Intel® Parallel Studio XE 2016 Cluster Edition (Масштабирование MPI – производительность гибридных приложений)

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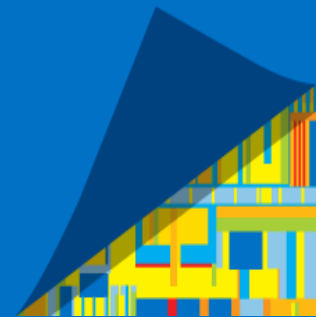
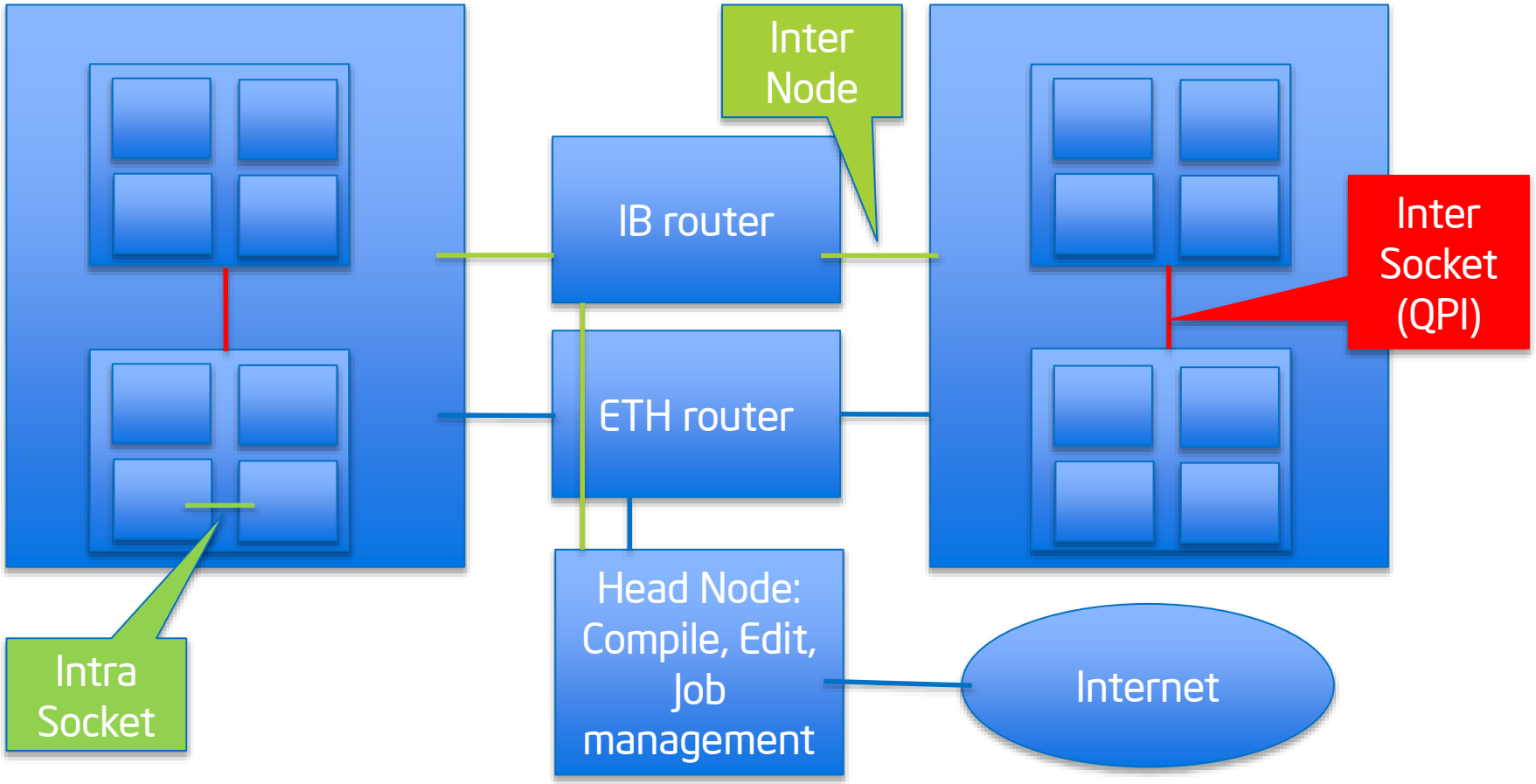
Intel



Challenges

Typical Structure of a Cluster



What Levels of Parallelism do exist?

- ILP - Instruction Level Parallelism
  - Pipelined Execution
  - Super-scalar execution
- DLP - Data Level Parallelism
  - SIMD (Single Instruction Multiple Data) vector processing
  - Implemented via vector registers and instructions
- TLP - Thread-Level Parallelism
  - Hardware support for hyper-threading
  - Multi-core architecture
  - Cache-coherent multiple sockets
- CLP - Cluster Level Parallelism
  - Multiple platforms connected via interconnection network
  - No hardware-supported cache coherence

