Cross-Architecture Programming for Accelerated Compute; Freedom of Choice for Hardware

Intel® Software Development Tools for HPC: Programming for Distributed HPC Systems using Intel® MPI Library

HPC wire
2021 Readers' Choice Awards
Best HPC Programming Tool or Technology
oneAPI

All information provided in this deck is subject to change without notice.
Contact your Intel representative to obtain the latest Intel product specifications and roadmaps.

Intel® oneAPI Tools for HPC

Intel® oneAPI HPC Toolkit

Deliver Fast Applications that Scale

What is it?

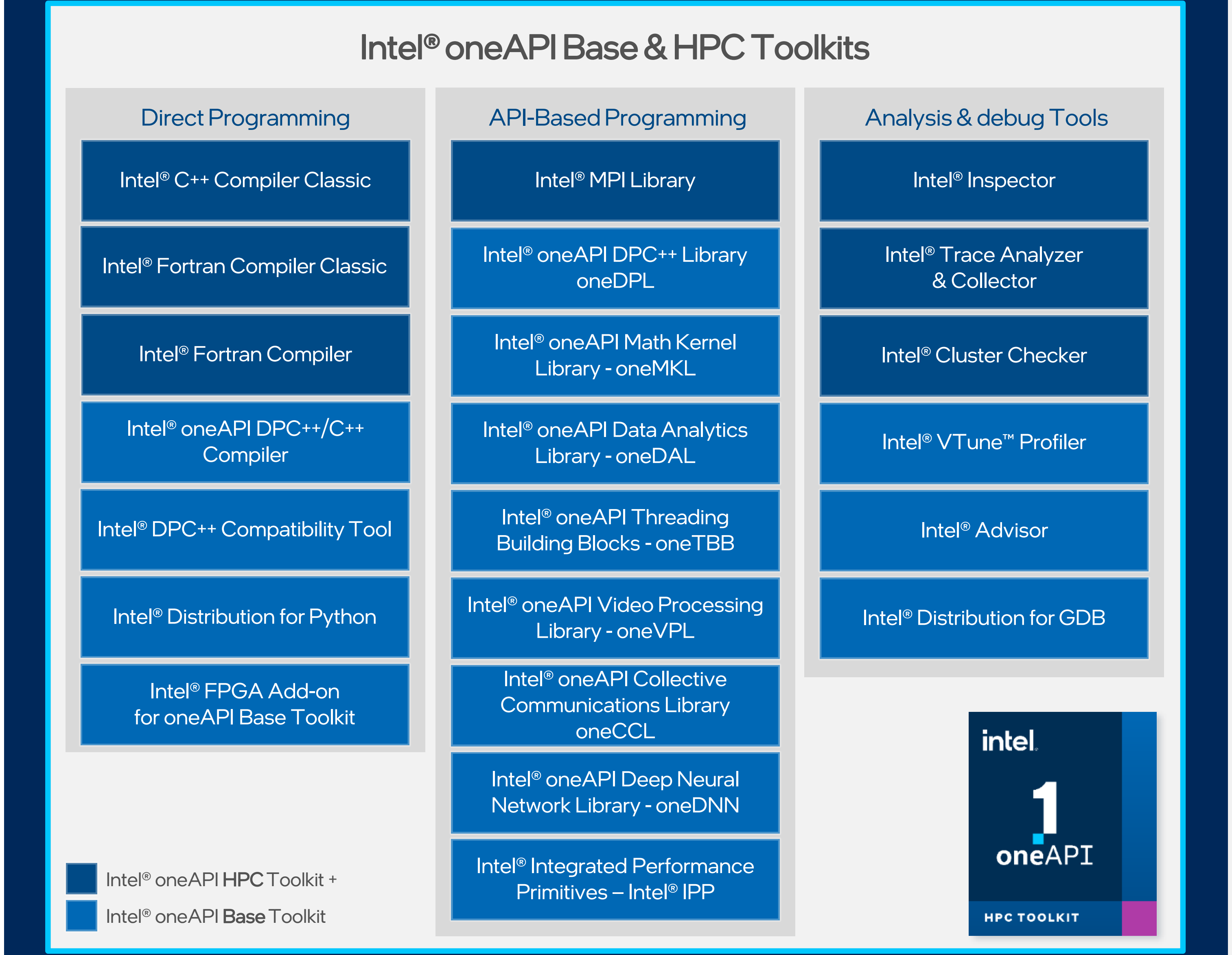
A toolkit that adds to the Intel® oneAPI Base Toolkit for building high-performance, scalable parallel code on C++, SYCL, Fortran, OpenMP & MPI from enterprise to cloud, and HPC to AI applications.

Who needs this product?

- OEMs/ISVs
- C++, Fortran, OpenMP, MPI Developers

Why is this important?

- Accelerate performance on Intel® Xeon® and Core™ Processors and Intel® Accelerators
- Deliver fast, scalable, reliable parallel code with less effort built on industry standards



Intel® oneAPI Base & HPC Toolkits

Direct Programming

- Intel® C++ Compiler Classic
- Intel® Fortran Compiler Classic
- Intel® Fortran Compiler
- Intel® oneAPI DPC++/C++ Compiler
- Intel® DPC++ Compatibility Tool
- Intel® Distribution for Python
- Intel® FPGA Add-on for oneAPI Base Toolkit

API-Based Programming

- Intel® MPI Library
- Intel® oneAPI DPC++ Library oneDPL
- Intel® oneAPI Math Kernel Library - oneMKL
- Intel® oneAPI Data Analytics Library - oneDAL
- Intel® oneAPI Threading Building Blocks - oneTBB
- Intel® oneAPI Video Processing Library - oneVPL
- Intel® oneAPI Collective Communications Library oneCCL
- Intel® oneAPI Deep Neural Network Library - oneDNN
- Intel® Integrated Performance Primitives – Intel® IPP

Analysis & debug Tools

- Intel® Inspector
- Intel® Trace Analyzer & Collector
- Intel® Cluster Checker
- Intel® VTune™ Profiler
- Intel® Advisor
- Intel® Distribution for GDB

■ Intel® oneAPI **HPC** Toolkit +

■ Intel® oneAPI **Base** Toolkit

Learn More: intel.com/oneAPI-HPCKit

Intel® MPI Library

Deliver Flexible, efficient, and Scalable Cluster Messaging

Standard Conformant

- MPI-1, MPI-2.2 and MPI-3.1. MPI-4 is WIP
- C, C++, Fortran 77, Fortran 90, and Fortran 2008 language bindings

Optimized MPI Application Performance

- Application-specific tuning
- Automatic tuning
- Support for latest Intel® Xeon® Scalable Processors

Lower Latency and Multi-vendor Interoperability

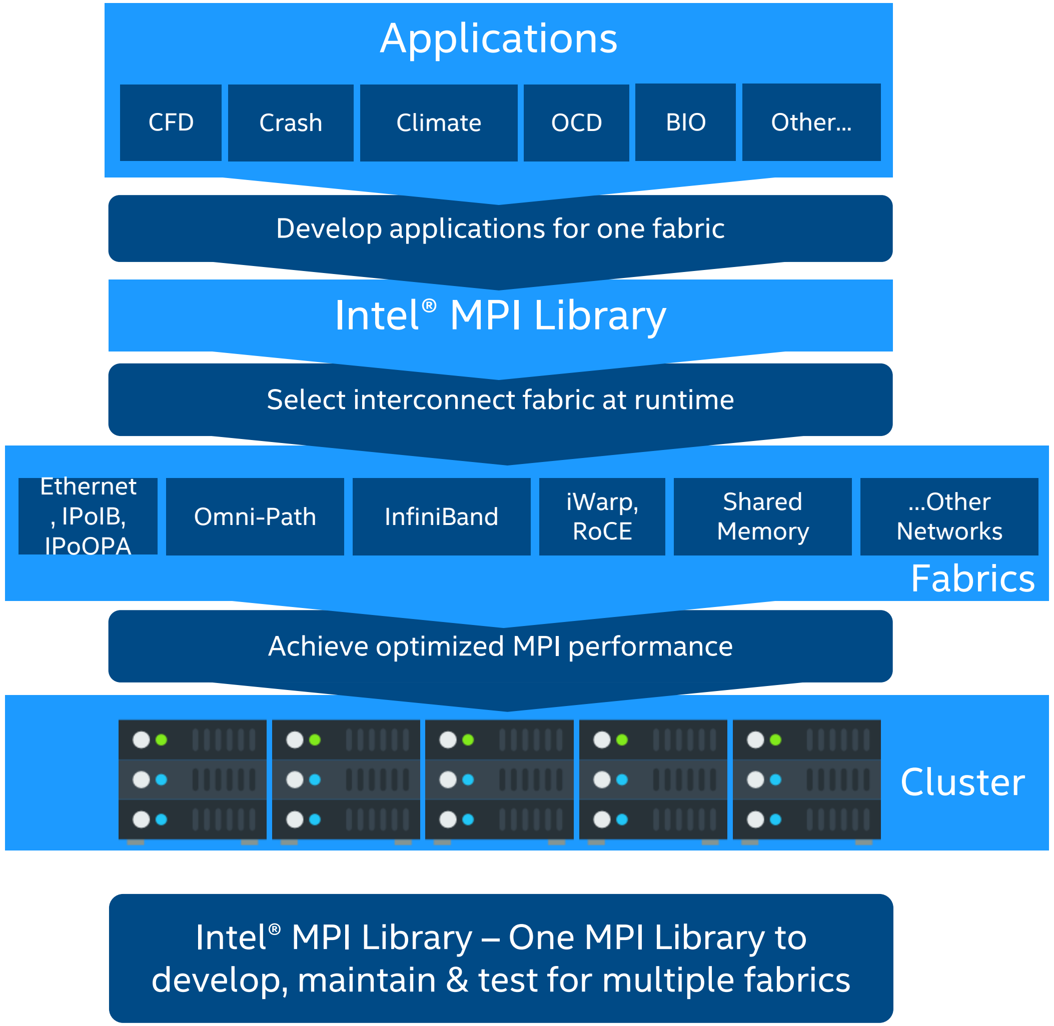
- Industry-leading latency
- Performance-optimized support for the fabric capabilities through OpenFabrics Interfaces (OFI)

Faster MPI Communication

- Optimized collectives

Sustainable scalability

- Native InfiniBand interface support allows for lower latencies, higher bandwidth, and reduced memory requirements


Applications
CFD
Crash
Climate
OCD
BIO
Other…
Develop applications for one fabric
Intel® MPI Library
Select interconnect fabric at runtime
Ethernet, IPoIB, IPoOPA
Omni-Path
InfiniBand
iWarp, RoCE
Shared Memory
…Other Networks
Fabrics
Achieve optimized MPI performance
Cluster
Intel® MPI Library – One MPI Library to develop, maintain & test for multiple fabrics

Intel® MPI Library version 2021 Key new features

HPC in cloud

- Google Cloud Platform* (GCP) and Amazon Web Services*(AWS) integrated support

Latest Hardware support

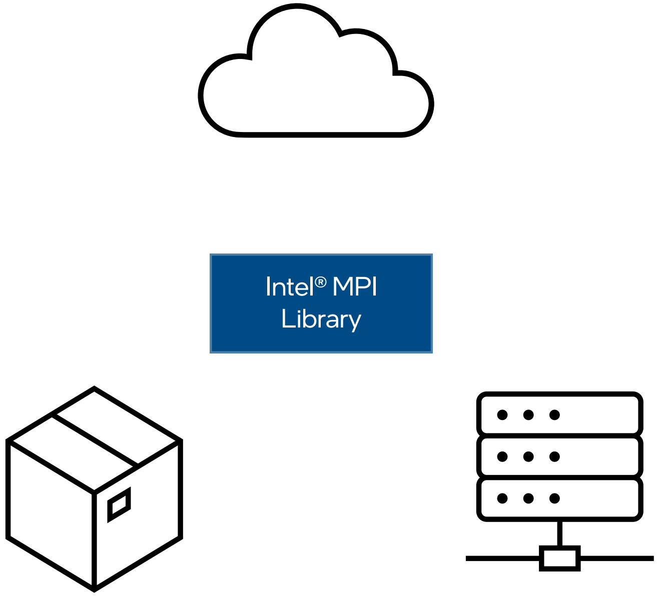
- Intel® Xeon® Scalable 3rd gen processors
- Performance on Intel® Ethernet 800 Series Network Adapters
- Mellanox* ConnectX*: 3/4/5/6 (FDR/EDR/HDR) support enhancements
- **Intel GPUs support**

