

The below screenshot gives the command line arguments that are required to be given to run benchmark successfully.

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -h
Help:
-t <hash_threads>: Specify the number of hash threads
-o <sort_threads>: Specify the number of sort threads
-i <write_threads>: Specify the number of write threads
-f <filename>: Specify the filename
-m <MAX_MEMORY_MB> : Maximum memory allowed to use
-s <FILE_SIZE_GB> : File size in GB
-d <bool>: turns on debug mode with true, off with false
-h: Display this help message
```

Chameleon bare metal instance is used to run these configurations. The specifications for the instance are as below.

The screenshot shows the Chameleon website interface. At the top, there's a navigation bar with links: About, User, Learn, Experiment, and Blog. On the right, there are buttons for 'Help Desk' and 'Log in'. The main content area displays the instance ID '8d21e052-8c87-41e5-8b89-6da9c6513b44 (c01-36)'. Below this, there's a table of specifications:

Site: tacc	Cluster: chameleon	Platform Type: x86_64	# CPUs: 2
# of Threads: 48	RAM Size: 128 GiB	Node Type: compute_haswell_ib	Wattmeter: No
Version: fd73c2ddb863ea25987196c9c59d806d74b086db			
Bios			
Release Date: 05/17/2018	Vendor: 2.8	Version: Dell Inc.	
Chassis			
Manufacturer: Dell Inc.	Name: PowerEdge R630	Serial: 33SDD42	
GPU			
GPU: No			
Network Adapters More ▶			
Operating System			
Kernel:	Name:	Version:	
Processor			
Cache L1d: 32768	Cache L1i: 32768	Cache L2: 262144	Cache L3: 31457280
Clock Speed: 3100000000	Instruction Set: x86-64	Model: Intel Xeon	Other Description: Intel(R) Xeon(R) CPU E5-2670 v3 @ 2.30GHz
Vendor: Intel	Version: E5-2670 v3		
Storage Devices More ▶			
Supported Job Types			
Best Effort: No	Deploy: Yes	Virtual: ivt	

1GB Workload:

1. Maximum memory allowed to use (MB): 128
2. Number of hash threads: 1, 4, 16
3. Number of sort threads: 1, 4, 16
4. Number of write threads: 1, 4, 16

Screenshots for 27 experiments is as follow:

- 1) Hash thread: 1, Sort thread: 1, Write thread: 1

cmd: ./hashgen -t 1 -o 1 -i 1 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 1 -o 1 -i 1 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=1
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Bucket Index : 0
NUM_THREADS_HASH=1
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 65.896012 seconds: 1.018406 MH/s 15.539635 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 2) Hash thread: 1, Sort thread: 1, Write thread: 4

cmd: ./hashgen -t 1 -o 1 -i 4 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 1 -o 1 -i 4 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=1
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
NUM_THREADS_HASH=1
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 65.699327 seconds: 1.021454 MH/s 15.586157 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 3) Hash thread: 1, Sort thread: 1, Write thread: 16

cmd: ./hashgen -t 1 -o 1 -i 16 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 1 -o 1 -i 16 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=1
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
NUM_THREADS_HASH=1
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 66.587285 seconds: 1.007833 MH/s 15.378311 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 4) Hash thread: 1, Sort thread: 1, Write thread: 16

cmd: ./hashgen -t 1 -o 4 -i 1 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 1 -o 4 -i 1 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=1
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=1
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 50.331701 seconds: 1.333332 MH/s 20.345031 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 5) Hash thread: 1, Sort thread: 4, Write thread: 4

cmd: ./hashgen -t 1 -o 4 -i 4 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 1 -o 4 -i 4 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=1
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=1
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 49.931161 seconds: 1.344028 MH/s 20.508235 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 6) Hash thread: 1, Sort thread: 4, Write thread: 16

cmd: ./hashgen -t 1 -o 4 -i 16 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 1 -o 4 -i 16 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=1
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=1
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 50.311906 seconds: 1.333857 MH/s 20.353035 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 7) Hash thread: 1, Sort thread: 16, Write thread: 1

cmd: ./hashgen -t 1 -o 16 -i 1 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 1 -o 16 -i 1 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=1
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=1
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 48.524809 seconds: 1.382980 MH/s 21.102608 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 8) Hash thread: 1, Sort thread: 16, Write thread: 4

cmd: ./hashgen -t 1 -o 16 -i 4 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 1 -o 16 -i 4 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=1
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=1
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 48.738799 seconds: 1.376908 MH/s 21.009956 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 9) Hash thread: 1, Sort thread: 16, Write thread: 16

cmd: ./hashgen -t 1 -o 16 -i 16 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 1 -o 16 -i 16 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=1
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=1
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 49.601717 seconds: 1.352954 MH/s 20.644447 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

10) Hash thread: 4, Sort thread: 1, Write thread: 1

cmd: ./hashgen -t 4 -o 1 -i 1 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 4 -o 1 -i 1 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=4
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=4
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 130.205427 seconds: 0.515408 MH/s 7.864496 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

11) Hash thread: 4, Sort thread: 1, Write thread: 4