Hybrid Computing

Combination of MPI programming model with threading model

=> Overcome limitations by adding threads

Memory gains in hybrid code

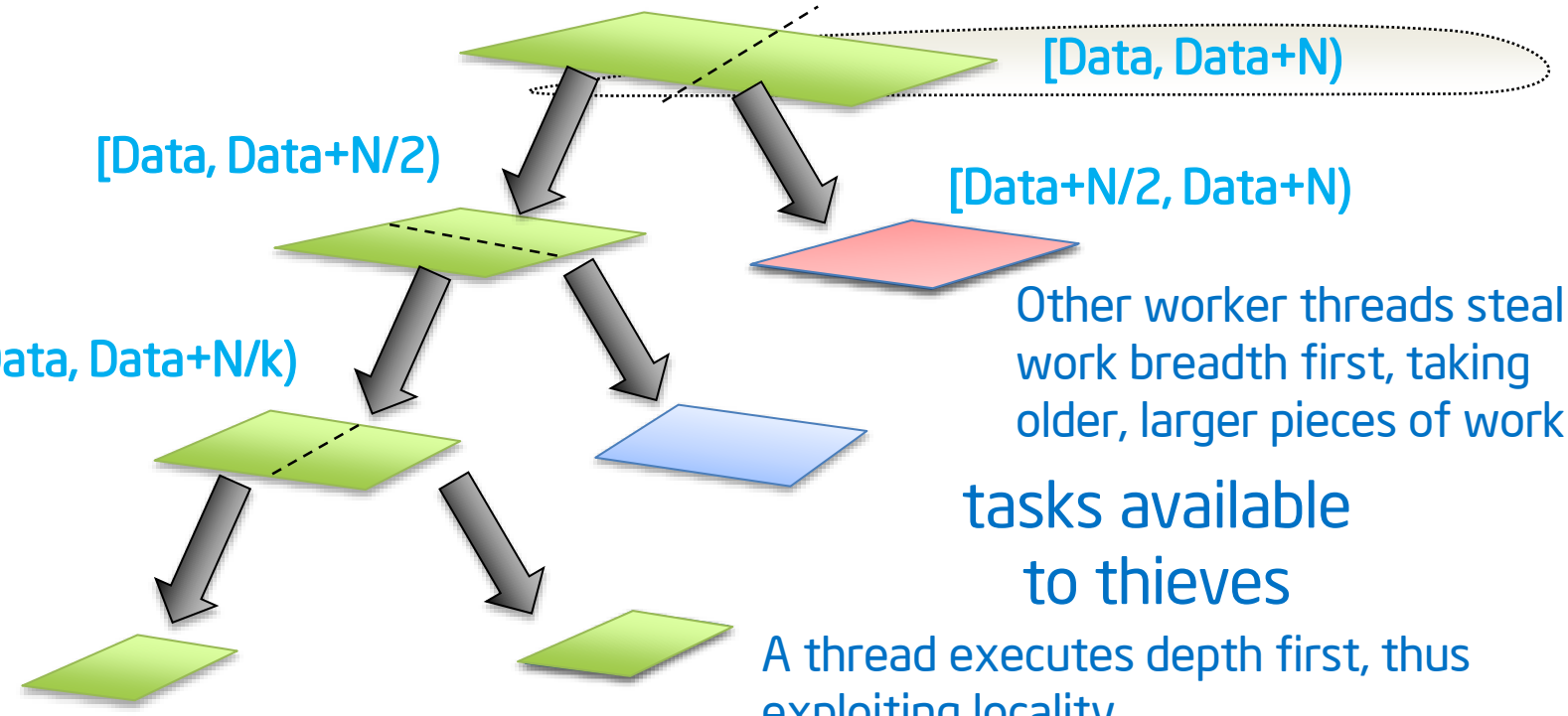
- Lower number of processes on the system
- Lower number of MPI – endpoints

Less MPI communication / more thread communication

Threading offers smart load balancing strategies

Result - maximize performance by better exploitation of available resources

Smart load balancing using Threads
Example: Intel® Threading Building Blocks (TBB) – Recursive Parallelism



Other worker threads steal work breadth first, taking older, larger pieces of work

tasks available to thieves

A thread executes depth first, thus exploiting locality

=> TBB is a tasking model - user deals with tasks rather than threads

What Threading Support does exist for MPI?

MPI_THREAD_SINGLE

Only one thread

MPI_THREAD_FUNNELED

Only the main thread executes MPI calls

MPI_THREAD_SERIALIZED

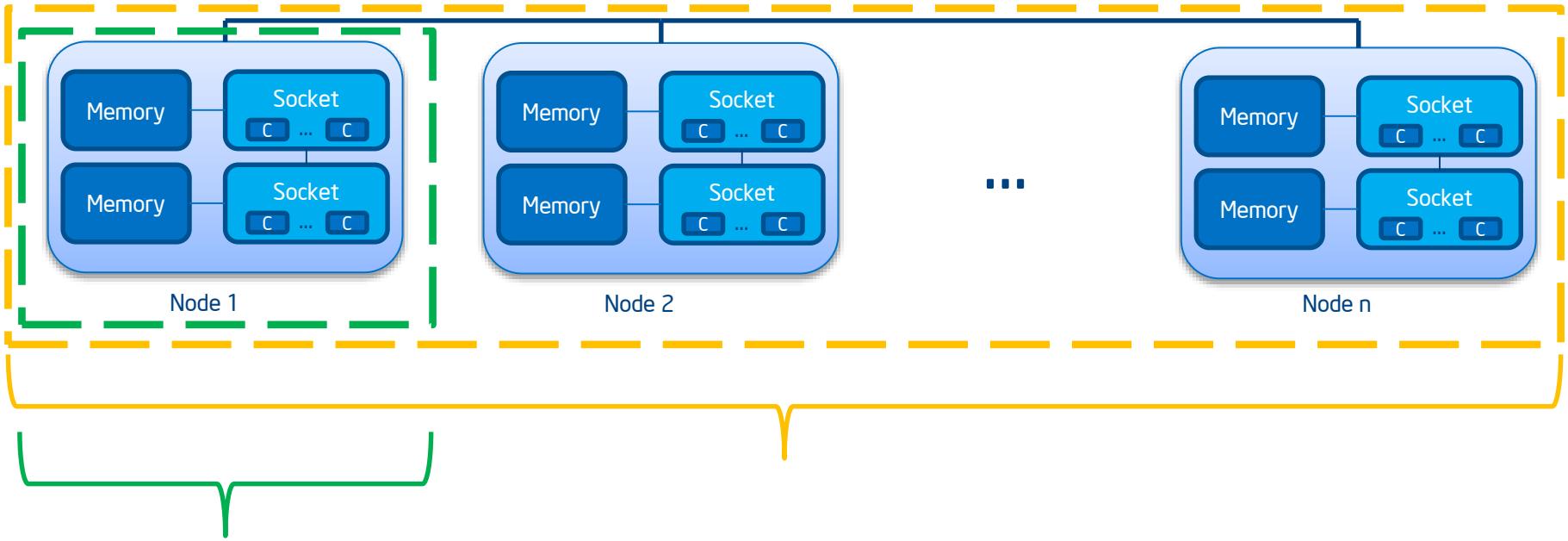
Threads exchange messages, only one at a time

MPI_THREAD_MULTIPLE

Threads exchange messages with other threads

Analyzing the Scalability of Your Code

Local- vs. Global Analysis



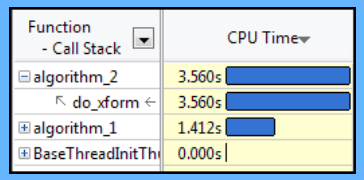
Intel® VTune™ Amplifier XE

Intel® Trace Analyzer & Collector (ITAC)
Intel MPI Performance Snapshot

Intel® VTune™ Amplifier XE
Performance Profiler

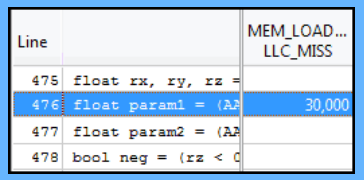
Where is my application...

Spending Time?



