CS 553 Cloud Computing
Programming Assignment 1
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Performance Evaluation Report

Introduction:

This report gives the performance evaluation of various system components like CPU, MEMORY, and DISK. The experiments were performed several times and average of each experiments are used to depict the final results. Each component module has been thoroughly analyzed on the parameters of System used for experiments, Graphs, Actual Results obtained, Theoretical Peak Performance, Efficiency and conclusions.
Also the report includes results from other benchmarks like Linpack, Iozone & Stream and the results of those benchmarks are compared with our benchmarks and efficiency is calculated.

System Configuration:
• Operating System: UBUNTU 14.04(Dual Boot)
• Model: Intel(R) Core(TM) i5-4210U CPU @ 1.70GHz
• RAM: 8GB

CPU Benchmarking

This module aims to calculate the processing speed in terms of Giga FLOPS and Giga IOPS on different levels on concurrency. (1, 2 and 4).

Calculations:

$$GFLOPS = \frac{\text{Number of Operations} * \text{No of Times operations performed}}{\text{Time Elapsed} * 10^9}$$

$$GIOPS = \frac{\text{Number of Operations} * \text{No of Times operations performed}}{\text{Time Elapsed} * 10^9}$$

- The theoretical peak performance is calculated using the following parameters,
- No of Operations: Several arithmetic operations (30) are performed for large number of times. A large number is used to get accurate results. In this experiment the no of times the operation is performed is 10^9.
- Time Elapsed: The time elapsed is the maximum time taken amongst any thread at any concurrency level to complete calculating all the operations.

Benchmarking Results:

CPU speed is calculated in terms of Giga FLOPS and Giga IOPS using threads 1, 2 and 4.
The average results obtained after performing the benchmarking an repeating it for 5 times is given below,

1 Thread:

Sr. No	GIOPS	Time	GFLOPS	Time
1 Thread				
1	12.1396332	2.635994	12.1400156	2.635911
2	12.1422958	2.635416	12.1809731	2.627048
3	12.1320305	2.637646	12.1415081	2.635587
4	12.170785	2.629247	11.3150339	2.828096
5	12.9137812	2.477973	12.8850508	2.483498
Average	**12.2997051**		**12.1325163**	

2 Threads:

Sr. No	GIOPS	Time	GFLOPS	Time
2 Thread				
1	12.1254539	5.278153	12.1036069	5.257275
2	12.0686016	5.303017	12.1730728	5.257506
3	12.1237917	5.278877	11.341507	5.642989
4	12.0975485	5.290328	12.0522575	5.275193
5	12.9072618	4.958449	12.9235964	4.952182
Average	**12.2645315**		**12.1188081**	

4 Threads:

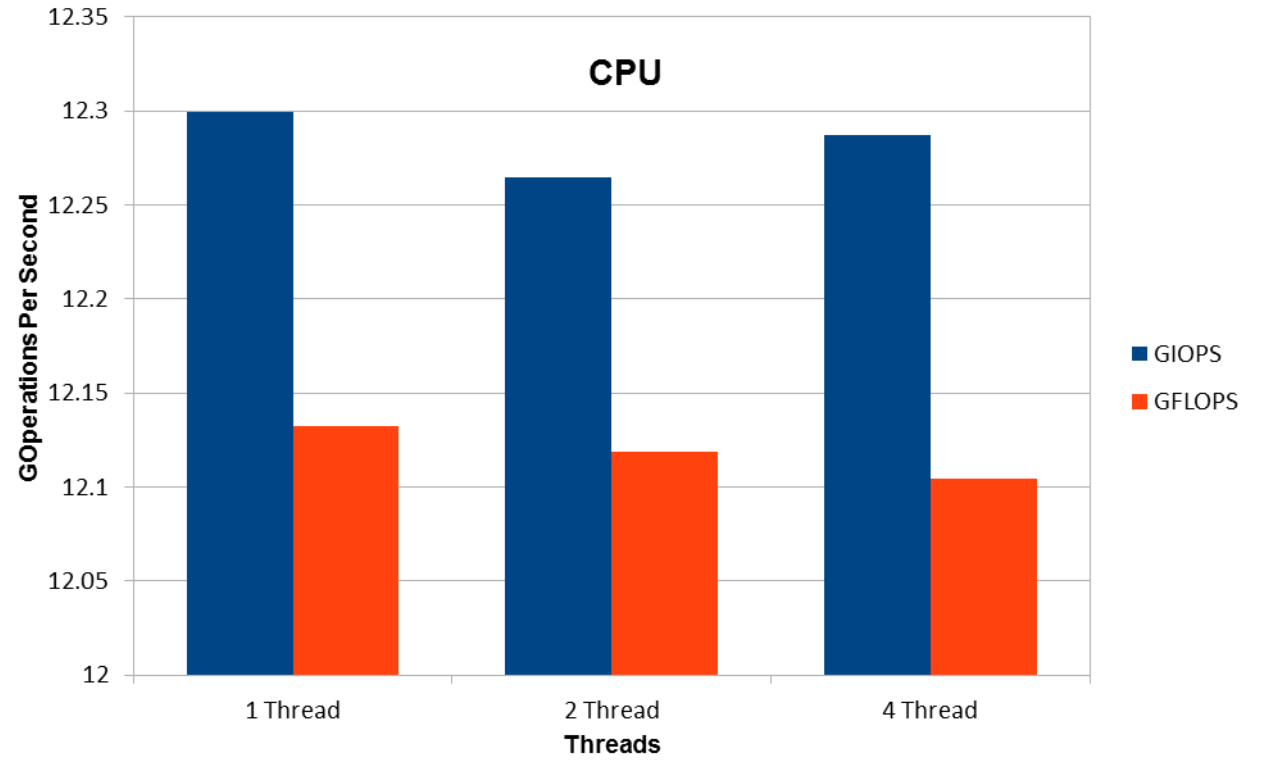
Sr. No	GIOPS	Time	GFLOPS	Time
4 Thread				
4	12.1252699	10.556466	12.0170698	10.651515
4	12.1158838	10.564644	11.6989565	10.941147
4	12.1264477	10.555441	12.1113195	10.568625
4	12.1474581	10.537184	12.1268585	10.563794
4	12.9193935	9.907586	12.5695662	9.907454
Average	**12.2868906**		**12.1047541**	

As per the result data shown above, the results obtained are

GIOPS for 1 Thread: **12.2997051**
GIOPS for 2 Threads: **12.2645315**
GIOPS for 4 Threads: **12.2868906**

GFLOPS for 1 Thread: **12.1325163**
GFLOPS for 2 Threads: **12.1188081**
GFLOPS for 4 Threads: **12.1047541**

- Hence the number of GIOPS for different concurrency levels is more than the the number of GFLOPS for all concurrency levels.
- Below shown is the data chart displaying the GIOPS and GFLOPS for 1 , 2 and 4 concurrency level.



