Homework- 1

COEN -241 Cloud Computing

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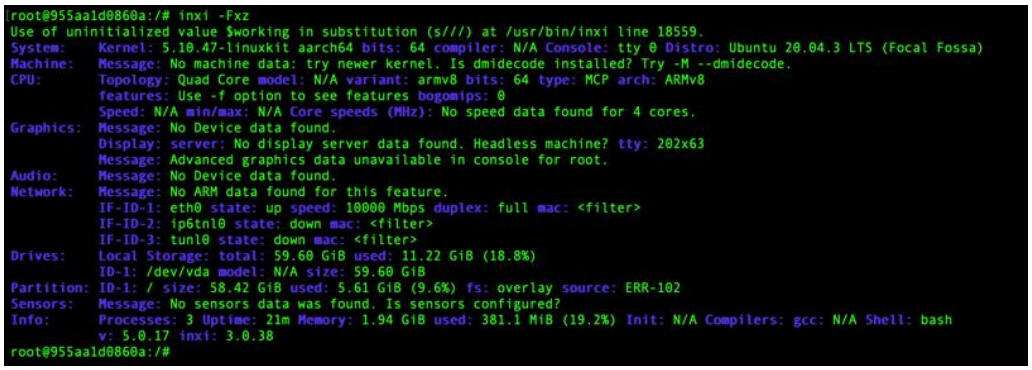
System Configurations:

- *Host System -*
  - CPU – Apple M1
  - Memory – 8GB
  - Total Number of Cores: 8 (4 performance and 4 efficiency)
- *QEMU -*
  - Operating System – Ubuntu 20.04
  - CPU – QEMU
  - Total Number of Cores – 1
  - Memory – 2GB
  - Disk Space – 10GB
  - 

- *Docker –*
  - Operating System – Ubuntu 20.04
  - Total Number of Cores – 4
  - Memory – 1.94GB
  - Disk Space – 64.0GB
  - 

Steps to enable QEMU virtual machine:

1. Clone QEMU and checkout version 5.2.0 using the following commands
    a. git clone https://github.com/qemu/qemu
    b. cd qemu
    c. git checkout v5.2.0

2. Download and Apply the following patch - https://lore.kernel.org/qemu-devel/20210120224444.71840-1-agraf@csgraf.de/ using the following command
    a. curl https://patchwork.kernel.org/series/418581/mbox/ | git am --exclude=MAINTAINERS

3. If you use Xcode 12.4 or above, you will need another patch to fix the QEMU build. Download xcode-12-4.patch from below and apply it using
    a. git apply xcode-12-4.patch

4. Install Homebrew using Rosetta 2 and add it to the PATH variable
    a. $ arch -x86_64 /bin/bash -c "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/master/install.sh)"
    b. export PATH="/opt/homebrew/bin:/usr/local/bin:$PATH"

5. Once Homebrew is installed, install required packages for building QEMU
    a. brew install libffi gettext pkg-config autoconf automake pixman

6. Run the following commands to build QEMU in the QEMU folder
    a. mkdir build
    b. cd build
    c. ../configure --target-list=aarch64-softmmu --disable-gnutls
    d. make -j8
    e. sudo make install

7. Creating the Ubuntu VM :
    a. Download the Ubuntu Server from here -> https://ubuntu.com/download/server/arm

b. Create a hard disk

   i. qemu-img create -f qcow2 disk.qcow2 10G

c. Create an empty file for persisting UEFI variables:

   i. dd if=/dev/zero conv=sync bs=1m count=64 of=ovmf_vars.fd

d. Run QEMU with the following arguments

   *i. qemu-system-aarch64 *

   *-accel hvf *

   *-m 2048 *

   *-cpu cortex-a57 -M virt,highmem=off *

   *-drive file=/usr/local/share/qemu/edk2-aarch64-code.fd,if=pflash,format=raw,readonly=on *

