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Effect of Meltdown and Spectre Patches on the Performance of HPC Applications

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Abstract—In this work we examine how the updates addressing Meltdown and Spectre vulnerabilities impact the performance of HPC applications. To study this we use the application kernel module of XDMoD to test the performance before and after the application of the vulnerability patches. We tested the performance difference for multiple application and benchmarks including: NWChem, NAMD, HPCC, IOR, MDTest and IMB. The results show that although some specific functions can have performance decreased by as much as 74%, the majority of individual metrics indicates little to no decrease in performance. The real-world applications show a 2-3% decrease in performance for single node jobs and a 5-11% decrease for parallel multi node jobs.

Index Terms—HPC, Security, Performance

I. Introduction

The recently discovered Meltdown [1] and Spectre [2] vulnerabilities allow reading of process memory by other unauthorized processes. This poses a significant security risk on multi-user platforms including HPC resources that can result in the compromise of proprietary or sensitive information [1, 2]. Software patches released to mitigate the security vulnerabilities have the potential to significantly impact performance. According to Redhat [3] Linux OS remedies can degrade performance overall by 1-20%. In order to quantify the impact, particularly on HPC applications, we performed independent tests utilizing XDMoD's application kernel capability [4].

The XD Metrics on Demand (XDMoD) tool, which is designed for the comprehensive management of HPC systems, provides users, managers, and operations staff with access to utilization data, job and system level performance data, and quality of service data for HPC resources [5]. Originally developed to provide independent audit capability for the XSEDE program, XDMoD was later open-sourced and is widely used by university, government, and industry HPC centers [6]. The application kernel performance monitoring module of XDMoD [4] allows automatic performance monitoring of HPC resources through the periodic execution of application kernels, which are based on benchmarks or real-world

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applications implemented with sensible input parameters (see Figure 1 for web interface screen-shot).

Since the application kernels, which are computationally lightweight, are designed to run continuously on a given HPC system, they are ideal for detecting differences in application performance when system wide changes (hardware or software) are made. Accordingly, XDMoD's application kernels were employed here to determine if the software patches that mitigate the Meltdown and Spectre vulnerabilities significantly impact performance.

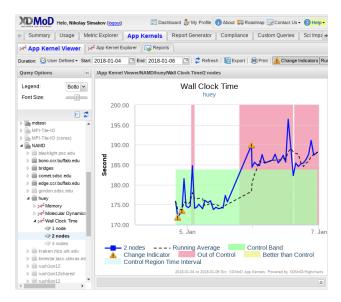


Fig. 1. Screen-shot of the application kernel performance monitoring module of XDMod showing the change in performance of NAMD executed on 2-nodes. The module automatically calculates control regions and performs an automatic detection of performance degradation and application environment changes.

II. METHODS

A. Selected Application Kernels

The following XDMoD application kernels were chosen for this test: NAMD [7], NWChem [8], HPC Challenge Benchmark suite (HPCC) [9] (which includes memory bandwidth micro-benchmark STREAM [10]

Application	Number of	Difference, %1	Are the means	Before Pat	ch Application	on	After Patch Application				
	Nodes	70	different? ²	Mean,	Standard Number		Mean,	Standard	Number		
	rtodes		different.	Seconds	Devi-	of Runs	Seconds	Devi-	of Runs		
					ation,			ation,			
					Seconds			Seconds			
NAMD	1	3.3	Y	306.6	1.44	24	316.9	3.05	56		
NAMD	2	6.9	Y	175.4	2.78	22	188.1	3.49	56		
NWChem	1	2.6	Y	77.8	1.91	23	79.9	1.11	59		
NWChem	2	10.7	Y	58.4	1.05	21	65.0	4.16	56		
HPCC	1	2.2	Y	304.1	6.39	23	310.9	4.88	56		
HPCC	2	5.3	Y	345.1	5.41	22	364.0	8.44	56		
IMB	2	4	Y	14.8	0.54	21	15.4	1.39	56		
IOR	1	3.9	Y	188.5	9.41	21	195.9	11.69	55		
IOR	2	1.5	N	371.1	12.23	22	376.7	19.50	56		
IOR.local	1	2.1	N	462.8	16.37	12	472.8	19.03	56		
MDTest	1	21.5	Y	30.5	3.17	21	37.8	4.10	56		
MDTest	2	9.3	Y	166.7	3.60	23	182.8	5.30	55		
MDTest.local	1	56.4	Y	3.8	0.62	12	6.7	2.61	56		

