HPC
ADVISORY COUNCIL

OpenFOAM
Performance Benchmark and Profiling

April 2013

DELL
intel
Mellanox TECHNOLOGIES
OpenFOAM

Note

- **The following research was performed under the HPC Advisory Council activities**
  - Participating vendors: Intel, Dell, Mellanox
  - Compute resource - HPC Advisory Council Cluster Center

- **The following was done to provide best practices**
  - OpenFOAM performance overview
  - Understanding OpenFOAM communication patterns
  - Ways to increase OpenFOAM productivity
  - MPI libraries comparisons

- **For more info please refer to**
  - http://www.dell.com
  - http://www.intel.com
  - http://www.mellanox.com
  - http://www.openfoam.org

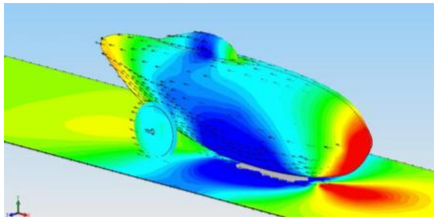
Objectives

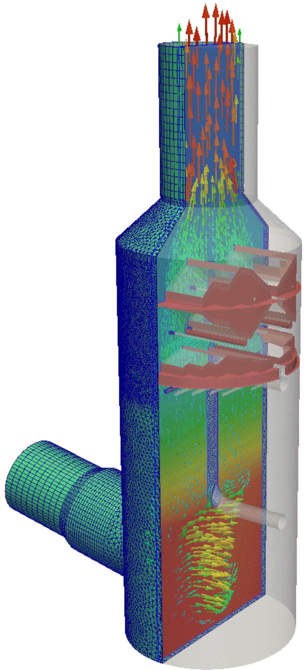
- **The following was done to provide best practices**
  - OpenFOAM performance benchmarking
  - Interconnect performance comparisons
  - MPI performance comparison
  - Understanding OpenFOAM communication patterns

- **The presented results will demonstrate**
  - The scalability of the compute environment to provide nearly linear application scalability
  - The capability of OpenFOAM to achieve scalable productivity

OpenFOAM Applications

- **OpenFOAM® (Open Field Operation and Manipulation) CFD Toolbox in an open source CFD applications that can simulate**
  - Complex fluid flows involving
    - Chemical reactions
    - Turbulence
    - Heat transfer
  - Solid dynamics
  - Electromagnetics
  - The pricing of financial options





- **OpenFOAM support can be obtained from OpenCFD Ltd**

Test Cluster Configuration

- **Dell™ PowerEdge™ R720xd 16-node (256-core) “Jupiter” cluster**
  - Dual-Socket Eight-Core Intel E5-2680 @ 2.70 GHz CPUs (Static max Perf in BIOS)
  - Memory: 64GB memory, DDR3 1600 MHz
  - OS: RHEL 6.2, OFED 1.5.3 InfiniBand SW stack
  - Hard Drives: 24x 250GB 7.2 RPM SATA 2.5” on RAID 0
- **Intel Cluster Ready certified cluster**
- **Mellanox ConnectX-3 FDR InfiniBand VPI adapters**
- **Mellanox SwitchX SX6036 InfiniBand switch**
- **MPI: Intel MPI 4 Update 3, Open MPI 1.6.2**
- **Application: OpenFOAM 2.1.0**
- **Benchmark datasets:**
  - Lid Driven Cavity Flow - 1 Million elements, 2D, icoFoam solver for laminar, isothermal, incompressible flow

About Intel® Cluster Ready

- **Intel® Cluster Ready systems make it practical to use a cluster to increase your simulation and modeling productivity**
  - Simplifies selection, deployment, and operation of a cluster
- **A single architecture platform supported by many OEMs, ISVs, cluster provisioning vendors, and interconnect providers**
  - Focus on your work productivity, spend less management time on the cluster
- **Select Intel Cluster Ready**
  - Where the cluster is delivered ready to run
  - Hardware and software are integrated and configured together
  - Applications are registered, validating execution on the Intel Cluster Ready architecture
  - Includes Intel® Cluster Checker tool, to verify functionality and periodically check cluster health

