COMP 464 - High Performance Computing
Stream2 Benchmark

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October 8, 2017

1 Overview

This report highlights the procedures and results of running the Stream2 C++ code that runs a series of experiments and generates a benchmark utilizing the Stampede2 supercomputer at The University of Texas at Austin's Texas Advanced Computing Center (TACC), the code is also execute on a Lenovo workstation running CentOS7 and Intel C++ library compilers, details and specifications to follow.

The Stream2 benchmark runs a number of tests measuring the bandwidth of L1, L2, L3 cache, and main DRAM. The first benchmark uses GNU C++ compiler to build the Stream2 program on Stampede2 compute and login nodes as well as and the Lenovo workstation. After building the code with GNU or Intel compiler, the program is run and the output is recorded in the tables below. The specifications of each system are also recorded in the tables at the end of the report. The idea behind this experiment is to examine how the memory and cache behave during the different experience and to compare the Intel and GNU C++ compilers.

2 Benchmark Analysis

The stream2 code runs a number of loops over a sequence of experiments and various benchmarks:

Benchmark	Description
FILL (MB/s)	Set all elements in an array to a particular value
COPY	Copy two arrays - one into the other
AXPY	Takes two arrays make changes and writes back (Alpha x plus y)
DOT	Sum of the product of two arrays (Dot Product)

The benchmarks above were run on Stampede2 following two approaches. The first the code runs on the compute Node by requesting a flat quadrant and executing the code on that node. The second approach uses the *numactl* command to run the code using the MCDRAM on the computer node.

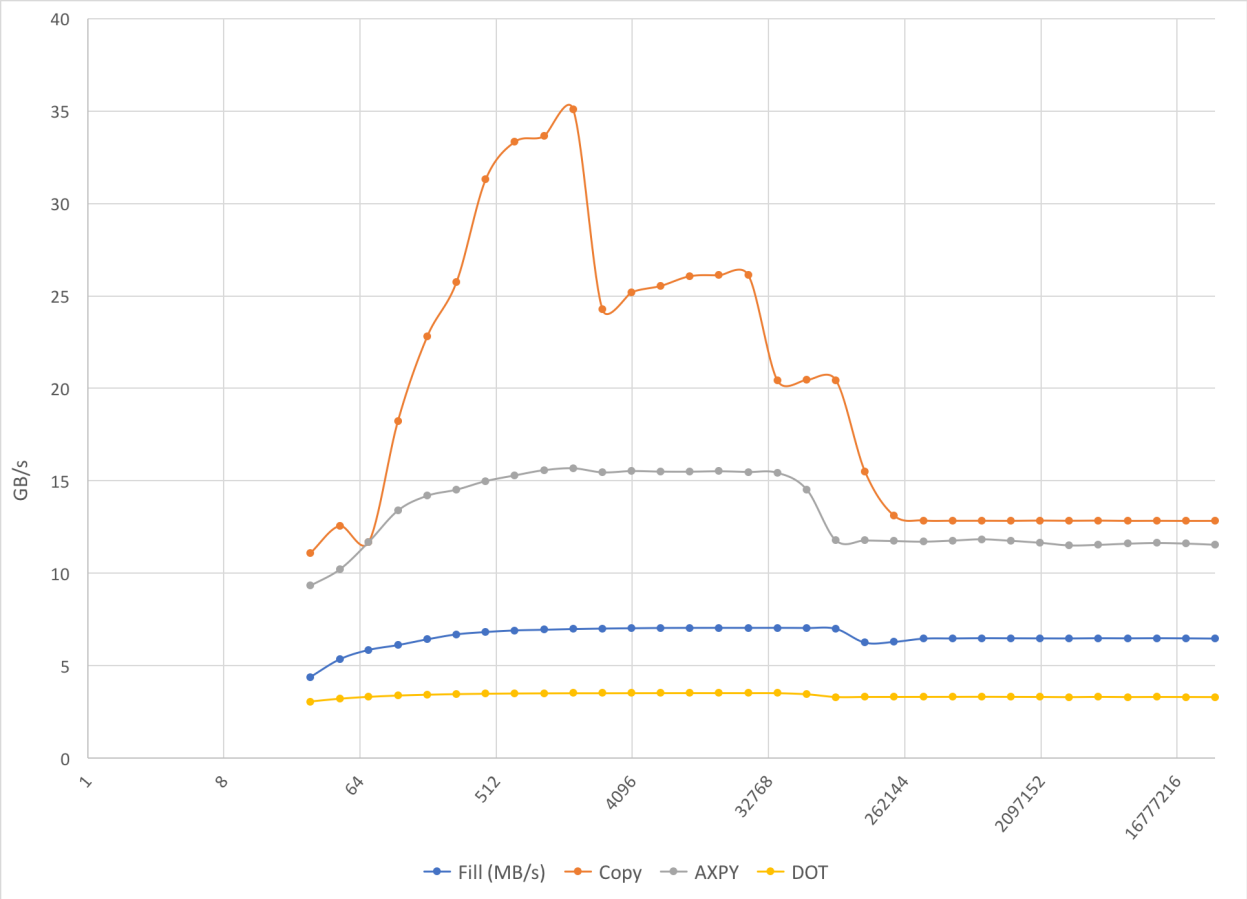
The benchmarks were run with a min array size of 30 Bytes and three different max array sizes (20Mb, 25Mb, and 30Mb).This report only highlights the results when using the largest array size (30Mb) as the goal is to stress the last level cache and setting the number of tests between the min and max array size to 50. The same parameters were used for all benchmarks, compilers and nodes. To calculate the size of the array at the n iteration the following metric was used:

Benchmark	Array Size (Metric)
FILL	(n_iteration)(8 bytes/double)(1 double/iteration)
COPY	(n_iteration)(8 bytes/double)(2 double/iteration)
AXPY	(n_iteration)(8 bytes/double)(3 double/iteration)
DOT	(n_iteration)(8 bytes/double)(2 double/iteration)

2.1 Benchmark Results

In Figure.1 Stampede2 compute node using the GNU compiler, we can see how the benchmark that uses most bandwidth is the COPY benchmark, with a top performance at $26kb$ right before filling the $32kb$ L1 cache then we see another drop at approximately after 534kb array size when L2 cache gets filled. The other benchmarks seem to behave more or less similarly, some of them show some drops but nothing close to what the COPY benchmark experience.

Figure 1: Stampede2 Compute Node - GNU Compiler



Now in Figure.2 we change the compiler to Intel's C++ compiler and we can see significant changes on all the benchmarks. The most prominent change from the previous figure is the AXPY benchmark that peeks approximately around $40kb$ with a much higher bandwidth almost 120 times higher compared with the GNU compiler. The FILL benchmark also shows signs of a significant drop with a peek at 32kb and 100Gbs to 40Gbs after the $L1$ gets filled.

Figure 2: Stampede2 Compute Node - Intel Compiler

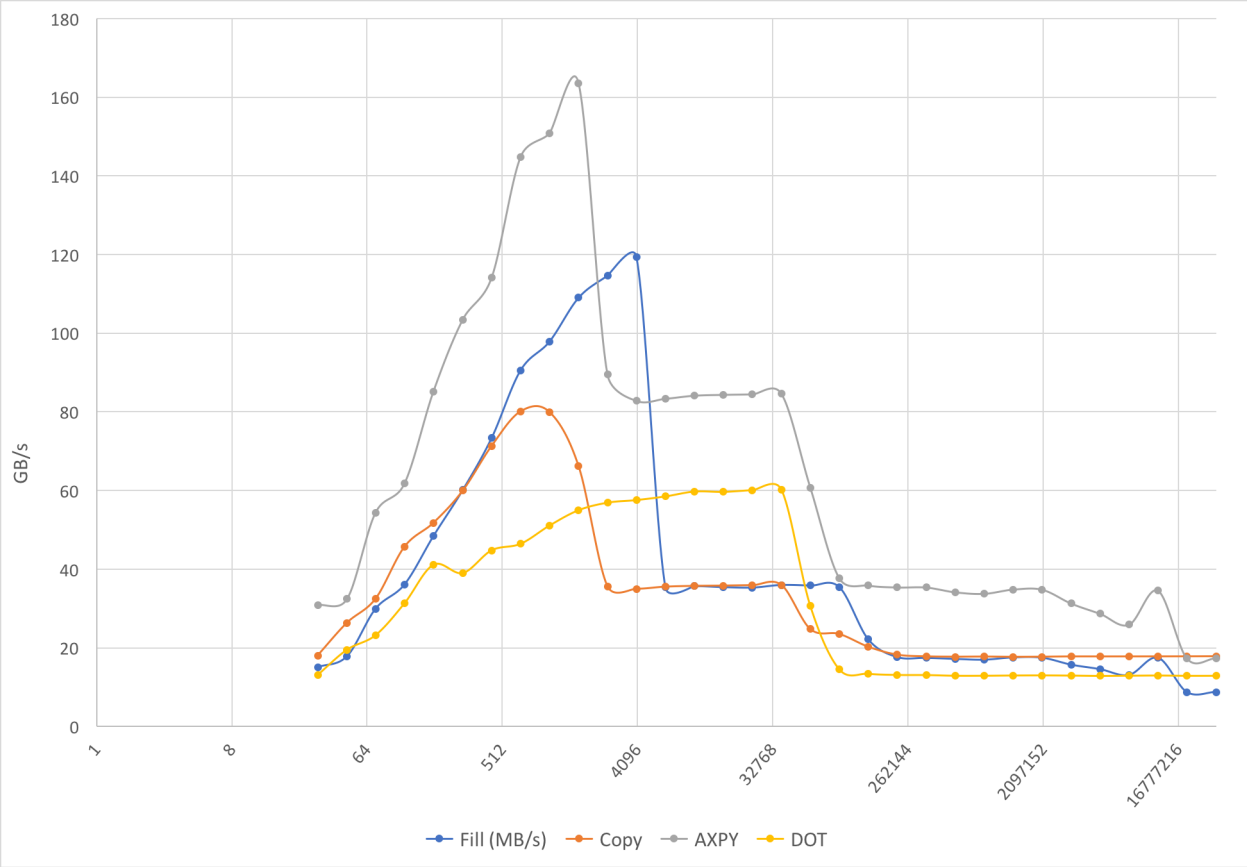


Figure.3 was generated using the `numactl` command on the compute node that allows to use a much faster memory (MCDRAM), this benchmark also uses the Intel library. The bandwidth increase almost twice compared with the previous benchmark but there is a more drastic drop of performance when the L1 cache is filled. We can see how when the array size is large enough almost all benchmarks behave similarly as they are accessing memory directly, here is the command use to run the benchmark:

```
numactl --membind=1 --cpunodebind=0 ./stream2 -max 30000000
```