Sustainable scalability

- Improved startup time
- Performance and stability improvements for OFI providers
- Spawn improvements

New technology

- Distributed Asynchronous Object Storage (DAOS) support
- Extended Singularity support for IBM* Spectrum* LSF*, SLURM

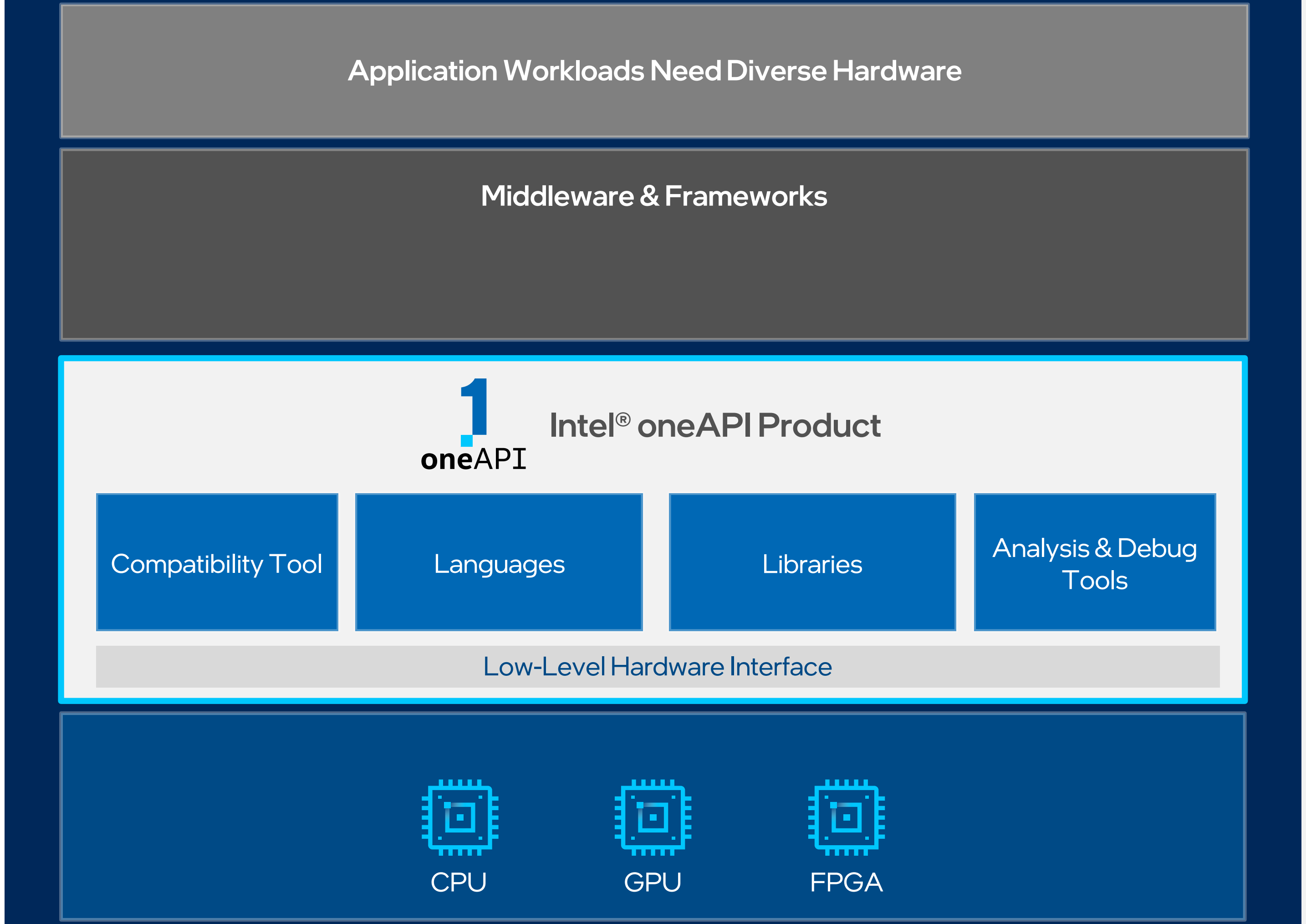


Intel® oneAPI Tools

Built on Intel's Rich Foundation of CPU Tools Expanded to Accelerators

A complete set of advanced compilers, libraries, and porting, analysis and debugger tools

- Accelerates compute by exploiting cutting-edge hardware features
- Interoperable with existing programming models and code bases (C++, Fortran, Python, OpenMP, etc.), developers can be confident that existing applications work seamlessly with oneAPI
- Eases transitions to new systems and accelerators—using a single code base frees developers to invest more time on innovation



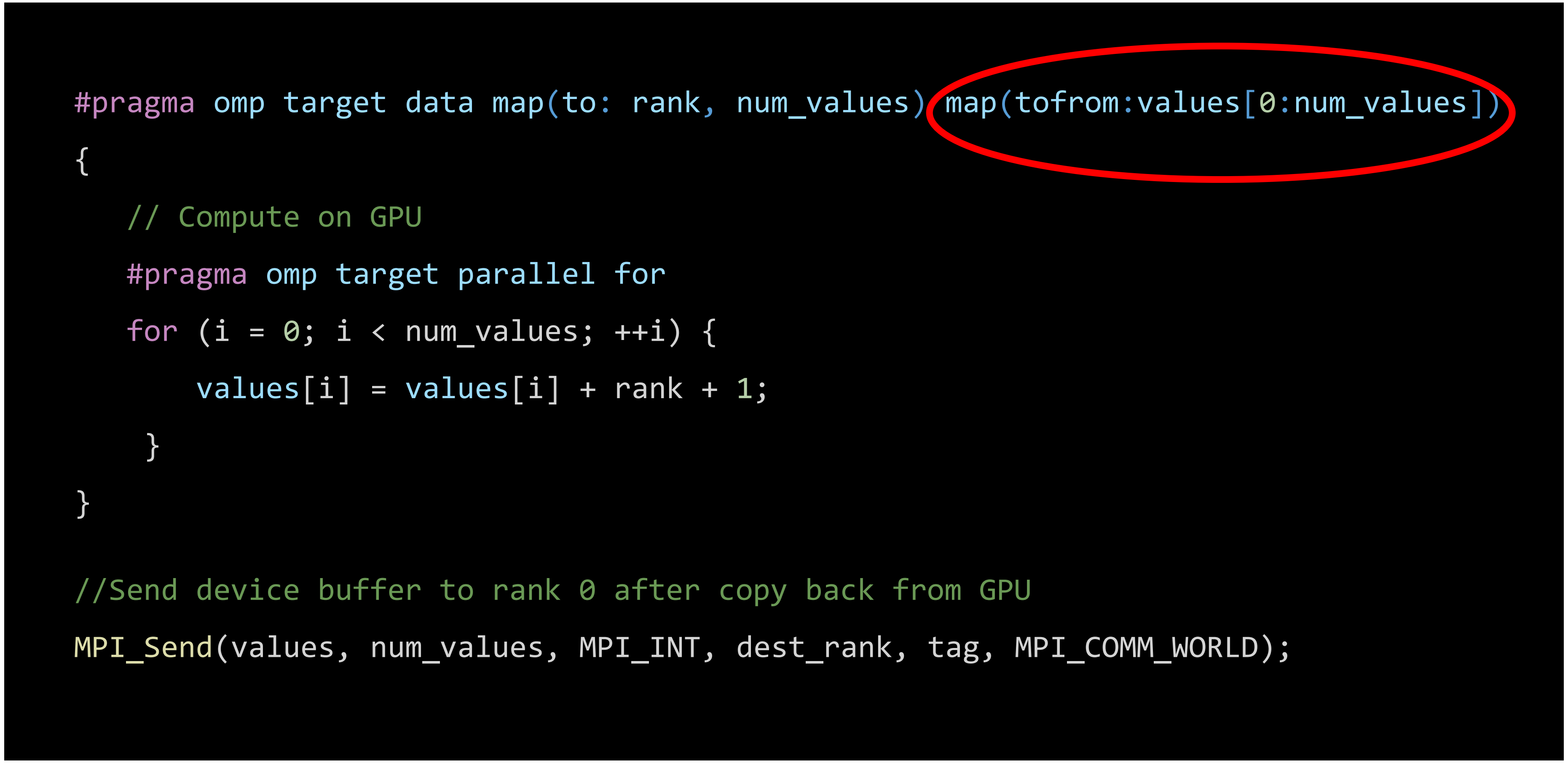
Available Now

Visit software.intel.com/oneapi for more details
Some capabilities may differ per architecture and custom-tuning will still be required. Other accelerators to be supported in the future.

Intel® MPI GPU Buffers Support

Execution models

Naïve (OpenMP 4.0): map(tofrom) clause

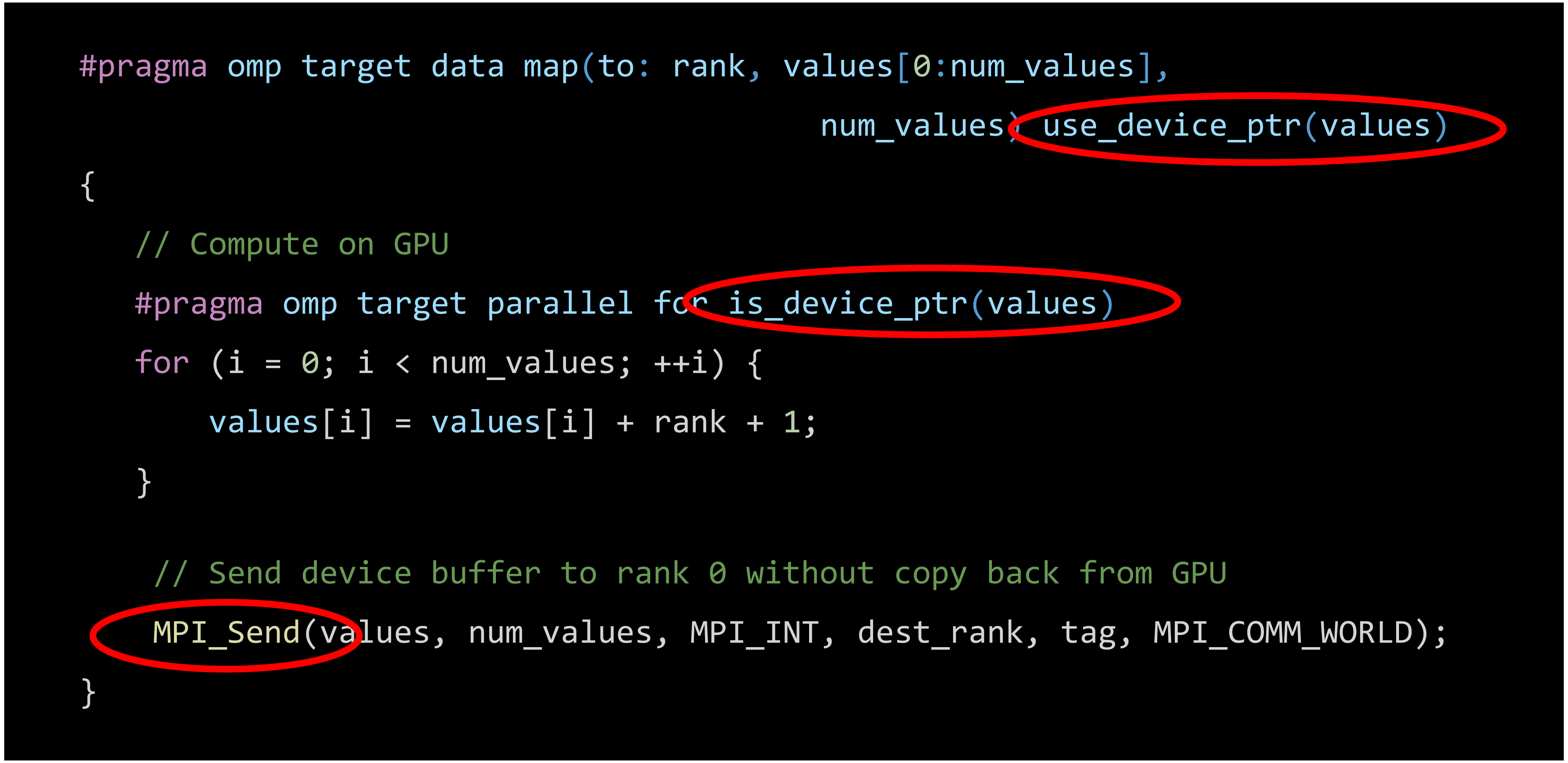


```
#pragma omp target data map(to: rank, num_values) map(tofrom:values[0:num_values])
{
   // Compute on GPU
   #pragma omp target parallel for
   for (i = 0; i < num_values; ++i) {
       values[i] = values[i] + rank + 1;
    }
}

//Send device buffer to rank 0 after copy back from GPU
MPI_Send(values, num_values, MPI_INT, dest_rank, tag, MPI_COMM_WORLD);
```