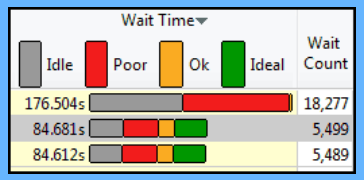
- Focus tuning on functions taking time
- See call stacks
- See time on source

Wasting Time?



- See cache misses on your source
- See functions sorted by # of cache misses

Waiting Too Long?



- See locks by wait time
- Red/Green for CPU utilization during wait

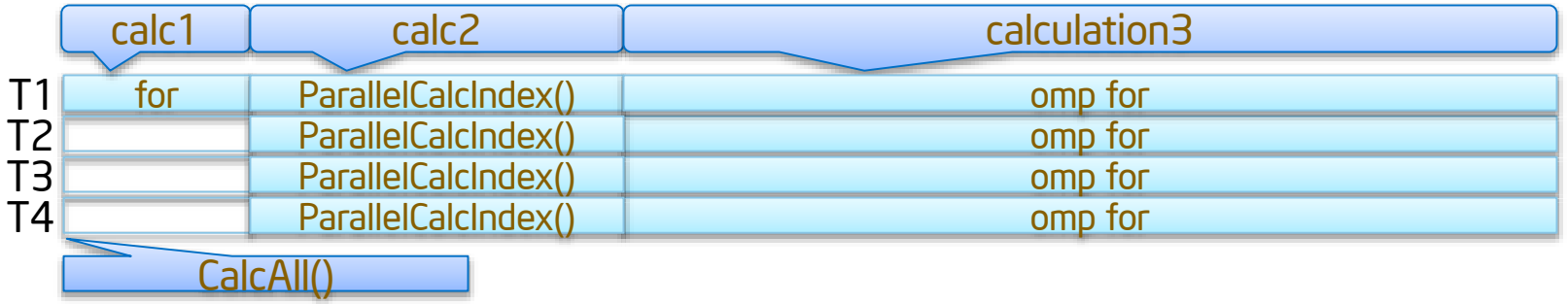
- Windows & Linux
- Low overhead
- No special recompiles

Continuously Improving Support for OpenMP

Vtune Amplifier is aware of all calls to Intel OpenMP run time which allows a detailed analysis of where the time is spend

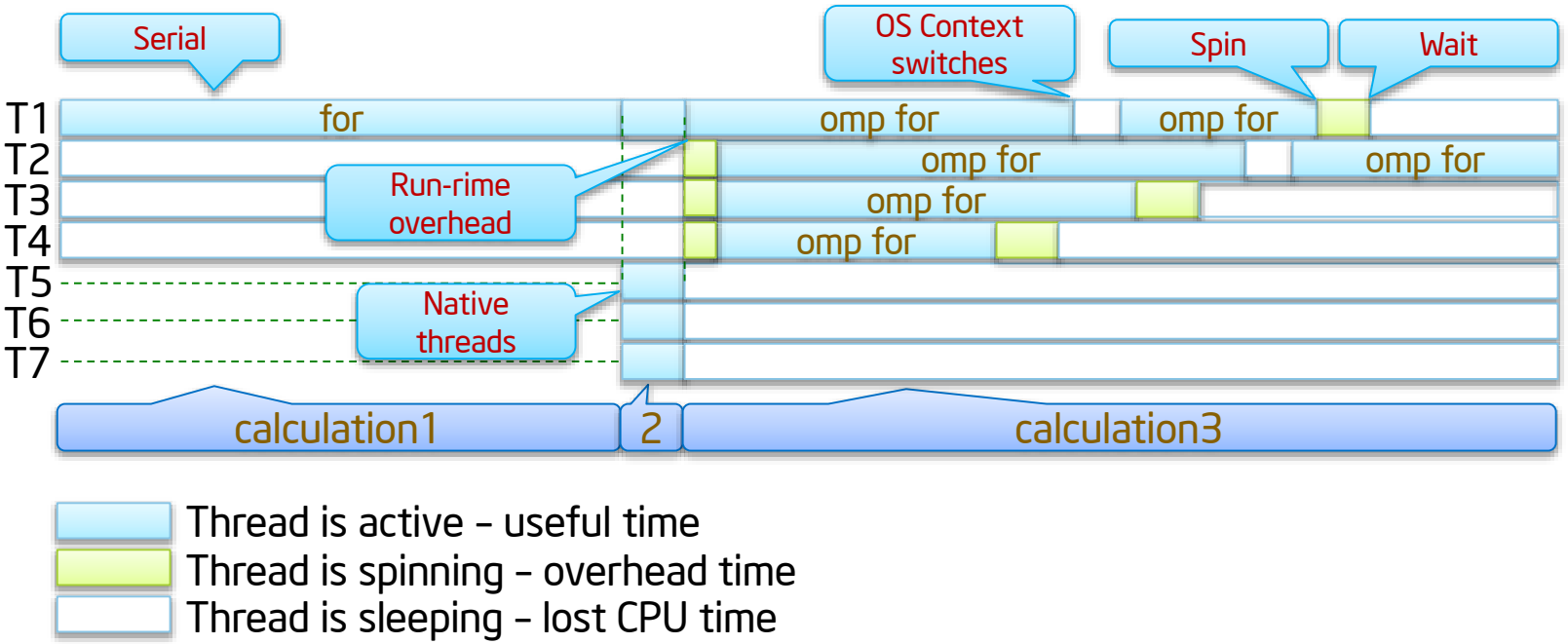
```
void CalcAll(double* p, int N)
{
  for(int i=0;i<N;i++) {…}   // calc 1
  ParallelCalcIndex(i, N);   // calc 2
  #pragma omp for
    for(i=0;  i<N; i++)      // calc 3
      {…}}
```