Theoretical Peak Performance:

The theoretical peak performance can be calculated using the below formula

GFLOPS = No of Cores * Clock Cycle * Instructions Per Cycle

System Configuration on Amazon t2 micro instance is
Model: Intel(R) Xeon(R) CPU E5-2676 v3 @ 2.40GHz
CPU Cores: 1
IPC: The system uses AVX2 instruction set extensions that can support 2x the FLOPS per core (16 Flops/Clock). Considering the minimum Flops = x, IPC = 8

GFLOPS = 1 * 2.40 * 8
= 19 .20 Instructions per second.

Efficiency:

The Efficiency can be measured as a comparison of actual results obtained to the theoretical performance of30720 the system.

$$\text{Efficiency} = \frac{\text{Actual Performance}}{\text{Theoretical Peak Performance}} * 100$$

According to the result obtained, the efficiency can be calculated as (FLOPS for 1 thread /Theoretical Peak Performance) *100

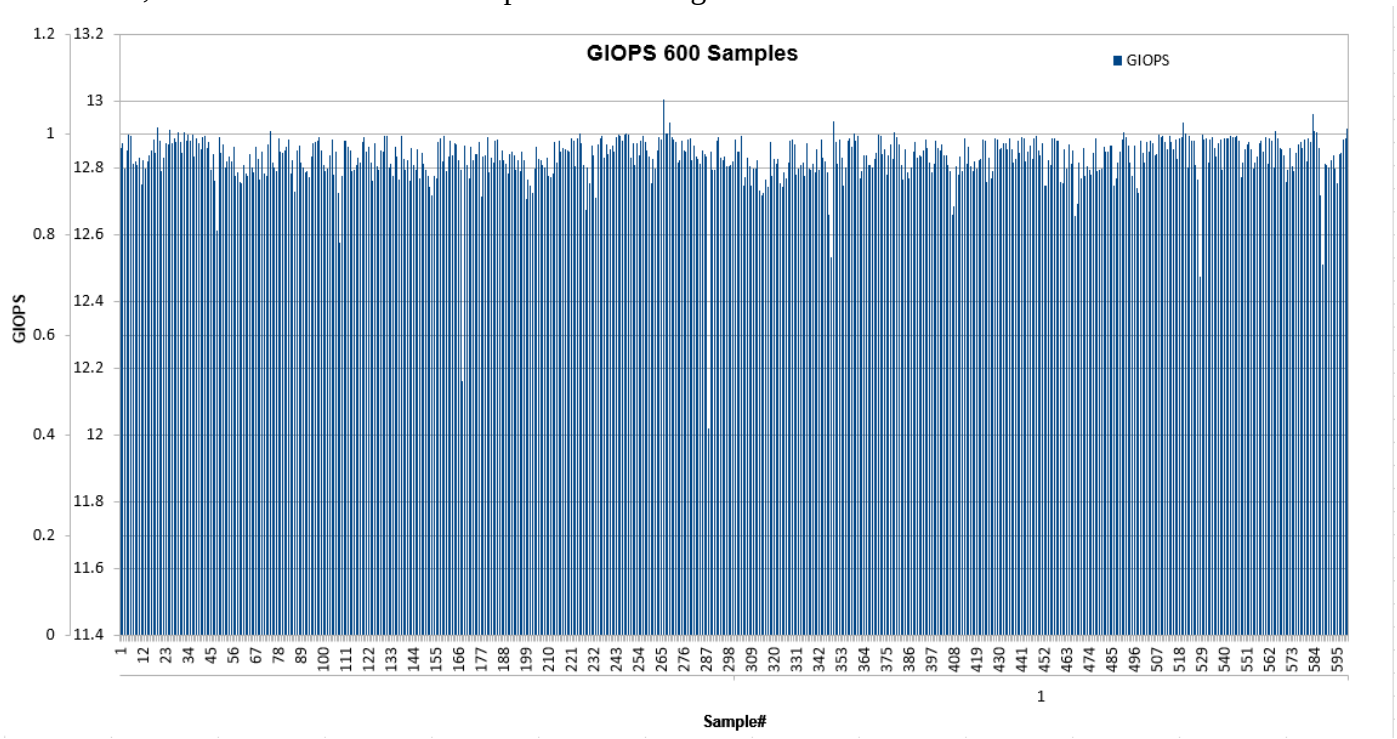
= (12.13 / 19.20) * 100
= 63.17 % Efficiency.

Conclusion:

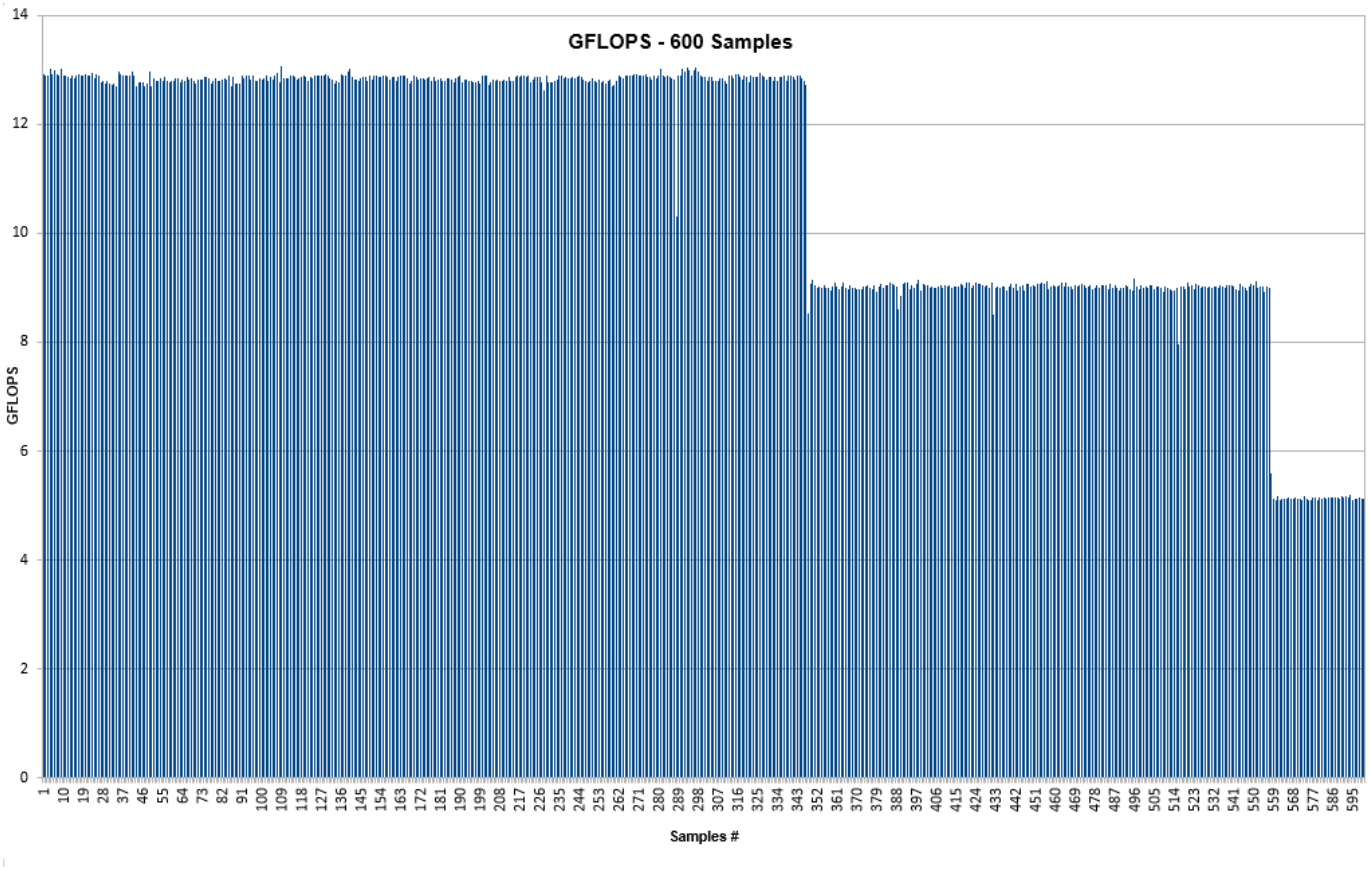
The optimal number of concurrency level for a good performance is 1. However, comparing the results with performance of other concurrency levels (2 & 4), the difference is very minimum.
The performance at concurrency level 1 is optimal since more threads bring up the overhead of thread maintenance and also time wait between switching between threads i.e. Wait time for other threads to complete their operations is also added.