Execution models

GPU buffer aware (OpenMP 4.5): use_device_ptr



```
#pragma omp target data map(to: rank, values[0:num_values],
                                        num_values) use_device_ptr(values)
{
   // Compute on GPU
   #pragma omp target parallel for is_device_ptr(values)
   for (i = 0; i < num_values; ++i) {
       values[i] = values[i] + rank + 1;
   }

    // Send device buffer to rank 0 without copy back from GPU
    MPI_Send(values, num_values, MPI_INT, dest_rank, tag, MPI_COMM_WORLD);
}
```

Compilation

- use **-fc=ifx** or **-cc=icx**, invokes LLVM compilers

- ifx/icc options:

  - use **-fiopenmp** instead of –qopenmp

  - **-fopenmp-targets=spir64** enables the offloading

Compilation

- Build

```
mpiicc -cc=icx -fiopenmp -fopenmp-targets=spir64 test.c -o test
```

  - or

```
mpiifort -fc=ifx -fiopenmp -fopenmp-targets=spir64 test.f90 -o test
```

- Execute

```
I_MPI_OFFLOAD=2 mpirun -n 2 ./test
```

I_MPI_OFFLOAD_* Variables Family

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG

Description

Enables handling of device buffers in MPI functions.

Syntax

I_MPI_OFFLOAD=<int>

Arguments

- 0: disabled [default]
- 1: auto
- 2: enabled, loads Level_Zero library

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG

Description

Specifies the base unit.

Syntax

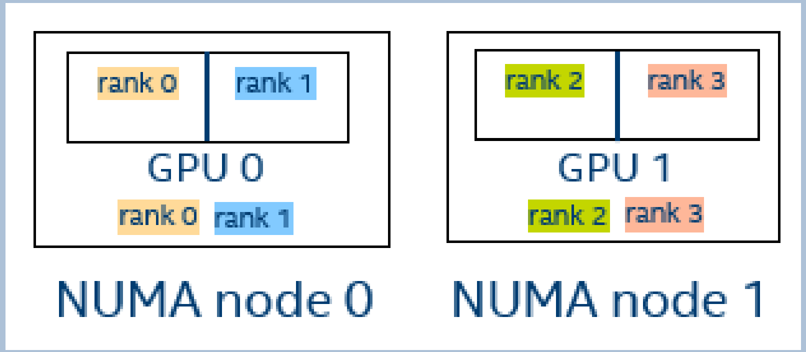
```
I_MPI_OFFLOAD_CELL=<cell>
```

Arguments

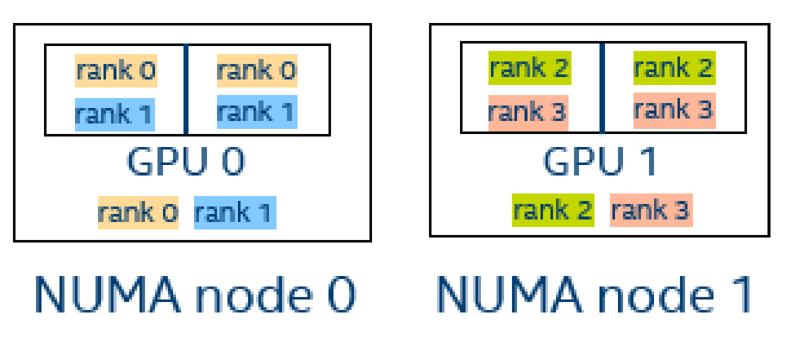
- tile: one tile/subdevice [default]
- device: whole device (GPU) with all subdevices

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG



4 MPI ranks, I_MPI_OFFLOAD_CELL=tile



4 MPI ranks, I_MPI_OFFLOAD_CELL=device

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG

Description

Defines number of base unit per MPI rank.

Syntax

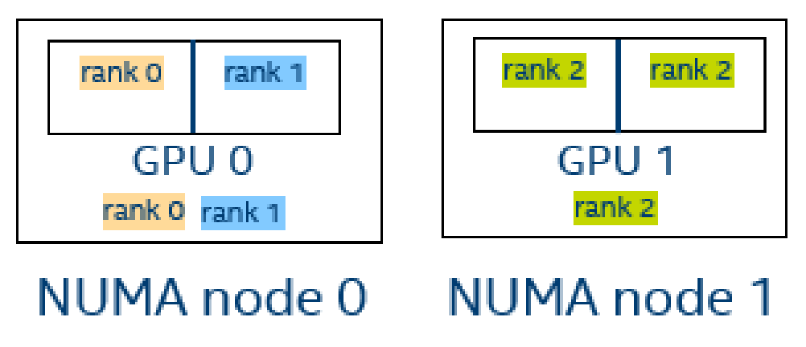
```
I_MPI_OFFLOAD_DOMAIN_SIZE=<int>
```

Arguments

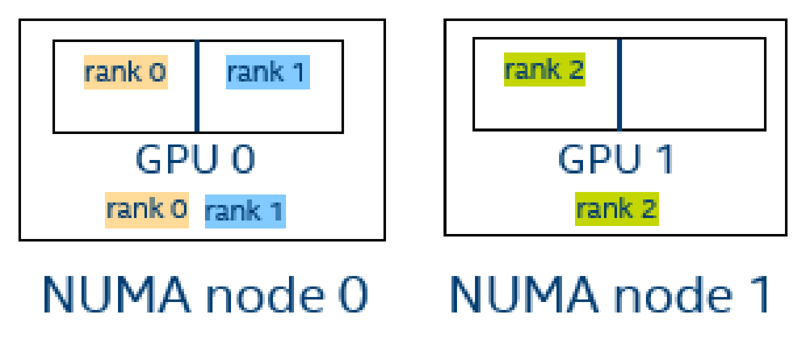
- -1: auto. IMPI will try to use all resources [default]
- >0: fixed size

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG



3 MPI ranks, I_MPI_OFFLOAD_DOMAIN_SIZE=-1



3 MPI ranks, I_MPI_OFFLOAD_DOMAIN_SIZE=1

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG

Description

Defines available devices

Syntax

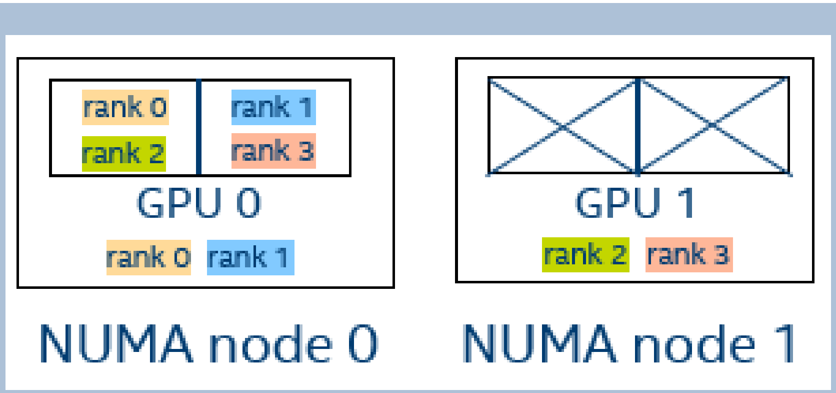
```
I_MPI_OFFLOAD_DEVICES=<list>
```

Arguments

- all: uses all visible devices [default]
- i: device with logical number i
- i-j: range, from i to j
- k, i-j: device k and devices from i to j

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG



4 MPI ranks, I_MPI_OFFLOAD_DEVICES=0

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG

Description

Pins MPI ranks to specified base unit (tile or device, depending on I_MPI_OFFLOAD_CELL)

Syntax

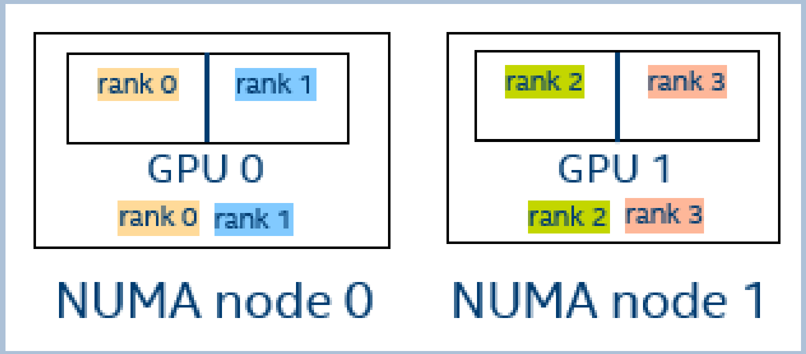
```
I_MPI_OFFLOAD_DEVICE_LIST=<list>
```

Arguments

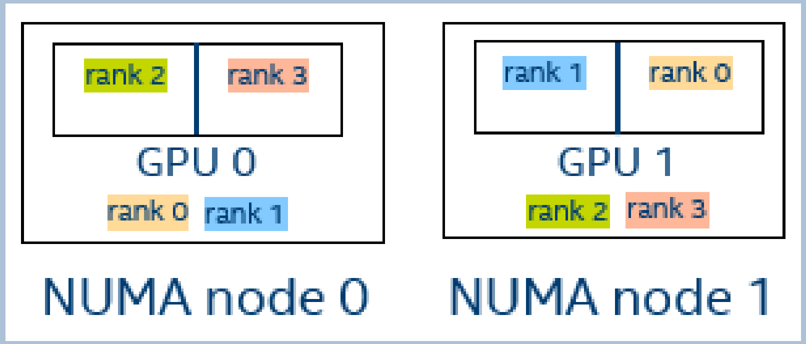
- i: device with logical number i
- i-j: range, from i to j
- k, i-j: device k and devices from i to j

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG



unset I_MPI_OFFLOAD_DEVICE_LIST



I_MPI_OFFLOAD_DEVICE_LIST=3,2,0,1

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG

Description

Define domains through a mask.