This is how you might believe the parallel application is working



VTune catches all OpenMP Threading Events

This is how the application might be working in reality



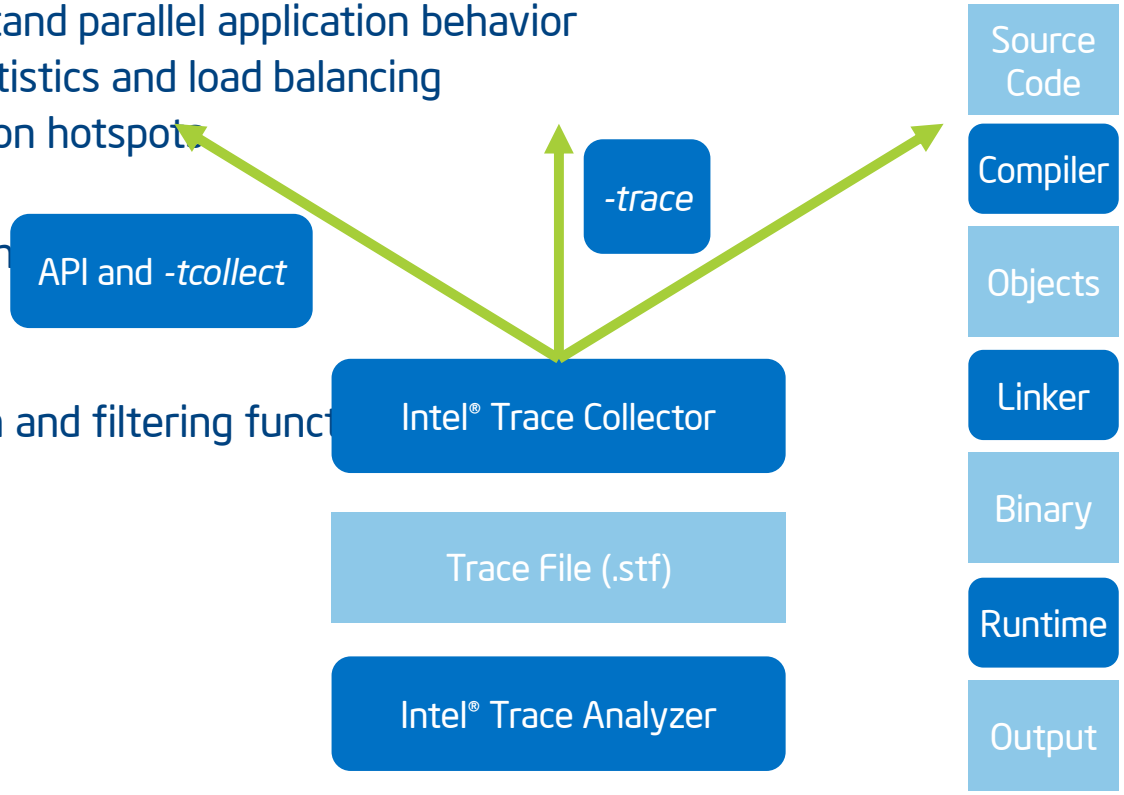
Intel® Trace Analyzer and Collector

Intel® Trace Analyzer and Collector (ITAC) helps to:

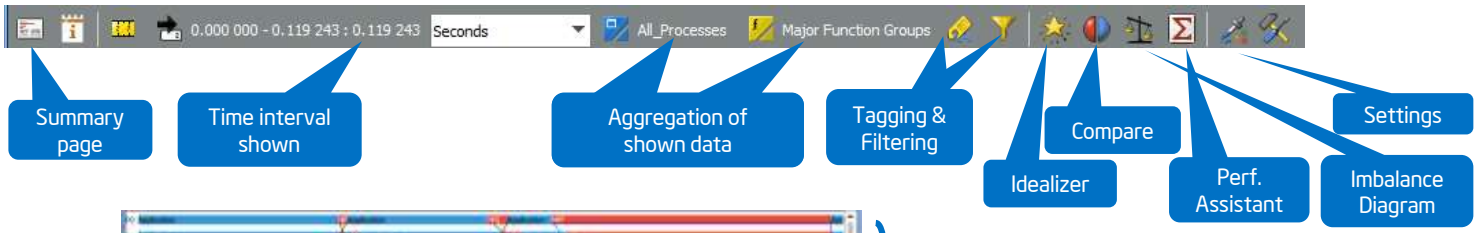
- Visualize and understand parallel application behavior
- Evaluate profiling statistics and load balancing
- Identify communication hotspots

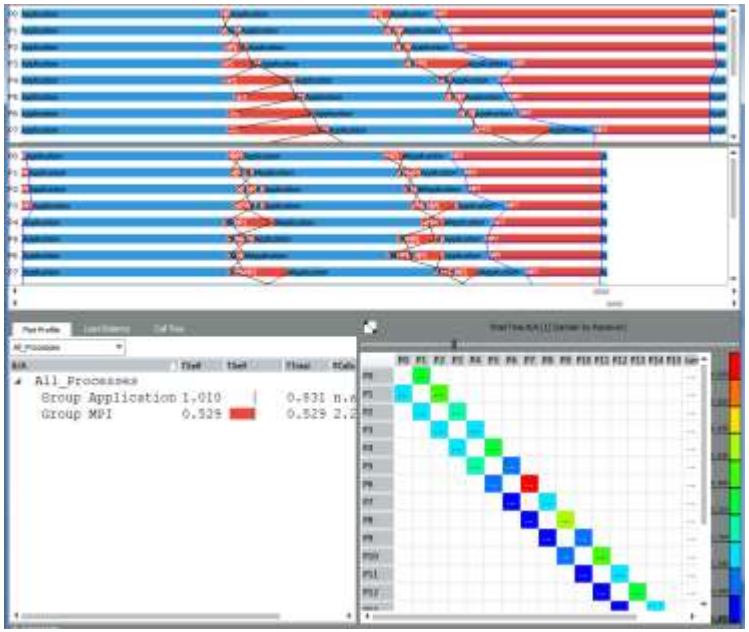
Features

- Event-based approach
- Low overhead
- Effective scalability
- Powerful aggregation and filtering funct
- Idealizer



Intel® Trace Analyzer and Collector





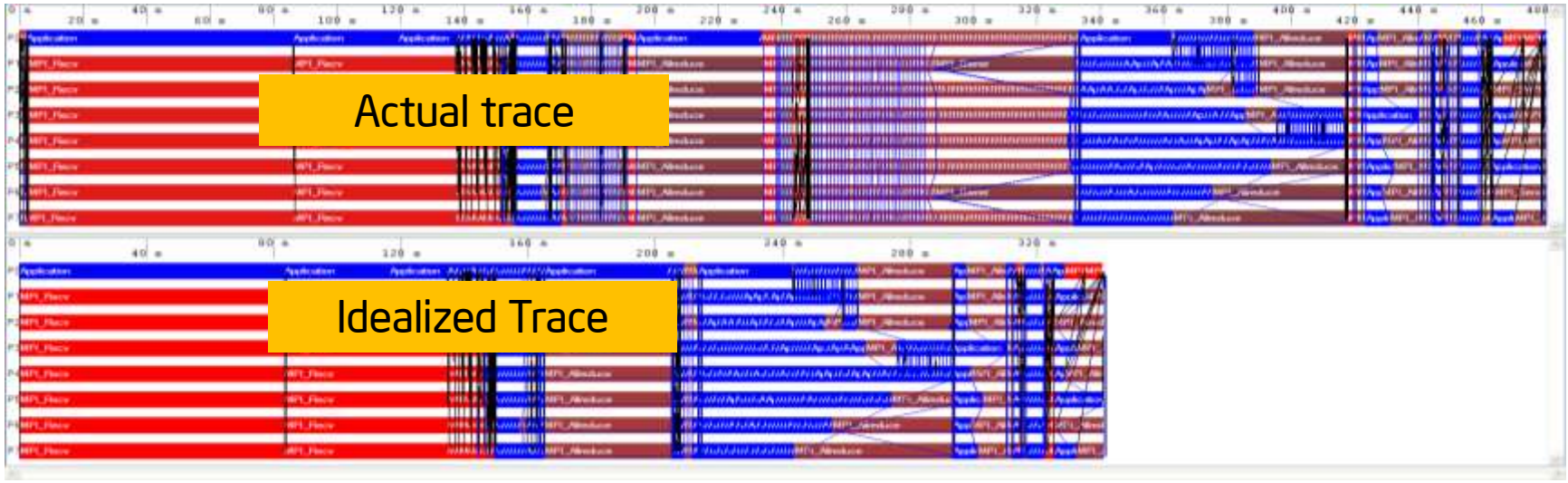
Compare the event timelines of two communication profiles

