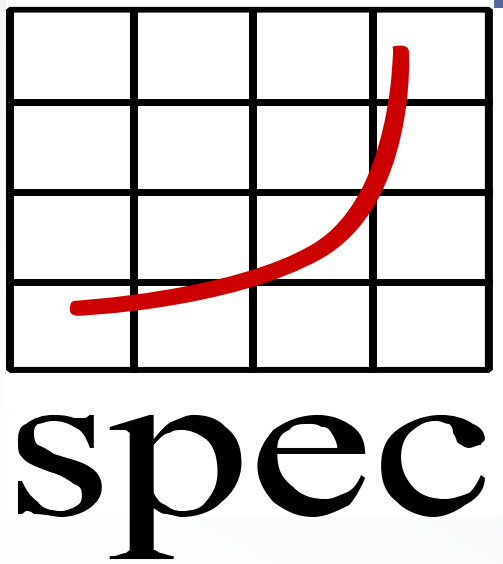
Using the new SPEChpc 2021 Scientific Application Benchmark Suite

Sunita Chandrasekaran, Robert Henschel, Junjie Li, Verónica G. Melesse Vergara



https://www.spec.org/hpg/publications

https://www.olcf.ornl.gov/sc20-spec-hpg-tutorial/

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Tutorial Overview

- Overview of SPEC and SPEC HPG (30 min)
- Benchmark selection and porting process (15 min)
- How to use SPEC benchmark results for decision making? (45 min)
- How to get and setup the HPC2020 benchmarks (15 min)
- Break (30 min)
- How to interpret and publish SPEC benchmark results (20 min)
- Hands-On (30 min)
- Conclusion and Wrap-Up (10 min)

Tutorial website:
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Overview of SPEC and the SPEC High Performance Group

Sunita Chandrasekaran, Robert Henschel, Junjie Li,
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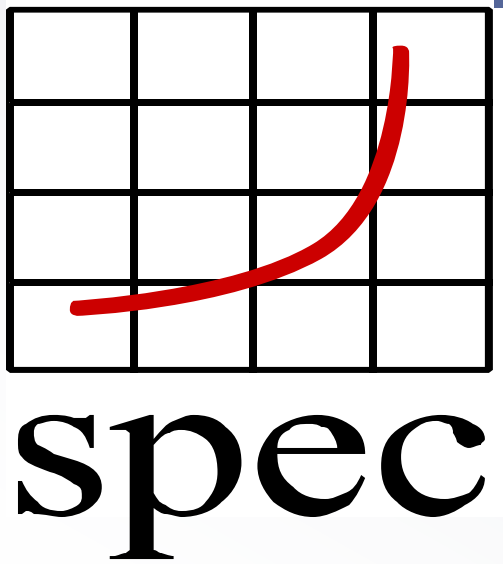

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Contents

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Why SPEC benchmarks?

- Let's take a quick look at a published SPEC result: https://www.spec.org/mpi2007/results/res2017q4/mpi2007-20171011-00580.html

More details will be discussed in later sections.

- How much information can you obtain for other benchmark results?

- Benchmark reports contain critical **details for reproducibility**.
- Published SPEC results are **peer-reviewed**.
- All benchmarks are based on **real applications.**
- Rich database of published results.

- *You will discover more details in this tutorial*

Results Table

Benchmark	Base							Peak						
	Ranks	Seconds	Ratio	Seconds	Ratio	Seconds	Ratio	Ranks	Seconds	Ratio	Seconds	Ratio	Seconds	Ratio
104.milc	640	15.4	102	14.9	105	**14.9**	**105**							
107.leslie3d	640	34.1	153	33.2	157	**33.4**	**156**							
113.GemsFDTD	640	187	33.8	**186**	**33.8**	186	33.9							
115.fds4	640	23.3	83.9	22.8	85.6	**23.2**	**84.0**							
121.pop2	640	77.5	53.2	**77.5**	**53.3**	77.3	53.4							
122.tachyon	640	31.4	89.0	**31.5**	**88.9**	32.1	87.2							
126.lammps	640	90.3	32.3	89.6	32.5	**89.7**	**32.5**							
127.wrf2	640	29.5	264	30.2	258	**29.6**	**264**							
128.GAPgeofem	640	8.10	255	8.31	249	**8.28**	**249**							
129.tera_tf	640	22.1	125	22.5	123	**22.3**	**124**							
130.socorro	640	30.7	124	**31.1**	**123**	31.8	120							
132.zeusmp2	640	19.8	157	**19.7**	**158**	19.7	158							
137.lu	640	19.1	192	18.9	195	**19.0**	**193**							