Syntax

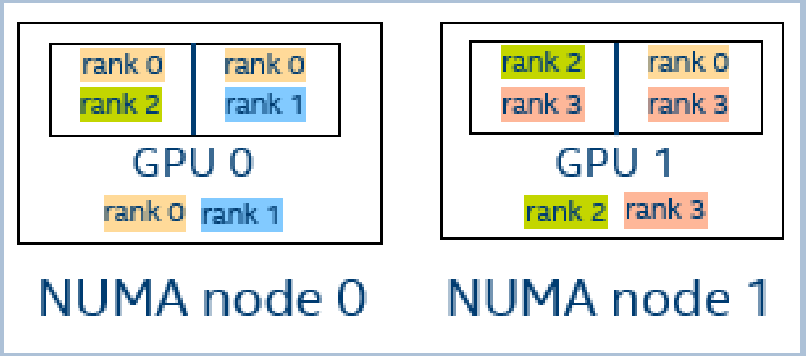
```
I_MPI_OFFLOAD_DOMAIN=<mask>
```

Arguments

- comma-separated list (one per MPI rank) of bitmasks translated into hexadecimals, e.g.
  - bitmask: [1101,0100,1010,0011]
  - hexadecimal: [B,2,5,C]

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG



Four MPI ranks.

I_MPI_OFFLOAD_DOMAIN=[B,2,5,C].

Parsed bit masks:
[1101,0100,1010,0011]

Environment Variables

- I_MPI_OFFLOAD
- I_MPI_OFFLOAD_CELL
- I_MPI_OFFLOAD_DOMAIN_SIZE
- I_MPI_OFFLOAD_DEVICES
- I_MPI_OFFLOAD_DEVICE_LIST
- I_MPI_OFFLOAD_DOMAIN
- I_MPI_DEBUG

I_MPI_DEBUG=120

```
[0] MPI startup(): ===== GPU topology on host1 =====
[0] MPI startup():   NUMA nodes : 2
[0] MPI startup():   GPUs                   : 2
[0] MPI startup():   Tiles                      : 4
[0] MPI startup(): =====  GPU Placement on packages
[0] MPI startup():  NUMA Id  GPU Id  Tiles  Ranks
[0] MPI startup():  0        0       (0,1)  0,1
[0] MPI startup():  1        1       (2,3)  2,3
```

I_MPI_DEBUG=3

```
[0] MPI startup(): ===== GPU pinning on host1 =====
[0] MPI startup(): Rank Pin tile
[0] MPI startup():   0       {0}
[0] MPI startup():   1       {1}
[0] MPI startup():   2       {2}
[0] MPI startup():   3       {3}
```

Tips to MPI Applications

Intel MPI Tunning

Out-of-the-box tuning is designed to "usual" workloads and topologies. Custom tuning may be profitable for:

- untested number of ranks configurations
- non-standard message sizes (e.g. 512 KB < msg_size < 1024 KB)
- new network topologies
- untested interconnects (e.g. Cray)
- applications with high imbalance
- non-standard/user defined datatypes
- uncommon collectives (e.g. reduce_scatter)

Even small performance gains (without code changes/rebuilding) build up over a cluster's service life => significant savings!

Autotuner – usage model

Step 1 – Enable autotuner and store results (store is optional):

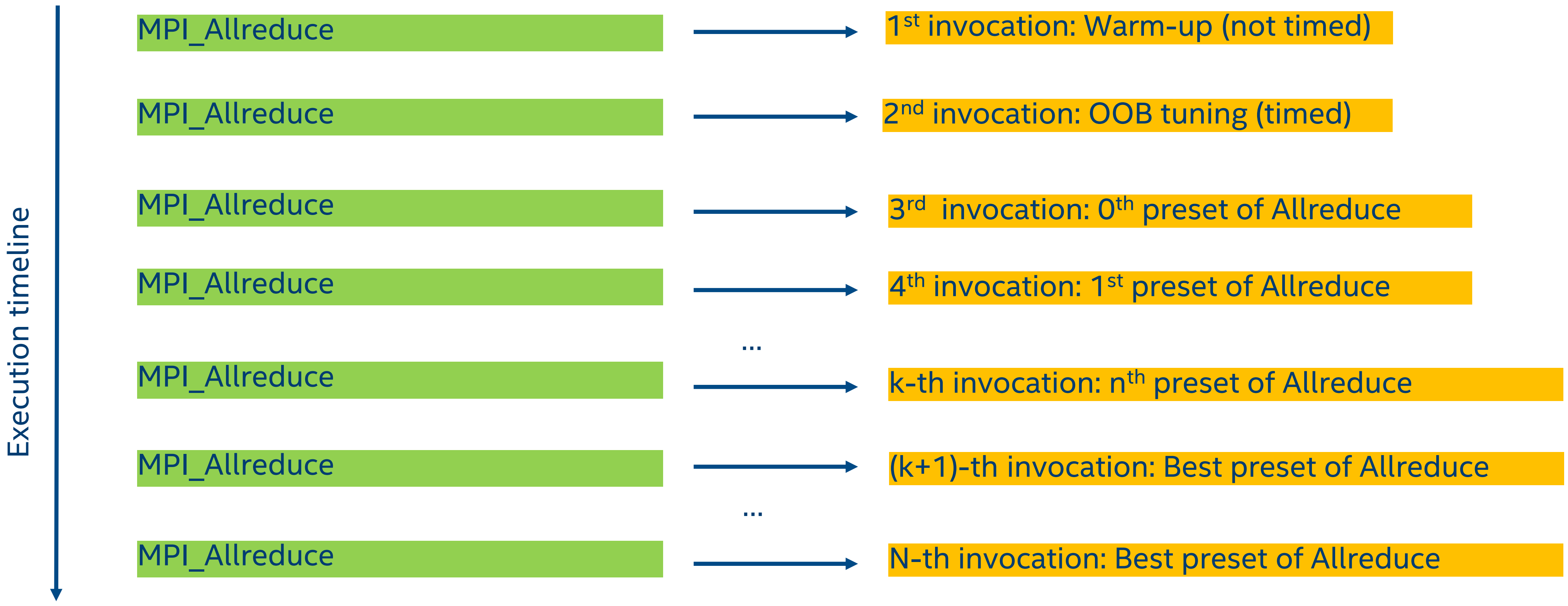
```
$ export I_MPI_TUNING_MODE=auto
$ export I_MPI_TUNING_BIN_DUMP=./tuning_results.dat
$ export I_MPI_TUNNING_AUTO_ITER_NUM=1
$ mpirun -n 96 -ppn 48 IMB-MPI1 allreduce <args>
```

(this run may be slower, due to the tunning)

Step 2 – Use the results of autotuner for consecutive launches (optional):

```
$ unset I_MPI_TUNING_MODE
$ export I_MPI_TUNING_BIN=./tuning_results.dat
$ mpirun -n 96 -ppn 48 IMB-MPI1 allreduce <args>
```

Autotuner – dynamic tuning



Execution timeline

MPI_Allreduce → 1st invocation: Warm-up (not timed)

MPI_Allreduce → 2nd invocation: OOB tuning (timed)

MPI_Allreduce → 3rd invocation: 0th preset of Allreduce

MPI_Allreduce → 4th invocation: 1st preset of Allreduce

…

MPI_Allreduce → k-th invocation: nth preset of Allreduce

MPI_Allreduce → (k+1)-th invocation: Best preset of Allreduce

…

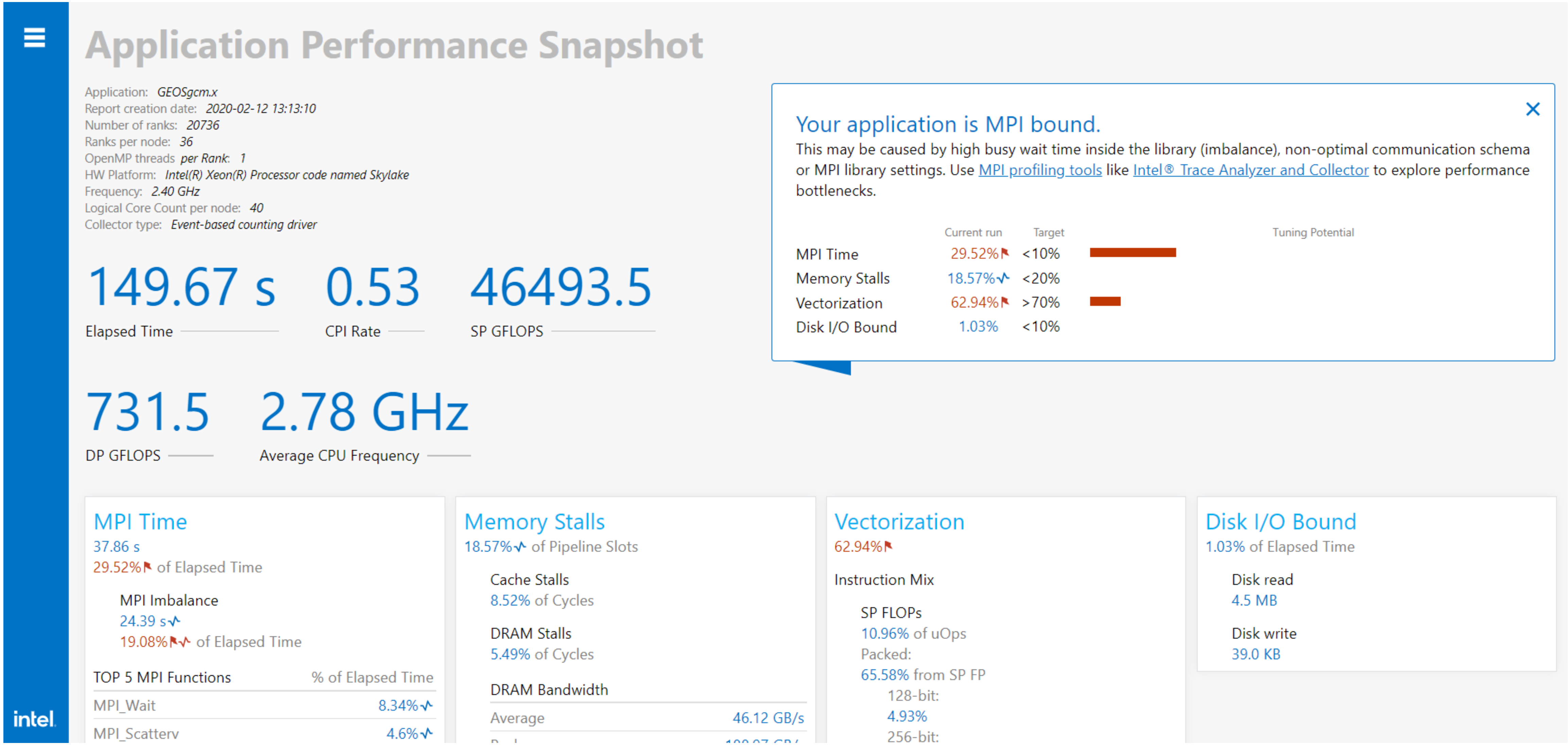
MPI_Allreduce → N-th invocation: Best preset of Allreduce

(performed for each message size/communicator)

Application Performance Snapshot

- Wide set of metrics – **MPI, OpenMP, GPU**, CPU, Memory, PCI, Vectorization, etc.
- Analysis at scale - proven successful collection on **96k ranks scale** by a customer.
- **Low overhead,** small trace size - runtime aggregation of MPI tracing and Hardware countersAPS is included in **VTune** profiler package.
- **Outlier analysis** localizes specific rank/node for detailed analysis with VTune.
- Easy to use – CL and **HTML reports**

Application Performance Snapshot



Application Performance Snapshot

Application: *GEOSgcm.x*
Report creation date: *2020-02-12 13:13:10*
Number of ranks: *20736*
Ranks per node: *36*
OpenMP threads *per Rank: 1*
HW Platform: *Intel(R) Xeon(R) Processor code named Skylake*
Frequency: *2.40 GHz*
Logical Core Count per node: *40*
Collector type: *Event-based counting driver*

149.67 s
Elapsed Time

0.53
CPI Rate

46493.5
SP GFLOPS

731.5
DP GFLOPS

2.78 GHz
Average CPU Frequency

Your application is MPI bound.

