ANSYS FLUENT Performance Benchmark and Profiling

May 2009
The following research was performed under the HPC Advisory Council activities:

- Participating vendors: AMD, ANSYS, Dell, Mellanox
- Compute resource - HPC Advisory Council Cluster Center

The participating members would like to thank ANSYS for their support and guidelines.

For more info please refer to:

• **Computational Fluid Dynamics (CFD) is a computational technology**
  - Enables the study of the dynamics of things that flow
    - By generating numerical solutions to a system of partial differential equations which describe fluid flow
    - Enable better understanding of qualitative and quantitative physical phenomena in the flow which is used to improve engineering design

• **CFD brings together a number of different disciplines**
  - Fluid dynamics, mathematical theory of partial differential systems, computational geometry, numerical analysis, Computer science

• **ANSYS FLUENT is a leading CFD application from ANSYS**
  - Widely used in almost every industry sector and manufactured product
Objectives

• The presented research was done to provide best practices
  – ANSYS FLUENT performance benchmarking
  – Interconnect performance comparisons
  – Performance enhancement of the latest FLUENT release
  – Ways to increase FLUENT productivity
  – Understanding FLUENT communication patterns
Test Cluster Configuration

- Dell™ PowerEdge™ SC 1435 24-node cluster
- Quad-Core AMD Opteron™ 2382 (“Shanghai”) CPUs
- Mellanox® InfiniBand ConnectX® 20Gb/s (DDR) HCAs
- Mellanox® InfiniBand DDR Switch
- Memory: 16GB memory, DDR2 800MHz per node
- OS: RHEL5U2, OFED 1.4 InfiniBand SW stack
- MPI: HP-MPI 2.3
- Application: FLUENT 6.3.37, FLUENT 12.0
- Benchmark Workload
  - New FLUENT Benchmark Suite
Mellanox InfiniBand Solutions

- **Industry Standard**
  - Hardware, software, cabling, management
  - Design for clustering and storage interconnect
- **Performance**
  - 40Gb/s node-to-node
  - 120Gb/s switch-to-switch
  - 1us application latency
  - Most aggressive roadmap in the industry
- **Reliable with congestion management**
- **Efficient**
  - RDMA and Transport Offload
  - Kernel bypass
  - CPU focuses on application processing
- **Scalable for Petascale computing & beyond**
- **End-to-end quality of service**
- **Virtualization acceleration**
- **I/O consolidation Including storage**

### The InfiniBand Performance Gap is Increasing

Fibre Channel

- 60Gb/s
- 120Gb/s
- 240Gb/s (12X)

Ethernet

- 20Gb/s
- 40Gb/s
- 80Gb/s (4X)

InfiniBand Delivers the Lowest Latency
Quad-Core AMD Opteron™ Processor

- **Performance**
  - Quad-Core
    - Enhanced CPU IPC
    - 4x 512K L2 cache
    - 6MB L3 Cache
  - Direct Connect Architecture
    - HyperTransport™ Technology
    - Up to 24 GB/s peak per processor
  - Floating Point
    - 128-bit FPU per core
    - 4 FLOPS/clk peak per core
  - Integrated Memory Controller
    - Up to 12.8 GB/s
    - DDR2-800 MHz or DDR2-667 MHz

- **Scalability**
  - 48-bit Physical Addressing

- **Compatibility**
  - Same power/thermal envelopes as 2nd / 3rd generation AMD Opteron™ processor
Dell PowerEdge Servers helping Simplify IT

- **System Structure and Sizing Guidelines**
  - 24-node cluster build with Dell PowerEdge™ SC 1435 Servers
  - Servers optimized for High Performance Computing environments
  - Building Block Foundations for best price/performance and performance/watt

- **Dell HPC Solutions**
  - Scalable Architectures for High Performance and Productivity
  - Dell's comprehensive HPC services help manage the lifecycle requirements.
  - Integrated, Tested and Validated Architectures

- **Workload Modeling**
  - Optimized System Size, Configuration and Workloads
  - Test-bed Benchmarks
  - ISV Applications Characterization
  - Best Practices & Usage Analysis
FLUENT Benchmark Results

- **Input Dataset**
  - EDDY_417K
    - Reacting Flow with Eddy Dissipation Model

- **FLUENT 12 provides better performance and scalability**
  - Utilizing InfiniBand DDR to delivers highest performance and scalability

![FLUENT Benchmark Result](image)

Higher is better

FLUENT 6.3.37
FLUENT 12
FLUENT Benchmark Results

- **Input Dataset**
  - Aircraft_2M
    - External Flow Over an Aircraft Wing

- **FLUENT 12 provides performance and scalability increase**
  - Up to 107% higher performance versus previous 6.3.37 version

![FLUENT Benchmark Result (Aircraft_2M)](chart)

*Higher is better*
**FLUENT Benchmark Results**

- **Input Dataset**
  - Truck_14M
    - External Flow Over a Truck Body

- **FLUENT 12 delivers higher performance and scalability**
  - For any cluster size
  - Up to 80% higher performance versus previous 6.3.37 version

**FLUENT Benchmark Result**
(Truck_14M)

Higher is better

InfiniBand DDR
FLUENT Benchmark Results

- **Input Dataset**
  - Truck_Poly_14M
    - External Flow Over a Truck Body with a Polyhedral Mesh
- **FLUENT 12 delivers higher performance and scalability**
  - For any cluster size
  - Up to 67% higher performance versus previous 6.3.37 version