CPU Benchmarking for 600 Samples
600 Samples for GIOPS and GFLOPS were recorded for concurrency level of 4 and the result data chart for GIOPS and GFLOPS is given below,

For GIOPS, the number of instructions per second ranges from 12.1 to 13.25 GIOPS



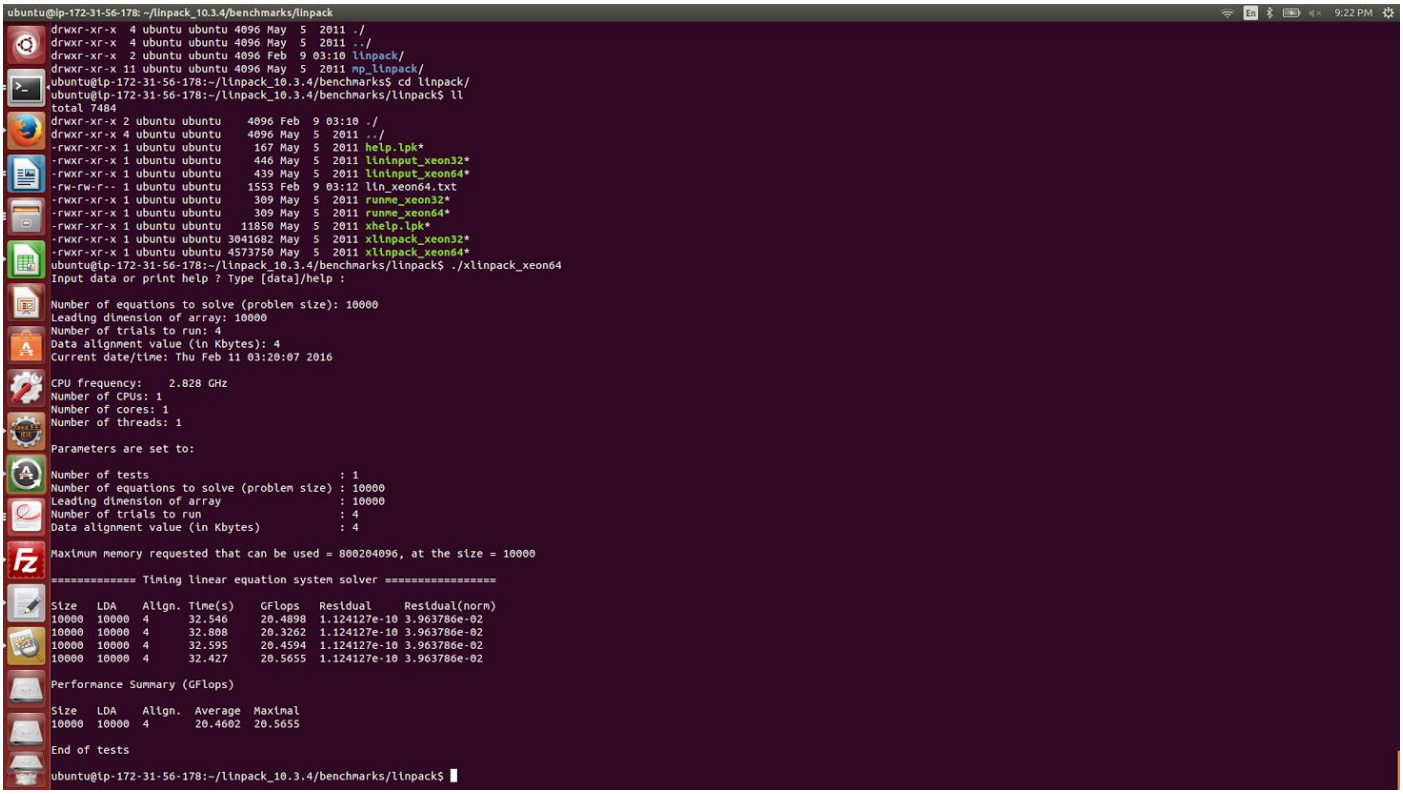
For GFLOPS, the number of instructions per second ranges from 5.92 to 13.01 GFLOPS



Extra Credits

The Linpack benchmarking tool was used to compare the accuracy of the results with the theoretical peak value obtained through this tool.

Below screenshot displays the Linpack Benchmarking results on Amazon T2 Micro Instance.



This benchmark was initialized with input as
No of Tests = 1
No of Equations to Solve = 10000
Leading Dimensions of Array = 10000
No of Trials to Run = 4
No of CPU = 1
No of Cores = 1
No of Threads = 1

The Linpack benchmark calculated the Average Theoretical Peak GFLOPS = 20.4602 Instructions per second.

Efficiency Achieved = (GFLOPS for 1 Thread / Theoretical Peak Performance) * 100
= (12.13/20.4602) *100
= 59.28%

The CPU benchmark gave efficiency of 59.28% when compared to Linpack Benchmark Theoretical peak Results.

DISK Benchmarking

This module aims to calculate the disk speed in terms of read and write for various block size of 1B, 1KB, 1 MB and accessing the disk sequentially or randomly.