This may be caused by high busy wait time inside the library (imbalance), non-optimal communication schema or MPI library settings. Use MPI profiling tools like Intel® Trace Analyzer and Collector to explore performance bottlenecks.

	Current run	Target	Tuning Potential
MPI Time	29.52%⚑	<10%	▬▬▬▬
Memory Stalls	18.57%∿	<20%	
Vectorization	62.94%⚑	>70%	▬
Disk I/O Bound	1.03%	<10%	

MPI Time

37.86 s
29.52%⚑ of Elapsed Time

MPI Imbalance
24.39 s∿
19.08%⚑∿ of Elapsed Time

TOP 5 MPI Functions	% of Elapsed Time
MPI_Wait	8.34%∿
MPI_Scatterv	4.6%∿

Memory Stalls

18.57%∿ of Pipeline Slots

Cache Stalls
8.52% of Cycles

DRAM Stalls
5.49% of Cycles

DRAM Bandwidth	
Average	46.12 GB/s

Vectorization

62.94%⚑

Instruction Mix

SP FLOPs
10.96% of uOps
Packed:
65.58% from SP FP
128-bit:
4.93%
256-bit:

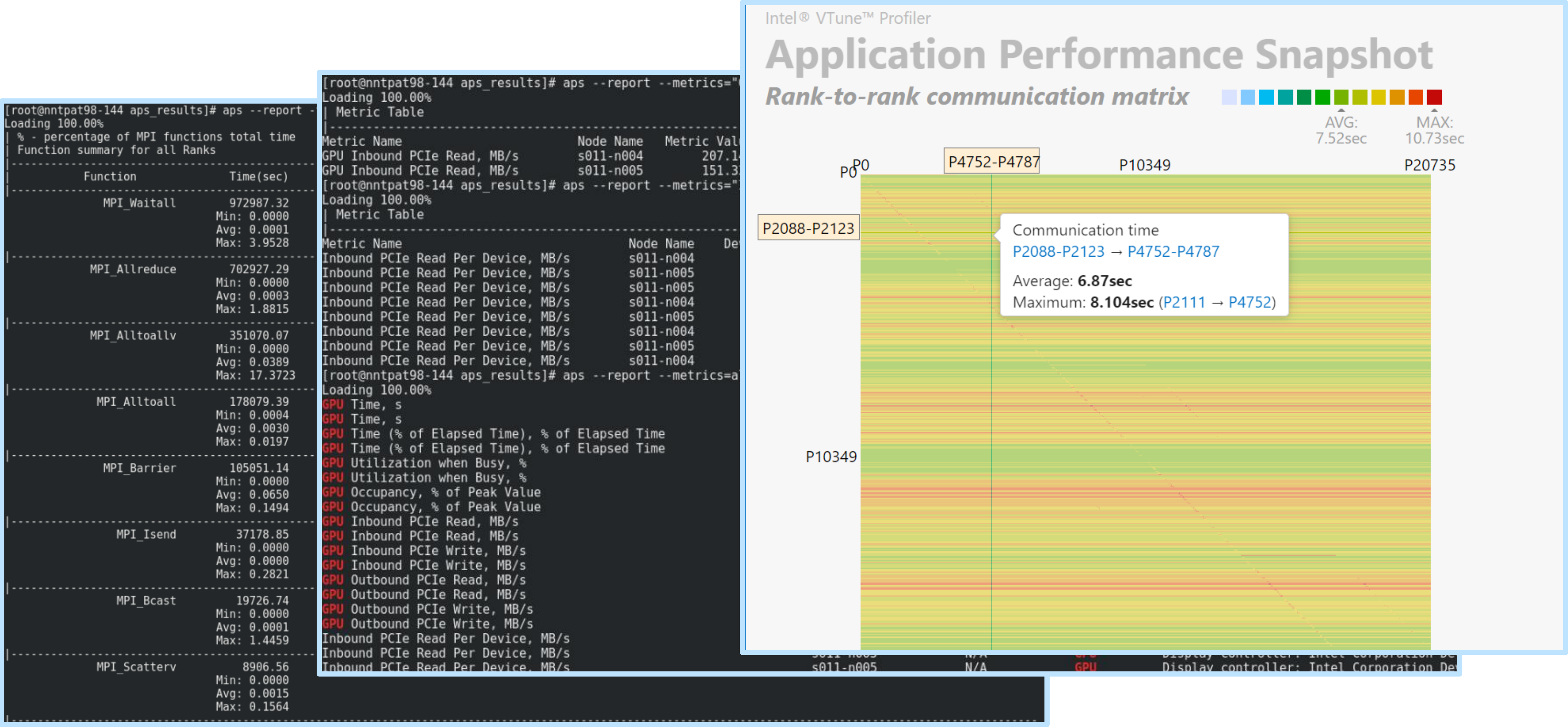
Disk I/O Bound

1.03% of Elapsed Time

Disk read
4.5 MB

Disk write
39.0 KB

Application Performance Snapshot



```
[root@nntpat98-144 aps_results]# aps --report -
Loading 100.00%
| % - percentage of MPI functions total time
| Function summary for all Ranks
|------------------------------------------------
|          Function                 Time(sec)
|------------------------------------------------
              MPI_Waitall         972987.32
                                Min: 0.0000
                                Avg: 0.0001
                                Max: 3.9528
|------------------------------------------------
            MPI_Allreduce         702927.29
                                Min: 0.0000
                                Avg: 0.0003
                                Max: 1.8815
|------------------------------------------------
            MPI_Alltoallv         351070.07
                                Min: 0.0000
                                Avg: 0.0389
                                Max: 17.3723
|------------------------------------------------
             MPI_Alltoall         178079.39
                                Min: 0.0004
                                Avg: 0.0030
                                Max: 0.0197
|------------------------------------------------
              MPI_Barrier         105051.14
                                Min: 0.0000
                                Avg: 0.0650
                                Max: 0.1494
|------------------------------------------------
                MPI_Isend          37178.85
                                Min: 0.0000
                                Avg: 0.0000
                                Max: 0.2821
|------------------------------------------------
                MPI_Bcast          19726.74
                                Min: 0.0000
                                Avg: 0.0001
                                Max: 1.4459
|------------------------------------------------
             MPI_Scatterv           8906.56
                                Min: 0.0000
                                Avg: 0.0015
                                Max: 0.1564
|------------------------------------------------
```

```
[root@nntpat98-144 aps_results]# aps --report --metrics="
Loading 100.00%
| Metric Table
|----------------------------------------------------
Metric Name                         Node Name    Metric Val
GPU Inbound PCIe Read, MB/s         s011-n004        207.1
GPU Inbound PCIe Read, MB/s         s011-n005        151.3
[root@nntpat98-144 aps_results]# aps --report --metrics="
Loading 100.00%
| Metric Table
|----------------------------------------------------
Metric Name                                Node Name     De
Inbound PCIe Read Per Device, MB/s         s011-n004
Inbound PCIe Read Per Device, MB/s         s011-n005
Inbound PCIe Read Per Device, MB/s         s011-n005
Inbound PCIe Read Per Device, MB/s         s011-n004
Inbound PCIe Read Per Device, MB/s         s011-n005
Inbound PCIe Read Per Device, MB/s         s011-n004
Inbound PCIe Read Per Device, MB/s         s011-n005
Inbound PCIe Read Per Device, MB/s         s011-n004
[root@nntpat98-144 aps_results]# aps --report --metrics=a
Loading 100.00%
GPU Time, s
GPU Time, s
GPU Time (% of Elapsed Time), % of Elapsed Time
GPU Time (% of Elapsed Time), % of Elapsed Time
GPU Utilization when Busy, %
GPU Utilization when Busy, %
GPU Occupancy, % of Peak Value
GPU Occupancy, % of Peak Value
GPU Inbound PCIe Read, MB/s
GPU Inbound PCIe Read, MB/s
GPU Inbound PCIe Write, MB/s
GPU Inbound PCIe Write, MB/s
GPU Outbound PCIe Read, MB/s
GPU Outbound PCIe Read, MB/s
GPU Outbound PCIe Write, MB/s
GPU Outbound PCIe Write, MB/s
Inbound PCIe Read Per Device, MB/s
Inbound PCIe Read Per Device, MB/s
Inbound PCIe Read Per Device, MB/s         s011-n005          N/A          GPU          Display controller: Intel Corporation Dev
```

Intel® VTune™ Profiler

Application Performance Snapshot

Rank-to-rank communication matrix

Communication time

P2088-P2123 → P4752-P4787

Average: **6.87sec**

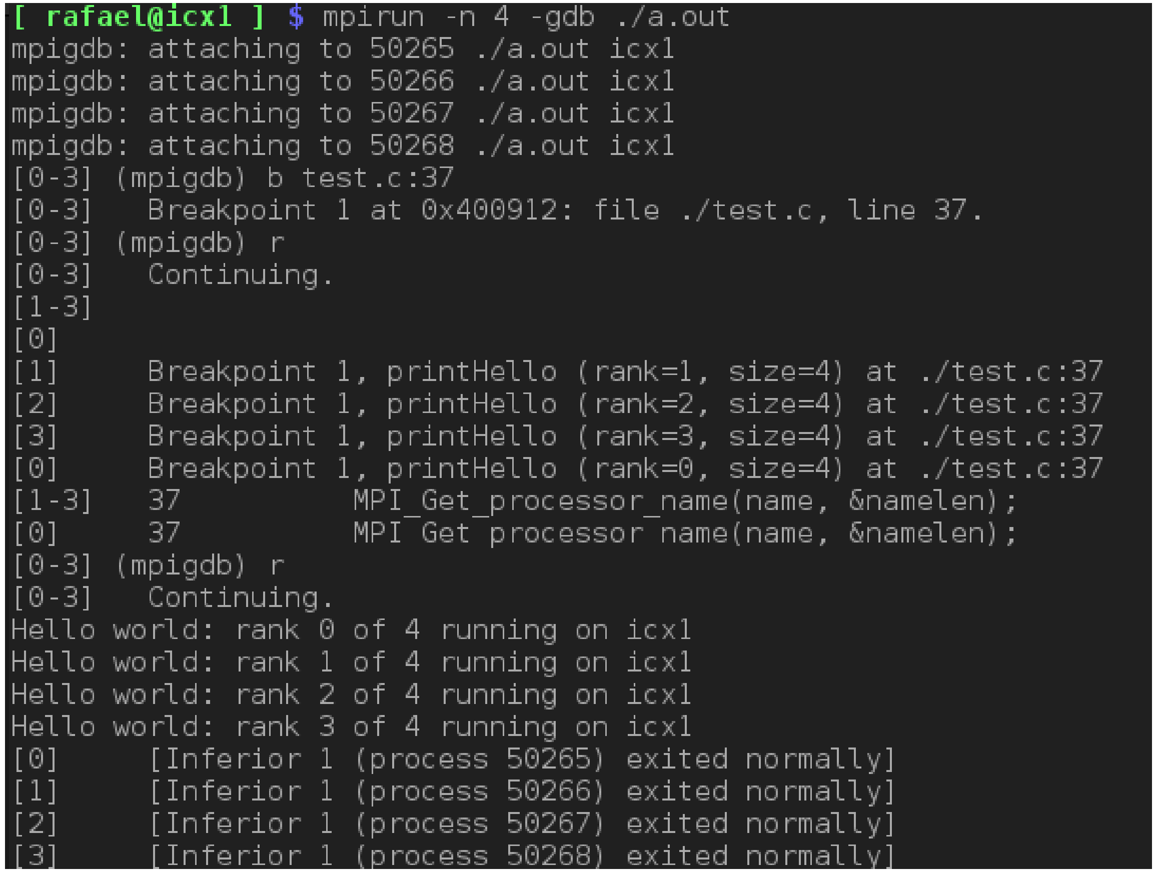
Maximum: **8.104sec** (P2111 → P4752)