Blue = computation
Red = communication

Chart showing how the MPI processes interact

ITAC - Ideal Interconnect Simulator (Idealizer)

Is your code ready to scale?



Easy way to identify application bottlenecks

MPI Performance Snapshot (MPS)

Delivered with Intel® Trace Analyzer & Collector (ITAC)

- Intel has separated statistical analysis from ITAC event analysis
- The capability is available now via command line

New developer capability

- MPS enables the developer to quickly gather and analyze statistics on up to 32,768 ranks
- Shows data from HW counters and MPI/OpenMP imbalances
- Enables ITAC trace file targeting for deeper event based analysis.

Why MPI Performance Snapshot?

Advantage

- Get an initial profile of the application very quickly
- Performance variation at scale can be detected sooner
- Provides development recommendations to developers based on analysis
- Easy to use functionality for out of the box use

Benefits

- Difficult performance issues are easier to spot
- Application performance is improved faster
- Experienced & non-experienced developers can adopt quickly

MPI Performance Snapshot
Adding High Level Analysis

	Intel® Trace Analyzer & Collector Core Released Functionality (for Detailed Analysis)		MPI Performance Snapshot (MPS) Functionality (Beta) (for High Level Analysis)
Scalability	0 – 4K ranks		1 – 32K ranks (tested)
Trace details	High (events, source hooks)		Low (aggregation)
Trace size	Huge (~17 GB for 1K ranks)		Much less (~0,8 GB for 1K ranks; ~4.5Gb for 32K)
Event-based analysis	Yes	+	Set of HW events
Statistics analysis	Yes		Yes
Quick processing	No		Yes
Small & flexible	No		Yes
Collector	Intel® Trace Collector		Built-in & separate: IMPI Statistics + MPI/OMP imbalance

MPS Functionality Added to Intel Trace Analyzer & Collector

MPI Performance Snapshot[1]

High Capacity MPI Profiler

Lightweight Scalable analysis of MPI applications:

- Computations/communications ratio
- Compute imbalance
- Times for used MPI routines
- Message sizes distribution

```
$ source
<IMPI_installdir>/intel64/bin/mpiv
ars.sh

$ source
<ITAC_installdir>/bin/mpi_perf_sna
pshot_vars.sh


$ mpirun -mps -n 2 ./myApp

…

======== GENERAL STATISTICS
========

WallClock: 21.077 sec (All
processes)

MIN: 10.538 sec (rank 1)

MAX: 10.539 sec (rank 0)
```

[1] Available as preview in Intel® Parallel Studio XE 2015 Cluster Edition Update 1 for Linux OS

Easy to use.

MPI Performance Snapshot

High Capacity MPI Profiler – Low overhead

```
$ source
<ITAC_installdir>/bin/mpi_perf_snapshot_vars.sh
```

```
$ export
I_MPI_JOB_RESPECT_PROCESS_PLACEMENT=disable
I_MPI_PIN_DOMAIN=socket OMP_NUM_THREADS=14
MKL_NUM_THREADS=14
```

Without MPS

```
$ time ( mpirun -n 4 -ppn 2
./xhpl_hybrid_intel64_dynamic )

…

real     4m51.676s

user     98m52.230s

sys      0m36.415s
```

With MPS

```
$ time ( mpirun -mps -n 4 -ppn 2
./xhpl_hybrid_intel64_dynamic )

…

real     4m53.572s

user     99m14.129s

sys      0m35.119s
```

Intel® MPI Performance Snapshot

High Capacity MPI Profiler - Memory & Counter Usage

New collector displays summary info immediately after end of application run. Detailed per process info can be found in output text file.

HW counters & memory usage info:

```
==================== GENERAL STATISTICS ====================
WallClock:          284.274 sec   (All processes)
      MIN:           31.998 sec   (rank 0)
      MAX:           35.534 sec   (rank 7)

================== HW COUNTERS STATISTICS ==================
GFlops:    9.563   MPI:  11.28%    NON_MPI:  88.72%

Floating-Point instructions:  45.77%
Vectorized  DP instructions:  24.69%
Memory  access instructions:  42.35%

================= MEMORY USAGE STATISTICS =================
All  processes:    256.740MB
           MIN:     30.608MB  (process      7)
           MAX:     33.136MB  (process      1)
```

Intel® MPI Performance Snapshot

High Capacity MPI Profiler - MPI & OpenMP Imbalance Analysis

```
================= MPI IMBALANCE STATISTICS =================
MPI Imbalance:          207.847 sec            73,12% (All processes)
          MIN:           23.044 sec            64,85% (rank  6)
          MAX:           30.113 sec            88,57% (rank  1)

==================== OpenMP STATISTICS ====================
OpenMP Regions:         228.631 sec           80,43%           56 region(s) (All processes)
           MIN:          25.348 sec           71,33%            7 region(s) (rank 7)
           MAX:          33.124 sec           97,42%            7 region(s) (rank 1)

OpenMP Imbalance:         103.924 sec            36,56%  (All processes)
             MIN:          11.522 sec            32,43%  (rank 3)
             MAX:          15.057 sec            44,29%  (rank 2)
```

MPI Performance Snapshot
High Capacity MPI Profiler - Diagrams

Further analysis:

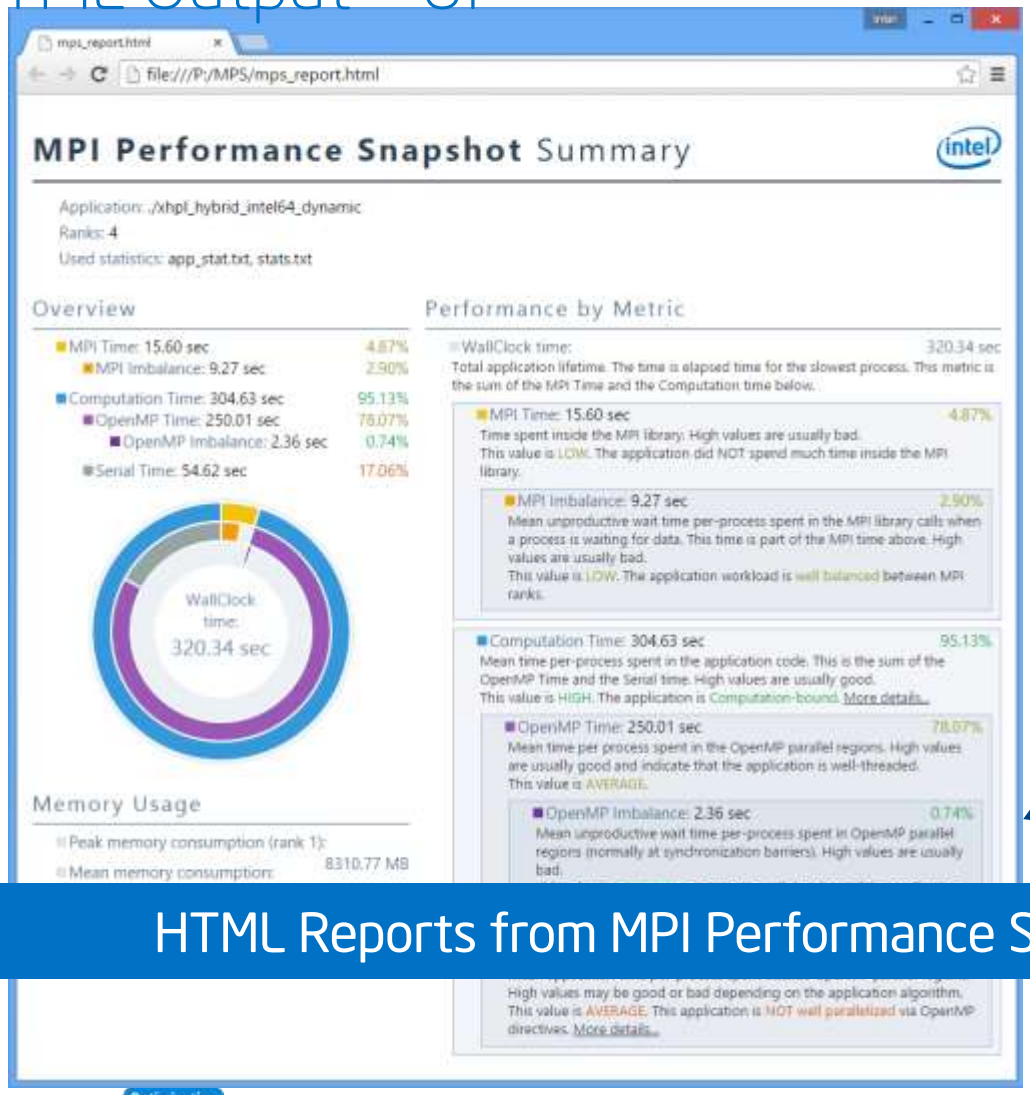
- Summary Information
  the essential information for novice users with further suggestions and guidance
- Counters and Memory usage
  general information about the application: execution time, memory and hardware resources usage
- Function summary
  the amount transferred data for each MPI function (for all ranks), and the time spent in each function
- MPI Time per Rank
  the time each rank spent in MPI functions
- Collective Operations Time
  the time each rank spent in MPI collective functions
- Message Sizes summary
  the amount of data transferred, and the number of MPI function calls for each message size used
- Data Transfers
  the transferred data volume for rank-to-rank, all ranks, MPI routines

MPI Performance Snapshot

High Capacity MPI Profiler – Diagram example

```
$ mpi_perf_snapshot -f ./stats.txt ./app_stat.txt
| Function summary for all ranks
|-------------------------------------------------------------------------------------------------------
|           Function        Time(sec)          Time(%)       Volume(MB)         Volume(%)             Calls
|-------------------------------------------------------------------------------------------------------
|               Send          25.1177           44.018          39443.6                50            130069
|              Probe          13.8178           24.2154                0                 0          12182371
|               Recv           10.337           18.1153          39443.6                50            130069
|               Wait          7.12479            12.486                0                 0            128997
|               Init          0.66177           1.15973                0                 0                 4
|             Gather       0.00261283        0.00457891      0.000366211       4.64221e-07                 4
| [skipped 2 lines]
|=======================================================================================================
| TOTAL                       57.0623               100          78887.2               100          12571530
```

HTML Output – UI



Application Analysis to Guide Development Efforts

HTML Reports from MPI Performance Snapshot

Optimization Notice

Tuning Your Code

Code- Modernization and Tuning

How to tune your code

- Algorithmic improvements
  - load balancing
  - Re- structuring of the workflow / memory
  - Alternative algorithms
- Use of non- blocking communication
- MPI 3 features
  - NBC
  - One-sided communication
  - Shared Memory
- OpenMP 4 Features
  - Threading
  - Vectorization

Tuning the MPI Library

… automatically …

MPI Tuning Motivation

"The **optimal algorithm** and the **optimal buffer** size for a given **message size** depends on a given configuration of the system including the gap values of the networks, memory models, the underlying communication layer etc. The **optimal parameters** for a system **can be best determined by conducting experiments on the system**."

[Automatically Tuned Collective Communications –

Sathish S. Vadhiyar, Graham E. Fagg, Jack Dongarra –

Computer Science Department - University of Tennessee, Knoxville]

Why automatic tuning?

