Intel® Cluster Studio XE 2013
for Distributed Performance

Boost Performance. Code Reliably. Scale Forward

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Notice revision #20110804
Intel® Cluster Studio XE
Scale Forward, Scale Faster – for HPC Clusters

• Scale Performance – Perform on More Nodes
  - MPI Latency - Intel® MPI Library - Up to 2.6X as fast as alternative MPI libraries
  - Compiler Performance – Industry leading Intel® C/C++ & Fortran compilers

• Scale Forward – multicore now, many-core ready
  - Intel® MPI Library scales beyond 120k processes
  - Parallel Programming Models – Commercially supported Intel® versions of open source Threading Building Blocks 4.0 and Intel® Cilk™ Plus 1.1, MPI, OpenMP 3.1, Coarray Fortran
  - Focused to preserve programming investments for multicore on future many-core machines

• Scale Efficiently – Tune & Debug on More Nodes
  - Thread & Memory Correctness Checking – Intel® Inspector XE now MPI enabled across many nodes
  - Rapid Node Level Performance Profiling – Intel VTune Amplifier XE can identify hotspots faster and on thousands of nodes

Windows*/Linux* Application Source
Build
- C, C++ & Fortran* Compilers
- Intel® MPI Library
- Intel® Cilk™ Plus
- Intel® Threading Building Blocks Library
- Intel® Math Kernel Library
- Intel® Integrated Performance Primitives Library
- OpenMP 3.1

Verify
- Intel® Inspector XE (Memory/Thread Correctness Checker)
- Intel® Debugger

Tune
- Intel® Trace Analyzer and Collector (MPA Analyzer)
- Intel® VTune™ Amplifier XE (Performance Analyzer)

Deploy
- TCP/IP
- Myrinet
- InfiniBand
- iWARP
- Shared Memory
- Other Networks

Optimized MPI application running on a variety of fabrics with threaded nodes
Intel® MPI Library Overview

- Optimized MPI application performance
  - Application-specific tuning
  - Automatic tuning
- Lower latency and multi-vendor interoperability
  - Industry leading latency
  - Performance optimized support for the latest OFED capabilities through DAPL 2.0
- Faster MPI communication
  - Optimized collectives
- Simplify and accelerate clusters
  - “Intel® Cluster Ready”
- Sustainable scalability beyond 120K cores
  - Native InfiniBand* interface support allows for lower latencies, higher bandwidth, and reduced memory requirements
- More robust MPI applications
  - Seamless interoperability with Intel® Trace Analyzer and Collector
MPI Latency: 96 Processes / 8 Nodes on Intel processor running Linux* 64
Intel® MPI Library vs. alternative MPI libraries

Industry Leading Performance with Intel® MPI Library 4.1
Relative (Geomean) MPI Latency Benchmarks on Linux* 64 (Higher is Better)
96 Processes on 8 nodes (InfiniBand + shared memory)

Up to 2.6X as fast as on 8 nodes

Configuration Info - SW Versions: Intel® C/C++ version 13.0, Intel® MPI Library 4.1, Platform MPI 8.2.1, MVAPICH2 1.8, Open MPI 1.6.1, Intel® MPI Benchmarks 3.2.4; Hardware: Intel® Xeon® CPU DP X5680 @ 3.33GHz, RAM 24GB; Interconnect: InfiniBand, ConnectX adapters; QDR; Operating System: SLES 11.1; Notes: 96 Processes on 8 nodes (InfiniBand + shared memory). All listed MPI libraries were built with the Intel® C++ Compiler 12.1 Update 10 for Linux*.

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Intel® MPI Library Overview (cont’d)

• Streamlined product setup
  – Installation under root or ordinary user ID
  – mpivars.(c)sh scripts for easy path setting

• Simplified process management
  – mpiexec -perhost and -nolocal options
  – mpirun script that automates usage of the Hydra process manager
  – System-, user-, and session-specific configuration files

• Environment variables for runtime control over
  – Process pinning
  – Optimized collective operations
  – Device-specific protocol thresholds
  – Collective algorithm thresholds
  – Enhanced memory registration cache
  – Many others ...
Compile and Link Commands

• Using Intel compilers
  – mpiicc, mpiicpc, mpiifort, ...

• Using Gnu compilers (same underlying Intel MPI library)
  – mpicc, mpicxx, mpif77, ...

• Ease of use
  – Commands find the Intel® MPI Library include files automatically
  – Commands link the Intel® MPI libraries automatically

• Commands use compilers from PATH (or selected through options); compilers not hard-wired!

