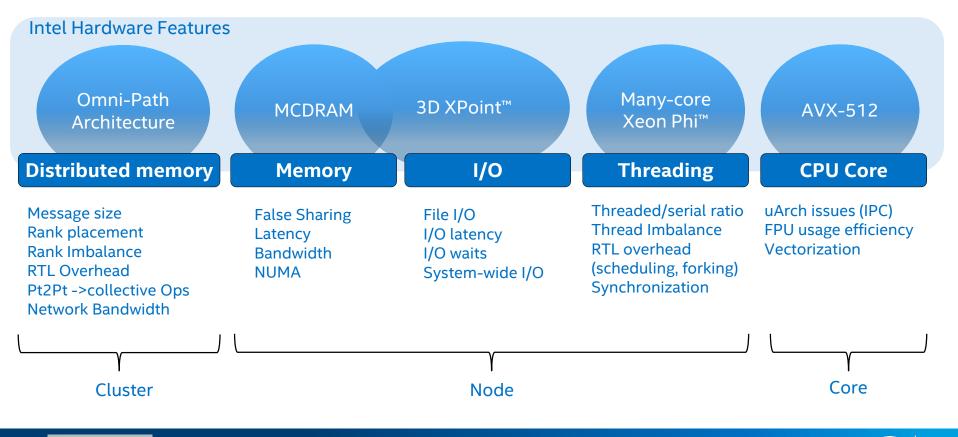


CONFIGURATION-FREE PROFILING AT SCALE

Bei Wang, Dmitry Prohorov and Carlos Rosales

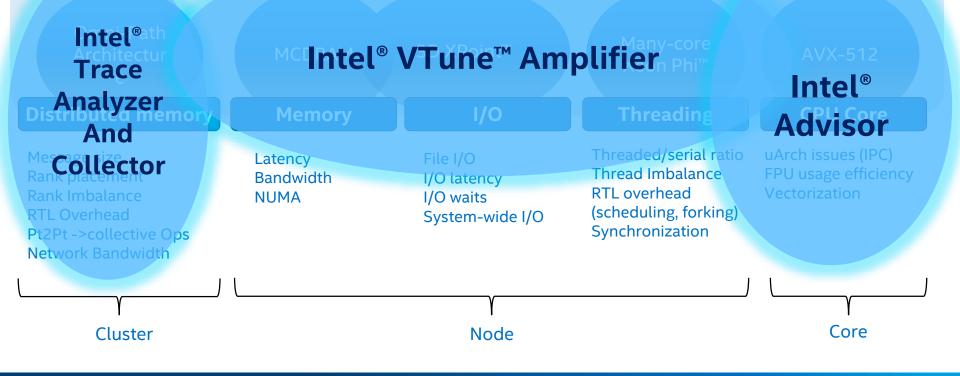
Aspects of Application Performance



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Intel[®] Tools Covering the Aspects

Intel Hardware Features



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Before diving Into a particular tool ...

- How to assess that I have potential in performance tuning?
- Which tool should I use first?
- What to use at large scale avoiding being overwhelmed with huge trace size, post processing time and collection overhead?
- How to quickly evaluate environment settings or incremental code changes?

VTune[™] Amplifier's Application Performance Snapshot



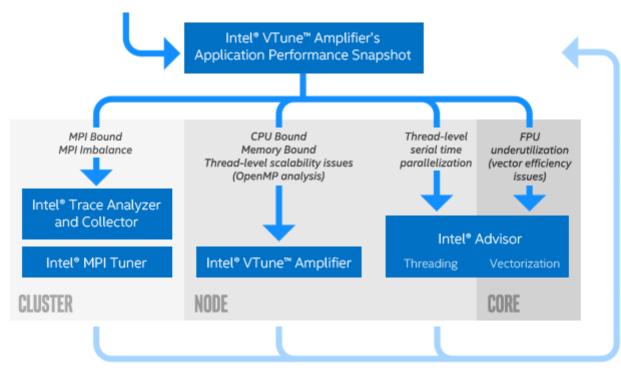
Application Performance Snapshot (APS)

- High-level overview of application performance
- Identify primary optimization areas and next steps in analysis
- **Easy** to install, run, explore results with CL or HTML reports
- Scales to large jobs
- Multiple ways to get started:
 - Part of Intel[®] Parallel Studio XE or VTune[™] Amplifier distributions
 - Separate free download (~100MB) from APS page

https://software.intel.com/sites/products/snapshots/application-snapshot/



Performance Optimization Workflow based on APS





APS Usage

Setup Environment

>source <APS_Install_dir>/apsvars.sh

Run Application

- >aps <application and args>
- MPI: >mpirun <mpi options> aps <application and args>