Figure 3: Stampede2 Compute Node - Intel Compiler

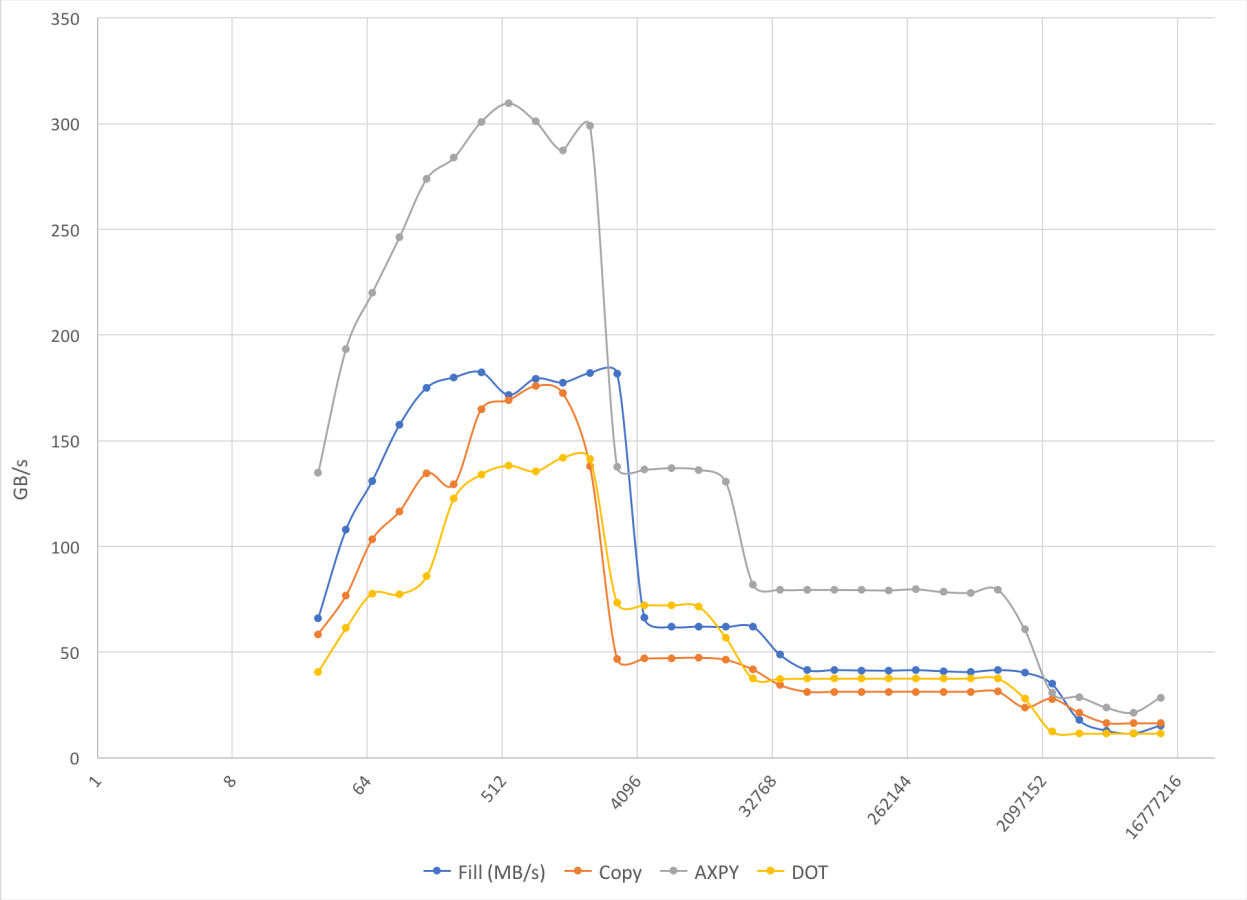
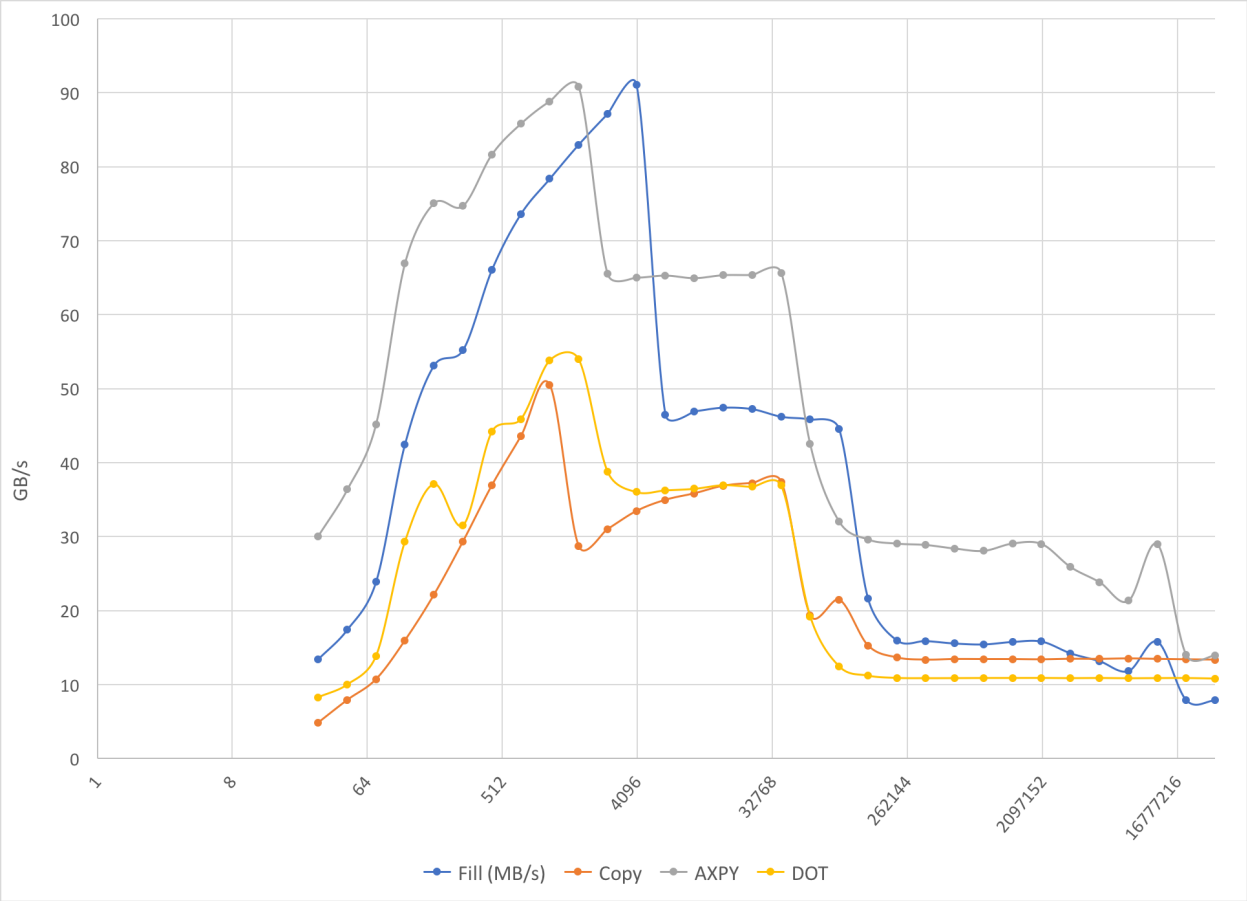