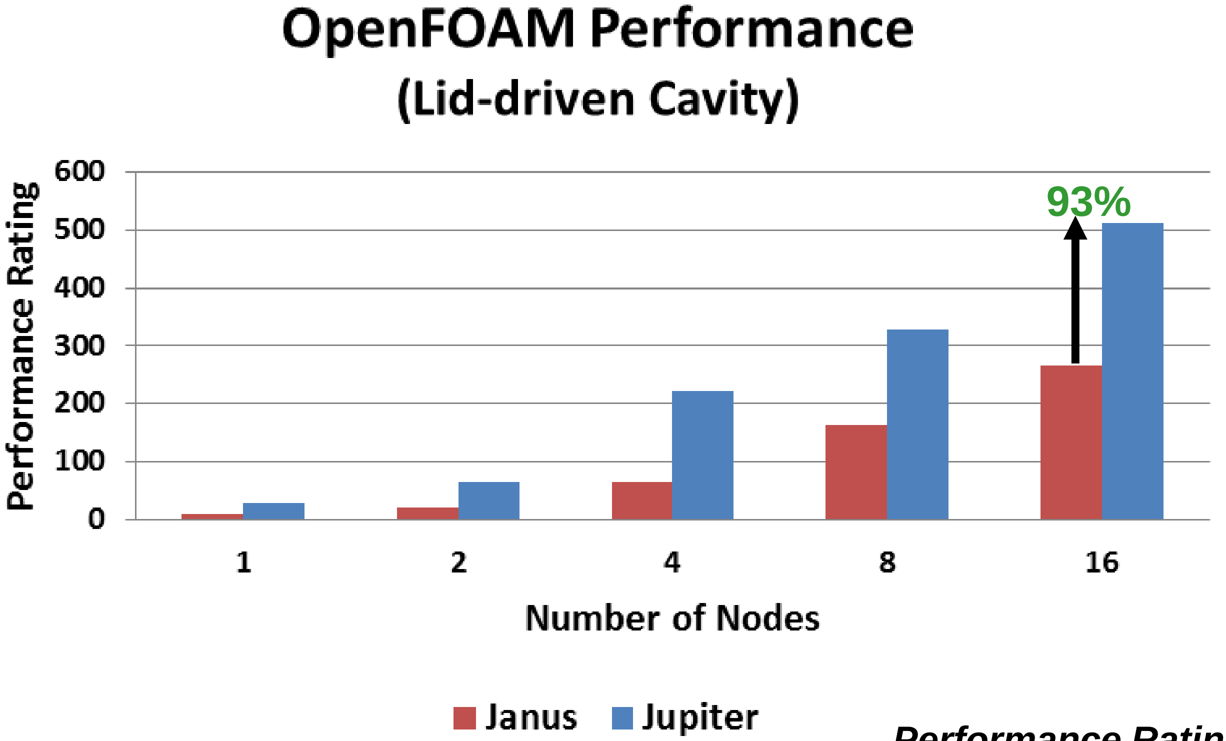
PowerEdge R720xd

Massive flexibility for data intensive operations

- **Performance and efficiency**
  - Intelligent hardware-driven systems management with extensive power management features
  - Innovative tools including automation for parts replacement and lifecycle manageability
  - Broad choice of networking technologies from GigE to IB
  - Built in redundancy with hot plug and swappable PSU, HDDs and fans
- **Benefits**
  - Designed for performance workloads
    - from big data analytics, distributed storage or distributed computing where local storage is key to classic HPC and large scale hosting environments
    - High performance scale-out compute and low cost dense storage in one package
- **Hardware Capabilities**
  - Flexible compute platform with dense storage capacity
    - 2S/2U server, 6 PCIe slots
  - Large memory footprint (Up to 768GB / 24 DIMMs)
  - High I/O performance and optional storage configurations
    - HDD options: 12 x 3.5" - or - 24 x 2.5 + 2x 2.5 HDDs in rear of server
    - Up to 26 HDDs with 2 hot plug drives in rear of server for boot or scratch

OpenFOAM Performance – Processors

- **Intel E5-2680 (Sandy Bridge) cluster outperforms prior generations**
  - Performs 93% better than X5670 cluster at 16 nodes
- **System components used:**
  - Jupiter: 2-socket Intel E5-2680 @ 2.7GHz, 1600MHz DIMMs, FDR IB, 24 disks
  - Janus: 2-socket Intel X5670 @ 2.93GHz, 1333MHz DIMMs, QDR IB, 1 disk

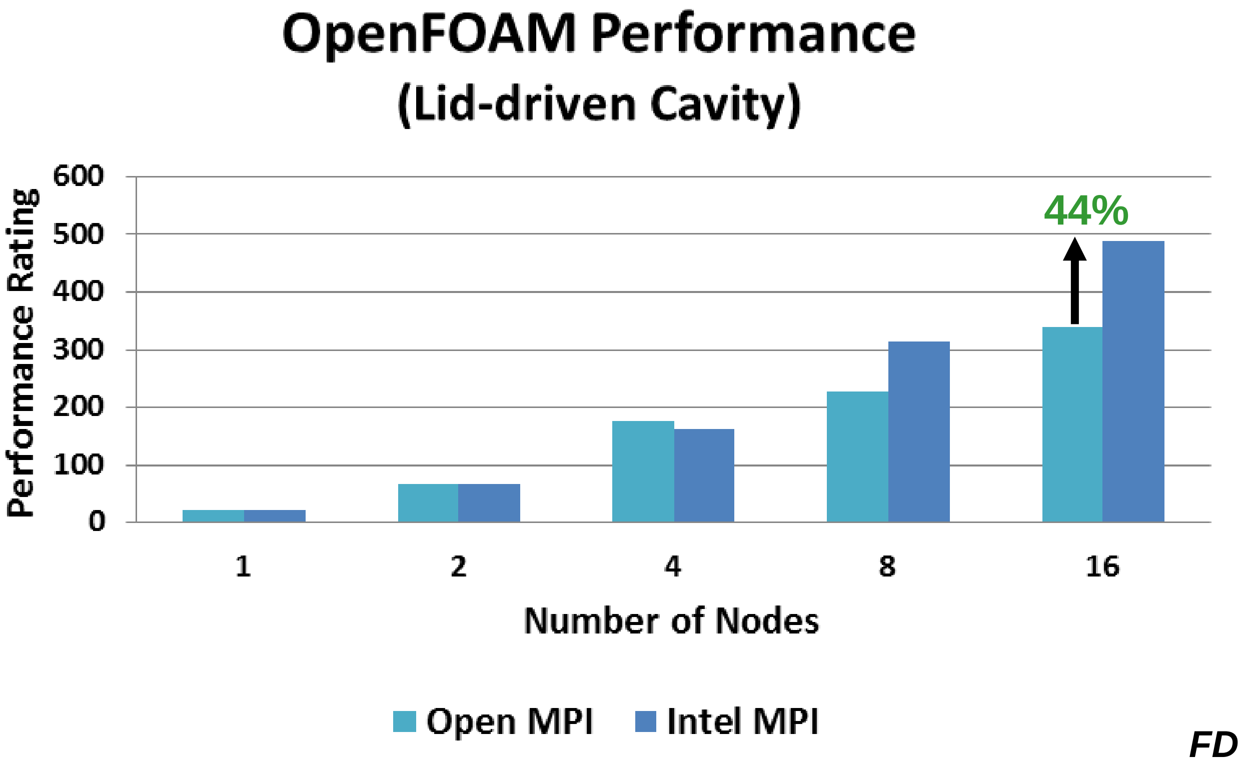


Higher is better

Performance Rating = Jobs/Day

OpenFOAM Performance – MPI

- **Intel MPI outperforms Open MPI at larger scale**
  - Up to 44% higher performance than Open MPI at 16-node
- **CPU binding optimization flag used in all cases shown**
  - No other optimization flags are used