Calculations

- The experiments and benchmarking done for this module gives us the throughput and latency for accessing disk & performing operations for different block sizes.
- **Cache Size:** 30720.00 Kb
- The text file used for benchmarking is 40Mb. The file size used to benchmark is greater than page cache so that it will fit the file contents in any of the caches and hence will generate accurate results as only disk memory will be used.
- Disk will be accessed sequentially and randomly.
- Disk operations include reading from file on the disk and writing in the file on the disk.
- Hence the performance will be measured on the Throughput and Latency of the disk for the operations on difference file access methods.

Throughput = No_of_operations * Num_Bytes
---------- Mb/Sec
Time_Elapsed * 1024 * 1024

No_of_operations: This is the total number of times the file is read or written to / from the disk.
Num_Bytes: The Bytes Read or written for each operation.
1B = 4000000 times (40Mb)
1Kb = 40000 times (40Mb)
1Mb = 40 times (40Mb)

Time Elapsed: The time taken to read or write 1B, 1Kb or 1Mb for a 40Mb file.

Latency: 1/Throughput

Benchmarking Results:

The Benchmarking result data shows the throughput for 1 Thread & 2 Threads Sequential and Random file access for 1B , 1Kb , 1Mb block size read/write operations.

1 Thread

	1B Read	1B Write	1Kb Read	1Kb Write	1Mb Read	1Mb Write
Sequential	35.120689	10.51446	4136.64258	1794.09119	7083.17822	3165.57227
	35.02203	9.933911	4047.13086	1860.82434	6755.47266	3311.20557
	35.751953	10.517959	4296.42822	1899.66028	4857.64014	3411.52881
Average	**35.4116563**	**10.3710723**	**4194.15747**	**1863.55902**	**5888.48279**	**3324.95886**

	1B Read	1B Write	1Kb Read	1Kb Write	1Mb Read	1Mb Write
Random	1.402331	0.529213	1191.65894	564.517822	7668.8833	3613.67651
	1.41225	0.501983	1221.92053	567.430908	8329.88281	3880.56079
	0.5127	0.5127	593.466248	593.466248	8001.34277	4514.12988
Average	**1.10909367**	**0.514632**	**1002.34857**	**575.138326**	**8000.0363**	**4002.78906**

2 Thread

	1B Read	1B Write	1Kb Read	1Kb Write	1Mb Read	1Mb Write
Sequential	17.595249	5.270917	2215.37842	997.157166	3736.78174	1925.87451
	17.266323	5.208666	2292.35669	929.584229	6745.14746	2012.29407
	17.386471	5.176753	1036.37891	932.081299	5496.95801	1738.10437
Average	**17.4160143**	**5.21877867**	**1848.038**	**952.940898**	**5326.29574**	**1892.09098**

	1B Read	1B Write	1Kb Read	1Kb Write	1Mb Read	1Mb Write
Random	0.687568	0.261782	671.5896	296.367371	5273.70801	2446.34473
	0.698517	0.202971	672.381592	304.878632	5035.48047	2033.0293
	0.720017	0.263469	658.052612	305.822723	4811.75391	2437.30908
Average	**0.702034**	**0.24274067**	**667.341268**	**302.356242**	**5040.31413**	**2305.56104**

- Three result sets were recorded for disk benchmarking and average of those results is calculated.
- The above results are shown for disk accessed sequentially and randomly for two different concurrency level for variable block sizes.

Based on the result sheets obtained, the average data chart is plotted for read /write operations.

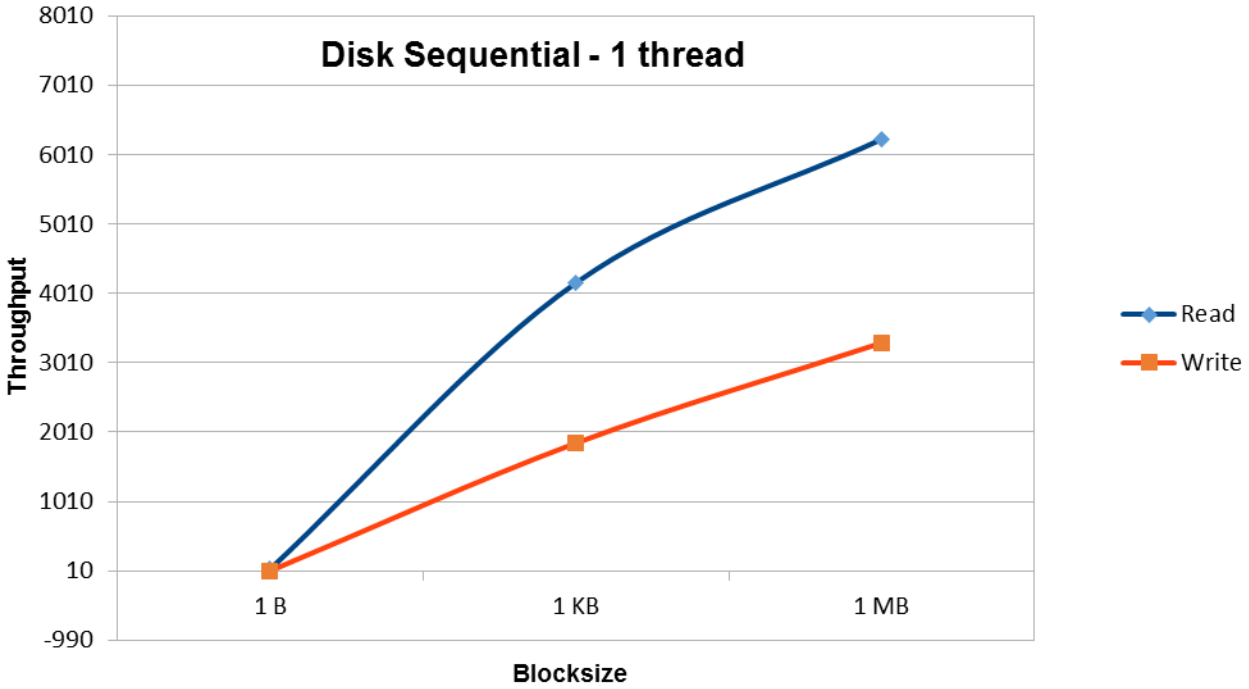


Fig. : Read/Write Sequential Disk access with 1 Thread.