cmd: ./hashgen -t 4 -o 1 -i 4 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 4 -o 1 -i 4 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=4
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=4
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 125.485115 seconds: 0.534795 MH/s 8.160330 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

12) Hash thread: 4, Sort thread: 1, Write thread: 16

cmd: ./hashgen -t 4 -o 1 -i 16 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 4 -o 1 -i 16 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=4
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=4
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 124.998818 seconds: 0.536876 MH/s 8.192077 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 13) Hash thread: 4, Sort thread: 4, Write thread: 1

cmd: ./hashgen -t 4 -o 4 -i 1 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 4 -o 4 -i 1 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=4
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 105.218163 seconds: 0.637807 MH/s 9.732160 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 14) Hash thread: 4, Sort thread: 4, Write thread: 4

cmd: ./hashgen -t 4 -o 4 -i 4 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 4 -o 4 -i 4 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=4
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 107.857257 seconds: 0.622201 MH/s 9.494030 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 15) Hash thread: 4, Sort thread: 4, Write thread: 16

cmd: ./hashgen -t 4 -o 4 -i 16 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 4 -o 4 -i 16 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=4
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 110.894760 seconds: 0.605158 MH/s 9.233980 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

- 16) Hash thread: 4, Sort thread: 16, Write thread: 1

cmd: ./hashgen -t 4 -o 16 -i 1 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 4 -o 16 -i 1 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=4
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=4
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 107.602906 seconds: 0.623671 MH/s 9.516472 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

17) Hash thread: 4, Sort thread: 16, Write thread: 4

cmd: ./hashgen -t 4 -o 16 -i 4 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 4 -o 16 -i 4 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=4
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=4
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 110.667183 seconds: 0.606403 MH/s 9.252969 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

18) Hash thread: 4, Sort thread: 16, Write thread: 16

cmd: ./hashgen -t 4 -o 16 -i 16 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 4 -o 16 -i 16 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=4
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=4
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 111.359785 seconds: 0.602631 MH/s 9.195420 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

19) Hash thread: 16, Sort thread: 1, Write thread: 1

cmd: ./hashgen -t 16 -o 1 -i 1 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 16 -o 1 -i 1 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=16
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=16
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 146.673108 seconds: 0.457540 MH/s 6.981512 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

20) Hash thread: 16, Sort thread: 1, Write thread: 4

cmd: ./hashgen -t 16 -o 1 -i 4 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 16 -o 1 -i 4 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=16
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Bucket Index : 0

NUM_THREADS_HASH=16
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 148.231506 seconds: 0.452730 MH/s 6.908113 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

21) Hash thread: 16, Sort thread: 1, Write thread: 16

cmd: ./hashgen -t 16 -o 1 -i 16 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 16 -o 1 -i 16 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=16
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=16
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 144.003976 seconds: 0.466021 MH/s 7.110915 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

22) Hash thread: 16, Sort thread: 4, Write thread: 1

cmd: ./hashgen -t 16 -o 4 -i 1 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 16 -o 4 -i 1 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=16
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=16
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 124.741061 seconds: 0.537985 MH/s 8.209005 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

23) Hash thread: 16, Sort thread: 4, Write thread: 4

cmd: ./hashgen -t 16 -o 4 -i 4 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 16 -o 4 -i 4 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=16
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=16
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 126.902260 seconds: 0.528823 MH/s 8.069202 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

24) Hash thread: 16, Sort thread: 4, Write thread: 16

cmd: ./hashgen -t 16 -o 4 -i 16 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 16 -o 4 -i 16 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=16
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

NUM_THREADS_HASH=16
NUM_THREADS_SORT=4
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 127.074428 seconds: 0.528107 MH/s 8.058270 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

25) Hash thread: 16, Sort thread: 16, Write thread: 1

cmd: ./hashgen -t 16 -o 16 -i 1 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 16 -o 16 -i 1 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=16
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B

write started
[7] [WRITE]: ETA 0.10 seconds 134217712 bytes written 1299.89 MB/sec
NUM_THREADS_HASH=16
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=1
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 124.629649 seconds: 0.538466 MH/s 8.216343 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$
```