Results appear in the order in which they were run. Bold underlined text indicates a median measurement.

Hardware Summary

Type of System:	Homogeneous
Compute Node:	HPE XA730i Gen10 Server Node
Interconnect:	InfiniBand (MPI and I/O)
File Server Node:	Lustre FS
Total Compute Nodes:	16
Total Chips:	32
Total Cores:	640
Total Threads:	1280
Total Memory:	3 TB
Base Ranks Run:	640
Minimum Peak Ranks:	--
Maximum Peak Ranks:	--

Software Summary

C Compiler:	Intel C Composer XE for Linux, Version 18.0.0.128 Build 20170811
C++ Compiler:	Intel C++ Composer XE for Linux, Version 18.0.0.128 Build 20170811
Fortran Compiler:	Intel Fortran Composer XE for Linux, Version 18.0.0.128 Build 20170811
Base Pointers:	64-bit
Peak Pointers:	Not Applicable
MPI Library:	HPE Performance Software - Message Passing Interface 2.17
Other MPI Info:	OFED 3.2.2
Pre-processors:	None
Other Software:	None

Node Description: HPE XA730i Gen10 Server Node

Hardware

Number of nodes:	16
Uses of the node:	compute
Vendor:	Hewlett Packard Enterprise
Model:	SGI 8600 (Intel Xeon Gold 6148, 2.40 GHz)
CPU Name:	Intel Xeon Gold 6148
CPU(s) orderable:	1-2 chips
Chips enabled:	2
Cores enabled:	40
Cores per chip:	20
Threads per core:	2
CPU Characteristics:	Intel Turbo Boost Technology up to 3.70 GHz
CPU MHz:	2400
Primary Cache:	32 KB I + 32 KB D on chip per core
Secondary Cache:	1 MB I+D on chip per core

Software

Adapter:	Mellanox MT27700 with ConnectX-4 ASIC
Adapter Driver:	OFED-3.4-2.1.8.0
Adapter Firmware:	12.18.1000
Operating System:	Red Hat Enterprise Linux Server 7.3 (Maipo), Kernel 3.10.0-514.2.2.el7.x86_64
Local File System:	LFS
Shared File System:	LFS
System State:	Multi-user, run level 3
Other Software:	SGI Management Center Compute Node 3.5.0, Build 716r171.rhel73-1705051353

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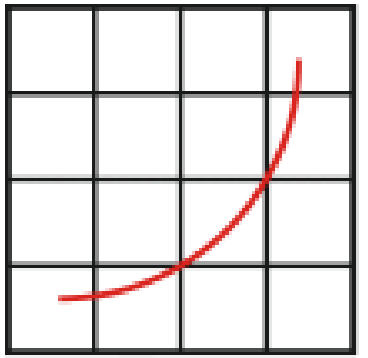
Standards Performance Evaluation Corporation (SPEC)

- **SPEC** is a non-profit corporation formed in 1988 to establish, maintain and endorse standardized benchmarks and tools to evaluate performance and energy efficiency for the newest generation of computing systems.
- Composed of four groups
  - Graphics and Workstation Performance Group (GWPG)
  - High Performance Group (HPG)
  - Open Systems Group (OSG)
  - Research Group (RG)
- https://www.spec.org
- https://www.spec.org/hpg/



spec®

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Largest & Oldest Group
- Cloud
- CPU
- Java
- Power
- Virtual Machine
- File Server