Generate Report on Result Folder

>aps –report <result folder>



Generate CL reports with detailed MPI statistics of Result Folder

aps-report -<option> <result folder>

	Volume (RB)	
	03.04	
[filtered out 16		
	60.00	
[filtered out 17		
	50.01	
	\$7.69	
	56,98	
[filtered out 11]		

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APS HTML Report

Ξ

Application Performance Snapshot

Application: wrf.exe Report creation date: 2018-08-13 21:05:57 Number of ranks: 64 Ranks per node: 2 OpenMP threads per rank: 24 HW Platform: Intel(R) Xeon(R) Processor code nam Logical Core Count per node: 96 Collector type: Event-based counting driver

848.30s Elapsed Time

3873.13 SP GFLOPS

2.3 CPI (MAX

7.01

0.37

0.11

0.07

0.06

MPI Time 65.48s

7.72% of Elapsed Time

MPI Imbalance 54.44s 6.42% ▲ of Elapsed Time

TOP 5 MPI Functions

Wait File_read_at_all Isend Irecv Init

I/O Bound

0.00% (AVG 0.00, PEAK 0.03)

le named .	Skylake		bre				dth, and correlation by memory	
			Qps Mei FPU	l.Time anMP.Imbalanse mory.Stalls I.Utilization Bound	Gurrent.run 7.72% 3.49% 74.64% № 1.90% № 0.00%	<10% <20%	Deita	
2.32 IPI MAX 2.4	18, <u>MIN</u> 2.11))						
	29.60s	MP Imbala Elapsed Time	nce	Memory 5 74.64% ▲ of p <u>Cache Sta</u> 8.92% of c	ipeline slot Il <u>s</u>	s	PU Utilization 90% SP. FLOPs per Cycle 1.21 Out of 64.00	
%	Memo Resident	<mark>ry Footpri</mark> _{PEAK}	nt AVG	DRAM Sta 43.01% N	lls of cycles		Vector Capacity Usage 58.08%	
7.01	Per node:	25752.69 MB		144.31	RAM Band GB/s	width	FP Instruction Mix % of <u>Packed FP Instr.</u> : 55.519 % of <u>128-bit</u> : 0.02%	6
0.11 0.07	Virtual	12897.27 MB PEAK	AVG	<u>NUMA</u> 0.10% of r	emote acce	esses	% of <u>256-bit</u> : 0.66% % of <u>512-bit</u> : 54.81% % of <u>Scalar FP Instr.</u> : 44.49%	•
0.06	Per node: Per rank:	53049.77 MB					FP Arith/Mem Rd Instr. Ratio 0.81	2
	- Cr TdHk	200001121000	2000041100				EP Arith/Mem Wr Instr. Rati	•

Your application is memory bound.

Use memory access analysis tools like Intel® VTune™ Amplifier for a detailed metric

RAM Stalls 43.01% ► of cycles

×

FP Arith/Mem Wr Instr. Ratio

Configuration Information - See Configuration Details Hardware: Intel® Xeon® Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel® Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. Software: CentOS 7.4; Intel® Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel® C++ Compiler XE 18.0.2.199 for Linux*; Intel® Fortran Compiler XE 18.0.2.199 for Linux*

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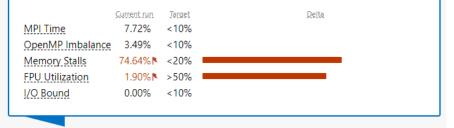


APS HTML Report Breakdown - Overview

- Overview shows all areas and relative impact on code performance
- Provides recommendation for next step in performance analysis
- "X" collapses the summary, removing the flags (objective numbers only)

Your application is memory bound.

Use <u>memory access analysis tools</u> like <u>Intel® VTune[™] Amplifier</u> for a detailed metric breakdown by memory hierarchy, memory bandwidth, and correlation by memory objects.