Troubleshooting MPI Applications

- Interactive debugging using System's gdb:

```
$ mpirun -n 8 -gdb \
  IMB-MPI1 allreduce
```

- Starts one gdb-server and one gdb-client per rank. User interacts with gdb-server only.



```
[ rafael@icx1 ] $ mpirun -n 4 -gdb ./a.out
mpigdb: attaching to 50265 ./a.out icx1
mpigdb: attaching to 50266 ./a.out icx1
mpigdb: attaching to 50267 ./a.out icx1
mpigdb: attaching to 50268 ./a.out icx1
[0-3] (mpigdb) b test.c:37
[0-3]   Breakpoint 1 at 0x400912: file ./test.c, line 37.
[0-3] (mpigdb) r
[0-3]   Continuing.
[1-3]
[0]
[1]     Breakpoint 1, printHello (rank=1, size=4) at ./test.c:37
[2]     Breakpoint 1, printHello (rank=2, size=4) at ./test.c:37
[3]     Breakpoint 1, printHello (rank=3, size=4) at ./test.c:37
[0]     Breakpoint 1, printHello (rank=0, size=4) at ./test.c:37
[1-3]   37          MPI_Get_processor_name(name, &namelen);
[0]     37          MPI Get processor name(name, &namelen);
[0-3] (mpigdb) r
[0-3]   Continuing.
Hello world: rank 0 of 4 running on icx1
Hello world: rank 1 of 4 running on icx1
Hello world: rank 2 of 4 running on icx1
Hello world: rank 3 of 4 running on icx1
[0]     [Inferior 1 (process 50265) exited normally]
[1]     [Inferior 1 (process 50266) exited normally]
[2]     [Inferior 1 (process 50267) exited normally]
[3]     [Inferior 1 (process 50268) exited normally]
```

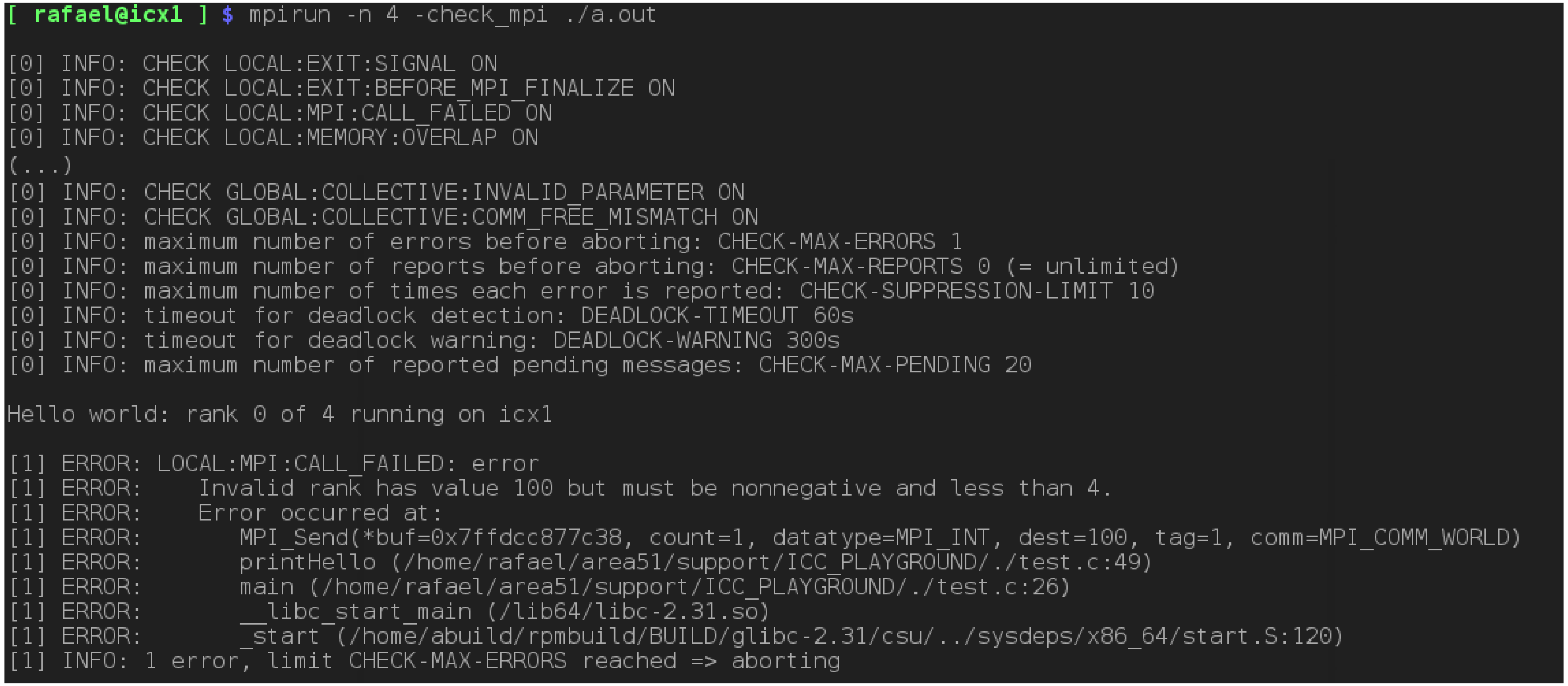
Troubleshooting MPI Applications

- Intel Trace Analyser and Collector – Correctness Check:

```
$ mpirun -n 8 -check_mpi IMB-MPI1 allreduce
```

(Attention: it can

be quite verbose!)



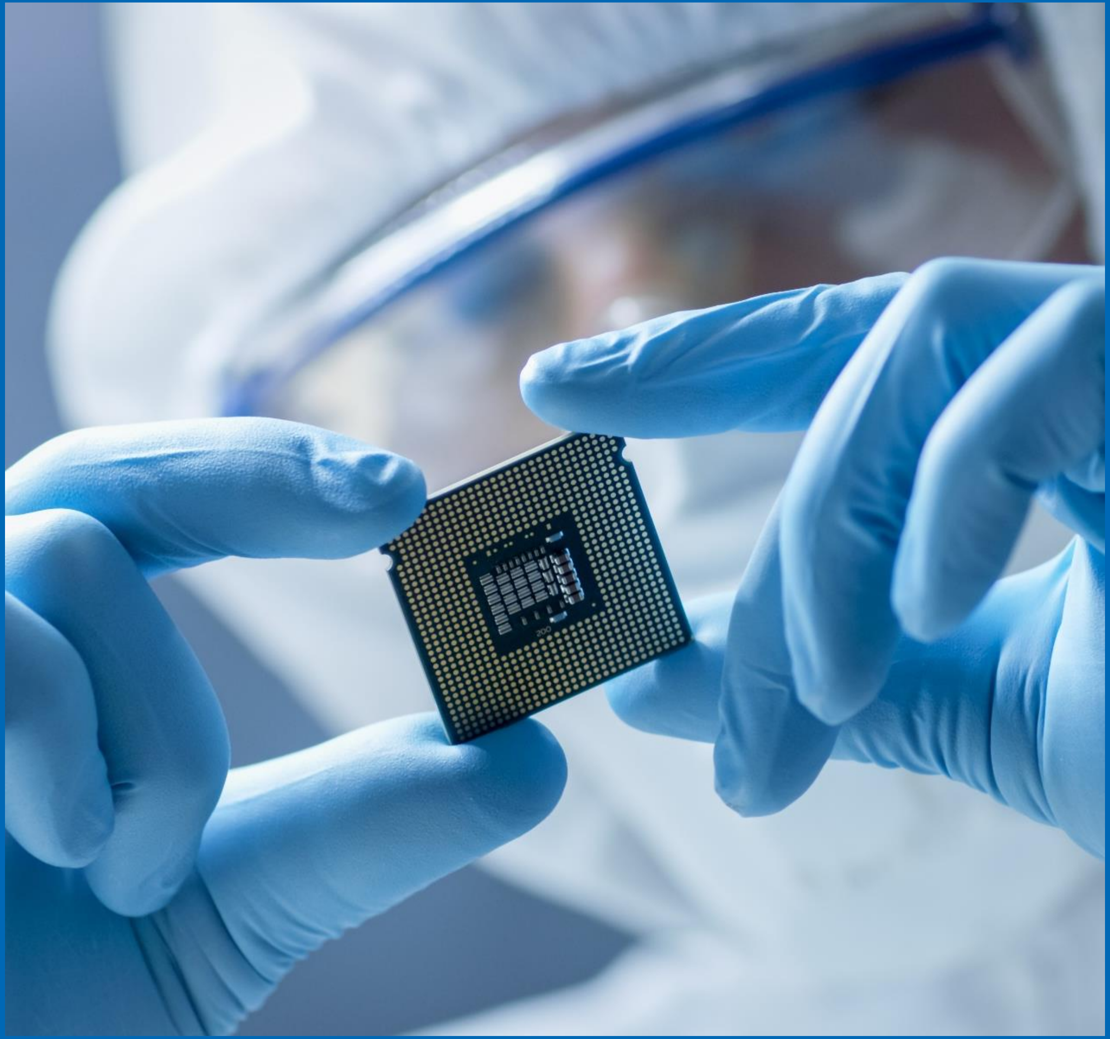
```
[ rafael@icx1 ] $ mpirun -n 4 -check_mpi ./a.out

[0] INFO: CHECK LOCAL:EXIT:SIGNAL ON
[0] INFO: CHECK LOCAL:EXIT:BEFORE_MPI_FINALIZE ON
[0] INFO: CHECK LOCAL:MPI:CALL_FAILED ON
[0] INFO: CHECK LOCAL:MEMORY:OVERLAP ON
(...)
[0] INFO: CHECK GLOBAL:COLLECTIVE:INVALID_PARAMETER ON
[0] INFO: CHECK GLOBAL:COLLECTIVE:COMM_FREE_MISMATCH ON
[0] INFO: maximum number of errors before aborting: CHECK-MAX-ERRORS 1
[0] INFO: maximum number of reports before aborting: CHECK-MAX-REPORTS 0 (= unlimited)
[0] INFO: maximum number of times each error is reported: CHECK-SUPPRESSION-LIMIT 10
[0] INFO: timeout for deadlock detection: DEADLOCK-TIMEOUT 60s
[0] INFO: timeout for deadlock warning: DEADLOCK-WARNING 300s
[0] INFO: maximum number of reported pending messages: CHECK-MAX-PENDING 20

Hello world: rank 0 of 4 running on icx1

[1] ERROR: LOCAL:MPI:CALL_FAILED: error
[1] ERROR:    Invalid rank has value 100 but must be nonnegative and less than 4.
[1] ERROR:    Error occurred at:
[1] ERROR:       MPI_Send(*buf=0x7ffdcc877c38, count=1, datatype=MPI_INT, dest=100, tag=1, comm=MPI_COMM_WORLD)
[1] ERROR:       printHello (/home/rafael/area51/support/ICC_PLAYGROUND/./test.c:49)
[1] ERROR:       main (/home/rafael/area51/support/ICC_PLAYGROUND/./test.c:26)
[1] ERROR:       __libc_start_main (/lib64/libc-2.31.so)
[1] ERROR:       _start (/home/abuild/rpmbuild/BUILD/glibc-2.31/csu/../sysdeps/x86_64/start.S:120)
[1] INFO: 1 error, limit CHECK-MAX-ERRORS reached => aborting
```