• Example:
  – Compile using the Intel Fortran compiler
    $ mpiifort -o testf test.f
Execution Commands

• All-inclusive
  – mpirun -f hostfile -n #processes executable
  – Most common usage scenario
    – Convenient

    – Uses new Hydra process manager by default

    – May be good for jobs in batch system
      “In-session” mode: mpirun acquires the list of nodes from the batch system

• Example:
  – Run the test program

    $ mpirun -f hosts.file -n 2 ./testc

    Hello world: rank 0 of 2 running on node1
    Hello world: rank 1 of 2 running on node1
Process Placement

• Simple process placement (consecutive assignment of MPI ranks to round robin selection of nodes)
  − `mpirun [-perhost #ppn] -n #procs executable`
  − Place #ppn processes per node until the total number #procs of processes is reached

• Exact process placement using Argument Sets:
  − `mpirun -n #p1 -hosts node1 exe1 : -n #p2 -hosts node2 exe2`
  − Argument Set (separated by “;”) is valid for the specified node:
    − Place #p1 processes of exe1 on node1
    − Place #p2 processes of exe2 on node2, ...
    − “exe” may actually be “executable exeparams”

• Exact process placement with a config file
  − One argument set per line in a file (without “;”)  
  − Handy: comment unused lines with “#”
  − Example config file:
    − `n #p1 -hosts node1 exe1`
    − `n #p2 -hosts node2 exe2`
    − `n #p3 -hosts dead_node3 exe3`
    − `n #p4 -hosts node4 exe4`
  − `mpirun -configfile theconfigfile`
  − No other `mpirun` flags on the command line!
Intel® MPI Library Fabric Selection

- Environment variable $I\_MPI\_FABRICS$ selects the interconnect device at runtime
  - $I\_MPI\_FABRICS$ values:
    - $shm$ (shared memory only)
    - $dapl$ (DAPL fabrics)
    - $tcp$ (sockets)
    - $tmi$
    - $ofa$

- $shm:dapl$ fabrics is default

- Example
  - Check selected device
    ```
    $ mpirun -f hosts.file -genv I_MPI_DEBUG 2 -n 2 ./testc
    ..... will use default fabric $shm:dapl$ (RDMA-enabled device + shared memory)
    ```
  - Change selected device
    ```
    $ mpirun -f hosts.file -genv I_MPI_DEBUG 2 \
      -genv I_MPI_FABRICS $shm:ofa -n 2 ./testc
    ..... will use fabric $shm:ofa$ (OFED verbs + shared memory)
    ```
Performance Tuning: mpitune

• Use the automatic tuning facility to tune the Intel® MPI Library for your cluster or application (done once, may take a long time)

• Example (see mpitune –h for options)
  – Cluster-wide tuning
    
  – Application-specific tuning

  Creates options settings which are used with the –tune flag

  mpiexec –n 32 ./exe

  mpirun –tune ...

mpitune ...

mpitune --application "mpiexec –n 32 ./exe" ...

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**Intel® MPI Library 4.1**

*What's New*

- Increased MPI application performance and scalability
  - Support for the latest Intel® Composer XE 2013 and new Intel® Architectures including:
    - Intel® Xeon Phi™ coprocessor in all programming models: offload, native, and symmetric
  - New Intel® MPI Library architecture provides industry-leading performance and sustainable scalability beyond 120K cores
  - Added conformance to the MPI-2.2 standard
  - Backwards compatibility with Intel® MPI Library 4.0.x based applications
  - Tighter integration with the PBS Pro* job manager
  - Improved heterogeneous support when running over different Intel® Architecture processors
  - Support for Berkeley Lab Checkpoint/Restart (BLCR)
  - Brand new HTML documentation format

*Intel® MPI Library 4.1 contains leading edge technology to further improve performance, scalability and usability*
Scale Performance
Tune Hybrid Cluster MPI and Thread Performance

Intel® Trace Analyzer and Collector

Tune cross-node MPI
• Visualize MPI behavior
• Evaluate MPI load balancing
• Find communication hotspots

Intel® VTune™ Amplifier XE

Tune single node threading
• Visualize thread behavior
• Evaluate thread load balancing
• Find thread sync. bottlenecks
Introduction – What is Tracing?