Configuration Information - See Configuration Details

Hardware: Intel® Xeon® Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel® Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. Software: CentOS 7.4; Intel® Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel® C++ Compiler XE 18.0.2.199 for Linux*; Intel® Fortran Compiler XE 18.0.2.199 for Linux*

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APS HTML Report Breakdown – Parallel Runtimes

MPI Time

- How much time was spent in MPI calls
- Averaged by ranks with % of Elapsed time
- Available for MPICH-based libraries

MPI Imbalance

- Unproductive time spent in MPI library waiting for data
- Available for Intel[®] MPI

OpenMP* Imbalance

- Time spent at OpenMP* Barriers normalized by number of threads
- Available for Intel[®] OpenMP*

Configuration Information - See Configuration Details

Hardware: Intel® Xeon® Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel® Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. Software: CentOS 7.4; Intel® Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel® C++ Compiler XE 18.0.2.199 for Linux*; Intel® Fortran Compiler XE 18.0.2.199 for Linux*

MPI Time	
65.48s	
7.72% of Elapsed Time	
MPI Imbalance	
54.44s	
6.42% Nof Elapsed Time	
TOP 5 MPI Functions	%
TOP 5 MPI Functions Wait	<u>%</u> 7.01
Wa <mark>it</mark>	7.01
Wait File_read_at_all	7.01

OpenMP Imbalance 29.60s 3.49% of Elapsed Time

APS HTML Report Breakdown – Memory Access

- Memory stalls measurement with breakdown by cache and DRAM
- Average DRAM Bandwidth⁽¹⁾
- NUMA ratio
- Intel[®] Xeon Phi[™]:
 - Back-end stalls with L2-demand access efficiency
 - Average DRAM AND MCDRAM Bandwidth ⁽¹⁾

(1) Average DRAM and MCDRAM bandwidth collection is available with Intel driver or perf system wide monitoring enabled on a system

Configuration Information - See Configuration Details

Hardware: Intel[®] Xeon[®] Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel[®] Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. **Software**: CentOS 7.4; Intel[®] Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel[®] C++ Compiler XE 18.0.2.199 for Linux*; Intel[®] Fortran Compiler XE 18.0.2.199 for Linux*

Optimization Notice Copyright © 2018, Intel Corporation. All rights reserved. *Other names and brands may be claimed as the property of others. Memory Stalls 74.64% of pipeline slots



Cache Stalls 8.92% of cycles

DRAM Stalls 43.01% of cycles

Average DRAM Bandwidth 144.31 CB/s

NUMA 0.10% of remote accesses

(intel)

Xeon Phi⁻ Processor

Back-End Stalls 35.00% ▶ of pipeline slots

> L2 Hit Bound 13.85% ► of cycles



Average DRAM Bandwidth 3.59 GB/s

Average MCDRAM Bandwidth 102.69 GB/s



APS HTML Report Breakdown – vectorization

FPU Utilization based on HW-event statistics with

- Breakdown by vector/scalar instructions
- Floating point vs memory instruction ratio

Intel[®] Xeon Phi[™]: SIMD Instr. per Cycle

Scalar vs. vectorized instructions

Configuration Information - See <u>Configuration Details</u> Hardware: Intel® Xeon® Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel® Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. **Software**: CentOS 7.4; Intel® Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel® C++ Compiler XE 18.0.2.199 for Linux*; Intel® Fortran Compiler XE 18.0.2.199 for Linux*

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FPU Utilization

1.90%

SP FLOPs per Cycle 1.21 Out of 64.00



FP Instruction Mix

% of <u>Packed FP Instr.</u>: 55.51% % of <u>128-bit</u>: 0.02% % of <u>256-bit</u>: 0.66% % of <u>512-bit</u>: 54.81% % of Scalar FP Instr.: <u>44.49%</u>▶

FP Arith/Mem Rd Instr. Ratio 0.81

FP Arith/Mem Wr Instr. Ratio 3.05

SIMD Instr. per Cycle 0.13

FP Instruction Mix

(Intel)

Xeon Phi⁻ Processor

% of Packed SIMD Instr.: 64.60% % of Scalar SIMD Instr.: 35.40%



TESTING WITH GTC-P AND WRF

About WRF

Weather Research and Forecasting Model

- Mesoscale numerical weather prediction using Finite Differences
- Operational model at National Centers for Environmental Prediction (NCEP)
- Parallelized using MPI and OpenMP*