TABLE I
CHANGE IN WALLTIME UPON PATCH APPLICATION.

and the NASA parallel benchmarks (NPB)[11]), interconnect/MPI benchmarks (IMB) [12, 13], IOR [14] and MDTest [15]. The first two are based on widely used scientific applications and the others are based on commonly deployed benchmarks. Most of the application kernels were executed on one or two nodes, 8 and 16 cores respectively. For more details on application kernels refer to [4].

IOR and MDTest were executed on the parallel file system (GPFS) as well as the local file system. In order to differentiate between the two file systems, we use a ".local" suffix in the reported results when the local file system is used (e.g. IOR.local).

B. System

The tests were performed on a development cluster at the Center for Computational Research (CCR), SUNY, University at Buffalo. The cluster consists of eight nodes (8-cores, 24GiB RAM) with two Intel L5520 CPUs connected by QDR Mellanox Infiniband. The nodes have access to a 3 PB IBM GPFS storage system shared with other HPC resources in CCR. The operating system is CentOS Linux release 7.4.1708.

C. Patches

To fix the Meltdown and Spectre vulnerabilities a new kernel was installed. Specifically, kernel-3.10.0-693.5.2.el7.x86_64 was updated with kernel-3.10.0-693.11.6.el7.x86_64 which fixes CVE-2017-5753, CVE-2017-5715 and CVE-2017-5754 vulnerabilities.

D. Comparison of the Results

The tests were run prior to and after application of the vulnerability updates. The "before" tests include approximately 20 runs for most of the application kernels. The "after" tests include approximately 50 runs for all application kernels. The comparison of before and after distributions were determine using the Welch two sample, two sided, t-test with α parameter equal to 0.05. That is, we consider the means of two distributions to be different if the probability that such test results could be obtained from equal distributions is less than or equal to 0.05.

III. RESULTS AND DISCUSSION

Table I and Figure 2 show the change in walltime before and after the patches for the suite of application kernels employed in this study. For the compute intensive applications (NAMD, NWChem and HPCC), the performance degradation is around 2-3% for parallel single node jobs. However it increases to 5-11% for the case of two nodes.

IOR and MDTest benchmarks measure the performance of the file system. As discussed in the introduction, we tested both the parallel and local file systems. Tables IV and V show selected results for these tests. In both cases there is a significant decrease in performance for file meta-data operations (10-20%). However, the performance degradation for read and write operations is only in the range of 0-3%. Based on these findings, the performance degradation should be smaller for applications that use a small number of large files versus those that use a large number of small files. Data processing

¹ Differences are calculated as the new mean value minus the old mean value divided by the average of the two means. A larger difference indicates poorer performance after the patch.

² The Welch two sample, two sided, t-test with $\hat{\alpha} = 0.5$ was used to determine if the before and after test results were drawn from distributions with statistically significantly different means.