   *-drive file=ovmf_vars.fd,if=pflash,format=raw *

   *-serial telnet::4444,server,nowait *

   *-drive if=none,file=disk.qcow2,format=qcow2,id=hd0 *

   *-device virtio-blk-device,drive=hd0,serial="dummyserial" *

   *-device virtio-net-device,netdev=net0 *

   *-netdev user,id=net0 *

   *-vga none -device ramfb *

   *-cdrom /path/to/ubuntu.iso *

   *-device usb-ehci -device usb-kbd -device usb-mouse -usb *

   -monitor stdio

   ii. Explanation of the arguments:

      1. **-accel name[,prop=value[,...]]**

      This is used to enable an accelerator. Depending on the target architecture, kvm, xen, hax, hvf, nvmm, whpx or tcg can be available. By default, tcg is used. If there is more than one accelerator specified, the next one is used if the previous one fails to initialize.

      2. **-m [size=]megs[,slots=n,maxmem=size]**

      Sets guest startup RAM size to megs megabytes. Default is 128 MiB. Optionally, a suffix of "M" or "G" can be used to signify a value in megabytes

or gigabytes respectively. Optional pair slots, maxmem could be used to set amount of hotpluggable memory slots and maximum amount of memory. Note that maxmem must be aligned to the page size.

3. **-cpu model**

Select CPU model (**-cpu help** for list and additional feature selection)

4. **-drive option[,option[,option[,...]]]**

Define a new drive. This includes creating a block driver node (the backend) as well as a guest device, and is mostly a shortcut for defining the corresponding **-blockdev** and **-device** options.

5. **-serial dev**

Redirect the virtual serial port to host character device dev. The default device is **vc** in graphical mode and **stdio** in non graphical mode.

6. **-netdev user,id=id[,option][,option][,...]**

Configure user mode host network backend which requires no administrator privilege to run.

7. **-vga type**

Select type of VGA card to emulate.

8. **-cdrom file**

Use file as CD-ROM image (you cannot use **-hdc** and **-cdrom** at the same time). You can use the host CD-ROM by using **/dev/cdrom** as filename.

9. **-device driver[,prop[=value][,...]]**

Add device driver. prop=value sets driver properties. Valid properties depend on the driver.

10. **-monitor dev**

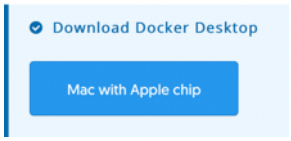
Redirect the monitor to host device dev (same devices as the serial port).

The default device is **vc** in graphical mode and **stdio** in non graphical mode.

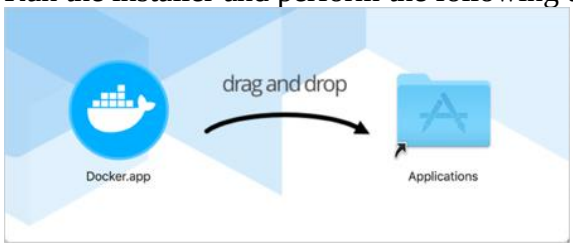
Use **-monitor none** to disable the default monitor.

Steps to enable Docker container:

1. Go to https://docs.docker.com/desktop/mac/apple-silicon/ and click on the following button :



2. Run the installer and perform the following action:



3. Open the Docker application in the application folder and the Docker engine starts running.
4. Open terminal and pull the Ubuntu Image with Sysbench from Docker Hub using the following command:
    a. docker pull csminpp/ubuntu-sysbench

5. Run the image and create the container by using the following command:
    a. docker run -it csminpp/ubuntu-sysbench

Some Important Docker Commands are as follows:

Containers

create — Create a container from an image.
start — Start an existing container.
run — Create a new container and start it.
ls — List running containers.
inspect — See lots of info about a container.
logs — Print logs.
stop — Gracefully stop running container.
kill —Stop main process in container abruptly.
rm — Delete a stopped container.

Images

build — Build an image.
push — Push an image to a remote registry.
ls — List images.
history — See intermediate image info.
inspect — See lots of info about an image, including the layers.
rm — Delete an image.