Tested configurations

- ASRC test case, limited to 10 minute evolution.
- Pnetcdf build without tiling.
- Timings from "Timing for main" in rsl output files, discarding input read at step 1.
- Hybrid build of version 3.8.1 Using Intel[®] Compiler 2018.2 and Intel[®] MPI Library 2018.2

https://www.mmm.ucar.edu/weather-research-and-forecasting-model



Typical HTML Report for WRF

Application Performance Snapshot Main bottleneck Application: wrf.exe identified and next Report creation date: 2018-08-13 21:05:57 Your application is memory bound. Number of ranks: 64 Ranks per node: 2 Use memory access analysis tools like Intel® VTune™ Amplifier for a detailed metric steps suggested OpenMP threads per rank: 24 breakdown by memory hierarchy, memory bandwidth, and correlation by memory HW Platform: Intel(R) Xeon(R) Processor code named Skylake Logical Core Count per node: 96 objects. Collector type: Event-based counting driver Delta Current run Target <10% MPI.Time 7.72% 848.30s OpenMP Imbalance 3.49% 74.64% ▲ <20% Memory Stalls Elapsed Time **FPU Utilization** 1.90% >50% 0.00% <10% High BW use and high stalls I/O Bound 3873.13 2.32 - Bad SP GFLOPS CPI (MAX 2.48, MIN 2.11) Negligible remote accesses **OpenMP** Imbalance **MPI** Time Memory Stalls FPU Utilization 74.64% of pipeline slots 65.48s 29.60s 1.90%N - Good 7.72% of Elapsed Time 3.49% of Elapsed Time Cache Stalls SP FLOPs per Cycle MPI Imbalance 8.92% of cycles 1.21 Out of 64.00 54.44s Memory Footprint DRAM Stalls Vector Capacity Usage 6.42% ▶ of Elapsed Time 43.01% ▶ of cycles 58.08% Resident PFAK AVG TOP 5 MPI Functions % Average DRAM Bandwidth FP Instruction Mix Per Wait 7.01 25752.69 MB 25706.12 MB 144.31 GB/s % of Packed FP Instr.: 55.51% node: Only 50% SIMD -File_read_at_all 0.37 % of 128-bit: 0.02% Per rank: 12897.27 MB 12853.06 MB NUMA % of 256-bit: 0.66% Isend 0.11 0.10% of remote accesses Secondary area of % of 512-bit: 54.81% 0.07 Virtual PFAK AVG Irecv % of Scalar FP Instr.: 44.49% 0.06 Per Init improvement 53049.77 MB 53012.81 MB FP Arith/Mem Rd Instr. Ratio node 0.81 Per rank: 26533.12 MB 26506.41 MB I/O Bound FP Arith/Mem Wr Instr. Ratio (intel 0.00% (AVG 0.00, PEAK 0.03)

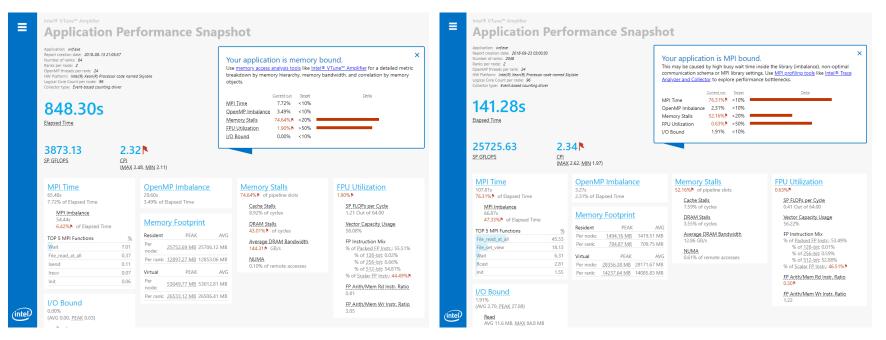
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Characteristics Change at Scale



Configuration Information - See Configuration Details

Hardware: Intel® Xeon® Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel® Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. Software: CentOS 7.4; Intel® Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel® C++ Compiler XE 18.0.2.199 for Linux*; Intel® Fortran Compiler XE 18.0.2.199 for Linux*

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Rank to Rank Communication Report (WRF)



Intel® VTune™ Amplifier



Full summary report can be generated with command ./aps-report -g path_to_aps_results_folder

A rank-to-rank communication heatmap based on aggregated communication time can be generated

Many other reports are available in postprocessing from the command line

- Message Size Summary
- MPI Time per Rank
- Collective Communications

Configuration Information - See Configuration Details

Hardware: Intel[®] Xeon[®] Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel[®] Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. **Software**: CentOS 7.4; Intel[®] Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel[®] C++ Compiler XE 18.0.2.199 for Linux*; Intel[®] Fortran Compiler XE 18.0.2.199 for Linux*



About GTC-P

Gyrokinetic Toroidal Code - Princeton

- Highly scalable Particle-In-Cell code solving 5D Vlasov-Poisson
- Run on many TOP 10 systems
- Parallelized with MPI and OpenMP*
- No external library dependencies
- Designed with architectural flexibility in mind