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HPC benchmarks
- MPI
- OpenMP
- Accelerator
  - OpenCL
  - OpenACC
  - OpenMP 4.5

SPEC Members

132 member organizations as of July-2019, including:

- 95 companies
- 37 academic institutions

Standard Performance Evaluation Corporation

Home | Benchmarks | Tools | Results | Contact | Site Map | Search | Help

Benchmarks
- Cloud
- CPU
- Graphics/Workstations
- ACCEL/MPI/OMP
- Java Client/Server
- Mail Servers
- Storage
- Power
- Virtualization
- Web Servers

Results Search

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SPECapc/SPECviewperf/SPECwpc

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SPEC
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HPG
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- Membership
Member organizations

The SPEC Consortium: Members and Associates

SPEC Members:

*Acer Inc. * Action S.A. * Advanced Micro Devices * Amazon Web Services, Inc. * Apple Inc. * ARM * Avere Systems * Bull SAS * Cavium Inc. * Ciara Technologies Inc. * Cisco Systems, Inc. * Dell, Inc. * Digital Ocean * E4 Computer Engineering SPA * Fujitsu * Gartner, Inc. * Guizhou Huaxintong Semiconductor Technology Co. Ltd * Hitachi Data Systems * Hitachi Ltd. * Hewlett Packard Enterprise * HP Inc. * Huawei Technologies Co. Ltd. * IBM * Inspur Corporation * Intel * Lenovo * M Computers s.r.o. * Microsoft * NEC - Japan * NetApp * New H3C Technologies Co., Ltd. * NVIDIA * Oracle * OVH SAS * Primary Data * Principled Technologies * Pure Storage * Qualcomm Technologies Inc. * Quanta Computer Inc. * Red Hat * Samsung * SAP AG * Seagate * Sugon * Super Micro Computer, Inc. * SUSE * Taobao (China) Software Co. Ltd. * Unisys * Veritas Technologies * Via Technologies * VMware * WekaIO *

SPEC Associates:

*Acadamia Sinica, Institute of Information Science * Argonne National Laboratory * Charles University * China Academy of Telecommunication Research * Dresden University of Technology ZIH * fortiss GmbH * Helmholtz-Zentrum Dresden Rossendorf (HZDR) * Indiana University * JAIST * Karlsruhe Institute of Technology * Leibniz Rechenzentrum - Germany * Linaro Limited * National University of Singapore * Oak Ridge National Laboratory * Ohio State University * Pennsylvania State University * Purdue University * RWTH Aachen University * Technische Universität Darmstadt * Technische Universität Dresden * Telecommunications Technology Association * Tsinghua University * University of Aizu - Japan * University of Basel * University of California - Berkeley * University of Cologne * University of Delaware * University of Illinois at Urbana-Champaign * University of Maryland * University of Miami * University of Texas at Austin * University of Tsukuba * University of Wuerzburg * Virginia Polytechnic Institute and State University *

SPEC Research Group:

*Advanced Strategic Technology LLC * Apple Inc. * ARM * bankmark UG * Barcelona Supercomputing Center * BEZNet * Charles University * Cisco Systems * Cloudera, Inc * Compilaflows * Delft University of Technology * Dell * Escuela Superior Politecnica del Litoral * fortiss GmbH * Friedrich-Alexander-University Erlangen-Nuremberg * Goethe University Frankfurt, Big Data Lab * Hewlett Packard Enterprise * Huawei * IBM * Imperial College London * Institute for Information Industry, Taiwan * Intel * Karlsruhe Institute of Technology * Kiel University * Linkoping University * Lund University * Microsoft * NICTA * NovaTec Consulting GmbH * Oracle * Purdue University * Queen's University * Red Hat * RETIT GmbH * RWTH Aachen University * SalesForce.com * San Diego Supercomputing Center * San Francisco State University * SAP AG * Stiftung University * SINTEF * Software Performance and Scalability Consulting * Tata Consultancy Services * Technica Corporation * Technische Universität Darmstadt * Technische Universität Dresden * The MITRE Corporation * Umea University * University of Alberta * University of Coimbra * University of Lugano * University of Minnesota * University of North Florida * University of Paderborn * University of Stuttgart * University of Texas at Austin * University of Wuerzburg * University Politehnica of Bucharest * VMware * York University *

To learn about SPEC Membership, please read the SPEC FAQ.