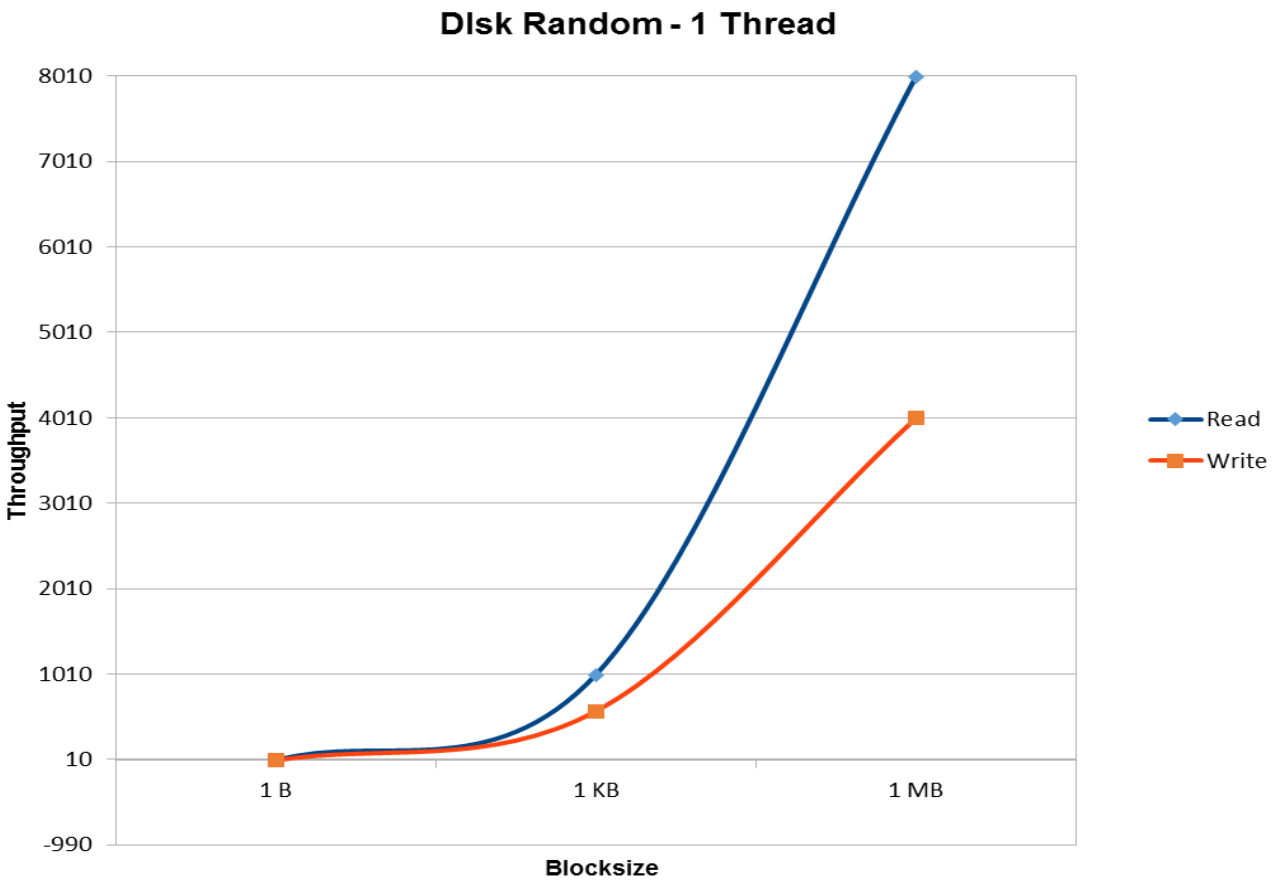


Fig. : Read/Write Random Disk access with 1 Thread.

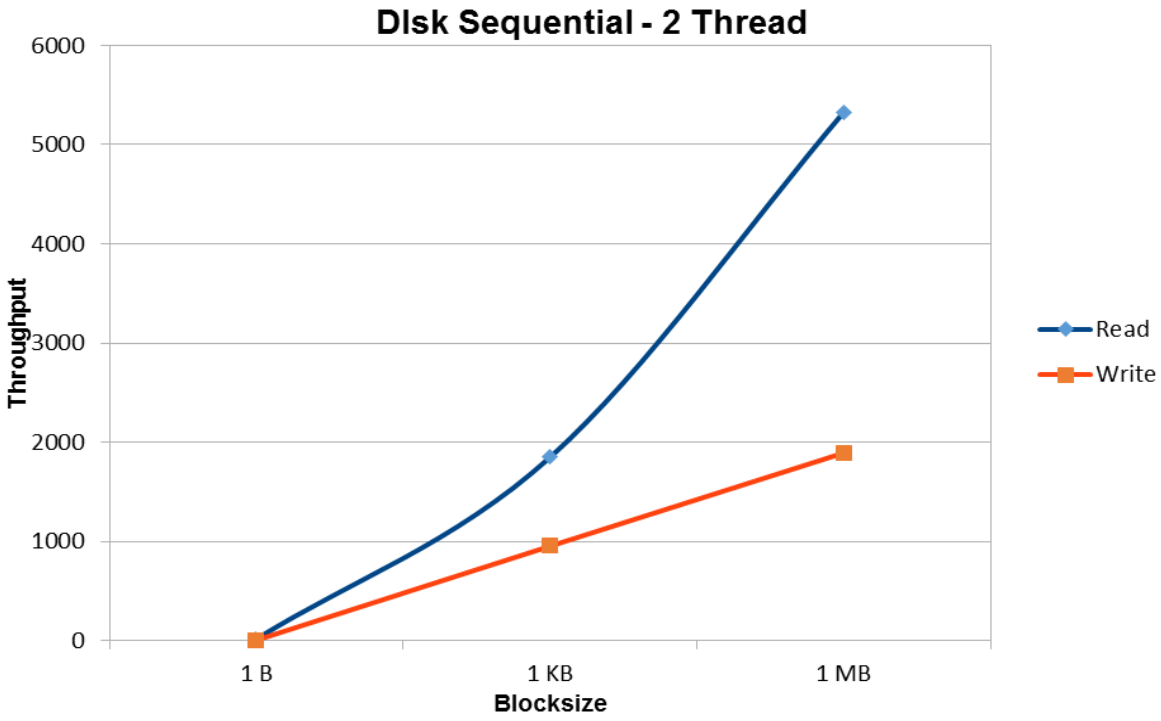


Fig. : Read/Write Sequential Disk access with 2 Thread.