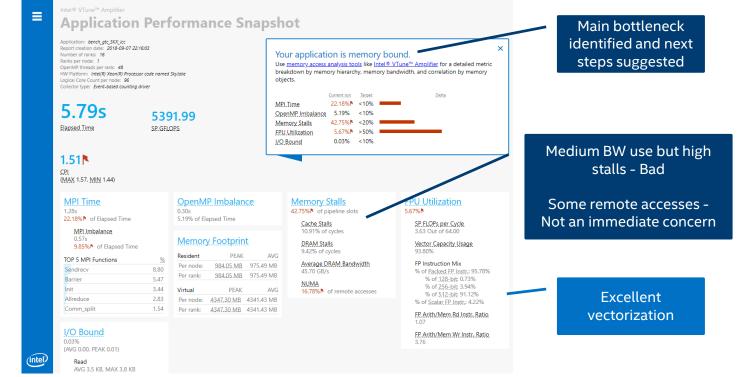
Tested configurations

- Standard benchmark workloads
 - 16 Nodes A.txt 100 16
 - 64 Nodes B.txt 100 16
 - 256 Nodes C.txt 100 16
 - 1024 Nodes D.txt 100 16
- Timings from "Total_time" in standard output.
- Hybrid build using Intel[®] Compiler 2018.2 and Intel[®] MPI Library 2018.2.

https://extremescaleglobalpic.princeton.edu/gtcp



Typical HTML Report for GTC-P



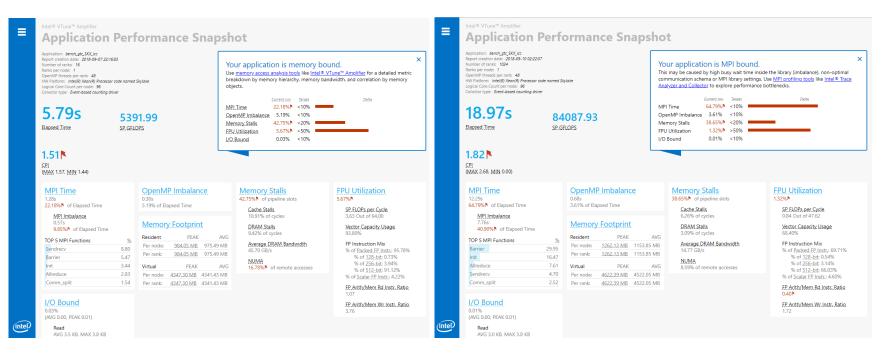
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Characteristics Change at Scale



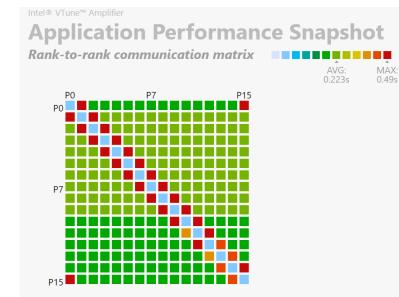
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Rank to Rank Communication Report (GTC-P)



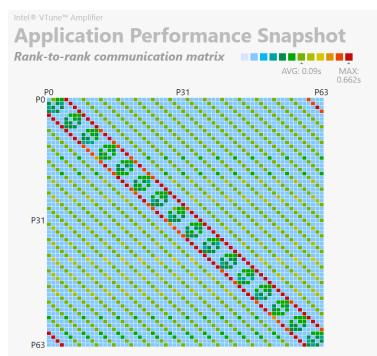
Full summary report can be generated with command ./aps-report -g path_to_aps_results_folder

Configuration Information - See Configuration Details

Hardware: Intel[®] Xeon[®] Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel[®] Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. **Software**: CentOS 7.4; Intel[®] Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel[®] C++ Compiler XE 18.0.2.199 for Linux*; Intel[®] Fortran Compiler XE 18.0.2.199 for Linux*

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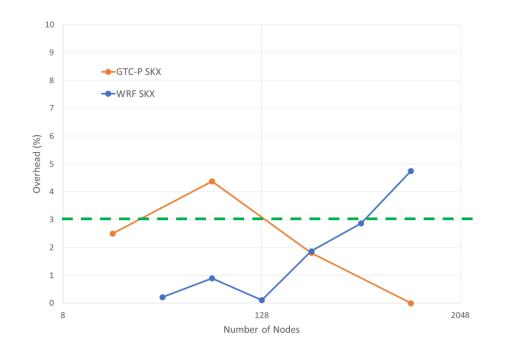
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Overhead for GTC-P and WRF on Intel[®] Xeon[®] Scalable processor (Skylake)