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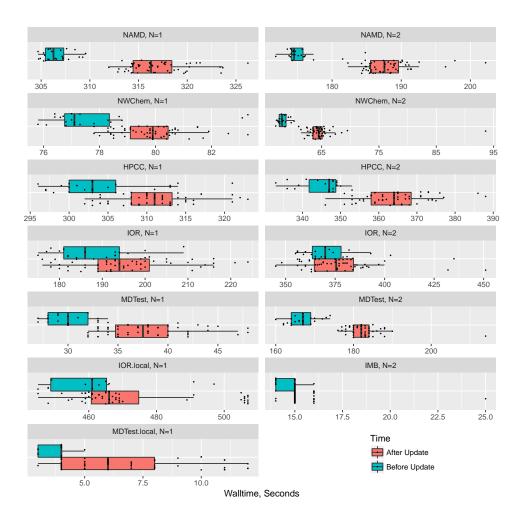


Fig. 2. Application kernel walltime comparisons before and after the updates. Box plot diagram is used to show sample statistics. Left side of the box, vertical line within the box and right side of the box show first quartile, medium and third quartile. In addition all measurements are plotted using round points.

applications may therefore be particularly sensitive to the patches employed to mitigate the vulnerabilities.

The IMB test shows that most reported metrics are degraded by more than by 2% (Table III).

The HPCC benchmark performs various tests from linear algebra, fast Fourier transformation (FFT) and memory manipulation. Interestingly the simple arrays manipulations (STREAM tests: arrays addition, copying and scaling) are actually faster in case of two nodes (Table II). However FFT, matrix manipulation and matrix transposition get slower. The surprising performance improvement in STREAM tests might be due to other changes in kernel. Anyway this improvement does not transfer to matrix manipulation and matrix transposition, which are 2% and 10% slower (two nodes).

IV. CONCLUSIONS AND FUTURE PLANS

Some of the individually measured simple metrics show a significant decrease in performance, notably MPI random access, memory copying and file metadata operations. Many other metrics show little to no change.

Overall the compute intensive single node applications have a moderate decrease in the performance around 2-3%. However, multi-node parallel jobs suffer a 5-11% decrease in performance. This can Probably be addressed in the compiler and MPI libraries.

These tests were executed in a relatively isolated environment. After the updates are applied on our production system we will perform additional tests with a larger number of nodes and for more application kernels.