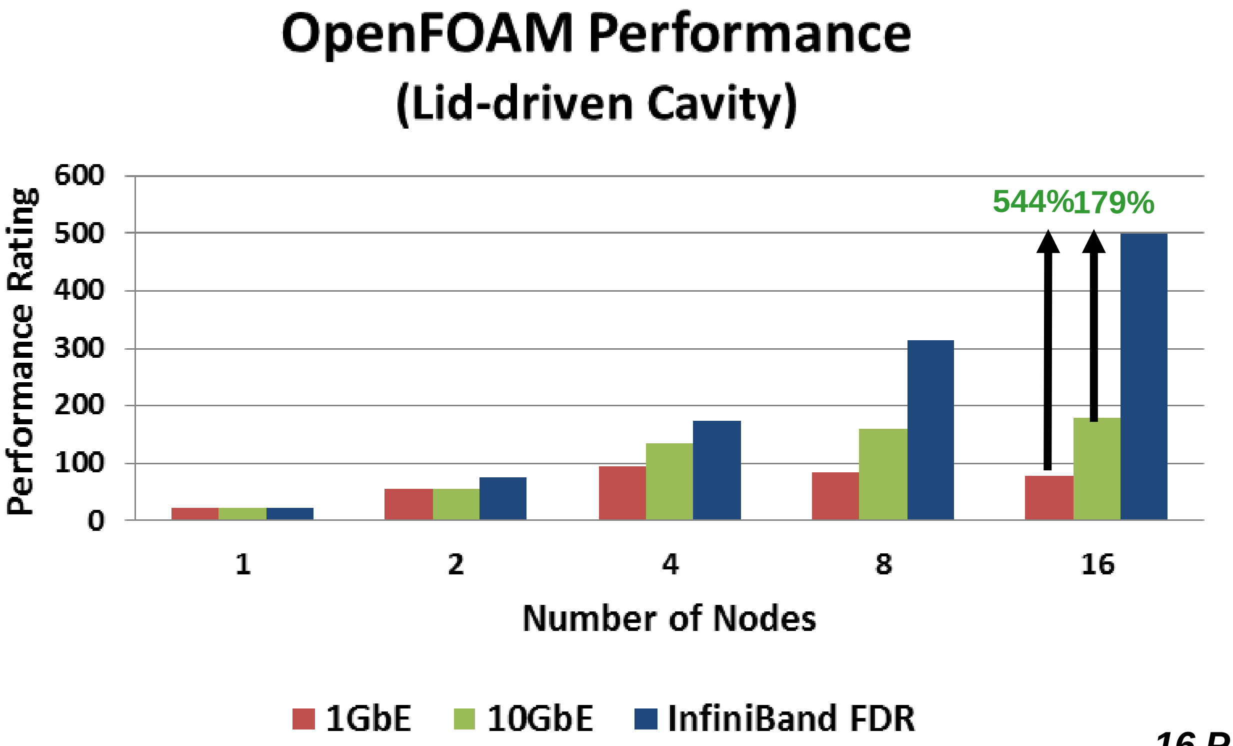


Higher is better

FDR InfiniBand

OpenFOAM Performance – Interconnects

- **FDR InfiniBand provides better scalability performance than Ethernet**
  - 544% better performance than 10GbE at 16 nodes / 256 processes
  - 179% better performance than 1GbE at 16 nodes / 256 processes
  - 1GbE does not scale at all