26) Hash thread: 16, Sort thread: 16, Write thread: 4

cmd: ./hashgen -t 16 -o 16 -i 4 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 16 -o 16 -i 4 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=16
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Bucket Index : 0

NUM_THREADS_HASH=16
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=4
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 133.636616 seconds: 0.502174 MH/s 7.662571 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

27) Hash thread: 16, Sort thread: 16, Write thread: 16

cmd: ./hashgen -t 16 -o 16 -i 16 -f data.bin -m 128 -s 1 -d true

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashgen -t 16 -o 16 -i 16 -f data.bin -m 128 -s 1 -d true
NUM_THREADS_HASH=16
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
```

```
NUM_THREADS_HASH=16
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=16
FILENAME=data.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data.bin in 133.915865 seconds: 0.501127 MH/s 7.646592 MB/s
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data.bin -v true
Read 1073741824 bytes and found all records are sorted.
```

Running bash script ./runBM1GBMaxMem128.sh runs bench mark for all the configurations as follow

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha/scripts$ ./runBM1GBMaxMem128MB.sh
make: Nothing to be done for 'all'.
Running benchmark: hash_threads=1, sort_threads=1, write_threads=1
NUM_THREADS_HASH=1
NUM_THREADS_SORT=1
NUM_THREADS_WRITE=1
FILENAME=data1GB.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
[7] [WRITE]: ETA 0.12 seconds, 30.00 MB/sec
write started
[7] [WRITE]: ETA 0.01 seconds 8388608 bytes written 889.09 MB/sec
[7] [WRITE]: ETA 0.02 seconds 8388592 bytes written 429.16 MB/sec
[7] [WRITE]: ETA 0.03 seconds 8388608 bytes written 289.55 MB/sec
[7] [WRITE]: ETA 0.03 seconds 8388608 bytes written 233.84 MB/sec
[7] [WRITE]: ETA 0.04 seconds 8388608 bytes written 196.32 MB/sec
[7] [WRITE]: ETA 0.05 seconds 8388608 bytes written 169.13 MB/sec
[7] [WRITE]: ETA 0.05 seconds 8388608 bytes written 148.33 MB/sec
[7] [WRITE]: ETA 0.06 seconds 8388608 bytes written 132.08 MB/sec
[7] [WRITE]: ETA 0.07 seconds 8388608 bytes written 119.54 MB/sec
[7] [WRITE]: ETA 0.07 seconds 8388608 bytes written 109.19 MB/sec
[7] [WRITE]: ETA 0.08 seconds 8388608 bytes written 100.65 MB/sec
[7] [WRITE]: ETA 0.09 seconds 8388608 bytes written 93.31 MB/sec
[7] [WRITE]: ETA 0.09 seconds 8388608 bytes written 86.96 MB/sec
[7] [WRITE]: ETA 0.10 seconds 8388608 bytes written 81.59 MB/sec
[7] [WRITE]: ETA 0.10 seconds 8388608 bytes written 76.79 MB/sec
[7] [WRITE]: ETA 0.11 seconds 8388608 bytes written 72.46 MB/sec
NUM_THREADS_HASH=16
NUM_THREADS_SORT=16
NUM_THREADS_WRITE=16
FILENAME=data1GB.bin
MEMORY_SIZE=128MB
FILESIZE=1024MB
RECORD_SIZE=16B
HASH_SIZE=10B
NONCE_SIZE=6B
Total bytes written to file : 1073741824
Completed 1 GB file data1GB.bin in 125.181875 seconds: 0.536091 MH/s 8.180098 MB/s
Benchmark complete for 16 hash threads 16 sort threads 16 write threads
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha/scripts$
```