V. ACKNOWLEDGEMENTS

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#	Application	Application Nodes Metric		Diff.,	Distr.	Before Patch Application			After Patch	Units		
				, ,	Different	Mean, Seconds	St.Dev., Seconds	Nruns	Mean, Seconds	St.Dev., Seconds	Nruns	
2	NAMD	1	Molecular Dynamics Simulation Performance	-3.5	TRUE	7.67E- 10	7.11E- 12	24	7.40E- 10	1.43E- 11	56	Second per Day
3	NAMD	1	Wall Clock Time	3.4	TRUE	3.07E+02	1.44E+00	24	3.17E+02	3.05E+00	56	Second
5	NAMD	2	Molecular Dynamics Simulation Performance	-6.6	TRUE	1.48E- 09	5.60E- 11	22	1.38E- 09	8.44E- 11	56	Second per Day
6	NAMD	2	Wall Clock Time	7.2	TRUE	1.75E+02	2.78E+00	22	1.88E+02	3.49E+00	56	Second
15	NWChem	1	User Time	1.1	TRUE	7.35E+01	7.36E- 01	23	7.43E+01	1.08E+00	59	Second
16	NWChem	1	Wall Clock Time	2.7	TRUE	7.78E+01	1.91E+00	23	7.99E+01	1.11E+00	59	Second
25	NWChem	2	User Time	10.2	TRUE	4.75E+01	8.37E- 01	21	5.23E+01	3.84E+00	56	Second
26	NWChem	2	Wall Clock Time	11.3	TRUE	5.84E+01	1.05E+00	21	6.50E+01	4.16E+00	56	Second
27	HPCC	1	Matrix Multiplication (DGEMM) Floating-Point Performance	-1.2	TRUE	8.50E+03	5.66E+01	23	8.40E+03	1.11E+02	56	MFLOP per Second
28	HPCC	1	Average STREAM 'Add' Memory Bandwidth	5	FALSE	3.17E+03	4.51E+02	23	3.33E+03	5.38E+02	56	MByte per Second
29	HPCC	1	Average STREAM 'Copy' Memory Bandwidth	3.4	FALSE	4.36E+03	4.96E+02	23	4.51E+03	5.61E+02	56	MByte per Second
30	HPCC	1	Average STREAM 'Scale' Memory Bandwidth	3.5	FALSE	2.95E+03	4.05E+02	23	3.05E+03	4.54E+02	56	MByte per Second
31	HPCC	1	Average STREAM 'Triad' Memory Bandwidth	8.8	TRUE	3.29E+03	5.01E+02	23	3.58E+03	6.68E+02	56	MByte per Second
32	HPCC	1	Fast Fourier Transform (FFTW) Floating-Point Performance	-5.9	TRUE	7.93E+03	5.55E+02	23	7.46E+03	1.50E+03	56	MFLOP per Second
33	HPCC	1	High Performance LINPACK Efficiency	-5.4	TRUE	9.26E+01	7.86E+00	23	8.76E+01	6.19E+00	56	Percent