Questions?



intel®

Collection

How to collect:

mpirun [mpi_options] **aps [aps_options]** <app> [app_options]

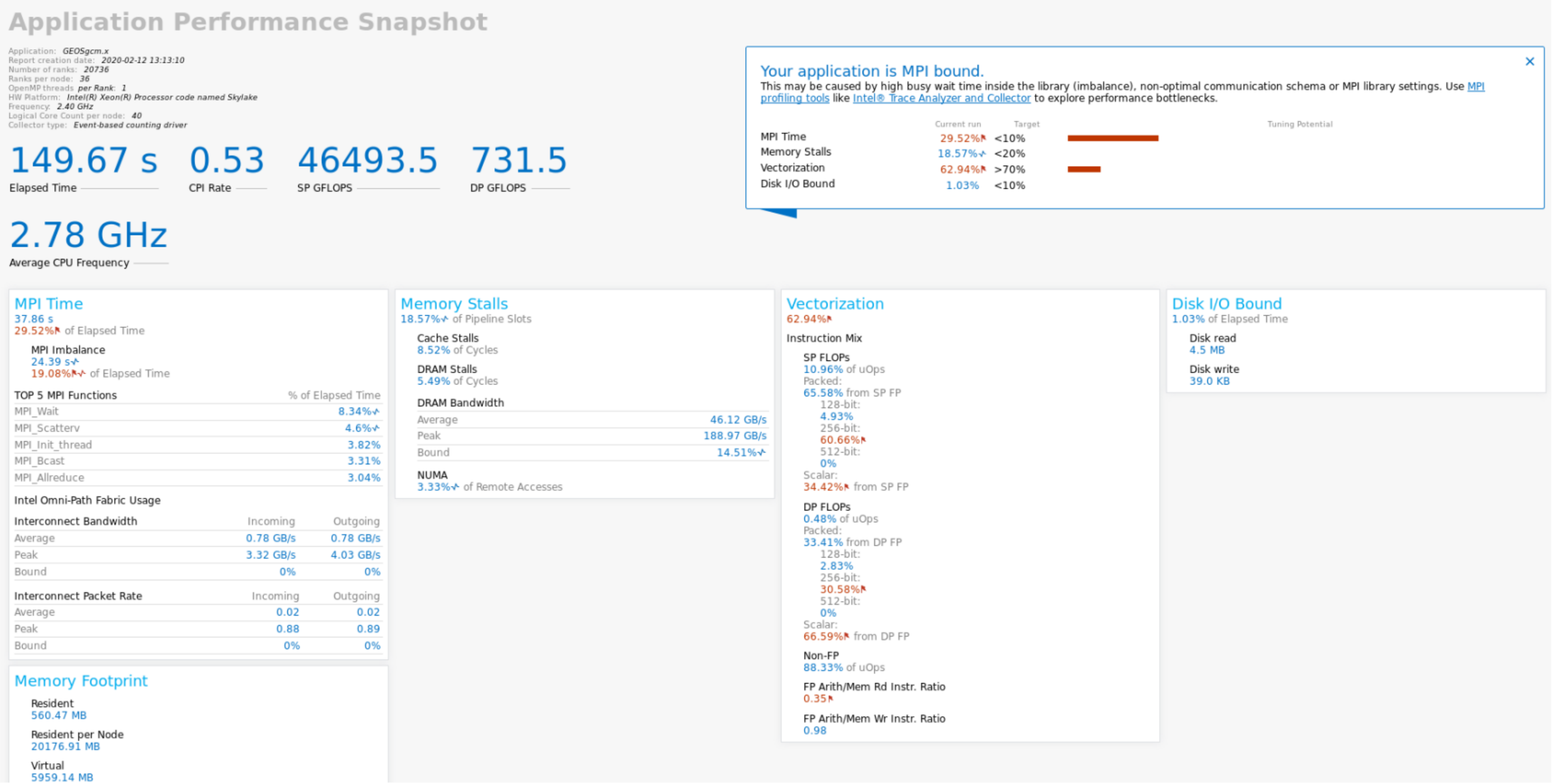
Adjustable collection:

- --collection-mode=[mpi|omp|hwc|all] – ‘all’ by default
- --stat-level=[1..5] – from timing to detailed info about message sizes, communicators, destinations.
- --mpi-imbalance=[0..2] – 0 – disabled, 1 – get imbalance from Intel MPI (default), 2 – using inserted barriers
- Collection control through MPI_Pcontrols and ITT API

Low overhead:

- ~ 1-2% in default mode
- < 10% in any other mode

Summary report (aps --report <result>)



Application Performance Snapshot

Application: *GEOSgcm.x*
Report creation date: *2020-02-12 13:13:10*
Number of ranks: *20736*
Ranks per node: *36*
OpenMP threads *per Rank*: *1*
HW Platform: *Intel(R) Xeon(R) Processor code named Skylake*
Frequency: *2.40 GHz*
Logical Core Count per node: *40*
Collector type: *Event-based counting driver*

149.67 s
Elapsed Time

0.53
CPI Rate

46493.5
SP GFLOPS

731.5
DP GFLOPS

2.78 GHz
Average CPU Frequency

Your application is MPI bound.

This may be caused by high busy wait time inside the library (imbalance), non-optimal communication schema or MPI library settings. Use MPI profiling tools like Intel® Trace Analyzer and Collector to explore performance bottlenecks.

	Current run	Target	Tuning Potential
MPI Time	29.52%	<10%	
Memory Stalls	18.57%	<20%	
Vectorization	62.94%	>70%	
Disk I/O Bound	1.03%	<10%	

MPI Time

37.86 s
29.52% of Elapsed Time

MPI Imbalance
24.39 s
19.08% of Elapsed Time

TOP 5 MPI Functions	% of Elapsed Time
MPI_Wait	8.34%
MPI_Scatterv	4.6%
MPI_Init_thread	3.82%
MPI_Bcast	3.31%
MPI_Allreduce	3.04%

Intel Omni-Path Fabric Usage

Interconnect Bandwidth	Incoming	Outgoing
Average	0.78 GB/s	0.78 GB/s
Peak	3.32 GB/s	4.03 GB/s
Bound	0%	0%

Interconnect Packet Rate	Incoming	Outgoing
Average	0.02	0.02
Peak	0.88	0.89
Bound	0%	0%

Memory Footprint

Resident
560.47 MB

Resident per Node
20176.91 MB

Virtual
5959.14 MB

Memory Stalls

18.57% of Pipeline Slots

Cache Stalls
8.52% of Cycles

DRAM Stalls
5.49% of Cycles

DRAM Bandwidth	
Average	46.12 GB/s
Peak	188.97 GB/s
Bound	14.51%

NUMA
3.33% of Remote Accesses

Vectorization

62.94%

Instruction Mix

SP FLOPs
10.96% of uOps
Packed:
65.58% from SP FP
128-bit:
4.93%
256-bit:
60.66%
512-bit:
0%
Scalar:
34.42% from SP FP

DP FLOPs
0.48% of uOps
Packed:
33.41% from DP FP
128-bit:
2.83%
256-bit:
30.58%
512-bit:
0%
Scalar:
66.59% from DP FP

Non-FP
88.33% of uOps

FP Arith/Mem Rd Instr. Ratio
0.35

FP Arith/Mem Wr Instr. Ratio
0.98

Disk I/O Bound

1.03% of Elapsed Time

Disk read
4.5 MB

Disk write
39.0 KB

Reports

How to generate a report:

```
aps --report [report_options] <result_directory>
```

Detailed reports:

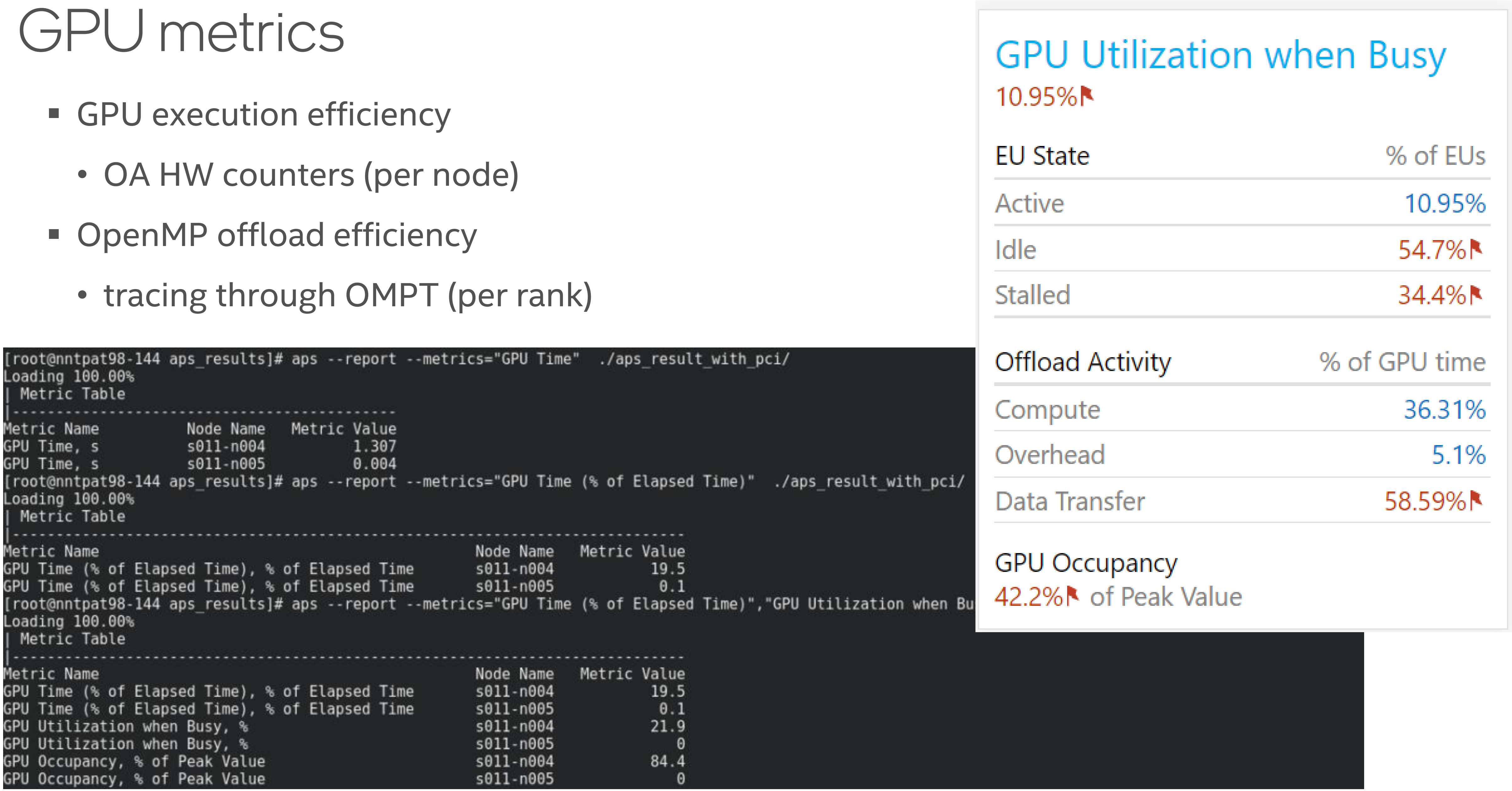
- MPI: functions, message sizes, communication matrix, list of MPI communicators, etc.
- Metrics: OpenMP Imbalance, CPU Utilization, IPC, Memory Bound, GPU Time, etc.
- Node topology