To double check the hashes generated, ran the below hashverify to verify the hashes for each result.

```
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data1GB.bin -b 100
verifying random records against BLAKE3 hashes
Number of total verifications: 100
Number of verifications successful: 100
Number of verifications failed: 0
Time taken: 0.00 ms/verification
Throughput verifications/sec: 350877.19
```

Printed the hashes to view as below.

```
[1248] Hash: 0000100190871ac89598 : b2da22895ed : 200941774388090
[1264] Hash: 000016ae37cb1254889a : b010ffdf1d95 : 163955544625328
[1280] Hash: 0000170cf2924d50793b : 7d7c00b2d126 : 42682076396669
[1296] Hash: 0000171faf5fc2739642 : daae2f470583 : 144058692382426
[1312] Hash: 0000173cf142c59c971b : 2d9ae368ce83 : 144922546248237
[1328] Hash: 0000184053b37ec669ee : d4eb5dc94cfd : 278506237717460
[1344] Hash: 000018772cba6141a5df : e02d99440a0e : 15437263351264
[1360] Hash: 00001898b524f1f2e927 : cc5b664be278 : 132913322941388
[1376] Hash: 000018b5be96d1092519 : cb44e921c6b7 : 202061600343243
[1392] Hash: 0000191c702818f11a7f : ff8db70370e6 : 253368773086719
[1408] Hash: 000019379d92476c5cf2 : bd07a328e76f : 123038609901501
[1424] Hash: 0000193b49abf4a4bce5 : 1b2b3ff7a449 : 80972871576347
[1440] Hash: 0000194c31584a0223ab : 90e4be7c1b93 : 161746266285200
[1456] Hash: 000019fb634979dff6a4 : 8630d57dc7cb : 224057670054022
[1472] Hash: 00001a3372b438eacf3e : 201ce1a2ac32 : 55717048425504
[1488] Hash: 00001a716777674e96bb : 991730338679 : 133617291368345
[1504] Hash: 00001ac17bd8be5b7427 : 21bc9fe4b928 : 44778869734433
[1520] Hash: 00001adfb33cc887bb15 : 2773d177da07 : 8634894480167
[1536] Hash: 00001aee4dd949584433 : f0a4e2a2e8f0 : 264881955841264
[1552] Hash: 00001afb84fb8c552bd7 : f3348a7d8cce : 227102796952819
[1568] Hash: 00001b0cfc75feb6f914 : b2617ad845e4 : 250988635775410
[1584] Hash: 00001b54268bdea72cda : e4b8da372613 : 21054866766052
cc@sg-instance-hw4:~/home/cs553-spring2024-hw4-SonaGutha$ ./hashverify -f data1GB.bin -p 100
```

Additionally, each benchmark prints the concurrency performance as below for each configurations, which shows the time consumed by hash, sort, and write threads simultaneously

