
  - NVIDIA Tesla C2075 GPGPU

- Third run set
  - 5 cores
  - 16 Gb RAM
  - Fusion-io ioDrive2 for scratch
  - NVIDIA Tesla C2075 GPGPU
As model complexity grows, greater effects are seen from the hardware configuration on the overall time, RAM, I/O, disk.
Tesla C2075 Assisted Workstation Performance Speedup V Baseline Configuration

- LS-RigFullLength 0%
- LS-EPP-Blank-C3D8R 0%
- LS-EPP-Blank-C3D8R-Mod 13%
- LS-EP-C3D8R 34%
- LS-EPP-C3D8R 31%
- LS-EPP-C3D8R-WC 32%
- LS-EPP-Combined-DistributedLoad 51%
- LS-EPP-Combined-WC-Mk1 47%
- LS-EPP-Combined-WC-Mk2 48%
- LS-EPP-Combined-WC-Mk3 48%
- LS-EPP-Combined-WC-Mk4 47%
- LS-EPP-Combined-EC-Mk1 59%
- LS-EPP-Global 58%
Tesla C2075 + ioDrive2 Assisted Workstation Performance Speedup V Baseline Configuration

- LS-RigFullLength 0%
- LS-EPP-Blank-C3D8R 0%
- LS-EPP-Blank-C3D8R-Mod 13%
- LS-EP-C3D8R 92%
- LS-EPP-C3D8R 87%
- LS-EPP-C3D8R-WC 82%
- LS-EPP-Combined-DistributedLoad 103%
- LS-EPP-Combined-WC-Mk1 96%
- LS-EPP-Combined-WC-Mk2 98%
- LS-EPP-Combined-WC-Mk3 103%
- LS-EPP-Combined-WC-Mk4 102%
- LS-EPP-Combined-EC-Mk1 149%
- LS-EPP-Global 147%
Workstation Performance (1)

- Baseline configuration (xw8600) a starting point, but four years old now
- Tesla GPGPU reduces run times, but in baseline configuration, only running at 45% capacity
- Tesla and Quadro on Gen2 16x PCIe bus
- ioDrive2 frees the I/O bottleneck and allows the Tesla card to run at 84% capacity
- ioDrive2 running at 50%, due to the PCIe architecture in the xw8600 being Gen1 for all 4x slots
- Combination of the two produces an overall speed enhancement, reducing the run times (seen more on complex models)
- Newer architecture will allow faster data flow, which in turn would allow for faster run times (future work planned)
- CPU type and brand will have an effect on speed
## Workstation Performance (2)

- **GPGPU usage from Tesla and Quadro Cards**

<table>
<thead>
<tr>
<th>Nb.</th>
<th>Name</th>
<th>Fan</th>
<th>Temp</th>
<th>Power Usage / Cap</th>
<th>Bus Id</th>
<th>Disp.</th>
<th>Volatile ECC SB / DB</th>
<th>GPU Util.</th>
<th>Compute M.</th>
<th>Memory Usage</th>
<th>GPU Memory Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Tesla C2075</td>
<td>45%</td>
<td>88 C</td>
<td>P0 93W / 225W</td>
<td>0000:80:00.0</td>
<td>Off</td>
<td>N/A</td>
<td>84%</td>
<td>Default</td>
<td>40% 2141MB / 5375MB</td>
<td>2122MB</td>
</tr>
<tr>
<td>1</td>
<td>Quadro 4000</td>
<td>36%</td>
<td>72 C</td>
<td>P12 N/A / N/A</td>
<td>0000:60:00.0</td>
<td>On</td>
<td>N/A</td>
<td>0%</td>
<td>Default</td>
<td>4% 90MB / 2047MB</td>
<td></td>
</tr>
</tbody>
</table>

Compute processes:

<table>
<thead>
<tr>
<th>GPU</th>
<th>PID</th>
<th>Process name</th>
<th>Memory Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11576</td>
<td>/local/apps/Simulia/6.12-1/code/bin/standard.exe</td>
<td>2122MB</td>
</tr>
</tbody>
</table>
Workstation Performance (3)

- ioDrive2 status from Fusion-io card

  Found 1 ioMemory device in this system
  Fusion-io driver version: 3.1.5 build 126

  fct0 Attached as 'fioa' (block device)
  ioDrive2 Adapter Controller, Product Number:F00-001-785G-CS-0001, SN:1210D0812
  ioDrive2 Adapter Controller, PN:PA004137008
  SMP(AVR) Versions: App Version: 1.0.15.0, Boot Version: 0.0.3.1
  Located in slot 0 Center of ioDrive2 Adapter Controller SN:1210D0812
  Powerloss protection: protected
  PCI:20:00.0, Slot Number:6
  Firmware v7.0.2, rev 108609 Public
  785.00 GBytes block device size
  Format: v500, 1533203125 sectors of 512 bytes
  PCIe slot available power: 25.00W
  PCIe negotiated link: 4 lanes at 2.5 Gt/sec each, 1000.00 MBytes/sec total
  Internal temperature: 62.51 degC, max 75.30 degC
  Internal voltage: avg 1.01V, max 1.02V
  Aux voltage: avg 2.50V, max 2.50V
  Reserve space status: Healthy; Reserves: 100.00%, warn at 10.00%
  Rated PBW: 11.00 PB, 99.52% remaining
  Lifetime data volumes:
    Physical bytes written: 52,570,473,983,728
    Physical bytes read : 68,354,768,669,568
  RAM usage:
    Current: 277,938,432 bytes
    Peak : 278,366,912 bytes
**NVIDIA Server tests - or what if...**

2 x Intel Xeon Quad Core X5670 2.93 GHz per node
2 x Tesla M2090 GPGPU Cards per Node
48 GB to 96 GB Memory per Node

C = Number of cores used
G = Number of GPGPU cards used
MB = RAM allocated in GB

Using 1 Node

Using 2 Nodes

Using 3 Nodes

Using 4 Nodes

Input deck = LS-EPP-Combined-WC-Mk1
Cost and CPU Usage v Time

Job runs in core memory

Job runs to scratch

Rolls-Royce data
Summary

- Biggest effect on run time?
  - **RAM** – as it will minimise the requirement for disk access via I/O, which is slow
  - **GPGPU** – offsets the slow I/O by adding additional RAM and processing power
  - **Disk I/O** – kills an analysis, try to avoid, or move to a faster location (*major bottleneck*)

- Is the analysis scalable?
  - **Yes**, run time for LS-EPP-Combined-WC-Mk1 down to 1 hour from 69 hours (extreme case is 185 hours to run)

- How effective are GPGPU’s?
  - 59% performance increase in workstation alone, by adding GPGPU capability
  - 149% performance increase in workstation alone, by adding GPGPU and ioDrive2 capability
Thanks to...

- NVIDIA – For the kind loan of the TESLA C2075 and Quadro 4000 Cards

- Support during testing:
  - Danny Kiernan
  - Joerg Krall
  - Timothy Lanfear
  - Srinivas Kodiyalam

(www.nvidia.com)
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Delivering today, investing for the future