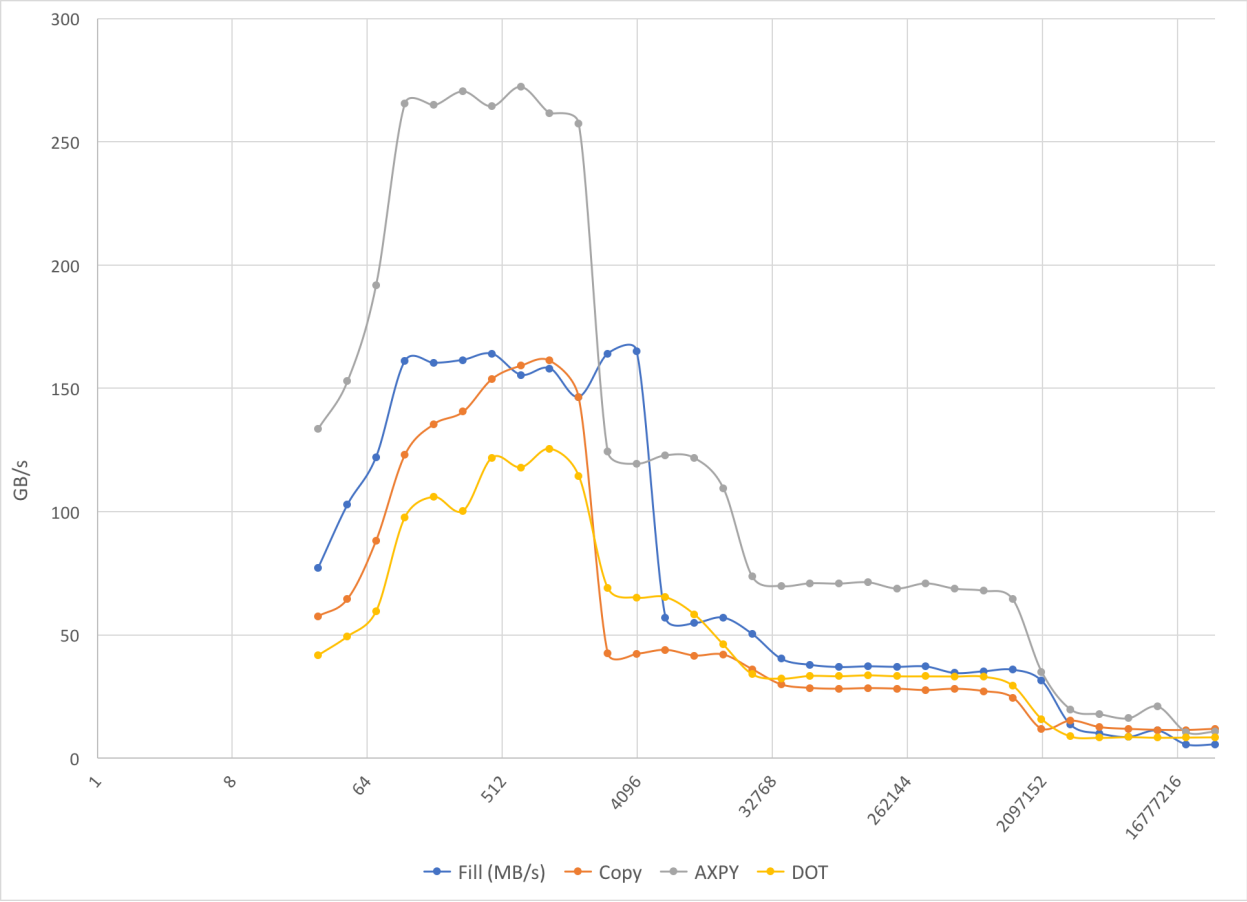
Figure.4 was generated using a Lenovo Workstation, the bandwidth is almost 1/3 compared with the Stampede2 compute node, we can see similar drops when the array size filled L1 cache, L2 cache an then access memory directly is interesting to see how the different benchmarks plateau in each cached level and they become flat at the when the array size is large enough.

Figure 4: Lenovo Workstation - Intel Compiler



The last chart was generated by running the same `numactl` command on the Stampede2 login node instate of the compute node. It is interesting to see how in this case the bandwidth plateau earlier and stay there for a couple of cycles before it drops again simnifically, when compared with the compute node the bandwidth are very similar.

Figure 5: Stampede2 Login Node - Intel Compiler



3 Reference

Stampede2 User Guide – Managing Memory
https://portal.tacc.utexas.edu/user-guides/stampede2#managingmemory

Introduction to High Performance Scientific Computing – Victor Eijkhout
http://pages.tacc.utexas.edu/~eijkhout/istc/istc.html

Table 1: Stampede2 - Compute Node (knl) - System Information

Architecture	x86_64
CPU op-mode(s)	32-bit, 64-bit
Byte Order	Little Endian
CPU(s)	272
On-line CPU(s) list	0-271
Thread(s) per core	4
Core(s) per socket	68
Socket(s)	1
NUMA node(s)	2
Vendor ID	GenuineIntel
CPU family	6
Model	87
Model name	Intel(R) Xeon Phi(TM) CPU 7250 @ 1.40GHz
Stepping	1
CPU MHz	1255.132
BogoMIPS	2793.44
L1d cache	32K
L1i cache	32K
L2 cache	1024K
NUMA node0 CPU(s)	0-271
NUMA node1 CPU(s)	

Table 2: Lenovo Workstation - CentOS7 - System Information

Architecture	x86_64
CPU op-mode(s)	32-bit, 64-bit
Byte Order	Little Endian
CPU(s)	40
On-line CPU(s) list	0-39
Thread(s) per core	2
Core(s) per socket	10
Socket(s)	2
NUMA node(s)	2
Vendor ID	GenuineIntel
CPU family	6
Model	79
Model name	Intel(R) Xeon(R) CPU E5-2630 v4 @ 2.20GHz
Stepping	1
CPU MHz	1291.382
CPU max MHz	3100.0000
CPU min MHz	1200.0000
BogoMIPS	4389.67
Virtualization	VT-x
Hypervisor vendor	vertical
Virtualization type	full
L1d cache	32K
L1i cache	32K
L2 cache	256K
L3 cache	25600K
NUMA node0 CPU(s)	0-9,20-29
NUMA node1 CPU(s)	10-19,30-39