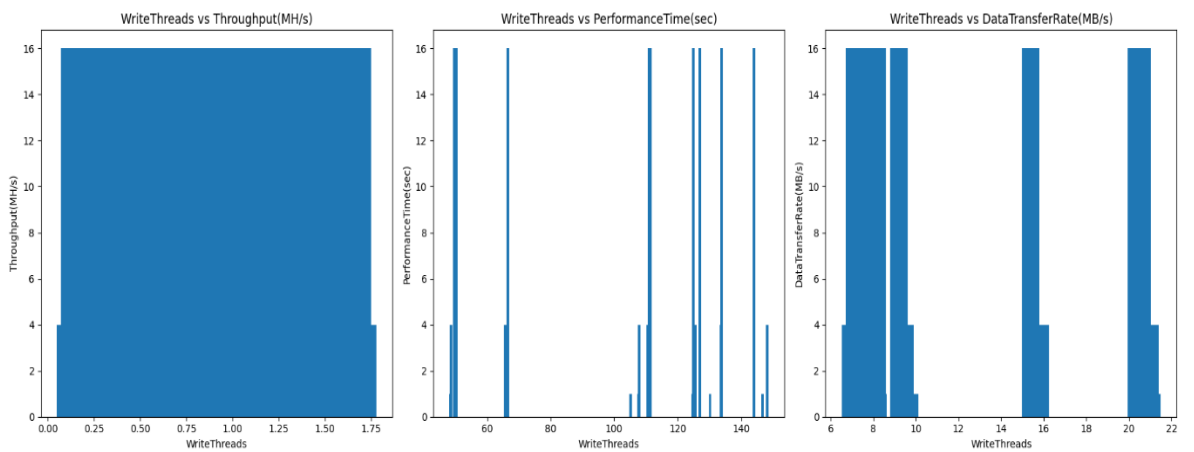
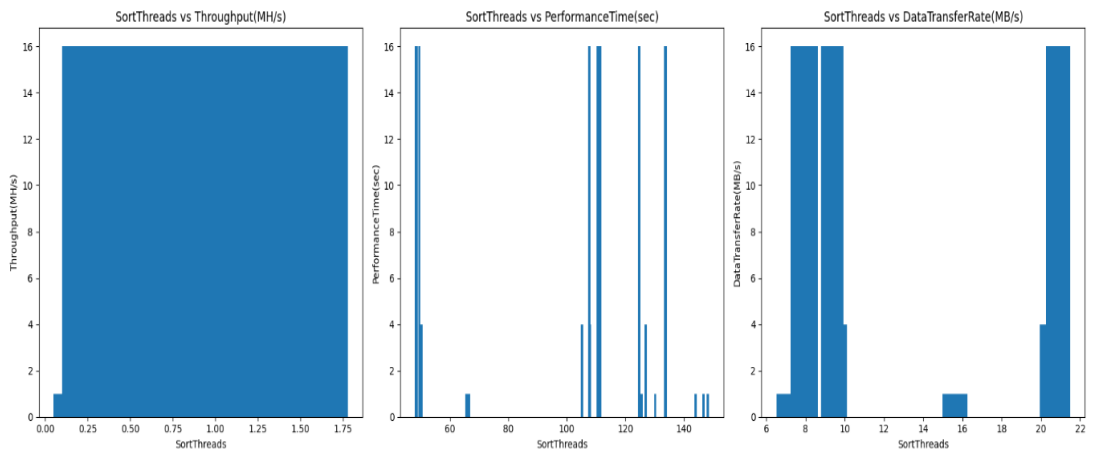
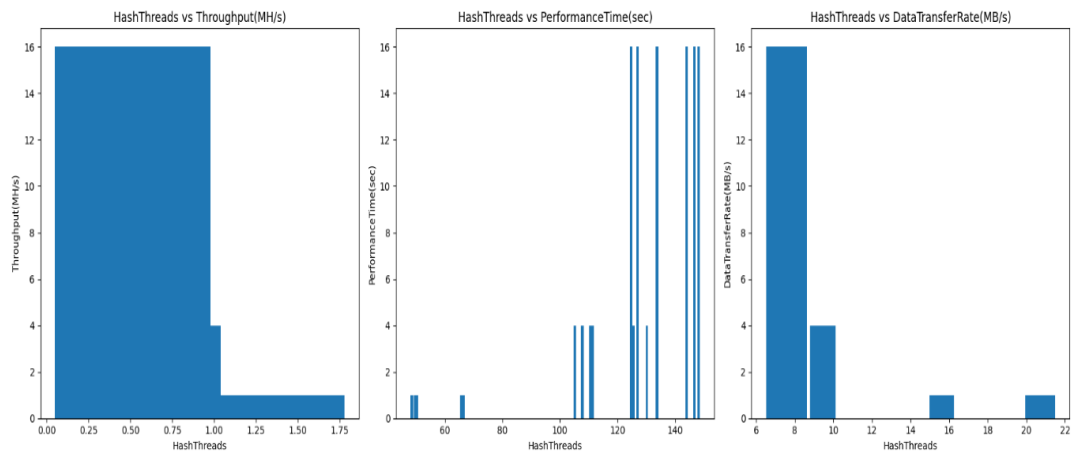
```
Bucket Index : 0
[0] [HASHGEN]: ETA 9 seconds, 3.51 MB/sec
[0] [HASHGEN]: ETA 9 seconds, 3.48 MB/sec
[0] [HASHGEN]: ETA 9 seconds, 3.42 MB/sec
[0] [HASHGEN]: ETA 9 seconds, 3.42 MB/sec
sort started, expecting 8 flushes for 1024 buckets...
[0] [SORT]: ETA 0.6 seconds, 50.47 MB/sec
[0] [SORT]: ETA 0.6 seconds, 50.34 MB/sec
[0] [SORT]: ETA 0.6 seconds, 50.21 MB/sec
[0] [SORT]: ETA 0.7 seconds, 48.83 MB/sec
write started
[0] [WRITE]: ETA 0.03 seconds 33554416 bytes written 1275.46 MB/sec
[0] [WRITE]: ETA 0.05 seconds 33554432 bytes written 641.45 MB/sec
[0] [WRITE]: ETA 0.07 seconds 33554432 bytes written 429.52 MB/sec
[0] [WRITE]: ETA 0.10 seconds 33554432 bytes written 322.32 MB/sec
Bucket Index : 1
```