- Intel® MPI library comes with wide area of configuration options - Environment variables all over
  - different algorithms for collective operations
  - different fabrics supported
  - different thresholds for library behavior (rendezvous, cache bypassing, ...)
  - different buffer sizes
  - ...
- Tuning the library itself – not the user application
- Library however, has already very good out-of-box settings ...
- MPITune is a tool that allows to explore the search space automatically

Tuning the MPI Library

… manually …

Prerequisite –
Make sure your cluster is properly configured

- Install the latest Intel® MPI Library
- Have the documentation at hand
- When benchmarking try to run on the same subset of nodes
- Understand the performance characteristics of your cluster
  - What is the lowest achievable latency
  - What is the maximum achievable bandwidth
  - What fabrics are available, how do they perform
  - Communication speeds differ
    - Intra-socket / Inter-socket
    - Intra-node / Inter-node
  - Use IMB to determine performances

Use best available communication fabric

Supported I_MPI_FABRICS	Description
shm	Shared-memory only; intra-node default
tcp	TCP/IP-capable network fabrics, such as Ethernet and InfiniBand* (through IPoIB*)
dapl	DAPL–capable network fabrics, such as InfiniBand*, iWarp*, and XPMEM* (through DAPL*)
ofa	OFA-capable network fabric including InfiniBand* (through OFED* verbs)
tmi	TMI-capable network fabrics including Intel IB, Myrinet* (through Tag Matching Interface)

- Intel MPI will select fastest available fabric by default (shared memory within a node and InfiniBand* across nodes – shm:dapl)
- Disable fallback to ensure fabric usage

Use connectionless communication

The connectionless feature works for the ‘dapl’ and ‘tmi’ fabrics only

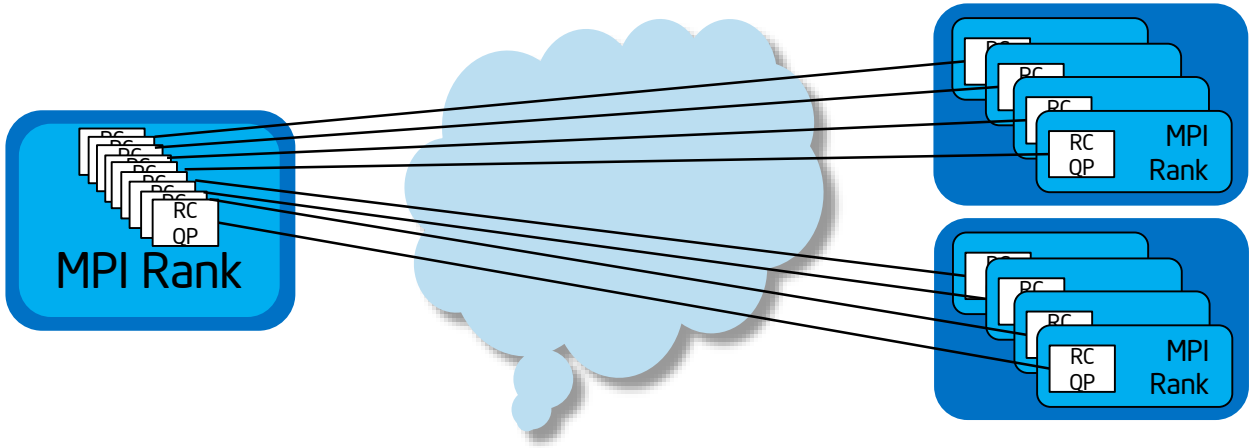
- Provides better scalability
- Significantly reduces memory requirements by reducing the number of receive queues
- Generally use for large jobs

```
$ export I_MPI_FABRICS=shm:dapl
$ export I_MPI_DAPL_UD=enable
```

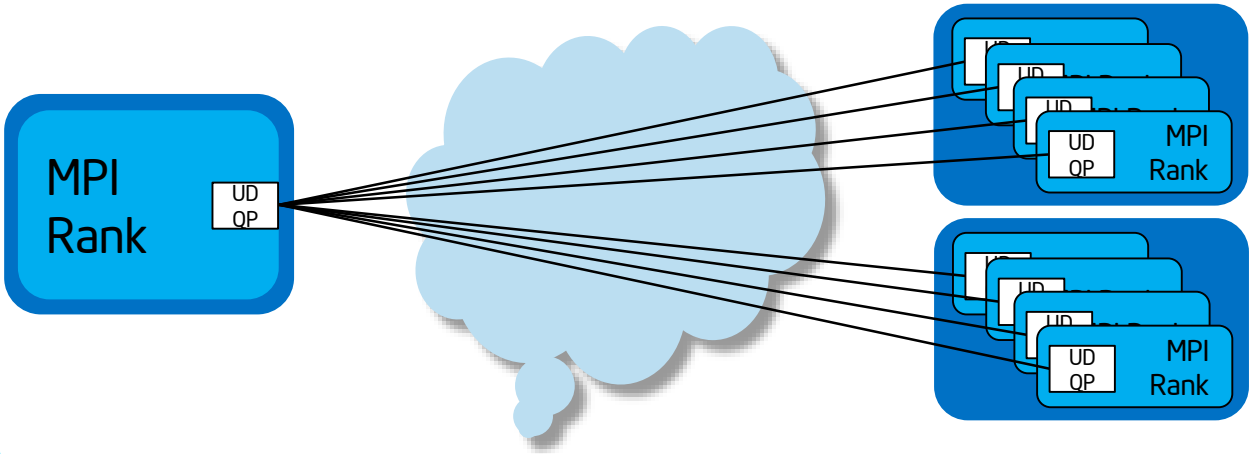
Use connectionless communication – Reliable Connection (RC) vs. User Datagram (UD)

(QP – Queue Pair)

RC



UD

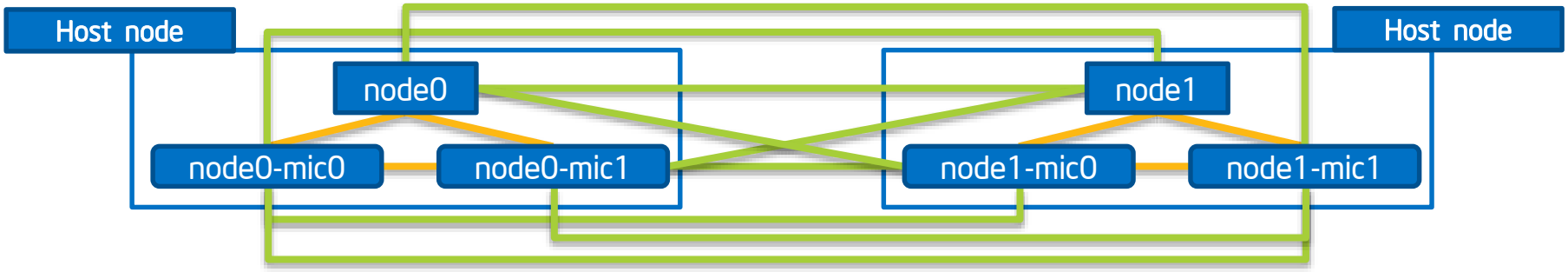


Optimization Notice

Use Multiple DAPL* Providers for Xeon Phi™

Multiple providers can be used based on message parameters

- I_MPI_DAPL_PROVIDER_LIST=<Prov1>,<Prov2>,<Prov3>
- Recommend using defaults for automatic selection
- All small messages use Prov1
- Large messages use Prov2 or Prov3
  - Prov2 if within same host node
  - Prov3 if not