34	HPCC	1	High Performance LINPACK Floating-Point Performance	-4.1	TRUE	6.18E+04	1.24E+03	23	5.93E+04	1.24E+03	56	MFLOP per Second
35	HPCC	1	High Performance LINPACK Run Time	4.3	TRUE	8.63E+01	1.88E+00	23	9.00E+01	1.97E+00	56	Second
36	HPCC	1	MPI Random Access	-23.3	TRUE	2.09E+00	8.59E- 02	23	1.61E+00	3.78E- 02	56	MUpdate per Second
37	HPCC	1	Parallel Matrix Transpose (PTRANS)	-12.3	TRUE	3.03E+03	4.37E+02	23	2.66E+03	8.46E+02	56	MByte per Second
38	HPCC	1	Wall Clock Time	2.2	TRUE	3.04E+02	6.39E+00	23	3.11E+02	4.88E+00	56	Second
39	HPCC	2	Matrix Multiplication (DGEMM) Floating-Point Performance	-2	TRUE	8.53E+03	4.22E+01	22	8.36E+03	9.18E+01	56	MFLOP per Second
40	HPCC	2	Average STREAM 'Add' Memory Bandwidth	14.1	TRUE	3.12E+03	2.91E+02	22	3.56E+03	6.40E+02	56	MByte per Second
41	HPCC	2	Average STREAM 'Copy' Memory Bandwidth	10.9	TRUE	4.35E+03	3.16E+02	22	4.82E+03	6.27E+02	56	MByte per Second
42	HPCC	2	Average STREAM 'Scale' Memory Bandwidth	13.8	TRUE	2.92E+03	3.09E+02	22	3.32E+03	5.95E+02	56	MByte per Second
43	HPCC	2	Average STREAM 'Triad' Memory Bandwidth	16.5	TRUE	3.21E+03	3.28E+02	22	3.75E+03	6.94E+02	56	MByte per Second
44	HPCC	2	Fast Fourier Transform (FFTW) Floating-Point Performance	-6.4	TRUE	1.23E+04	6.35E+02	22	1.16E+04	1.65E+03	56	MFLOP per Second
45	HPCC	2	High Performance LINPACK Efficiency	-12.4	TRUE	9.62E+01	1.01E+01	22	8.42E+01	7.16E+00	56	Percent
46	HPCC	2	High Performance LINPACK Floating-Point Performance	-8.6	TRUE	1.22E+05	4.85E+02	22	1.11E+05	2.75E+03	56	MFLOP per Second
47	HPCC	2	High Performance LINPACK Run Time	9.5	TRUE	1.24E+02	4.94E- 01	22	1.35E+02	3.42E+00	56	Second
48	HPCC	2	MPI Random Access	-54	TRUE	9.59E+00	3.29E- 01	22	4.41E+00	2.69E- 01	56	MUpdate per Second
49	HPCC	2	Parallel Matrix Transpose (PTRANS)	-9.6	TRUE	2.62E+03	1.87E+02	22	2.36E+03	3.44E+02	56	MByte per Second
	HPCC		Wall Clock Time		TRUE	3.45E+02	5.41E+00		3.64E+02	8.44E+00	U.	Second