• Record program execution
  – Program events such as function enter/exit, communication

• 1:1 protocol of the actual program execution
  – Sampling gathers statistical information

• Accurate data

• Easily get loads of data
Intel® Trace Analyzer and Collector helps the developer:

- Visualize and understand parallel application behavior
- Evaluate profiling statistics and load balancing
- Identify communication hotspots
Event based approach

• Event = time stamp + thread ID + description
• Function entry/exit
• Messages
• Collective operations
• Counter samples
Strengths of Event-based Tracing

- Predict detailed program behavior
- Record **exact sequence** of program states – keep timing consistent
- Collect information about exchange of messages: at what times and in which order

An event-based approach is able to detect temporal dependencies!
Key Features

- Low Overhead
- Catch all MPI events
- Powerful configuration mechanism
  - Filters, settings, features
- Automatic source-code references
- Instrumentation
  - Rich API
  - Binary instrumentation (itcpin)
  - Compiler based (-tcollect)
- Fail-safe version
- Comparison of multiple profiles
- Idealizer
- MPI Correctness Checking
How to use Intel® Trace Analyzer and Collector

**Step 1:** Run your binary and create a tracefile
run the binary for a representative amount of time (to reduce initialization influences) on representative data (no corner cases)

$ mpirun -trace -n 2 ./test

- Alternative 1: Generate an instrumented binary via re-linking
  $ mpiicc -trace test.c -o test.inst
  $ mpirun -n 2 ./test.inst

- Alternative 2: Instrument binary
  itcpin --run -- ./test

**Step 2:** To view the generated trace file, start the GUI:
traceanalyzer &
Support for the Intel® Xeon Phi™ coprocessor

- The tracing libraries have been fully ported to Xeon Phi™

- Make sure the necessary libraries are accessible to the card via:
  - NFS-sharing the /opt/intel & $HOME directories (*preferred*)
  - Manually copying the files:
    $ scp /opt/intel/itac/<version>/mic/slib/libVT.so mic0:/lib64

- Now run as shown previously:
  $ mpirun -trace -n 2 ./test

- Make sure you have all trace files in the same directory:
  - If your card is NFS-shared, all trace files will be accessible in the directory where the executable is located (*preferred*)
  - If your card is not NFS-shared, you might have partial trace files created on the Xeon Phi™ coprocessor that you need to copy:
    $ scp mic0:/home/<user>/test.stf.* node0:~

- Finally view using the GUI:
  $ traceanalyzer test.single.stf &
Intel® Trace Analyzer and Collector

Compare the event timelines of two communication profiles

Blue = computation
Red = communication

Chart showing how the MPI processes interact
A Chart is a numerical or graphical diagram.
**Timelines: Event Timeline**

- Get impression of program structure
- Display functions, messages and collective operations for each process/thread along time-axis
- Retrieval of detailed event information

<table>
<thead>
<tr>
<th>P0</th>
<th>Application</th>
<th>OpenMP</th>
<th>OpenMP</th>
<th>Application</th>
<th>OpenMP</th>
<th>OpenMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Application</td>
<td>OpenMP</td>
<td>OpenMP</td>
<td>Application</td>
<td>OpenMP</td>
<td>OpenMP</td>
</tr>
<tr>
<td>P2</td>
<td>Application</td>
<td>OpenMP</td>
<td>OpenMP</td>
<td>Application</td>
<td>OpenMP</td>
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</tr>
<tr>
<td>P3</td>
<td>Application</td>
<td>OpenMP</td>
<td>OpenMP</td>
<td>Application</td>
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<tr>
<td>P4</td>
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<tr>
<td>P5</td>
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<tr>
<td>P7</td>
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<td>OpenMP</td>
<td>OpenMP</td>
<td>Application</td>
<td>OpenMP</td>
<td>OpenMP</td>
</tr>
</tbody>
</table>
Timelines: Qualitative Timeline

- Find patterns and irregularities
- Display attributes of functions, messages or collective operations as they occur for any process/thread
- Retrieval of detailed event information
Timelines: Quantitative Timeline

- Get impression on parallelism and load balance
- Show for every function how many threads/processes are currently executing it
Profiles: Flat Function Profile

- Statistics about functions
Profiles: Call-Tree and Call-Graph

- Function statistics including calling hierarchy
  - Tree: call-stack
  - Graph: calling dependencies
Communication Profiles

- Statistics about point-to-point or collective communication
- Generic matrix supports grouping by several attributes in each dimension
  Sender, Receiver, Data volume per msg, Tag, Communicator, Type
- Available attributes
  Count, Bytes transferred, Time, Transfer rate
View

- Helps navigating through the trace data and keep orientation
- Every View can contain several Charts
- A View on a file is defined by a triplet of
  - time-span
  - set of threads
  - set of functions
- All Charts follow changes to View (e.g. zooming)
- Timelines are correctly aligned along time
View - zooming
Grouping and Aggregation

• Allow analysis on different levels of detail by aggregating data upon group-definitions

• Functions and threads can be grouped hierarchically
  - Function Groups and Thread Groups