SPEC High Performance Group (HPG)

HPG develops benchmarks for high-performance computing systems, using real world applications.

- 33 member organizations as of November 2020
- 11 companies
- 22 academic

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SPEC Benchmark Philosophy

- The result of a SPEC benchmark suite is always a SPEC score.
  - Higher is better
  - Some benchmarks also have a power score, in addition to a performance score

- This score is always in relation to a reference machine.
  - Each benchmark has its own reference machine

SPEC Benchmark Philosophy cont'd

- SPEC (HPG) benchmarks are full applications.
  - Including all the overhead of a real application
- SPEC harness ensures correctness of results.
  - To detect "overly aggressive optimization"
  - To guard against tampering
- Each benchmark suite has a set of run rules.
- Benchmarks support "Base" and "Peak" configuration
  - These yield separate SPEC scores.

SPEC Power

- SPEC provides a standard methodology to measure and report power usage which can be incorporated into a SPEC benchmark.
- Normalizes the power usage across the full run of the suite


```
me,03-10-2014 14:14:20.458,Watts,308.159000,Volts,120.442000,Amps,2.633360,PF,0.971602
me,03-10-2014 14:14:21.457,Watts,308.196000,Volts,120.513000,Amps,2.632220,PF,0.971564
me,03-10-2014 14:14:22.458,Watts,308.445000,Volts,120.520000,Amps,2.634020,PF,0.971622
me,03-10-2014 14:14:23.458,Watts,308.497000,Volts,120.530000,Amps,2.634310,PF,0.971602
me,03-10-2014 14:14:24.457,Watts,308.460000,Volts,120.521000,Amps,2.634150,PF,0.971614
-10-2014 14:14:29.833: Response to client sent: Time,03-10-2014 14:14:25.458,Watts,308.751000,Volts,120.
1000,Amps,2.636360,PF,0.971645
me,03-10-2014 14:14:26.458,Watts,308.834000,Volts,120.519000,Amps,2.637210,PF,0.971678
me,03-10-2014 14:14:27.457,Watts,308.958000,Volts,120.524000,Amps,2.638180,PF,0.971677
me,03-10-2014 14:14:28.458,Watts,309.092000,Volts,120.529000,Amps,2.639180,PF,0.971690
-10-2014 14:14:52.250: Go with mark '304.olbm'
-10-2014 14:14:52.250: Response to client sent: Starting untimed measurement, maximum 500000 samples at
00ms with 0 rampup samples
-10-2014 14:14:52.747,Watts,163.014000,Volts,120.827000,Amps,1.417630,PF,0.951701,Mark,304.olbm
-10-2014 14:14:53.746,Watts,153.447000,Volts,120.836000,Amps,1.336960,PF,0.949820,Mark,304.olbm
-10-2014 14:14:54.747,Watts,166.402000,Volts,120.858000,Amps,1.457690,PF,0.944537,Mark,304.olbm
-10-2014 14:14:55.747,Watts,199.812000,Volts,120.779000,Amps,1.730290,PF,0.956115,Mark,304.olbm
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-10-2014 14:14:58.747,Watts,265.822000,Volts,120.550000,Amps,2.282260,PF,0.966183,Mark,304.olbm
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-10-2014 14:15:01.747,Watts,261.673000,Volts,120.550000,Amps,2.252590,PF,0.963624,Mark,304.olbm
-10-2014 14:15:02.746,Watts,266.597000,Volts,120.577000,Amps,2.288130,PF,0.966299,Mark,304.olbm
```

Result Submission Process

- Perform a valid run
- Supply hardware and software description
- Submit result to SPEC HPG for review (and publication)
  - 2 week review process
- Use the published result as you like, respecting the SPEC fair use guidelines.
  (you can access the results even if you are not a member)

The Value of a Curated Result Repository

- Given appropriate hardware…. a published result should be reproducible just with the information available in the submission.
- Peer reviewed results are so much better than “everyone can upload a result”!
- The value of a benchmark suite lies in public results, their correctness and the ability to compare them.