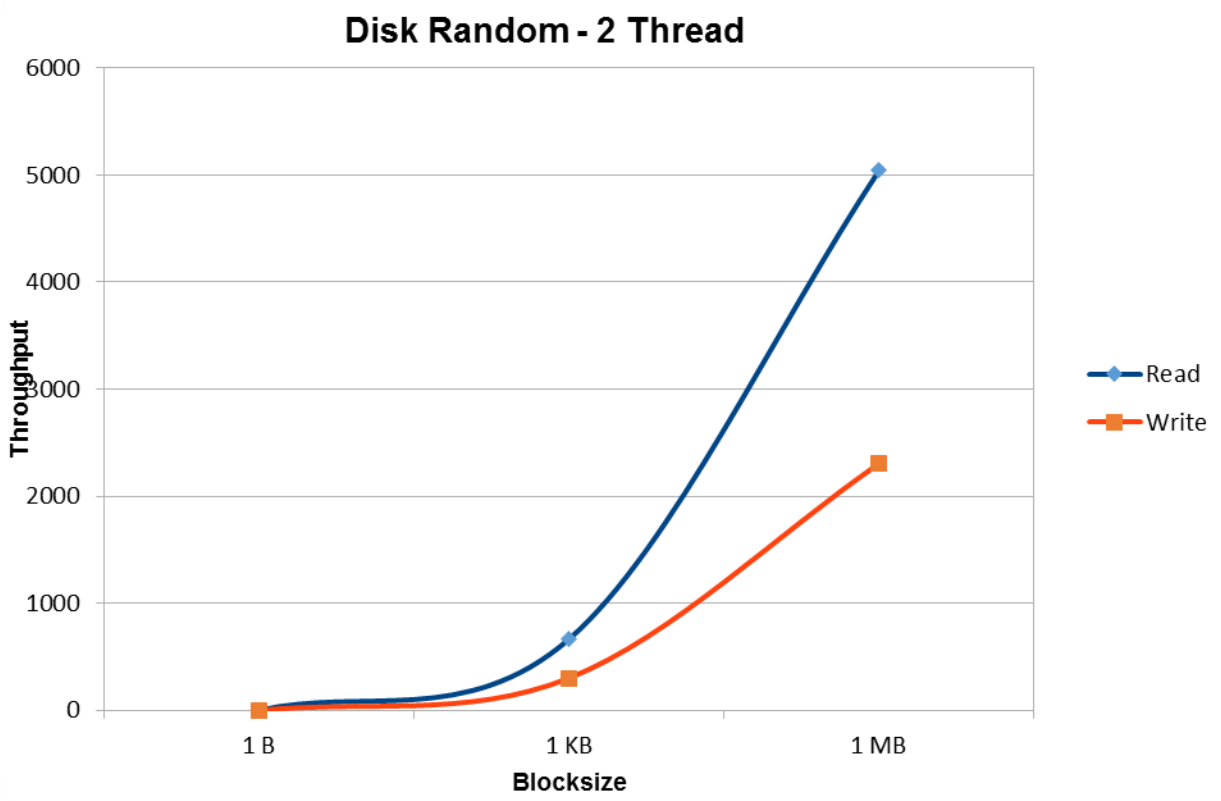


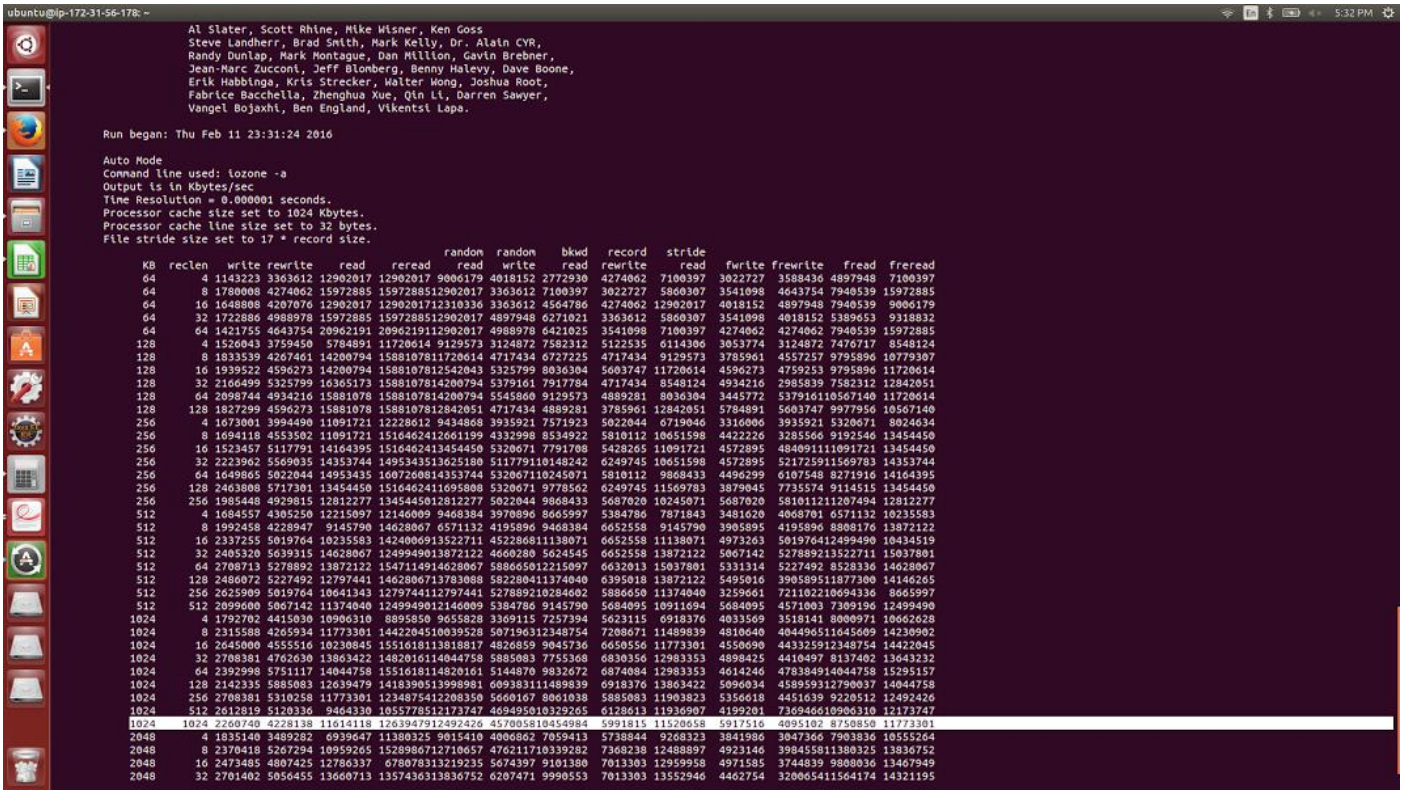
Fig. : Read/Write Random Disk access with 2 Thread.

Conclusion:

- The optimal performance achieved is for concurrency level 1. The average throughput and Latency shown in the results and graphs shows the optimal performance at concurrency level 1.
- Accessing the file randomly for 1Mb block size and performing read/write operations on concurrency level 1 gives optimal performance as less blocks are accessed since the block size is high.
- Also as per the data charts the random access is slower as compared to sequential since there is additional overhead of seeking the file pointer to any random location across the disk and then perform read/write operations on that location.

Extra Credits

IOzone Benchmark is used to find the best performance of the system and this performance is compared with the result set that we receive through this benchmarking program.



As shown in the screenshot, iozone 3 is run on the amazon t2 micro instance. The Output is in the format of **Kb/Sec**.