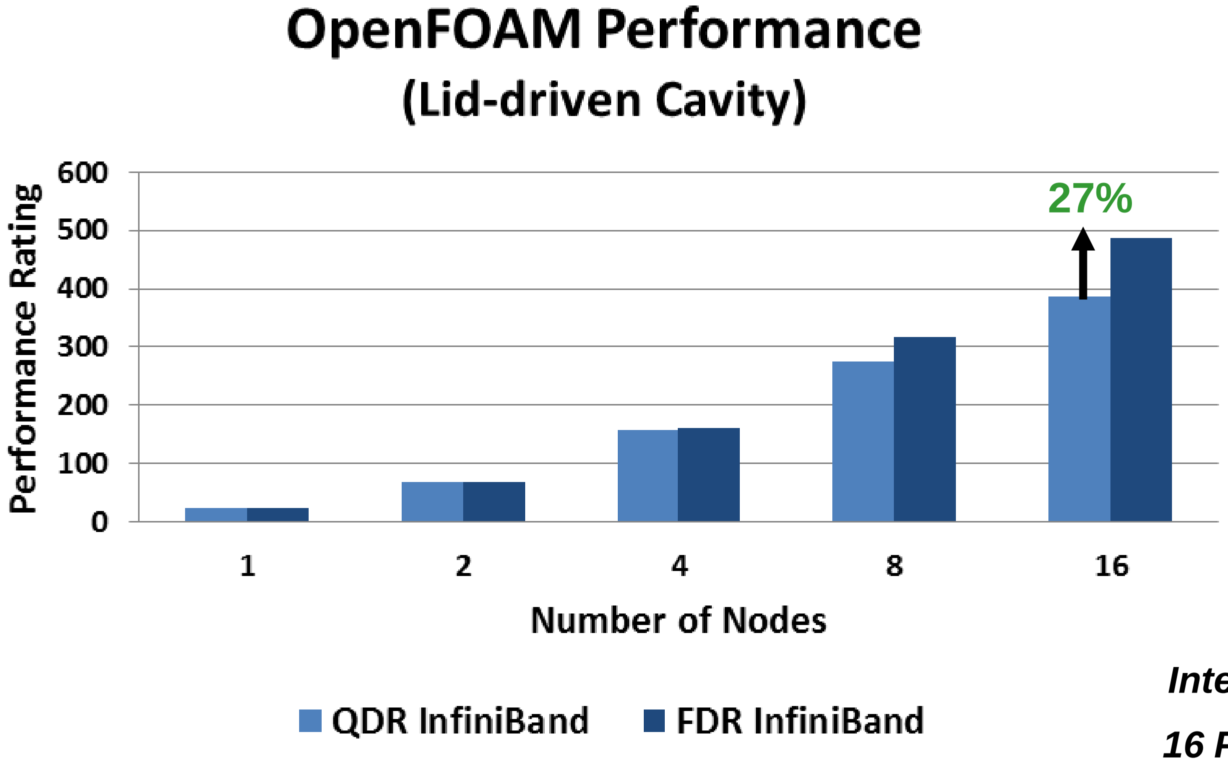


Higher is better

16 Processes/Node

OpenFOAM Performance – Interconnects

- **FDR InfiniBand delivers better application performance**
  - Up to 27% better performance than InfiniBand QDR
  - Using Mellanox ConnectX-3 PCIe Gen3 in FDR mode and QDR mode