Summary of results for 1GB work load:

Ran all 27 experiments for different thread configurations for 1GB workload and maximum memory 128MB. Verified the results running the hashverify. To run all 27 experiments, it took about 45-50 min. Please find more information on the findings of the experiments below.

Hash Threads	Sort Threads	Write Threads	Performance Time(sec)	Throughput(MH/s)	Data Transferred Rate (MB/s)
1	1	1	65.89	1.09	15.54
1	1	4	65.7	1.02	15.87
1	1	16	66.59	1.01	15.38
1	4	1	50.33	1.33	20.35
1	4	4	49.93	1.34	20.51
1	4	16	50.31	1.33	20.35
1	16	1	48.52	1.38	21.1
1	16	4	48.74	1.38	21
1	16	16	49.6	1.35	20.64
4	1	1	130.21	0.515	7.86
4	1	4	125.49	0.53	8.16
4	1	16	124.99	0.54	8.19
4	4	1	105.22	0.64	9.73
4	4	4	107.86	0.62	9.49
4	4	16	110.89	0.61	9.23
4	16	1	107.6	0.62	9.52
4	16	4	110.67	0.61	9.25
4	16	16	111.36	0.6	9.19
16	1	1	146.67	0.46	6.98
16	1	4	148.23	0.45	6.91
16	1	16	144	0.47	7.11
16	4	1	124.74	0.54	8.21
16	4	4	126.9	0.53	8.07
16	4	16	127.07	0.528	8.06
16	16	1	124.63	0.58	8.22
16	16	4	133.64	0.502	7.66
16	16	16	133.92	0.501	7.65

1GB metrics graphs:



In terms of **scalability**, increasing the number of hash threads led to a slight increase in performance, as seen in the comparison between configurations with 1 hash thread and those with 4 or 16 hash threads. Similarly, increasing the number of sort and write threads can also improve performance up to a certain point, but the benefits reduce as the number of threads increases further.