Table 3: Stampede2 Compute Node - GNU Compiler

Size (iterations)	**Fill (MB/s)**	**Copy**	**AXPY**	**DOT**	**Uncertainty (%)**
30	4393.162231	11104.6881	9336.596419	3051.421911	1.90%
47	5350.378441	12565.39118	10220.65398	3209.223289	1.50%
73	5853.695055	11687.71559	11702.86902	3316.590107	1.10%
114	6116.984412	18242.91233	13398.08149	3388.55338	0.70%
178	6427.522021	22800.19441	14194.47704	3438.065904	0.50%
279	6698.122428	25768.72093	14527.06717	3472.020319	0.30%
435	6824.597812	31305.48923	14986.95631	3493.9909	0.20%
679	6911.333146	33345.25901	15297.0655	3507.619116	0.10%
1060	6948.028771	33650.79479	15578.51236	3515.477478	0.10%
1656	6985.001187	35089.74094	15680.55274	3520.668913	0.10%
2586	7012.81148	24271.79651	15462.08087	3521.383827	0.00%
4038	7029.597848	25202.06851	15531.84052	3525.104143	0.00%
6305	7044.938436	25549.57693	15502.22589	3527.599249	0.00%
9846	7050.075265	26072.88131	15498.96218	3529.112917	0.00%
15374	7051.78082	26124.29129	15519.55808	3528.904854	0.00%
24008	7050.994641	26121.05296	15482.61471	3527.958451	0.00%
37488	7051.782966	20421.04818	15437.97559	3523.761178	0.00%
58539	7042.233872	20459.72158	14530.19158	3463.650355	0.00%
91410	6996.433371	20445.17519	11782.12811	3306.784882	0.00%
142738	6248.110944	15491.29423	11778.74414	3309.431658	0.00%
222889	6290.558991	13109.06205	11746.50454	3311.366333	0.00%
348047	6464.796754	12858.42716	11715.18304	3313.983805	0.00%
543483	6477.457041	12841.93352	11772.74996	3316.270979	0.00%
848661	6489.448093	12842.14791	11843.17557	3319.445295	0.00%
1325203	6485.506785	12838.69628	11761.03164	3314.821514	0.00%
2069336	6480.942411	12851.09811	11653.18953	3309.260037	0.00%
3231315	6477.659875	12842.6458	11513.15796	3300.587295	0.00%
5045773	6487.756168	12849.37284	11543.48494	3313.220334	0.00%
7879091	6483.470428	12836.38542	11605.7627	3304.53413	0.00%
12303381	6488.676065	12838.86536	11641.5715	3308.75048	0.00%
19212013	6481.651785	12834.44793	11610.01186	3306.78088	0.00%
30000000	6470.497548	12835.64937	11548.34264	3302.602269	0.00%

Table 4: Stampede2 Compute Node - Intel Compiler

Size (iterations)	**Fill (MB/s)**	**Copy**	**AXPY**	**DOT**	**Uncertainty (%)**
30	15076.32499	18053.85978	30906.00129	13095.05445	6.60%
47	17845.85505	26331.5801	32417.78294	19488.76166	5.00%
73	29924.64285	32466.36848	54363.37106	23197.67158	5.40%
114	36117.31918	45700.79007	61812.05105	31316.48663	4.20%
178	48447.62984	51785.3116	85184.33885	41119.4245	3.60%
279	60122.11714	59952.00819	103393.6844	39016.32316	2.80%
435	73345.94715	71328.83551	114061.8083	44778.14129	2.20%
679	90559.47399	80118.81023	144701.2393	46433.42544	1.70%
1060	97900.40832	79957.29085	150806.9369	51074.56497	1.20%
1656	109010.6951	66252.65334	163545.0942	54977.686	0.90%
2586	114663.1208	35637.41072	89477.22895	56897.35007	0.60%
4038	119417.9424	34996.98606	82780.89141	57565.11103	0.40%
6305	35355.22437	35523.42247	83304.1754	58488.79063	0.10%
9846	35690.26359	35714.49021	84088.76572	59724.16582	0.00%
15374	35436.22662	35793.96904	84307.55835	59648.55565	0.00%
24008	35322.30819	35900.19821	84432.10233	60073.95713	0.00%
37488	35981.74332	35955.22864	84592.11752	60231.84392	0.00%
58539	35828.34256	24737.90178	60757.13892	30640.1173	0.00%
91410	35446.20978	23479.55979	37724.09292	14512.03045	0.00%
142738	22159.83159	20235.74442	35858.4413	13378.82375	0.00%
222889	17643.34403	18218.83898	35368.76334	13088.50196	0.00%
348047	17438.23319	17792.17854	35354.06848	13054.44029	0.00%
543483	17176.52069	17709.30278	34143.76344	12884.22877	0.00%
848661	16982.16663	17734.60235	33759.5537	12884.06601	0.00%
1325203	17554.79988	17680.34222	34829.10835	12947.07033	0.00%
2069336	17483.75813	17706.67857	34799.37236	12972.67719	0.00%
3231315	15715.29774	17768.26712	31289.79077	12922.9988	0.00%
5045773	14569.38395	17767.62359	28677.94044	12841.36212	0.00%
7879091	13100.15665	17772.13825	25901.08037	12891.50194	0.00%
12303381	17474.37463	17779.8349	34532.61176	12941.04067	0.00%
19212013	8732.041736	17793.79032	17318.09854	12866.99193	0.00%
30000000	8762.057034	17817.95605	17392.93009	12871.03108	0.00%