Higher is better

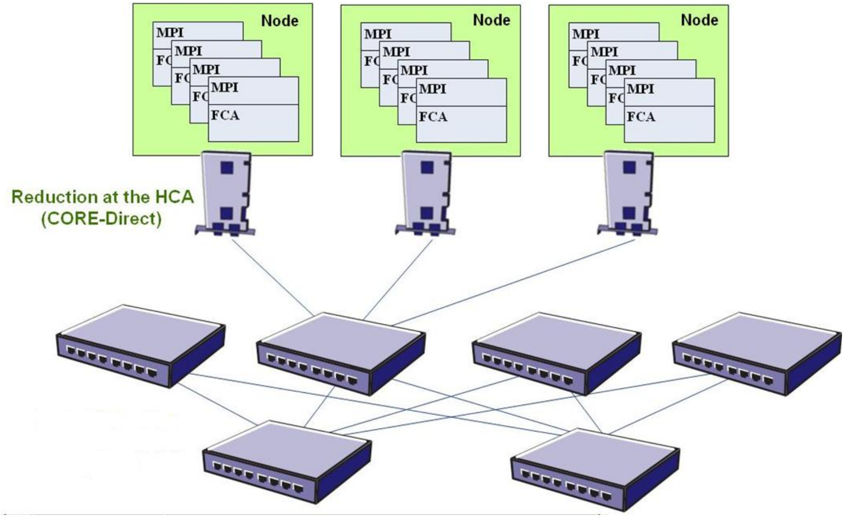
Intel MPI

16 Processes/Node

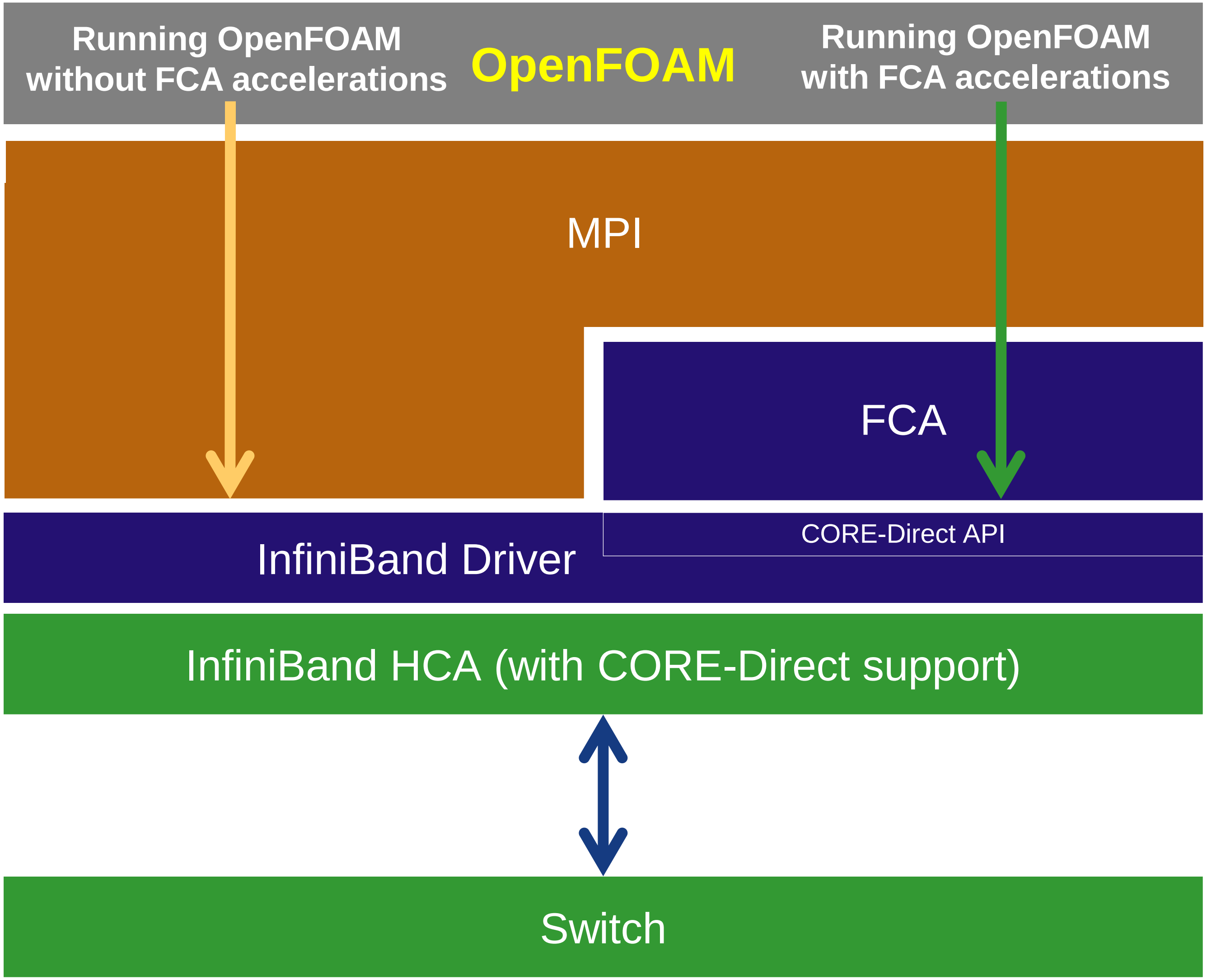
About Mellanox FCA

- **Mellanox Fabric Collectives Accelerator (FCA)**
  - Utilized hardware accelerations on the adapter (CORE-Direct)
  - Accelerating MPI collectives operations by offloading them to the network
  - The world first complete solution for MPI collectives offloads

- **FCA 2.2 supports accelerations/offloading for**
  - MPI_Barrier
  - MPI_Broadcast
  - MPI_Allreduce and MPI_Reduce
  - MPI_Allgather and MPI_Allgatherv

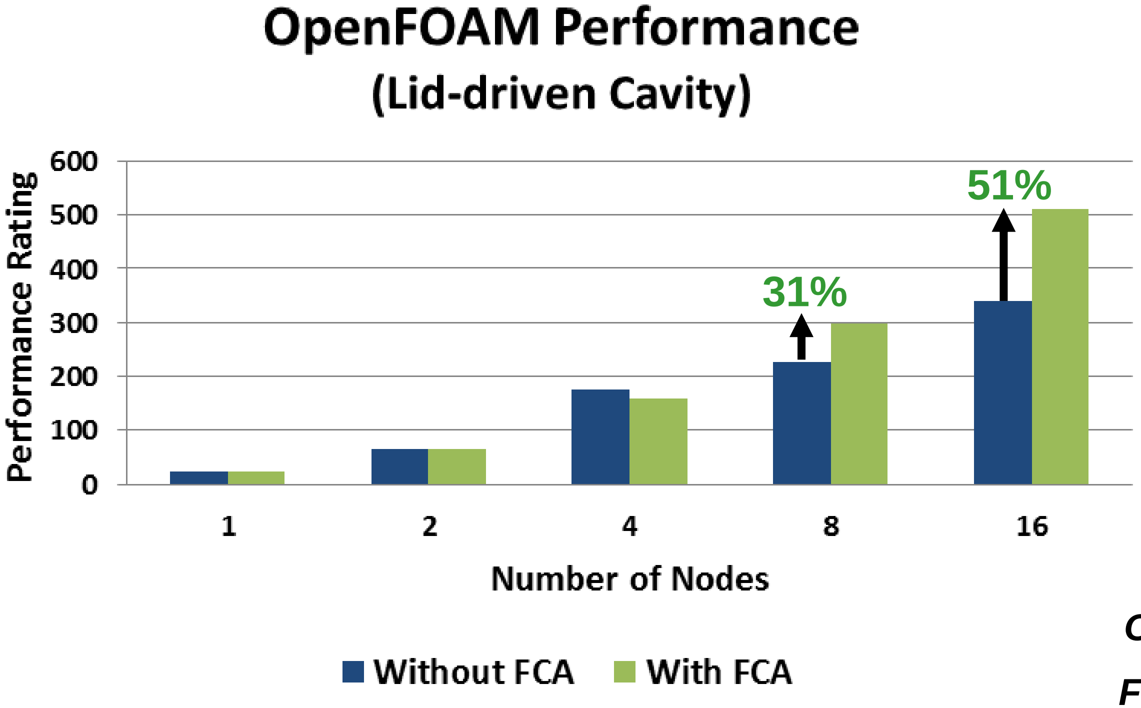


Software Layers Overview


Running OpenFOAM without FCA accelerations
OpenFOAM
Running OpenFOAM with FCA accelerations
MPI
FCA
InfiniBand Driver
CORE-Direct API
InfiniBand HCA (with CORE-Direct support)
Switch

OpenFOAM Performance – FCA

- **FCA enables nearly 51% performance gain at 16 nodes / 256 cores**
  - Bigger advantage expected at higher node count / core count
  - Normally FCA is enabled for >64 cores; FCA is enabled for all processes shown below
- **Flags used:**
  - To enable FCA at runtime: --mca coll_fca_enable 1 --mca coll_fca_np 0
  - Both cases at runtime: --bind-to-core -mca btl openib,sm,self