Theoretical Peak Performance

As per Iozone 3, Write 1Mb with Record Length of 1024,
Iozone Throughput fwrite = 5917.516Mb/sec
Benchmark fwrite = 3324.9588

Efficiency (write) = (Benchmark Result / Theoretical Result) * 100
= (3324.9588/5917.516) * 100
= 56.18 %

Iozone Throughput fread = 8750.850Mb/sec
Benchmark fread = 5888.4827

Efficiency (read) = (Benchmark Result / Theoretical Result) * 100
= (5888.4827/8750.850) * 100
= 67.29%

Memory Benchmarking

This module aims to calculate the performance of the memory speed on the parameter of throughput and latency. Memory speed is being tested by performing read write operations and accessing the memory sequentially and randomly for different block size of 1B, 1Kb, 1Mb for different concurrency level of 1 and 2.

Calculations:

For Memory Benchmarking, the system will perform 2 different read write operations on the memory for different block sizes at different concurrency levels while accessing the memory sequentially and randomly.

$$\text{Throughput} = \frac{\text{No\_of\_times operations performed} * (\text{No of Reads/Writes}) * \text{Num\_Bytes}}{\text{Time\_Elapsed} * 1024 * 1024} \text{ Mb/Sec}$$

No_of_operations: This is the total number of times the file is read or written to / from the disk.
No of Read/Writes: The Benchmarking is done using memory operations like memmove(Read and Write) and memcopy(Read and Write).
Num_Bytes: The Bytes Read or written for each operation.

1B = 100000000 times (100Mb)
1Kb = 100000 times (100Mb)
1Mb = 100 times (100Mb)

Time Elapsed: The time taken to read or write 1B, 1Kb or 1Mb of memory.

Latency: 1/Throughput

Benchmarking Results:

1 Thread

	1B	1Kb	1Mb
Sequential	305.828522	4909.44629	5327.79297
	320.768677	5693.5542	5582.09717
	322.572968	5695.57324	5672.60449
Average	**316.390056**	**5432.85791**	**5527.49821**

	1Bof your memory	1Kb	1Mb
Random	14.270962	3356.45532	5118.37549
	14.557113	3504.68897	5095.80225
	14.770414	3429.17896	5033.09424
Average	**14.5328297**	**3430.10775**	**5082.42399**

2 Thread

	1B	1Kb	1Mb
Sequential	86.274536	2835.85596	2787.92383
	162.887741	2704.50244	2621.56055
	161.612534	2813.43018	2551.84351
Average	**136.924937**	**2784.59619**	**2653.77596**

	1B	1Kb	1Mb
Random	7.334429	1766.55347	2570.69824
	7.31721	1708.13989	2578.58594
	7.331349	1666.70789	2484.93359
Average	**7.32766267**	**1713.80042**	**2544.73926**

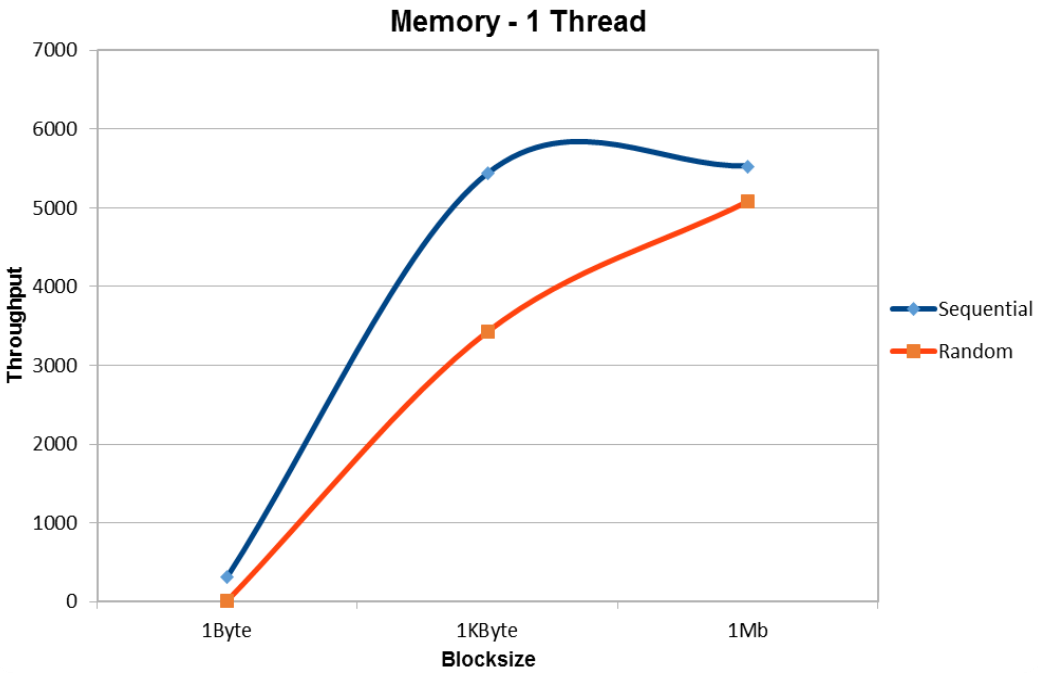


Fig. Sequential/ Random access for Memory 1 Thread for varying Block Size.