Table 5: Lenovo Workstation - CentOS7 - Intel Compiler

Size (iterations)	**Fill (MB/s)**	**Copy**	**AXPY**	**DOT**	**Uncertainty (%)**
30	66112.72533	58494.27656	134909.179	40619.71983	28.90%
46	107910.7797	76766.52557	193409.6647	61297.77476	30.70%
69	131018.6842	103335.0823	219953.1734	77714.30418	24.90%
105	157502.2839	116613.9987	246384.2462	77300.33301	19.70%
160	175129.5372	134572.54	274035.1305	86039.6104	14.30%
243	179923.0444	129394.9134	284017.764	122605.4301	9.70%
370	182336.1625	164909.6116	300930.7027	134019.6058	6.50%
562	171646.9864	169175.5295	309648.0482	138134.4576	4.00%
854	179338.9732	175876.4115	301052.1975	135499.101	2.80%
1299	177569.0737	172436.555	287403.8853	141861.5093	1.80%
1974	181933.6138	137961.4597	298952.7175	141246.6269	1.20%
3000	181689.9355	46677.21941	137599.8811	73303.62157	0.80%
4560	66294.53431	46951.2049	136461.8837	72265.89014	0.20%
6930	61947.0533	47126.57187	137075.3031	72080.50043	0.10%
10534	62085.73111	47294.61523	136236.9395	71501.87772	0.10%
16010	61887.38334	46297.24168	130475.9878	56835.23762	0.10%
24334	61897.49265	41682.42222	82049.22806	37425.72688	0.00%
36985	48730.63166	34364.53723	79511.82794	37367.38853	0.00%
56215	41510.74144	31183.59622	79469.7578	37471.68968	0.00%
85441	41525.41689	31219.04874	79435.23126	37474.80757	0.00%
129863	41344.24669	31220.22917	79342.64781	37491.71092	0.00%
197380	41254.7179	31216.44603	79209.32696	37515.96126	0.00%
300000	41503.17189	31256.80558	79713.45021	37510.80866	0.00%
455973	40959.99264	31203.52912	78420.6297	37465.92692	0.00%
693039	40618.69146	31220.99827	78055.93614	37520.53999	0.00%
1053358	41525.32377	31291.52515	79592.06727	37559.89124	0.00%
1601010	40290.38112	23776.60734	60766.36824	28031.33537	0.00%
2433392	34974.68649	27871.30887	30769.47228	12396.83631	0.00%
3698540	17808.87434	21262.54232	28721.01682	11508.43849	0.00%
5621452	12897.40071	16474.08835	23783.24898	11505.41855	0.00%
8544108	11542.83049	16287.19191	21397.39039	11511.22639	0.00%
12986284	15352.79346	16281.66038	28517.51769	11513.94538	0.00%
19737997	7670.274794	16212.78072	14316.01372	11523.11111	0.00%
30000000	7641.866965	16298.98445	14316.03209	11512.70405	0.00%