 $\begin{tabular}{ll} TABLE III \\ Changes in selected measured metrics from IMB. \\ \end{tabular}$

#	Application Nodes		Metric	Diff.,	Distr. are	Before Pat	ch Application	on	After Patcl	h Application	1	Units
				,-	Different	Mean, Seconds	St.Dev., Seconds	Nruns	Mean, Seconds	St.Dev., Seconds	Nruns	
51	IMB	2	Max Exchange Bandwidth	0.2	FALSE	3.90E+03	3.60E+01	21	3.91E+03	6.30E+01	56	MByte per Second
52	IMB	2	Max MPI-2 Bidirectional 'Get' Bandwidth (aggregate)	-0.7	FALSE	1.99E+03	4.31E+01	21	1.98E+03	5.40E+01	56	MByte per Second
53	IMB	2	Max MPI-2 Bidirectional 'Get' Bandwidth (non- aggregate)	-2.8	TRUE	2.11E+03	5.71E+01	21	2.05E+03	4.68E+01	56	MByte per Second
54	IMB	2	Max MPI-2 Bidirectional 'Put' Bandwidth (aggregate)	0.4	FALSE	2.05E+03	6.51E+01	21	2.06E+03	3.02E+01	56	MByte per Second
55	IMB	2	Max MPI-2 Bidirectional 'Put' Bandwidth (non- aggregate)	-1.7	TRUE	2.12E+03	3.61E+01	21	2.08E+03	4.37E+01	56	MByte per Second
56	IMB	2	Max MPI-2 Unidirectional 'Get' Bandwidth	-0.1	FALSE	3.10E+03	1.45E+01	21	3.10E+03	8.30E+00	56	MByte per Second
57	IMB	2	(aggregate) Max MPI-2 Unidirectional 'Get' Bandwidth (non-aggregate)	-1	TRUE	2.93E+03	5.45E+01	21	2.90E+03	5.59E+01	56	MByte per Second
58	IMB	2	Max MPI-2 Unidirectional 'Put' Bandwidth (aggregate)	0	FALSE	3.12E+03	6.18E+00	21	3.12E+03	7.70E+00	56	MByte per Second
59	IMB	2	Max MPI-2 Unidirectional 'Put' Bandwidth (non-aggregate)	-1.1	TRUE	2.96E+03	4.11E+01	21	2.92E+03	5.11E+01	56	MByte per Second
60	IMB	2	Max PingPing Bandwidth	-0.1	FALSE	2.60E+03	3.43E+01	21	2.60E+03	3.00E+01	56	MByte per Second
61	IMB	2	Max PingPong Bandwidth	-0.1	FALSE	3.08E+03	9.99E+00	21	3.08E+03	7.15E+00	56	MByte per Second
62	IMB	2	Max SendRecv Bandwidth	-0.4	FALSE	5.22E+03	7.35E+01	21	5.20E+03	7.24E+01	56	MByte per Second
63	IMB	2	Min AllGather Latency	1.5	TRUE	2.54E- 06	5.12E- 08	21	2.58E- 06	6.88E- 08	56	Second
64	IMB	2	Min AllGatherV Latency	-1	FALSE	2.99E- 06	1.16E- 07	21	2.96E- 06	6.92E- 08	56	Second
65	IMB	2	Min AllReduce Latency	-2.3	TRUE	3.02E- 06	1.22E- 07	21	2.95E- 06	7.10E- 08	56	Second
66	IMB	2	Min AllToAll Latency	0.9	TRUE	2.53E- 06	3.66E- 08	21	2.55E- 06	3.56E- 08	56	Second
67	IMB	2	Min AllToAllV Latency	3.8	TRUE	3.21E- 06	3.01E- 08	21	3.33E- 06	1.14E- 07	56	Second
68	IMB	2	Min Barrier Latency	3.3	TRUE	2.41E- 06	8.48E- 08	21	2.48E- 06	1.24E- 07	56	Second
69	IMB	2	Min Broadcast Latency	-0.7	FALSE	2.40E- 06	2.53E- 08	21	2.39E- 06	8.71E- 08	56	Second
70	IMB	2	Min Gather Latency	-0.4	FALSE	2.60E- 06	9.05E- 08	21	2.59E- 06	3.39E- 08	56	Second
71	IMB	2	Min GatherV Latency	0.9	FALSE	2.44E- 06	2.10E- 08	21	2.46E- 06	8.03E- 08	56	Second
72	IMB	2	Min MPI-2 'Accumulate' Latency (aggregate)	0.5	FALSE	1.00E- 06	7.08E- 08	21	1.01E- 06	6.05E- 08	56	Second
73	IMB	2	Min MPI-2 'Accumulate' Latency (non-aggregate)	1.8	FALSE	6.29E- 06	2.50E- 07	21	6.40E- 06	3.00E- 07	56	Second
74	IMB	2	Min MPI-2 Window Creation Latency	0.3	FALSE	2.44E- 05	1.36E- 07	21	2.45E- 05	2.06E- 07	56	Second
75	IMB	2	Min Reduce Latency	3.5	TRUE	2.74E- 06	6.69E- 08	21	2.84E- 06	1.05E- 07	56	Second
76	IMB	2	Min ReduceScatter Latency	0.8	FALSE	1.65E- 06	8.98E- 08	21	1.67E- 06	1.03E- 07	56	Second
77	IMB	2	Min Scatter Latency	1.6	TRUE	2.58E- 06	1.60E- 08	21	2.63E- 06	5.97E- 08	56	Second
78	IMB	2	Min ScatterV Latency	0.1	FALSE	2.54E- 06	7.85E- 08	21	2.54E- 06	4.09E- 08	56	Second
79	IMB	2	Wall Clock Time	4	TRUE	1.48E+01	5.39E- 01	21	1.54E+01	1.39E+00	56	Second