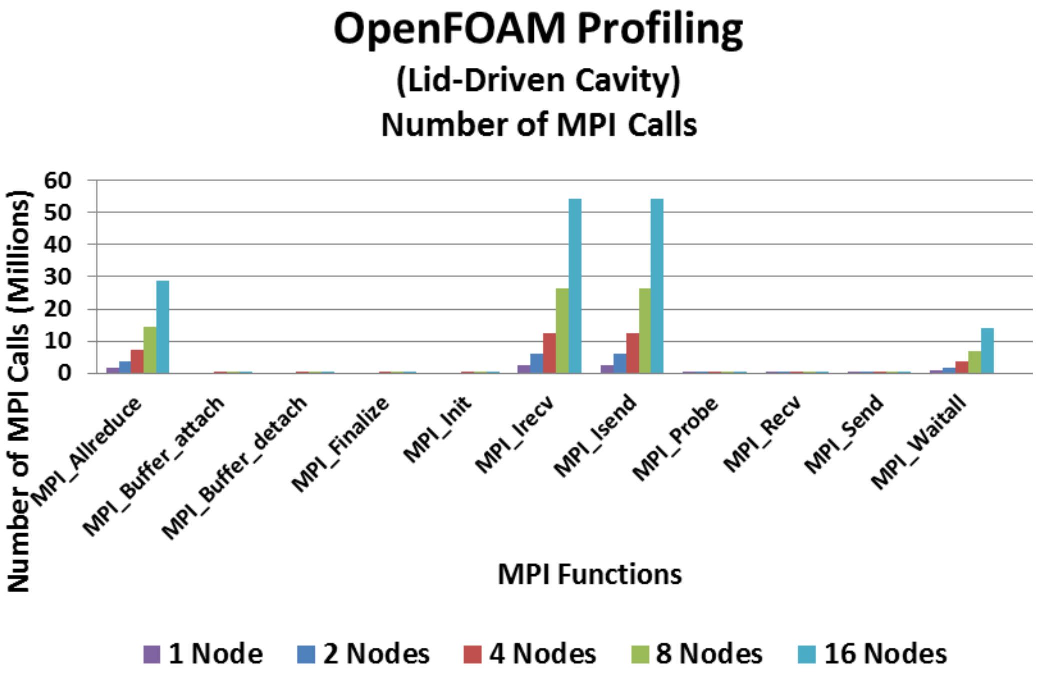
Higher is better

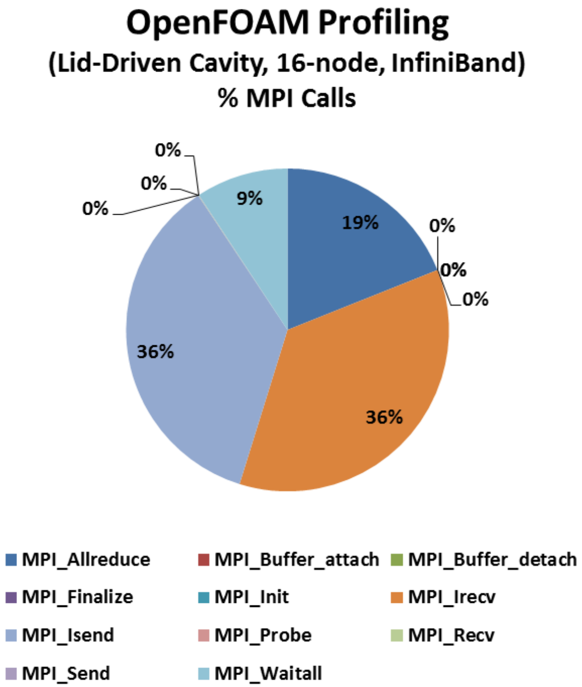
Open MPI

FDR InfiniBand

OpenFOAM Profiling – Number of MPI Calls

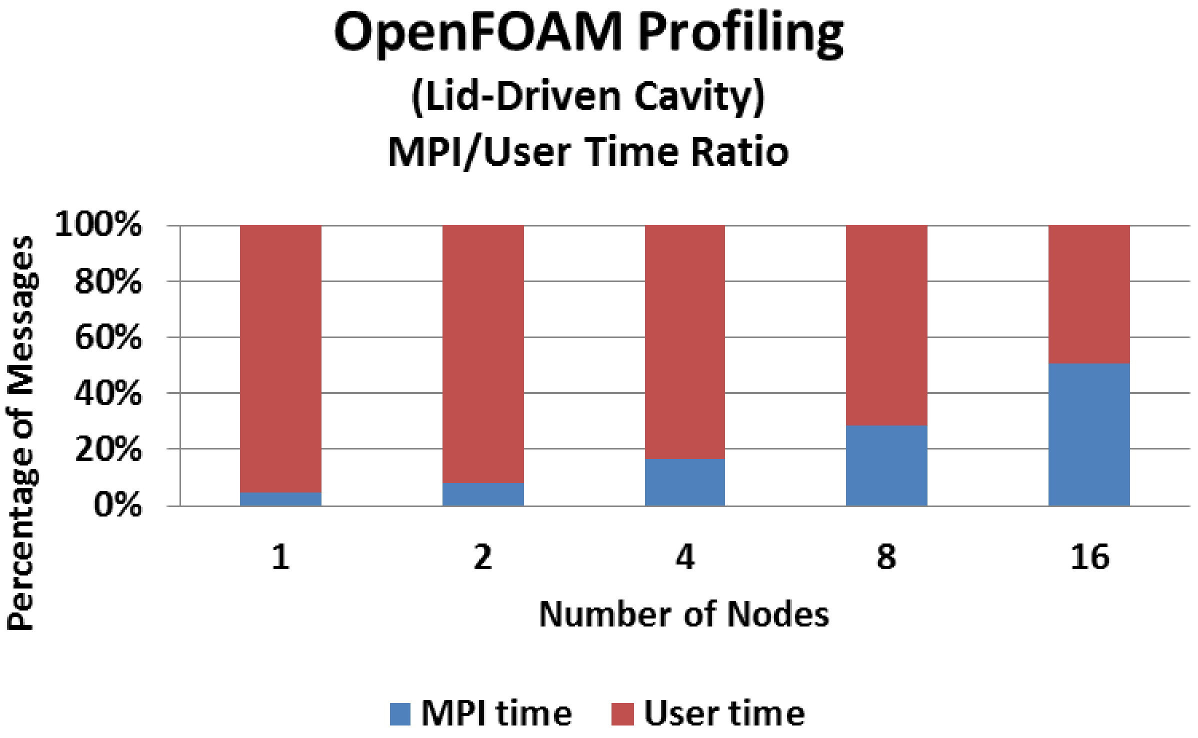
- **OpenFOAM utilizes a wide range of MPI APIs**
  - – 11 MPI APIs used in total
  - – 4 MPI APIs account for almost all of MPI calls
- **MPI_Waitall, MPI_Irecv and MPI_Isend are almost used exclusively**
  - – MPI_Irecv, MPI_Isend (26% each), MPI_Alltoallv (19%) at 16 nodes