• Arbitrary nesting is supported
  - Functions/threads on the same level as groups
  - User can define his/her own groups

• Aggregation is part of View-definition
  - All charts in a View adapt to requested grouping
  - All charts support aggregation
Aggregation Example
Tagging & Filtering

- Help concentrating on relevant parts
- Avoid getting lost in huge amounts of trace data

Define a set of interesting data
  - E.g. all occurrences of function x
  - E.g. all messages with tag y on communicator z

Combine several filters:
  Intersection, Union, Complement

Apply it
  - Tagging: Highlight messages
  - Filtering: Suppress all non-matching events
Tagging Example
Filtering Example

![Software & Services Group, Developer Products Division](image)

> Optimization Notice
Ideal Interconnect Simulator (Idealizer)

• Helps to figure out application's imbalance simulating its behavior in the "ideal communication environment"

Easy way to identify application bottlenecks
Application Imbalance diagram

- Intuitive diagram for simplified application analysis

Basic building block: breakdown of a single run time into 3 colors

- Combined information in one location:
  - Load Imbalance
  - MPI overall time
  - MPI Interconnect time
  - Different Breakdowns etc

Simplified application analysis helps to identify performance issues
Application Imbalance diagram (cont.)

Breakdown mode

![Application Imbalance Diagram (Breakdown Mode)](image-url)
MPI Correctness Checking: automatically checks MPI correctness

• Solves two problems:
  1. Finding programming mistakes in MPI application which need to be fixed by the application developer.
  2. Detecting errors in the execution environment.

• Two aspects:
  1. *error detection* – done automatically by the tool
  2. *error analysis* – manually by the user based on
     - information provided about an error
     - knowledge of source code, system, ...

MPI Correctness Checking: How it works

- All checks are done at runtime in MPI wrappers.
- Detected problems are reported on stderr immediately in textual format.
- A debugger can be used to investigate the problem at the moment when it is found.
**MPI Correctness Checking: Categories of checks**

- **Local checks**: isolated to single process
  - Unexpected process termination
  - Buffer handling
  - Request and data type management
  - Parameter errors found by MPI

- **Global checks**: all processes
  - Global checks for collectives and p2p ops
    - Data type mismatches
    - Corrupted data transmission
    - Pending messages
    - Deadlocks (hard & potential)
  - Global checks for collectives – one report per operation
    - Operation, size, reduction operation, root mismatch
    - Parameter error
    - Mismatched MPI_Comm_free()
MPI Correctness Checking: Severity of Checks

• Levels of severity:
  – **Warnings**: application can continue
  – **Error**: application can continue but almost certainly not as intended
  – **Fatal error**: application must be aborted

• Some checks may find both warnings and errors
  – Example: CALL_FAILED check due to invalid parameter
    – Invalid parameter in MPI_Send() => msg cannot be sent => **error**
    – Invalid parameter in MPI_Request_free() => resource leak => **warning**
MPI Correctness Checking: Usage (Part I)

- Command line option via `--check_mpi` flag for Intel MPI Library:

```
$ mpirun --check_mpi -n 2 overlap
[...]
[0] WARNING: LOCAL:MEMORY:OVERLAP: warning
[0] WARNING: New send buffer overlaps with currently active send buffer at address 0x7fbfffe30.
[0] WARNING: Control over active buffer was transferred to MPI at:
[0] WARNING: MPI_Isend(*buf=0x7fbfffe30, count=4, datatype=MPI_INT, dest=0, tag=103, comm=COMM_SELF [0], *request=0x508980)
[0] WARNING: overlap.c:104
[0] WARNING: Control over new buffer is about to be transferred to MPI at:
[0] WARNING: MPI_Isend(*buf=0x7fbfffe30, count=4, datatype=MPI_INT, dest=0, tag=104, comm=COMM_SELF [0], *request=0x508984)
[0] WARNING: overlap.c:105
```
MPI Correctness Checking: Usage (Part II)

- Enable correctness checking info to be added to the trace file:
  
  - Enable `VT_CHECK_TRACING` env variable:
    
    ```
    $ mpirun -check_mpi -genv VT_CHECK_TRACING on -n 4 ./a.out
    ```
**Warnings** indicate potential problems that could cause unexpected behavior (e.g., incomplete message requests, overwriting a send/receive buffer, potential deadlock, etc.).

**Errors** indicate problems that violate the MPI standard or definitely cause behavior not intended by the programmer (e.g., incomplete collectives, API errors, corrupting a send/receive buffer, deadlock, etc.).
MPI Correctness Checking: Debugger Integration

- Debugger must be in control of application before error is found.