TABLE IV
CHANGES IN ALL MEASURED METRICS FROM IOR

#	Application	Nodes	Metric	Diff., %	Distr. Can	Before Patch Application			After Patcl	Units		
					be Distin- gui- shed?	Mean, Seconds	Standard Deviation, Seconds	Nruns	Mean, Seconds	Standard Deviation, Seconds	Nruns	
88	IOR	1	HDF5 Independent N-to-1 File Open Time (Read)	36.9	FALSE	2.13E- 01	1.30E- 01	21	2.92E- 01	2.88E- 01	55	Second
89	IOR	1	HDF5 Independent N-to-1 File Open Time (Write)	0.5	FALSE	1.65E- 01	2.06E- 01	21	1.66E- 01	2.12E- 01	55	Second
90	IOR	1	HDF5 Independent N-to-1 Read Aggregate Throughput	-6.3	FALSE	1.64E+02	2.17E+01	21	1.53E+02	2.04E+01	55	MByte per Second
91	IOR	1	HDF5 Independent N-to-1 Write Aggregate Throughput	-3.7	FALSE	1.66E+02	2.67E+01	21	1.60E+02	2.26E+01	55	MByte per Second
138	IOR	1	POSIX N-to-N File Open Time (Read)	1.2	FALSE	1.44E+00	1.77E+00	21	1.45E+00	1.75E+00	55	Second
139	IOR	1	POSIX N-to-N File Open Time (Write)	-28.9	TRUE	4.41E+00	2.25E+00	21	3.14E+00	1.99E+00	55	Second
140	IOR	1	POSIX N-to-N Read Aggregate Throughput	0	FALSE	2.32E+02	5.47E+00	21	2.32E+02	6.43E+00	55	MByte per Second
141	IOR	1	POSIX N-to-N Write Aggregate Throughput	14.6	TRUE	2.33E+02	4.37E+01	21	2.67E+02	3.47E+01	55	MByte per Second
142	IOR	1	Wall Clock Time	3.9	TRUE	1.88E+02	9.41E+00	21	1.96E+02	1.17E+01	55	Second
151	IOR	2	HDF5 Independent N-to-1 File Open Time (Read)	-18.2	FALSE	7.01E- 01	1.10E+00	22	5.74E- 01	6.34E- 01	56	Second
152	IOR	2	HDF5 Independent N-to-1 File Open Time (Write)	4.1	FALSE	2.24E- 01	1.35E- 01	22	2.33E- 01	1.86E- 01	56	Second
153	IOR	2	HDF5 Independent N-to-1 Read Aggregate Throughput	-1.9	FALSE	1.95E+02	2.29E+01	22	1.92E+02	2.06E+01	56	MByte per Second
154	IOR	2	HDF5 Independent N-to-1 Write Aggregate Throughput	-3.6	FALSE	1.59E+02	2.48E+01	22	1.54E+02	2.28E+01	56	MByte per Second
201	IOR	2	POSIX N-to-N File Open Time (Read)	26.6	FALSE	3.06E+00	3.08E+00	22	3.88E+00	3.06E+00	56	Second
202	IOR	2	POSIX N-to-N File Open Time (Write)	-20	FALSE	8.43E+00	3.29E+00	22	6.75E+00	3.92E+00	56	Second
203	IOR	2	POSIX N-to-N Read Aggregate Throughput	0.2	FALSE	2.67E+02	3.25E+00	22	2.68E+02	2.43E+00	56	MByte per Second
204	IOR	2	POSIX N-to-N Write Aggregate Throughput	3.2	FALSE	2.29E+02	3.33E+01	22	2.36E+02	3.17E+01	56	MByte per Second
205	IOR	2	Wall Clock Time	1.5	FALSE	3.71E+02	1.22E+01	22	3.77E+02	1.95E+01	56	Second
214	IOR.local	1	HDF5 Independent N-to-1 File Open Time (Read)	7.6	TRUE	5.57E- 02	3.66E- 03	12	5.99E- 02	4.41E- 03	56	Second
215	IOR.local	1	HDF5 Independent N-to-1 File Open Time (Write)	18.4	TRUE	5.60E- 02	3.42E- 03	12	6.63E- 02	7.70E- 03	56	Second
216	IOR.local	1	HDF5 Independent N-to-1 Read Aggregate Throughput	-1.1	FALSE	2.61E+03	6.21E+01	12	2.58E+03	3.94E+01	56	MByte per Second
217	IOR.local	1	HDF5 Independent N-to-1 Write Aggregate Throughput	-2.4	FALSE	2.90E+01	2.05E+00	12	2.84E+01	1.79E+00	56	MByte per Second
264	IOR.local	1	POSIX N-to-N File Open Time (Read)	-1.9	FALSE	4.95E- 02	5.36E- 03	12	4.85E- 02	3.67E- 03	56	Second
265	IOR.local	1	POSIX N-to-N File Open Time (Write)	12.5	TRUE	4.86E- 02	5.50E- 03	12	5.47E- 02	7.31E- 03	56	Second
266	IOR.local	1	POSIX N-to-N Read Aggregate Throughput	-11.3	TRUE	2.73E+03	3.23E+01	12	2.42E+03	4.63E+02	56	MByte per Second
267	IOR.local	1	POSIX N-to-N Write Aggregate Throughput	-4.1	TRUE	9.13E+02	5.07E+01	12	8.76E+02	6.76E+01	56	MByte per Second
268	IOR.local	1	Wall Clock Time	2.2	FALSE	4.63E+02	1.64E+01	12	4.73E+02	1.90E+01	56	Second