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SPEC CPU – Not an HPG Benchmark!!

- SPEC CPU (2006 and 2017) is the most well known SPEC benchmark.
- Created by the Open Systems Group of SPEC
- HPG uses the same framework, if you are familiar with running SPEC CPU, you can run SPEC HPG benchmarks (And the other way around!).

SPEC OMP2012

- Follow on to SPEC OMP2001
- 14 applications
- Scales up to 512 threads
- **Support for power measurement**

- Citation:

Matthias S. Müller, John Baron, William C. Brantley, Huiyu Feng, Daniel Hackenberg, Robert Henschel, Gabriele Jost, Daniel Molka, Chris Parrott, Joe Robichaux, Pavel Shelepugin, Matthijs van Waveren, Brian Whitney, and Kalyan Kumaran. 2012. **SPEC OMP2012 -- an application benchmark suite for parallel systems using OpenMP**. In Proceedings of the 8th international conference on OpenMP in a Heterogeneous World (IWOMP'12), Barbara M. Chapman, Federico Massaioli, Matthias S. Müller, and Marco Rorro (Eds.). Springer-Verlag, Berlin, Heidelberg, 223-236. DOI=http://dx.doi.org/10.1007/978-3-642-30961-8_17

SPEC OMP2012

Code	Memory MB	LOC	Language	OMP call sites	OMP direc-tives	Area
350.md	5	1,768	Fortran	14	3	Molecular Dynamics
351.bwaves	22,800	876	F77	29	1	Computational Fluid Dynamics
352.nab	618	11,485	C	60	5	Molecular Modeling
357.bt331	11,188	2,331	Fortran	44	5	Computational Fluid Dynamics
358.botsalgn	156	1,277	C	4	3	Sequence Alignment
359.botsspar	7,179	209	C	8	4	LU factorization
360.ilbdc	16,482	978	Fortran	7	1	Lattice Boltzmann
362.fma3d	5,205	19,681	F90	142	5	Finite Element Method
363.swim	6,490	212	Fortran	14	3	Finite Difference
367.imagick	1,733	96,810	C	312	6	Image Processing
370.mgrid331	13,972	806	Fortran	20	5	Multi-Grid Solver
371.applu331	14,884	1,782	Fortran	81	9	PDE/SSOR
372.smithwa	177	2,561	C	22	3	Optimal Pattern Matching
376.kdtree	119	287	C++	4	3	Sorting and Searching

SPEC ACCEL

- SPEC Accel provides a comparative performance measure of
  - Hardware accelerator devices (GPU, Co-processors, etc.)
  - Supporting software tool chains (Compilers, Drivers, etc.)
  - Host systems and accelerator interface (CPU, PCIe, etc.)
- Computationally-intensive parallel HPC applications and mini-apps
- Portable across multiple accelerators
- Three distinct benchmarks
  - OpenACC
  - OpenCL
  - OpenMP 4.5 (first OpenMP 4.x benchmark supporting target offload)
- **Support for power measurement**