- A breakpoint must be set in MessageCheckingBreakpoint()

Can be done automatically by configuring the debugger, instructions for TotalView, gdb and idb contained in documentation.
MPI Correctness Checking: Usage of Debugger

- Error detected, process stopped at breakpoint.
- Access to MPI parameters via debug information in wrapper.
- Full access to application source code and data.
Tune MPI Apps Single Node Threading
Intel® VTune™ Amplifier XE Performance Profiler

• Launch Intel® VTune™ Amplifier XE
  – Use mpirun or mpiexec
  – List your app as a parameter

• Results organized by MPI rank

• Review results
  – Graphical user interface
  – Command line report

Tune for Scalable Multicore Performance
Using the Intel® VTune™ Amplifier XE with MPI

• Use the command-line tool under the MPI run scripts to gather report data
  $ mpirun -n 4 amplxe-cl --result-dir ampl_results -collect hotspots -- ./example.exe

• A results directory is created for each MPI rank
  – Can use arg sets to filter on a subset of ranks

• Launch the GUI and view the results for each particular rank
  $ amplxe-gui ampl_results.<rank#>
Scale Efficiently
Intel® Cluster Studio XE correctness tools find errors early in the design cycle

Where are the application’s...

**Memory Errors**
- Invalid Accesses
- Memory Leaks
- Uninitialized Memory Accesses

**Threading Errors**
- Races
- Deadlocks
- Cross Stack References

**Security Errors**
- Buffer overflows and underflows
- Incorrect pointer usage
- Over 250 error types...

- MPI aware, cluster friendly
- Both dynamic and static analysis
- Multiple tools – common GUI
- Windows* & Linux*

"Having such a tool this early in the development stage frees the validation from trivial bug reports and gives our engineers the opportunity to code more efficiently from the very beginning of the product cycle."

Jean Kypreos
Advanced Video Processing Team Manager
Envivio

Developer friendly tools help you find errors earlier
Intel® Cluster Studio XE Correctness Tools
Analyze MPI Apps For Memory, Threading and Security Errors

**Dynamic Analysis**
- Launch Intel® Inspector XE
  - Use mpirun or mpiexec
  - List your app as a parameter
- Results organized by MPI rank
- Review results
  - Graphical user interface
  - Command line report

**Static Analysis**
- Source analyzed for errors (similar to a build)
- Review results
  - Graphical user interface
  - Command line report

Find errors earlier when they are less expensive to fix.
Using the Intel® Inspector XE with MPI

• Use the command-line tool under the MPI run scripts to gather report data
  
  $ mpirun -n 4 inspxe-cl --result-dir insp_results -collect mi1 -- ./insp_example.exe

• A results directory is created for each MPI rank
  – Can use arg sets to filter on a subset of ranks

• Launch the GUI and view the results for each particular rank
  
  $ inspxe-gui insp_results.<rank#>
Intel® MPI Benchmarks 3.2.4
Overview and What's New

Standard benchmarks with OSI-compatible CPL license
• Enables testing of interconnects, systems, and MPI implementations
• Comprehensive set of MPI kernels that provide performance measurements for:
  – Point-to-point message-passing
  – Global data movement and computation routines
  – One-sided communications
  – File I/O

Enhancements:
• Support for the Intel® Xeon Phi™ Coprocessor

The Intel® MPI Benchmarks provide a simple and easy way to measure MPI performance on your cluster
“Intel Trace Analyzer and Collector for Linux helped to drastically improve the performance of RIKEN’s molecular dynamics cluster software. We were able to shorten MPI communication time by half by finding and removing bottlenecks with non-blocking communication patterns. Since Intel Trace Analyzer and Collector can embed instrumentation into the program, we can tell the execution time of each function and its load balance, which enabled us to very easily understand where to optimize. Intel’s MPI library and Cluster tools provide us the best cluster development environment.”

Dr. Takahiro Koishi, Computational Astrophysics Laboratory, RIDEN, Japan.

“Using Intel VTune Amplifier XE makes my work easier and speeds up the development process…it has helped us achieve performance gains from 20% to 360%”

Sergey Zaritchny – Open Cascade SAS

“We’re delighted by the efforts of the Intel cluster tools team in helping us scale our applications to 10s of thousands of cores with Intel MPI Library 4.0. and raising the performance bar in providing us with the most scalable commercial MPI library for Intel architecture based processors.”

Dr. Daniel Gruner, Chief Technical Officer - Software, University of Toronto

“Intel Inspector XE 2011 is a must-use to craft reliable code in C++. It helped me to quickly localize threading and memory problems in my code, making it easier to fix even the most difficult ones”

Jorge Martinis - Research & Development Engineer, BR&E Inc.