Customizable output:

- Filtering by ranks, nodes, mpi functions, communicators, volume
- Changing the size of communication diagram
- Adjusting level of details
- Different groupings in MPI related repots

GPU metrics

- GPU execution efficiency
  - OA HW counters (per node)
- OpenMP offload efficiency
  - tracing through OMPT (per rank)



```
[root@nntpat98-144 aps_results]# aps --report --metrics="GPU Time"  ./aps_result_with_pci/
Loading 100.00%
| Metric Table
|-----------------------------------------------
Metric Name          Node Name   Metric Value
GPU Time, s          s011-n004          1.307
GPU Time, s          s011-n005          0.004
[root@nntpat98-144 aps_results]# aps --report --metrics="GPU Time (% of Elapsed Time)"  ./aps_result_with_pci/
Loading 100.00%
| Metric Table
|---------------------------------------------------------------------------------
Metric Name                                    Node Name   Metric Value
GPU Time (% of Elapsed Time), % of Elapsed Time      s011-n004           19.5
GPU Time (% of Elapsed Time), % of Elapsed Time      s011-n005            0.1
[root@nntpat98-144 aps_results]# aps --report --metrics="GPU Time (% of Elapsed Time)","GPU Utilization when Bu
Loading 100.00%
| Metric Table
|---------------------------------------------------------------------------------
Metric Name                                    Node Name   Metric Value
GPU Time (% of Elapsed Time), % of Elapsed Time      s011-n004           19.5
GPU Time (% of Elapsed Time), % of Elapsed Time      s011-n005            0.1
GPU Utilization when Busy, %                   s011-n004           21.9
GPU Utilization when Busy, %                   s011-n005              0
GPU Occupancy, % of Peak Value                 s011-n004           84.4
GPU Occupancy, % of Peak Value                 s011-n005              0
```

GPU Utilization when Busy

10.95%

EU State	% of EUs
Active	10.95%
Idle	54.7%
Stalled	34.4%

Offload Activity	% of GPU time
Compute	36.31%
Overhead	5.1%
Data Transfer	58.59%

GPU Occupancy

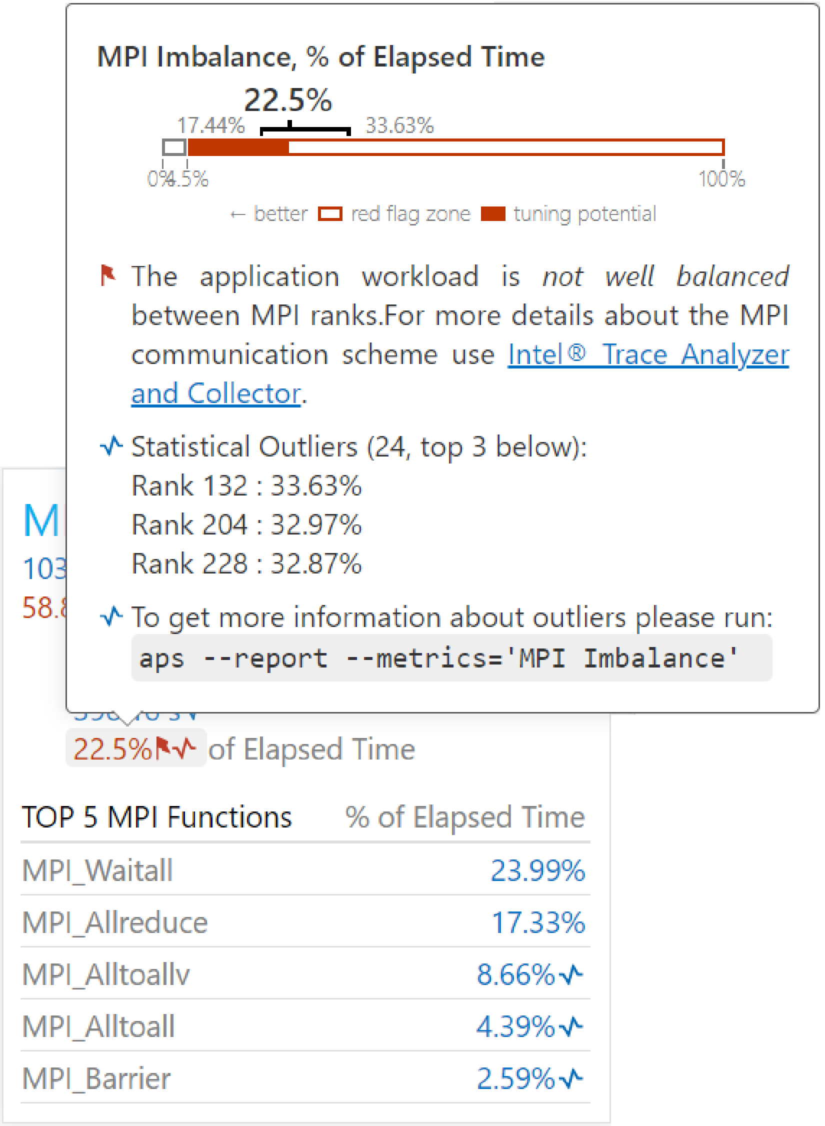
42.2% of Peak Value

Outliers

Provide Min, Max, Average

Detect statistical and threshold outliers

- Statistical outlier is based on two-sided Grubbs's test with 0.05 significance level
  - Highlighting anomalies and asymmetric distribution of work
  - Show a potential target for detailed analysis
- Threshold outlier – a metric value breaking the threshold.
  - Show an additional tuning potential for a source breaking the threshold.



The application workload is *not well balanced* between MPI ranks.For more details about the MPI communication scheme use Intel® Trace Analyzer and Collector.

Statistical Outliers (24, top 3 below):
Rank 132 : 33.63%
Rank 204 : 32.97%
Rank 228 : 32.87%

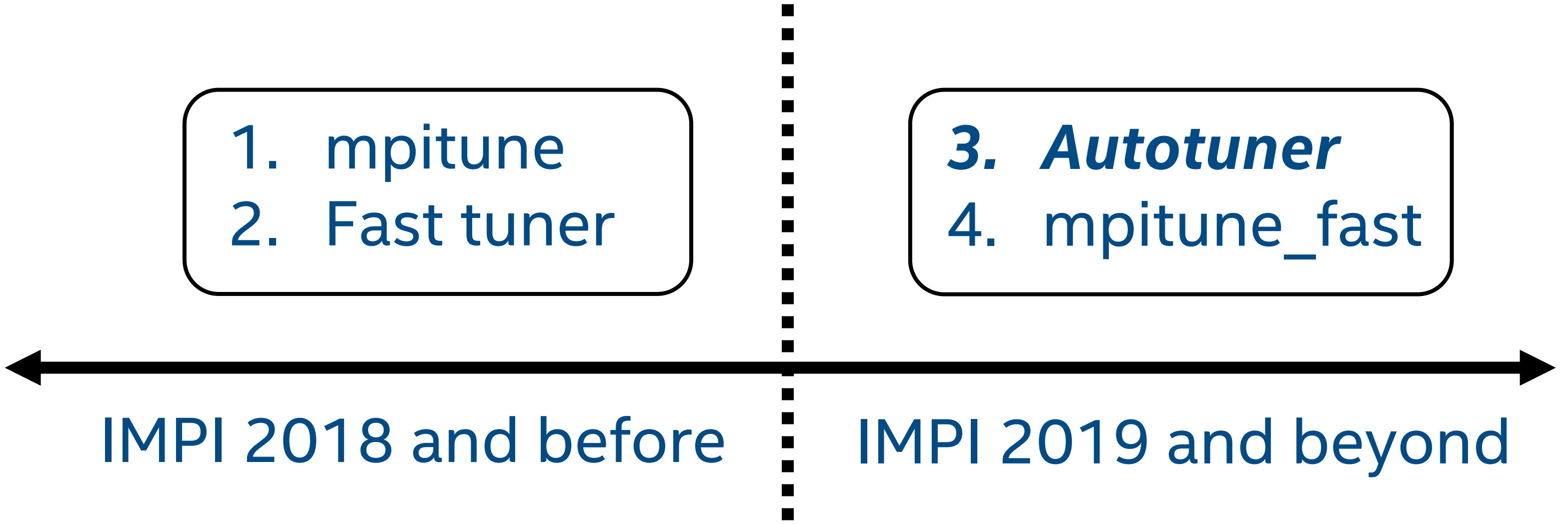
To get more information about outliers please run:

```
aps --report --metrics='MPI Imbalance'
```

22.5% of Elapsed Time

TOP 5 MPI Functions	% of Elapsed Time
MPI_Waitall	23.99%
MPI_Allreduce	17.33%
MPI_Alltoallv	8.66%
MPI_Alltoall	4.39%
MPI_Barrier	2.59%

Intel MPI Tuning



1. mpitune
2. Fast tuner

3. Autotuner

4. mpitune_fast

IMPI 2018 and before

IMPI 2019 and beyond

Good 🟩
Ok 🟨
Bad 🟥

Introduction

Tuning utility Parameter	MPItune	Fast Tuner	Autotuner	mpitune_fast
Tuning overhead	🟥	🟨	🟩	🟩
Ease of use	🟥	🟥	🟩	🟩
Application tuning	🟥	🟨	🟩	🟥
Microbenchmark tuning	🟩	🟩	🟩	🟩
Adoption in production environments	🟥	🟥	🟩	🟩

Environment variables – Main flow control

I_MPI_TUNING_MODE=<auto|auto:application|auto:cluster> (**disabled** by default)

I_MPI_TUNING_AUTO_ITER_NUM=<number> Tuning iterations number (**1** by default).

I_MPI_TUNING_AUTO_SYNC=<0|1> Call internal barrier on every tuning iteration (**disabled** by default)

Guidance on I_MPI_TUNING_AUTO_ITER_NUM

Min invocations required for a certain collective call for a certain message size in a certain communicator = I_MPI_TUNING_AUTO_WARMUP_ITER_NUM + [(range+1)* I_MPI_TUNING_AUTO_ITER_NUM]

Autotuner Example

Configuration possibly slowing down tuning run in favour of results.:

- I_MPI_TUNING_MODE=auto
- I_MPI_TUNING_AUTO_WARMUP_ITER_NUM=1
- I_MPI_TUNING_AUTO_ITER_NUM=128
- I_MPI_TUNING_AUTO_SYNC=1
- I_MPI_TUNING_AUTO_ITER_POLICY_THRESHOLD=4194304
- I_MPI_TUNING_AUTO_STORAGE_SIZE=4194304
- I_MPI_TUNING_BIN_DUMP=./my_tuning_file.dat

Apply tuning results via

- I_MPI_TUNING_BIN=./my_tuning_file.dat

Restricting the scope of implementations

Remove failed implementation/s and switch back to the release version of Intel MPI Library and rerun autotuner. E.g. removing 11th implementation.:

```
$ export I_MPI_ADJUST_ALLREDUCE_LIST=0-10,12-25
```

This technique can also be used outside of tuning scenarios to find failed implementations in Intel MPI Library.

mpitune_fast

	Autotuner	mpitune_fast
Scope	**Application specific tuning**	**Cluster wide tuning**
Intended for	**Regular users**	**System administrators**

- tunes the Intel® MPI Library to the cluster configuration using autotuner functionality.
- iteratively launches the Intel® MPI Benchmarks with the proper autotuner environment and generates a tuning file.
- supports Slurm and LSF job managers. mpitune_fast automatically finds job allocated hosts and performs launches.
- **Example**

```
$ mpitune_fast -f ./hostfile -c alltoall,allreduce,barrier
```