OpenFOAM MPI Profiling Results – Time Ratio

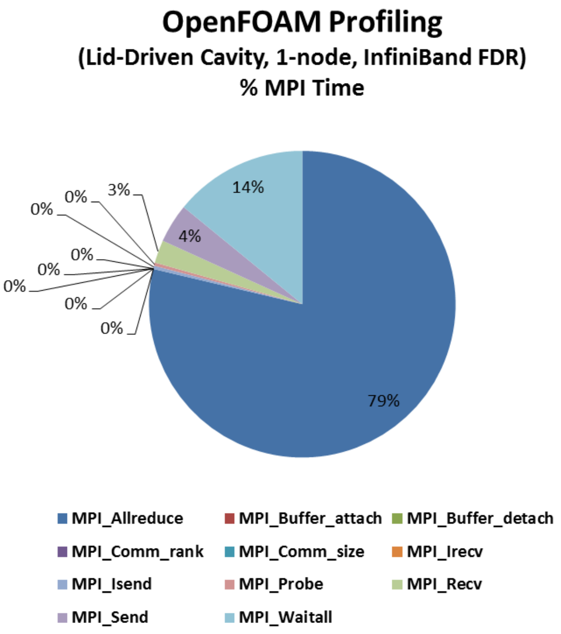
- **MPI communication time accounts for 50%**
  - With 16 nodes / 256 cores
  - The Lid-driven cavity flow is a highly communicative workload

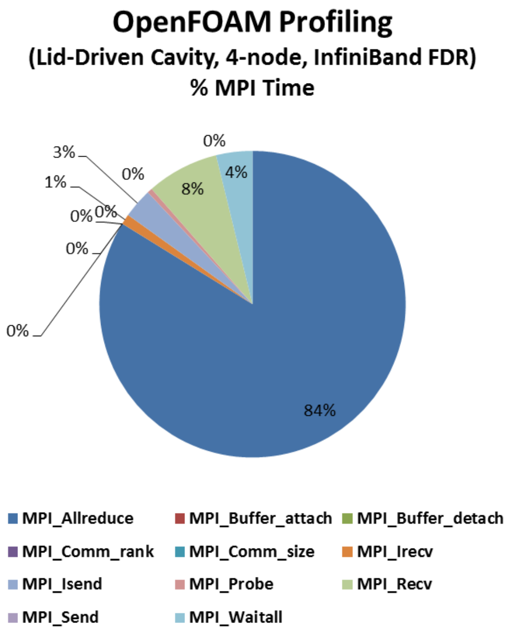


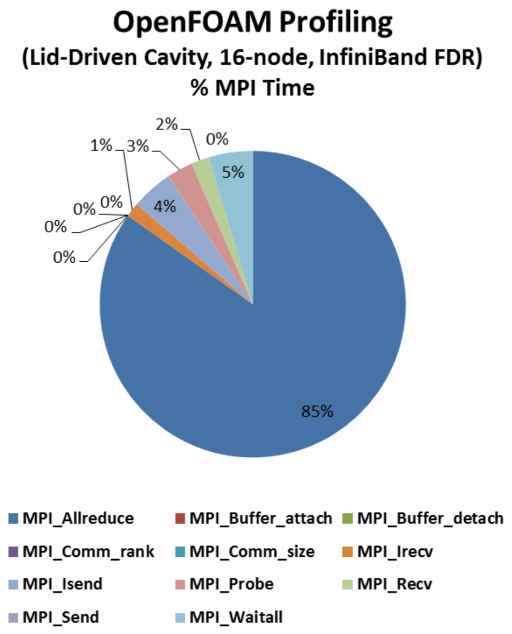
FDR InfiniBand

OpenFOAM Profiling – % MPI Time

- **MPI profiling clearly shows large time usage in MPI collective operations**
  - MPI_Allreduce accounts for 79% to 85% of all MPI time
- **Tuning MPI libraries for MPI collective offloading related to collective operations**
  - Will greatly influence the system performance