Table 6: Stampede2 Compute Node - Intel Compiler

c457-092[knl](6)$ numactl –membind=1 –cpunodebind=0 ./stream2 -max 30000000

Size (iterations)	**Fill (MB/s)**	**Copy**	**AXPY**	**DOT**	**Uncertainty (%)**
30	13444.62622	4867.047852	30080.38471	8277.354236	5.90%
47	17450.42697	7932.455789	36397.55152	10021.64778	4.90%
73	23876.00266	10719.45837	45169.42216	13868.21308	4.30%
114	42474.25404	15969.00343	66928.91142	29358.29742	4.90%
178	53116.05412	22131.00365	75043.23335	37116.99226	3.90%
279	55251.01729	29365.28307	74727.193	31552.82404	2.60%
435	66060.6151	36936.17853	81660.73603	44222.33475	2.00%
679	73593.50456	43552.624	85808.96056	45903.55742	1.40%
1060	78374.12079	50490.49953	88850.75902	53865.72418	1.00%
1656	82998.93403	28714.98783	90813.68013	54011.05984	0.70%
2586	87165.83993	31022.84346	65509.40374	38776.00835	0.40%
4038	91062.60188	33461.61844	65042.97168	36037.0767	0.30%
6305	46467.00655	34964.33382	65306.7438	36267.94762	0.10%
9846	46956.81687	35842.661	64958.82569	36483.12324	0.10%
15374	47452.43273	36866.17455	65357.8632	36973.05349	0.00%
24008	47252.25874	37234.12093	65393.76772	36758.7835	0.00%
37488	46228.46033	37398.51148	65664.2177	36903.20321	0.00%
58539	45848.37736	19362.39581	42503.27155	19218.99005	0.00%
91410	44561.07148	21479.83861	32061.99234	12458.92492	0.00%
142738	21628.4267	15272.97866	29637.48621	11198.96202	0.00%
222889	15994.22824	13656.97837	29077.15197	10889.15536	0.00%
348047	15907.63596	13363.66032	28891.67454	10855.47306	0.00%
543483	15576.00669	13443.8467	28406.11065	10863.19492	0.00%
848661	15455.7254	13437.33153	28100.62123	10878.16443	0.00%
1325203	15788.04002	13431.58734	29092.19767	10882.69595	0.00%
2069336	15835.16845	13399.69392	29014.01865	10885.20818	0.00%
3231315	14248.2346	13472.93891	25903.89093	10861.53659	0.00%
5045773	13181.51965	13464.71959	23863.78101	10877.72851	0.00%
7879091	11855.16038	13523.43927	21346.34227	10847.50052	0.00%
12303381	15815.13893	13461.82294	28969.02595	10865.31721	0.00%
19212013	7897.038755	13401.839	13991.41983	10872.49837	0.00%
30000000	7875.220695	13362.17734	13966.95306	10803.63974	0.00%

Table 7: Stampede2 Login Node - Intel Compiler

login3.stampede2(1)$ numactl –membind=1 –cpunodebind=0 ./stream2 -max 30000000

Size (iterations)	**Fill (MB/s)**	**Copy**	**AXPY**	**DOT**	**Uncertainty (%)**
30	77295.40885	57547.41911	133631.3266	41818.96509	33.80%
47	102780.5543	64531.08752	152891.4897	49395.90922	28.70%
73	122098.2301	88187.99685	191770.789	59567.3754	21.90%
114	161115.0496	123121.2717	265656.1257	97741.76808	18.50%
178	160253.7953	135545.3143	264918.1513	105910.0896	11.80%
279	161502.6426	140563.2239	270528.2632	100337.4739	7.60%
435	163968.2409	153822.935	264492.6268	121798.1133	4.90%
679	155455.984	159249.7651	272407.5267	117894.0974	3.00%
1060	158076.9365	161294.8407	261730.6498	125438.3638	2.00%
1656	146503.3881	146327.2671	257497.5794	114446.9313	1.20%
2586	164039.066	42630.40203	124477.9241	69107.65086	0.80%
4038	165111.9418	42350.26611	119531.3789	65172.25769	0.50%
6305	57040.17835	43912.23257	122908.0278	65318.93561	0.10%
9846	54859.69278	41602.23902	121768.3319	58279.26628	0.10%
15374	57010.89827	41988.29923	109503.9582	46073.8776	0.00%
24008	50353.96269	36008.20231	73626.4406	34069.58335	0.00%
37488	40326.58345	29864.08217	69826.80499	32291.27084	0.00%
58539	37869.1821	28445.62821	70955.59397	33397.1028	0.00%
91410	36971.83153	28098.55951	70835.3705	33257.32017	0.00%
142738	37270.68888	28361.16246	71343.63855	33628.70156	0.00%
222889	37047.80247	28134.34841	68848.30428	33245.70772	0.00%
348047	37189.6855	27570.0144	70922.35354	33219.51089	0.00%
543483	34556.48748	28093.03304	68768.0117	33168.8056	0.00%
848661	35258.25476	27163.3455	67898.97369	33046.82787	0.00%
1325203	35894.24954	24532.4936	64443.67687	29473.61877	0.00%
2069336	31394.88816	11889.18103	35047.61606	15893.04417	0.00%
3231315	13549.5788	15163.03011	19774.16739	8873.499744	0.00%
5045773	10045.66548	12545.91923	17808.55273	8326.652729	0.00%
7879091	8654.22959	11800.24029	16178.66342	8581.412933	0.00%
12303381	11241.97602	11422.11827	20956.41518	8357.194357	0.00%
19212013	5619.171458	11366.48592	10546.07143	8436.609585	0.00%
30000000	5617.037508	11831.42564	10749.00064	8533.761041	0.00%