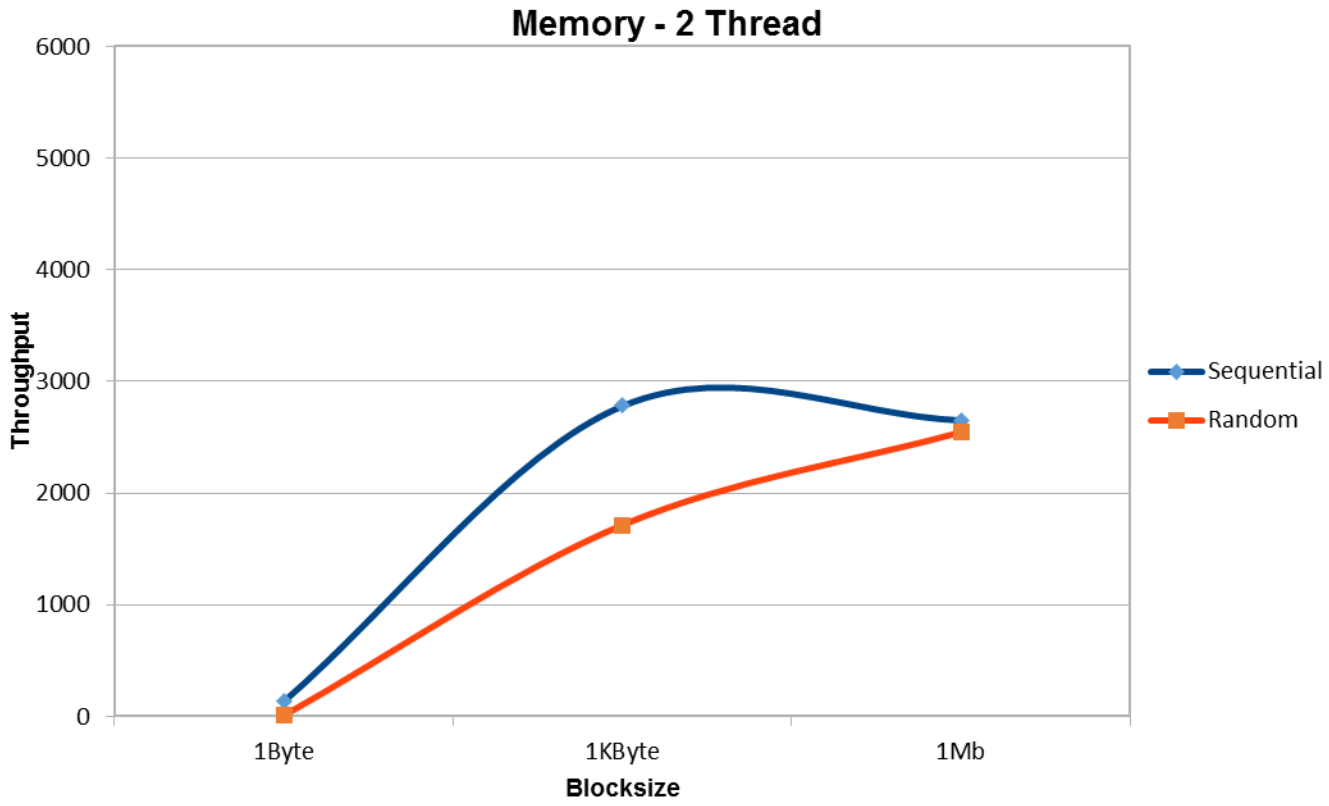


Fig. Sequential/ Random access for Memory 2 Thread for varying Block Size.

Theoretical Peak Performance:

The Theoretical is calculated using the references for finding clock speed and bitrate for DDR3_SDRAM. of your memory

System Configuration on T2.Mirco Instance:

Architecture: x86_64
Clock Speed: 2394.926 MHz
The theoretical peak performance can be calculated using the below formula
Throughput = Bitrate (Bits per clock) * Clock Speed

$$\frac{\text{Bitrate (Bits per clock)} * \text{Clock Speed}}{8} \text{ Mb/Sec}$$

= 19159.408 Mb/Sec

Efficiency:

The Efficiency of the performance for benchmarking on this system can be calculated by comparing the results with the theoretical peak performance obtained.

$$\text{Efficiency} = \frac{\text{Actual Performance}}{\text{Theoretical Peak Performance}} * 100 \text{ Mb/sec}$$

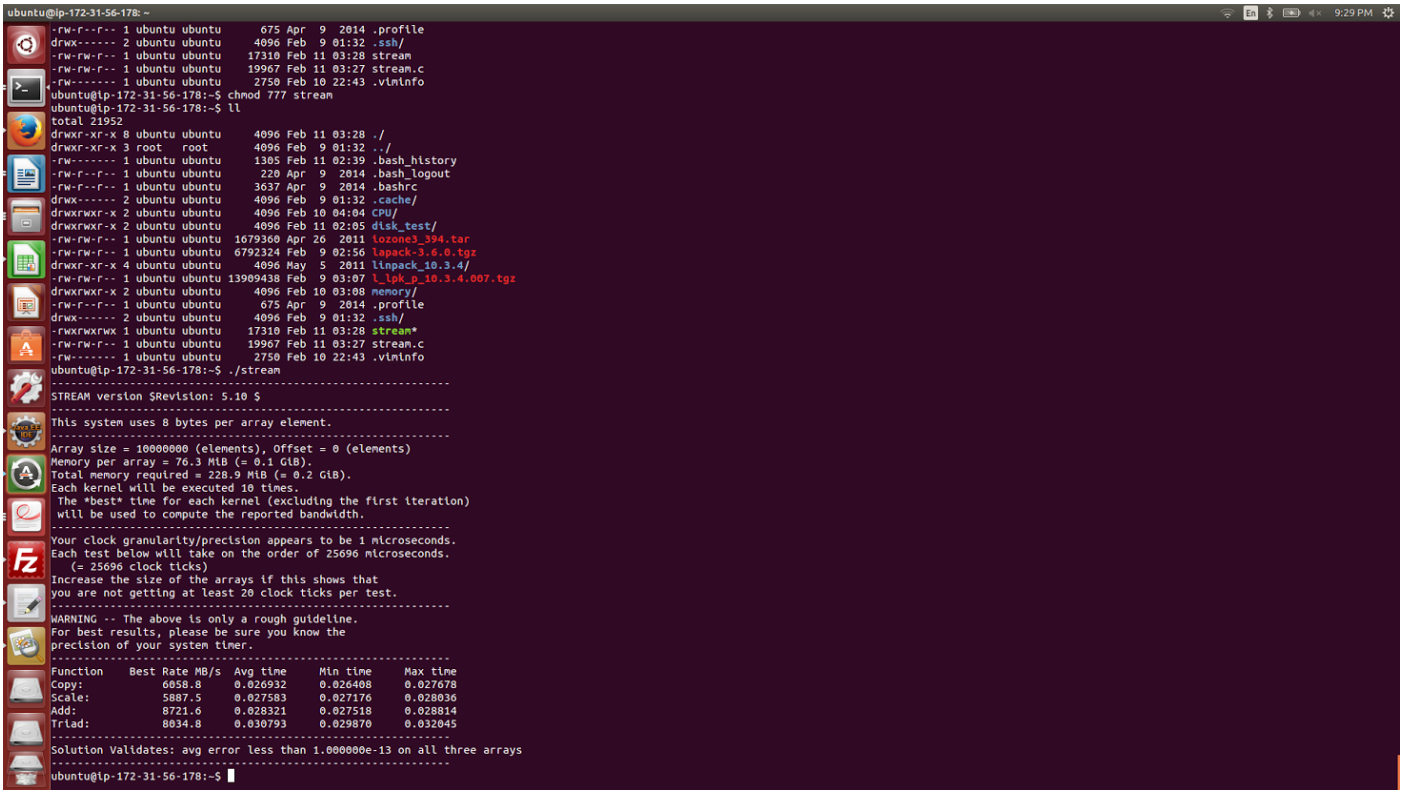
= (5527.49821/ 19159.408) * 100
= 28.85 %

Conclusion:

- The optimal performance achieved is for concurrency level 1. The average throughput and Latency shown in the results and graphs shows the optimal performance at concurrency level 1.
- Here again the sequential access is faster than the random access because the overhead of accessing any random memory and seeking the file pointer to that random location is avoided.

Extra Credits:

Stream Benchmark is used to find best performance of the Memory. The results of stream benchmark are mentioned in the below screenshot,



Efficiency:

Throughput in Stream Benchmark (Mb/sec) = 6058.80
Result Throughput (Mb/Sec) = 5527.49821

$$\text{Efficiency} = \frac{\text{Actual Performance}}{\text{Theoretical Peak Performance}} * 100 \text{ Mb/sec}$$

$$= (5527.4982/6058.80) * 100$$
$$= 91.23\%$$