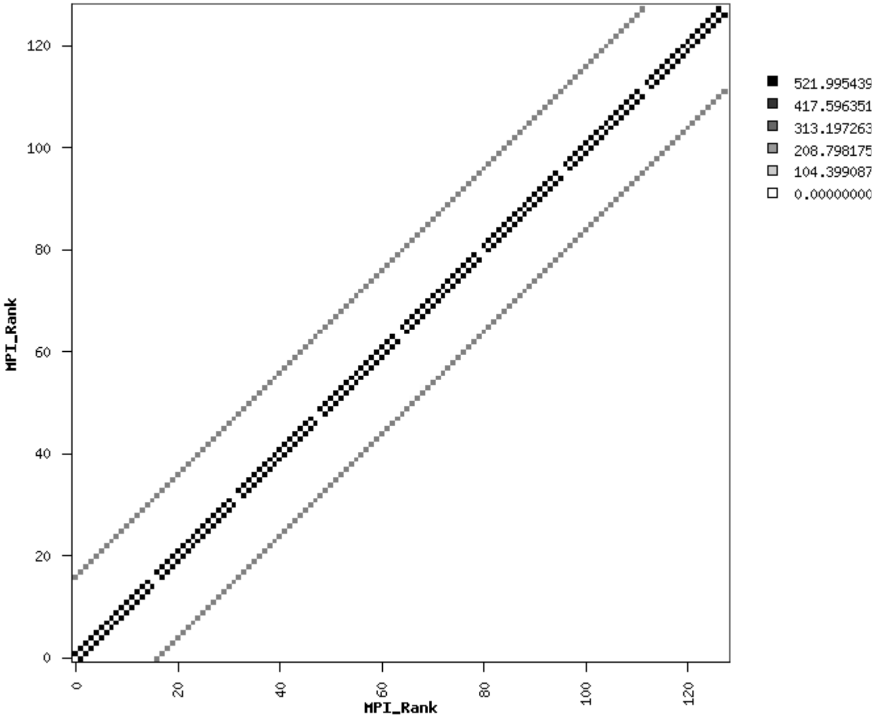




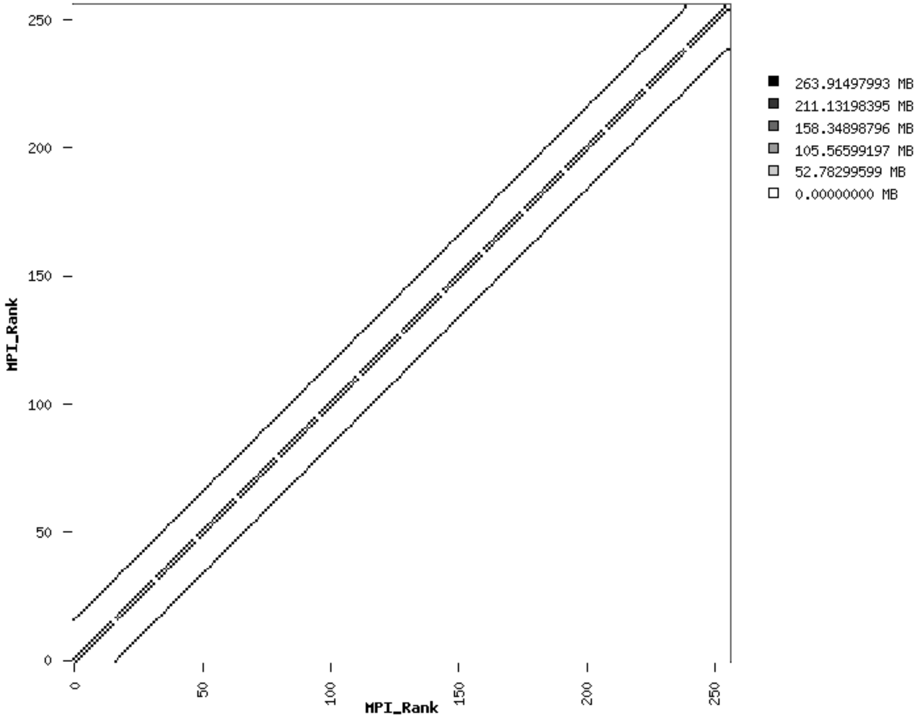
OpenFOAM Profiling – MPI Data Transfer

- **As the cluster grows, less data is transferred between MPI processes**
  - Decrease from 523MB max (8 nodes) at to 263MB max per rank (16 nodes)
  - Majority of communications are between neighboring ranks
  - Non-blocking (point to point) data transfers are shown in the graph
  - Collective data communications are small compared to non-blocking communications

8 Nodes



16 Nodes



OpenFOAM – Summary

- **OpenFOAM performance**
  - Intel Xeon E5-2600 series and FDR InfiniBand enable OpenFOAM to scale with 16 nodes
  - The E5-2680 cluster outperforms X5670 cluster by 93% at 16 nodes
  - Intel MPI scales better than Open MPI at large node counts (16 nodes) by 44%
- **FDR InfiniBand delivers the best application performance for OpenFOAM**
  - Up to 27% higher performance than InfiniBand QDR at 16 nodes
  - Up to 179% higher performance than 10GbE at 16 nodes
  - Up to 544% higher performance than 1GbE at 16 nodes
- **OpenFOAM MPI profiling**
  - Time used by MPI accounts for 50% of total runtime at 16 nodes / 256 processes
  - MPI_Allreduce accounts for 79% to 85% of all MPI time
  - Shows MPI_Allreduce is the main MPI collective routines that impacts OpenFOAM performance
- **FCA package has proven to accelerate application**
  - Nearly 51% faster runtime at 16 nodes / 256 cores for OpenFOAM with Open MPI
  - Higher performance boost expected at larger scale

Thank You

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