SPEC MPI2007

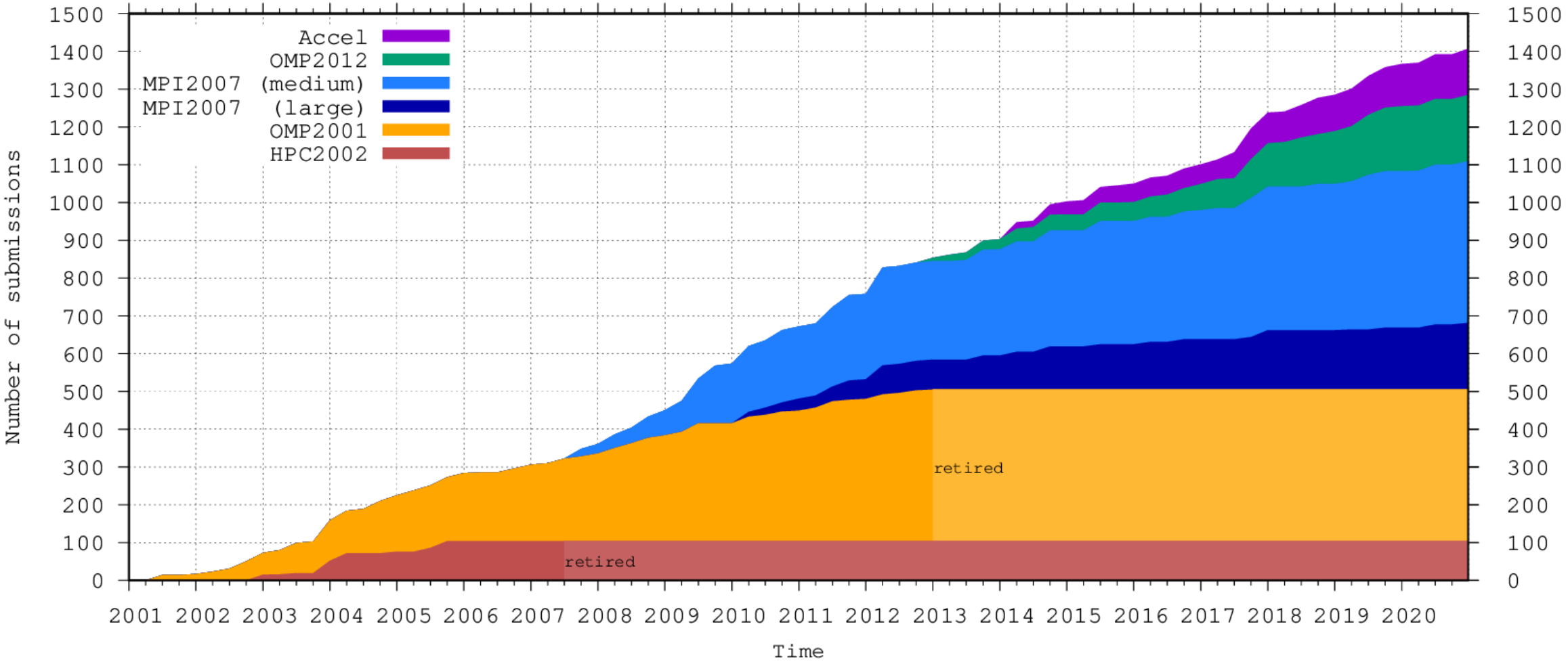
- Large and medium data set
- 13 applications
- Scales to 2048 MPI processes
- Power not supported

- Citation:

SPEC MPI2007 -- an application benchmark suite for parallel systems using MPI, Matthias S. Müller Matthijs van Waveren Ron Lieberman Brian Whitney Hideki Saito Kalyan Kumaran John Baron William C. Brantley Chris Parrott Tom Elken Huiyu Feng Carl Ponder, Special Issue: International Supercomputing Conference 2007 – Concurrency and Computation, https://doi.org/10.1002/cpe.1535

Result Submissions by Benchmark

- 1400+ published results, include all latest hardware
- Rich database for performance study



Result Submissions by Benchmark

Most active result submitters:

245	Intel Corporation
173	SGI
148	Indiana University
77	Lenovo Global Technology
35	Technische Universität Dresden
29	Huawei
25	HPE
23	NVIDIA Corporation
21	RWTH University Aachen

Join and Contribute

- Submit results
- Become a member ($800 for academic member)
- Contribute benchmark components
- Help with benchmark suite development
- Test release candidates