Choose the best collective algorithm

- Use one of the I_MPI_ADJUST_<opname> knobs to change the algorithm
- Recommendations:
  - Focus on the most critical collective operations (see stats output)
  - Run the Intel MPI Benchmarks by selecting various algorithms to find out the right protocol switchover points for hot collective operations
  - … or … use mpitune

```
$ mpirun -genv I_MPI_ADJUST_REDUCE <algorithm #> …
```

Select proper process layout

- Default process layout is that all physical cores will be used
- If running hybrid applications, might want to reduce the number of ranks/node
- Set I_MPI_PERHOST or use the -perhost (/-ppn) option to override the default process layout:

```
$ mpirun –ppn <#processes per node> -n <#processes> …
```

- Same can be achieved using a “machinefile”
- On batch scheduler environments, the Intel MPI library respects the scheduler settings
- To overwrite the batch scheduler settings (at your own risk ☺):

```
$ export I_MPI_JOB_RESPECT_PROCESS_PLACEMENT=0
```

Use proper hybrid process pinning

- Link with thread safe library (**-openmp** / **-mt_mpi**)
- Choose MPI threading model (SINGLE / **FUNNELED** / SERIALIZED / MULTIPLE) – either using MPI_Init_thread(...) or env. var. I_MPI_THREAD_LEVEL_DEFAULT

```
$ export I_MPI_THREAD_LEVEL_DEFAULT=SINGLE
```

- Choose distribution of MPI ranks & threads – (ranks x threads = cores)

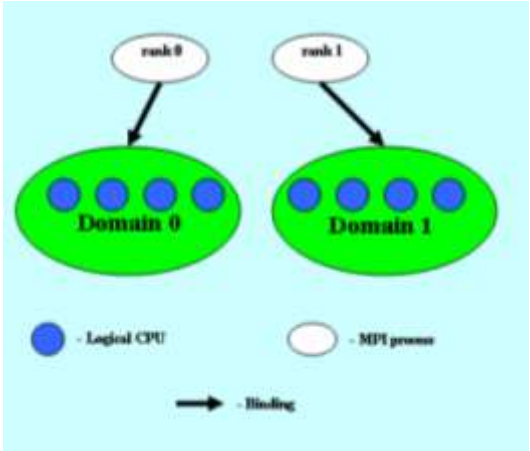
```
$ mpirun –n <#ranks> -genv OMP_NUM_THREADS <#threads>
```

- Pin MPI ranks using I_MPI_PIN_DOMAIN (e.g. „omp“ according to #OpenMP t.):

```
$ export I_MPI_PIN_DOMAIN=omp
```

- Pin threads e.g. KMP_AFFINITY

```
$ export KMP_AFFINITY=compact
```

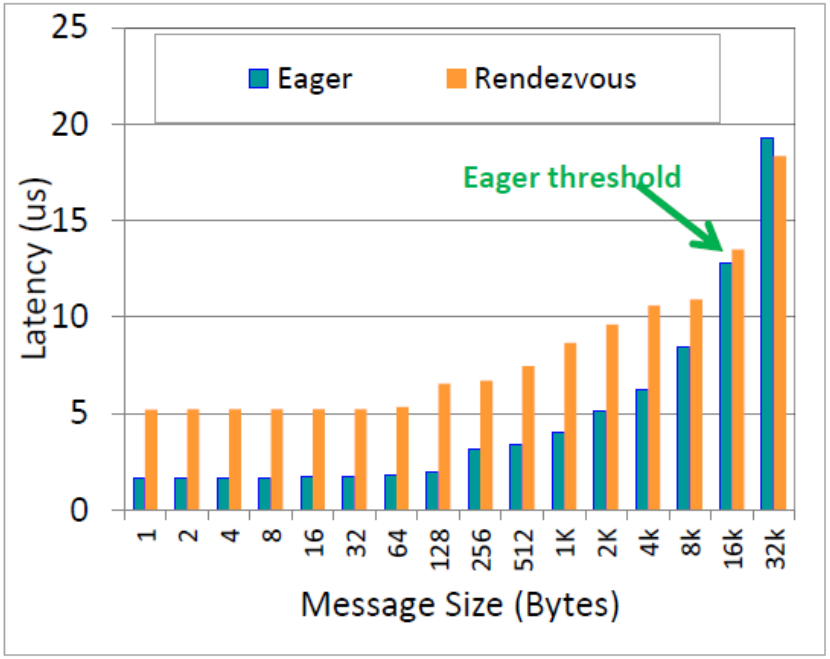


Adjust the eager / rendezvous protocol threshold

Two communication protocols:

"Eager" sends data immediately regardless of receive request availability and uses for short messages

"Rendezvous" notices receiving site on data pending and transfers when receive request is set



Eager vs Rendezvous

```
$ export I_MPI_EAGER_THRESHOLD=<#bytes>
```

Tuning for Memory Consumption

Reduce the amount of memory consumed by the DAPL- provider on large scale applications

Environment Variable	Default Value	Tuned Value
I_MPI_DAPL_UD_SEND_BUFFER_NUM	Runtime dependent	8208
I_MPI_DAPL_UD_RECV_BUFFER_NUM	Runtime dependent	8208
I_MPI_DAPL_UD_ACK_SEND_POOL_SIZE	256	8704
I_MPI_DAPL_UD_ACK_RECV_POOL_SIZE	Runtime dependent	8704
I_MPI_DAPL_UD_RNDV_EP_NUM	4	2

Intel MPI Library ships ready configurations

Located in **`$I_MPI_ROOT/intel64/etc`** you can find some configurations for common benchmarks

```
$ cat $I_MPI_ROOT/intel64/etc/hpl.conf
```

```
-genv I_MPI_EAGER_THRESHOLD 128000 # or 134000
-genv I_MPI_FALLBACK_DEVICE disable
-genv I_MPI_RDMA_RECV_QUEUE_SIZE 0
-genv OMP_NUM_THREADS 1
-genv I_MPI_FAIR_READ_SPIN_COUNT 10000
-genv RDMA_DEFAULT_MAX_WQE 500
-genv RDMA_READ_RESERVE 20
```

Summary

Summary

- Hybrid computing is key to reduce the memory footprint compared to pure MPI codes
- Analysis tools will help to know where to tune
- Code Modifications adopting newer standards can increase scalability
- … but … don't forget the low hanging fruits …
- Automatic MPI library tuning can help to find the optimal settings
- Manual MPI library tuning is still essential to some degree

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