#	Application	Nodes	s Metric	Diff.,	Distr. Can	Before Pat	tch Application	on	After Patc'	ch Application	n	Units
				70	be Distin- gui- shed?	Mean, Seconds	Standard Deviation, Seconds	Nruns	Seconds	Standard Devi- ation, Seconds	Nruns	
272	MDTest	1	Directory creation (single tree directory)	-15.1	TRUE	8.55E+03	3.26E+02		7.26E+03			Operations/Second
276	MDTest	1	Directory removal (single tree directory)	-16	TRUE	2.02E+04	7.18E+02		1.70E+04			Operations/Second
280	MDTest	1	Directory stat (single tree directory)	-18.4	FALSE	1.90E+05	7.09E+04		1.55E+05			Operations/Second
284	MDTest	1	File creation (single tree directory)	-12.3	TRUE	8.09E+03	3.13E+02		7.10E+03			Operations/Second
288	MDTest	1	File read (single tree directory)	-12.7	TRUE	3.28E+04	1.96E+03		2.86E+04			Operations/Second
292	MDTest	1	File removal (single tree directory)	-15.5	TRUE	1.33E+04	6.72E+02		1.13E+04			Operations/Second
305	MDTest	1	Wall Clock Time	24.1	TRUE	3.05E+01	3.17E+00		3.78E+01	4.10E+00		Second
309	MDTest	2	Directory creation (single tree directory)	-9.8	TRUE	4.30E+03	2.38E+02		3.88E+03			Operations/Second
313	MDTest	2	Directory removal (single tree directory)	-8.5	TRUE	3.27E+03	2.92E+02		2.99E+03			Operations/Second
317	MDTest	2	Directory stat (single tree directory)	-10.3	TRUE	2.81E+04	1.86E+03	23	2.53E+04			Operations/Second
321	MDTest	2	File creation (single tree directory)	-7.3	TRUE	2.25E+03	1.08E+02	23	2.09E+03	1.67E+02	55	Operations/Second
325	MDTest	2	File read (single tree directory)	-24.4	TRUE	5.94E+04	2.90E+03		4.50E+04			Operations/Second
329	MDTest	2	File removal (single tree directory)	-10.5	TRUE	1.62E+03	1.25E+02		1.45E+03			Operations/Second
333	MDTest	2	File stat (single tree directory)	-10	TRUE	2.19E+04			1.97E+04			Operations/Second
342	MDTest	2	Wall Clock Time	9.7	TRUE	1.67E+02	3.60E+00		1.83E+02			Second
346	MDTest.local	1	Directory creation (single tree directory)	2	FALSE	1.04E+05	7.44E+03		1.06E+05			Operations/Second
350	MDTest.local	1	Directory removal (single tree directory)	-11.1	TRUE	1.30E+05	3.70E+03		1.15E+05			Operations/Second
354	MDTest.local	1	Directory stat (single tree directory)	-25.6	TRUE	1.92E+06			1.43E+06			Operations/Second
358	MDTest.local	1	File creation (single tree directory)	-10.9	TRUE	1.79E+05	1.45E+04		1.59E+05			Operations/Second
362	MDTest.local	1	File read (single tree directory)	-25.1	TRUE	1.39E+06	3.10E+04		1.04E+06			Operations/Second
366	MDTest.local	1	File removal (single tree directory)	-8.6	TRUE	2.08E+05	7.99E+03		1.90E+05			Operations/Second
370	MDTest.local	1	File stat (single tree directory)	-26.3	TRUE	1.92E+06			1.41E+06			Operations/Second
379	MDTest.local	1	Wall Clock Time	78.6	TRUE	3.75E+00	6.22E- 01	12	6.70E+00	2.61E+00	56	Second