![FLUENT Benchmark Result](Truck_poly_14M)

*Higher is better*
• **Input Dataset**
  - EDDY_417K (417 thousand elements)
    - Reacting Flow with Eddy Dissipation Model

• **InfiniBand DDR delivers higher performance and scalability**
  - For any cluster size
  - Up to 192% higher performance versus Ethernet (GigE)

Higher is better

**FLUENT 12.0 Benchmark Result (Eddy_417K)**

- InfiniBand DDR
- Ethernet

**Higher is better**

192%
FLUENT 12 Benchmark Results - Interconnect

- **Input Dataset**
  - Aircraft_2M (2 million elements)
    - External Flow Over an Aircraft Wing
- **InfiniBand DDR delivers higher performance and scalability**
  - For any cluster size
  - Up to 99% higher performance versus Ethernet (GigE)

**Higher is better**

99%
FLUENT 12 Benchmark Results - Interconnect

- **Input Dataset**
  - Truck_14M (14 millions elements)
    - External Flow Over a Truck Body
- **InfiniBand DDR delivers higher performance and scalability**
  - Up to 36% higher performance versus Ethernet (GigE)
- **For bigger cases (# of elements) CPU is the bottleneck for larger node count configuration**
  - More server nodes (or cores) are required for increased paternalism interconnect dependency

**FLUENT 12.0 Benchmark Result**
(Truck_14M)

```
Number of Nodes
0  200  400  600  800  1000
0  2  4  8  12  16  20  24
Rating

InfiniBand DDR  Ethernet
```

Higher is better
Enhancing FLUENT Productivity

- **Test cases**
  - Single job over the entire system
  - 2 jobs, each runs on four cores per server
- **Running multiple jobs simultaneously improves FLUENT productivity**
  - Up to 90% more jobs per day for Eddy_417K
  - Up to 30% more jobs per day for Aircraft_2M
  - Up to 3% more jobs per day for Truck_14M
- **As bigger the # of elements, higher node count is required for increased productivity**
  - The CPU is the bottleneck for larger number of servers

![FLUENT 12.0 Productivity Result](chart.png)

*Higher is better InfiniBand DDR*
Power Cost Savings with Different Interconnect

- InfiniBand saves up to $8000 power to finish the same number of FLUENT jobs compared to GigE
  - Yearly based for 24-node cluster
- As cluster size increases, more power can be saved

Power Cost Savings
(InfiniBand vs GigE)

$\text{/KWh} = \text{KWh} \times 0.20$

Power Cost Savings with FLUENT upgrade

- FLUENT 12 saves up to ~$6000 power to finish the same number of FLUENT jobs compared to FLUENT 6.3.37
  - Yearly based for 24-node cluster
- As cluster size increases, more power can be saved

Power Cost Savings
(FLUENT 12 vs FLUENT 6.3.37)

$KWh = KWh \times 0.20$

FLUENT Productivity Results Summary

• FLUENT 12 has tremendous performance improvement over version 6.3.37
  – Optimizations made for higher performance and scalability
  – Optimizations included for AMD Opteron™ processor technology
    • AMD contributed to the development and the QA stages of Fluent 12
    • Performance results on AMD technology established baseline performance
• InfiniBand enables higher performance and scalability than Ethernet
  – Performance advantage extends as cluster size increases
• Efficient job placement can increase FLUENT productivity significantly
• Interconnect comparison shows
  – InfiniBand delivers superior performance in every cluster size
  – Low latency InfiniBand enables unparalleled scalability
• InfiniBand enables up to $8000/year power savings compared to GigE
• FLUENT 12 reduces yearly power consumption by up to $6000 compared to FLUENT 6.3.37
• **Mostly used MPI functions**
  – MPI_Send, MPI_Recv, MPI_Reduce, and MPI_Bcast
• MPI_Recv shows the highest communication overhead

FLUENT 6.3.37 Benchmark Profiling Result
(Truck_poly_14M)
Most data related MPI messages are within 256B-1KB in size
Typical MPI synchronization messages are lower than 64B in size
Number of messages increases with cluster size
Mostly used MPI functions
- MPI_Iprobe, MPI_Allreduce, MPI_Isend, and MPI_Irecv

FLUENT 12 Benchmark Profiling Result
(Truck_poly_14M)
• MPI_Recv and MPI_Allreduce show highest communication overhead
Most data related MPI messages are within 256B-1KB in size.
• Typical MPI synchronization messages are lower than 64B in size.
• Number of messages increases with cluster size.
• FLUENT 12 reduces total number of messages
• Further optimization can be made to take bigger advantage of high-speed and low latency interconnects
FLUENT Profiling Summary

- FLUENT 12 and FLUENT 6.3.37 were profiled to identify their communication patterns
- Frequent used message sizes
  - 256-1KB messages for data related communications
  - <64B for synchronizations
  - Number of messages increases with cluster size
- MPI Functions
  - FLUENT 12 introduced MPI collective functions
    - MPI_Allreduce help improves the communication efficiency
- Interconnects effect to FLUENT performance
  - Both interconnect latency (MPI_Allreduce) and throughput (MPI_Recv) highly influence FLUENT performance
  - Further optimization can be made to take bigger advantage of high-speed networks
Thank You
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