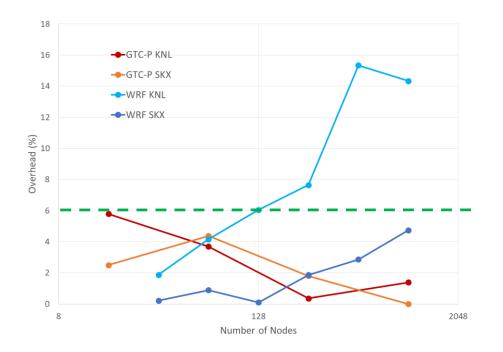
Most collections show average overhead below 3%

Suspect IO related issues on large scale WRF runs influence overhead

Configuration Information - See <u>Configuration Details</u> Hardware: Intel® Xeon® Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel® Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. **Software**: CentOS 7.4; Intel® Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel® C++ Compiler XE 18.0.2.199 for Linux*; intel® Fortran Compiler XE 18.0.2.199 for Linux*

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Overhead for GTC-P and WRF on Intel[®] Xeon[®] Scalable processor (Skylake) and Intel[®] Xeon Phi[™] (KNL)



Most collections show average overhead below 6%

Suspect IO related issues on large scale WRF runs influence overhead

Configuration Information - See <u>Configuration Details</u> Hardware: Intel® Xeon Phi™ CPU 7250 @ 1.40GHz; 96 GB DDR4 RAM, configured in Cache-Quadrant mode (KNL). Intel® Xeon® Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel® Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription.

Software: CentOS 7.4; Intel® Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel® C++ Compiler XE 18.0.2.199 for Linux*; intel® Fortran Compiler XE 18.0.2.199 for Linux*

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Collection Control API (2018 Update 2 and Newer)

To measure a particular application phase or exclude initialization/finalization the following control API calls may be used

MPI applications:

- Pause: MPI_Pcontrol(0)
- Resume: MPI_Pcontrol(1)

Non-MPI applications:

- Pause: __itt_pause()
- Resume: __itt_resume()

Use aps "-start-paused" option to start application without profiling and skip initialization phase





- Application Performance Snapshot provides overall program performance characteristics with moderate overhead and no configuration requirements
- Simple presentation provides simple means for tracking performance changes with scale and code modifications.
- Overhead for production workloads on Intel[®] Xeon[®] Scalable processors (Skylake) is typically below 3% and on Intel[®] Xeon Phi[™] (KNL) typically below 6%
- Instances of high overhead (over 5% on Skylake, over 15% on KNL) have been observed and required further investigation
- Also, I need larger workloads to run at 1k nodes...

Configuration Information - See Configuration Details

Hardware: Intel® Xeon® Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake/SKX). Intel® Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription. Software: CentOS 7.4; Intel® Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel® C++ Compiler XE 18.0.2.199 for Linux*; Intel® Fortran Compiler XE 18.0.2.199 for Linux*

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25

Configuration Details

Hardware:

Intel[®] Xeon Phi[™] CPU 7250 @ 1.40GHz; 96 GB DDR4 RAM, configured in Cache-Quadrant mode (KNL). Intel[®] Xeon[®] Platinum 8160 @ 2.1 GHz; 192 GB DDR4 RAM (Skylake). Intel[®] Omni-Path Host Fabric Interface, fat tree topology with 28/20 oversubscription.

Software: CentOS 7.4; Intel[®] Fabric Software 10.6.1.0.2; MPI Library 2018 Update 2; Intel[®] C++ Compiler XE 18.0.2.199 for Linux*; Intel[®] Fortran Compiler XE 18.0.2.199 for Linux*

Runtime (WRF):

- 2 MPI ranks / Node and 24 threads per rank (Skylake)
- 4 MPI Ranks / Node and 16 threads per rank (KNL)

Runtime (GTC-P):

- 1 MPI rank / node and 48 threads per rank (Skylake)
- 1 MPI rank / node and 128 threads per rank (KNL)



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The benchmark results reported above may need to be revised as additional testing is conducted. The results depend on the specific platform configurations and workloads utilized in the testing, and may not be applicable to any particular user's components, computer system or workloads. The results are not necessarily representative of other benchmarks and other benchmark results may show greater or lesser impact from mitigations.

Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark and MobileMark, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. For more complete information visit <u>www.intel.com/benchmarks</u>.

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Software