SPEChpc 2021 - Benchmark selection and porting process

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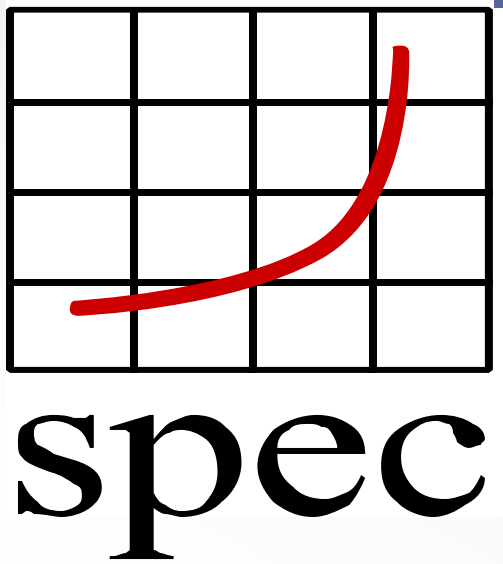

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The new benchmark: SPEChpc 2021

- The State of SPEChpc 2021
- Benchmark Development Process

The State of SPEChpc 2021

- BETA version available to license holders of other SPEC HPG benchmarks today.
- Final release expected in the first half of 2021.
- Hands on later in the tutorial will include SPEChpc 2021.
- Timeline
  - Search program from May to December 2017
  - SPEC internal development 2018 to October 2020
  - Beta release November 2020
  - Final release first half of 2021

The State of SPEChpc 2021

- Leverage SPEC infrastructure and SPEC office, for development and sustainability.
- Strong scaling benchmark, with very ambitious scaling targets.
- Support for 4 parallel models across all applications and workloads.
- Broad support for relevant hardware and software platforms.

SPEChpc 2021 – Parallel Models

- MPI
  - MPI 3.1
- MPI+OpenMP
  - "traditional" OpenMP 3.1 for parallelism across a multi-core CPUs. Specify as many or as few threads per MPI rank as needed.
- MPI+OpenMP with Target Offload
  - OpenMP 5.0 with "target" directives, supported on very different hardware depending on compiler.
- MPI+OpenACC
  - OpenACC 2.7 directives, supported on very different hardware depending on compiler.

SPEChpc 2021 – Candidate Benchmarks

SPEChpc 2021 Candidate Benchmarks	Domain	Language
LBM D2Q37	CFD	C
PIConGPU	Plasma Physics particle-cell-simulation	C++11
PALM	CFD, atmospheric science	Fortran
SOMA	physics of soft matter	C
TeaLeaf	High energy physics	C/C++
CloverLeaf	High energy physics	Fortran
MiniSweep	nuclear engineering	C
POT3D	Solar Physics	Fortran
SPH-EXA	Astro-physics	C++
HPGMG-FV	Multigrid Solver used in Astro-Physics, Combustion	C
miniWeather	Weather modeling	Fortran

Benchmark candidates will change between beta and final release!

Benchmark Development Process

- Group effort, with lots of discussions.
- Final decisions are by vote, even though we strive for consensus.
- If there is no global pandemic going on, members meet in person multiple times a year.
- Weekly telephone conferences.
- Diverse expertise within the group: compiler developers and support, hardware vendors, operators of HPC centers, researchers of parallel models and optimizations, …

Details of the benchmark development process

- Step 1: Solicit applications and complete paperwork
- Step 2: Port applications into SPEC harness
  - “ifdef” platform/compiler specific code, create “test” workload, provide result checking code, create benchmark documentation
- Step 3: Create workloads
  - Supply workloads and show scalability. Reduce I/O and dependency on outside libraries,
- Step 4: Testing, Testing, Testing
  - Scalability, compilers, hardware platforms, parallel models, …
  - Run rules
- Step 5: Acceptance into the final benchmark

Thank you!

Questions?

Contact

SPEC Headquarters: info@spec.org