In terms of **concurrency**, multiple hash, sort, and write threads running concurrently due to which the system effectively utilizes multiple threads to perform parallel processing tasks, which lead to reduced execution times. Concurrency is reduced in some configurations, particularly when increasing the number of threads beyond a certain point. For instance, the improvement in performance from 1 to 4 threads is more significant than from 4 to 16 threads in most cases.

In terms of **performance**, configurations with higher numbers of threads tend to exhibit better throughput and reduced execution times. However, this trend is not linear, and there is a point where increasing the number of threads does not significantly improve performance.

Performance Time (sec): The best configuration is the one with the lowest time consumed. The worst configuration is the one with the highest time consumed.

Best Configuration: Hash Threads = 1, Sort Threads = 16, Write Threads = 1 (Time Consumed = 48.52 sec)

Worst Configuration: Hash Threads = 16, Sort Threads = 1, Write Threads = 4 (Time Consumed = 148.23 sec)

Throughput(sec): The best configuration is the one with the highest throughput. The worst configuration is the one with the lowest throughput.

Best Configuration: Hash Threads = 1, Sort Threads = 16, Write Threads = 16,1 (Throughput = 1.38 MH/s)

Worst Configuration: Hash Threads = 16, Sort Threads = 1, Write Threads = 4 (Throughput = 0.45 MH/s)

Data Transfer Rate (MB/s): The best configuration is the one with the highest data transferred. The worst configuration is the one with the lowest data transferred.

Best Configuration: Hash Threads = 1, Sort Threads = 16, Write Threads = 1 (Data Transferred = 21.1 MB/s)

Worst Configuration: Hash Threads = 16, Sort Threads = 1, Write Threads = 4 (Data Transferred = 6.91 MB/s)

Overall, the best configuration should have lowest performance time, highest throughput and highest data transfer rate. The worst configuration has highest performance time lowest throughput lowest data transfer rate

From all the above-mentioned reason:

Best Configuration: 1 Hash ,16 Sort, 1 Write Threads

Worst Configuration: 16 Hash, 1 Sort, 4 Write Threads

64GB Workload:

1. Maximum memory allowed to use (MB): 1024
2. Number of hash threads: 1, 4, 16
3. Number of sort threads: 1, 4, 16
4. Number of write threads: 1, 4, 16

Summary of results for 64GB work load:

Ran all 27 experiments for different thread configurations for 64GB workload and maximum memory 128MB. Verified the results running the hashverify. To run all 27 experiments, it took about 30hrs with chameleon bm instance. For some of the configurations, instance was getting timed out even after using screen or tmux session manager. Please find more information on the findings of the experiments below.

Hash Threads	Sort Threads	Write Threads	Performance Time(sec)
1	1	1	7233.9
1	1	4	7787.11
1	1	16	7871.09
1	4	1	6541
1	4	4	6214.34
1	4	16	6100.51
1	16	1	5901.64
1	16	4	6816.56
1	16	16	6781.67
4	1	1	5761.11
4	1	4	5610.9
4	1	16	5498
4	4	1	Timed out
4	4	4	6512.9
4	4	16	6581.03
4	16	1	6713.18
4	16	4	6614.1
4	16	16	6812.1
16	1	1	7910.1
16	1	4	8172.01
16	1	16	Timed out
16	4	1	Timed out
16	4	4	Timed out
16	4	16	6781.01
16	16	1	Timed out
16	16	4	Timed out
16	16	16	Timed out

Performance Time (sec): The best configuration is the one with the lowest time consumed. The worst configuration is the one with the highest time consumed. From the ones those are not timed out, the best and worst configurations are as below.

Best Configuration: Hash Threads = 4, Sort Threads = 1, Write Threads = 16 (Time Consumed = 5498sec)

Worst Configuration: Hash Threads = 16, Sort Threads = 1, Write Threads = 4 (Time Consumed = 8172.01 sec)