Miscellaneous

docker version — List info about your Docker Client and Server versions.
docker login — Log in to a Docker registry.
docker system prune — Delete all unused containers, unused networks, and dangling images.

Benchmarking Experiments:

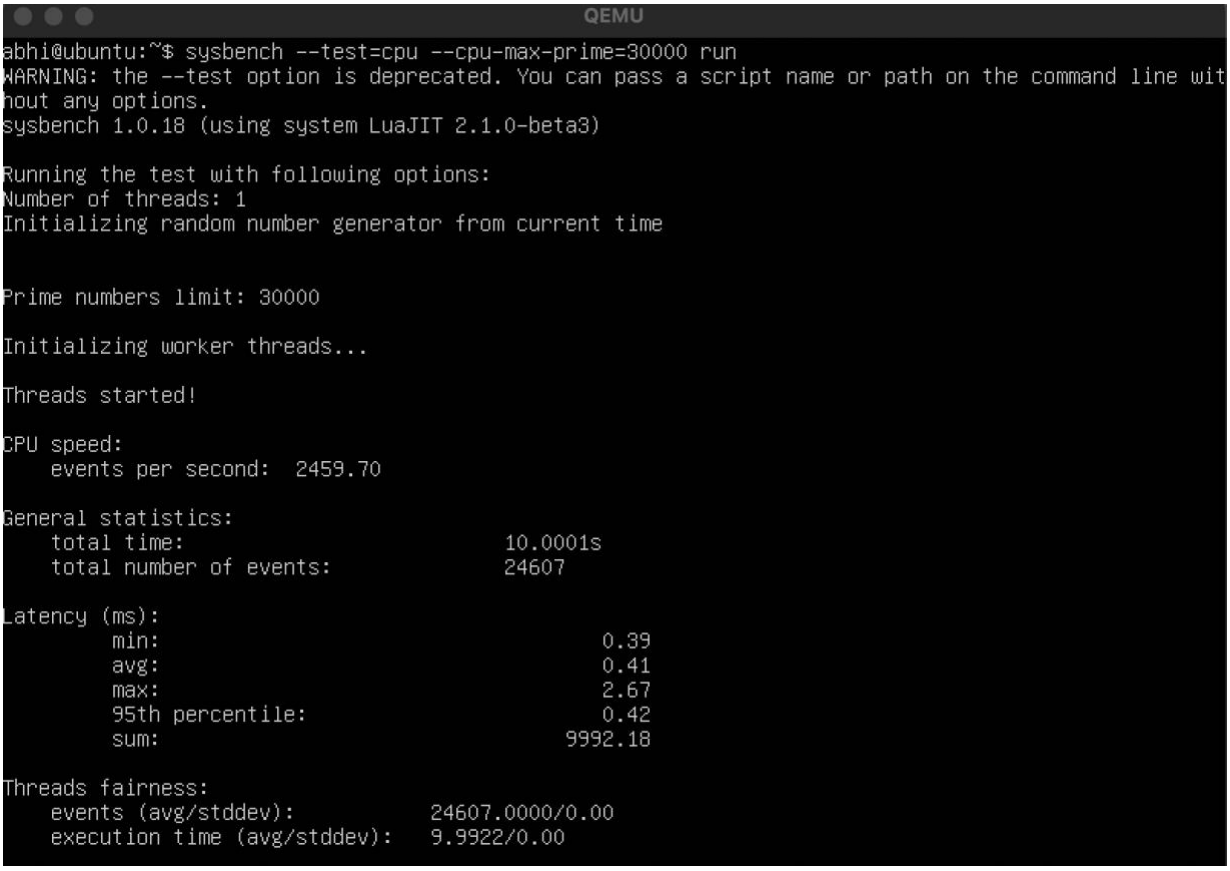
For benchmarking, the sysbench tool was used to compare OS virtualization and System virtualization by running CPU and File I/O tests in 3 different scenarios on Ubuntu VM in QEMU and the Ubuntu Docker container.

- ### Testing on QEMU (System Virtualization)
    - #### Experiment 1 – CPU Performance:

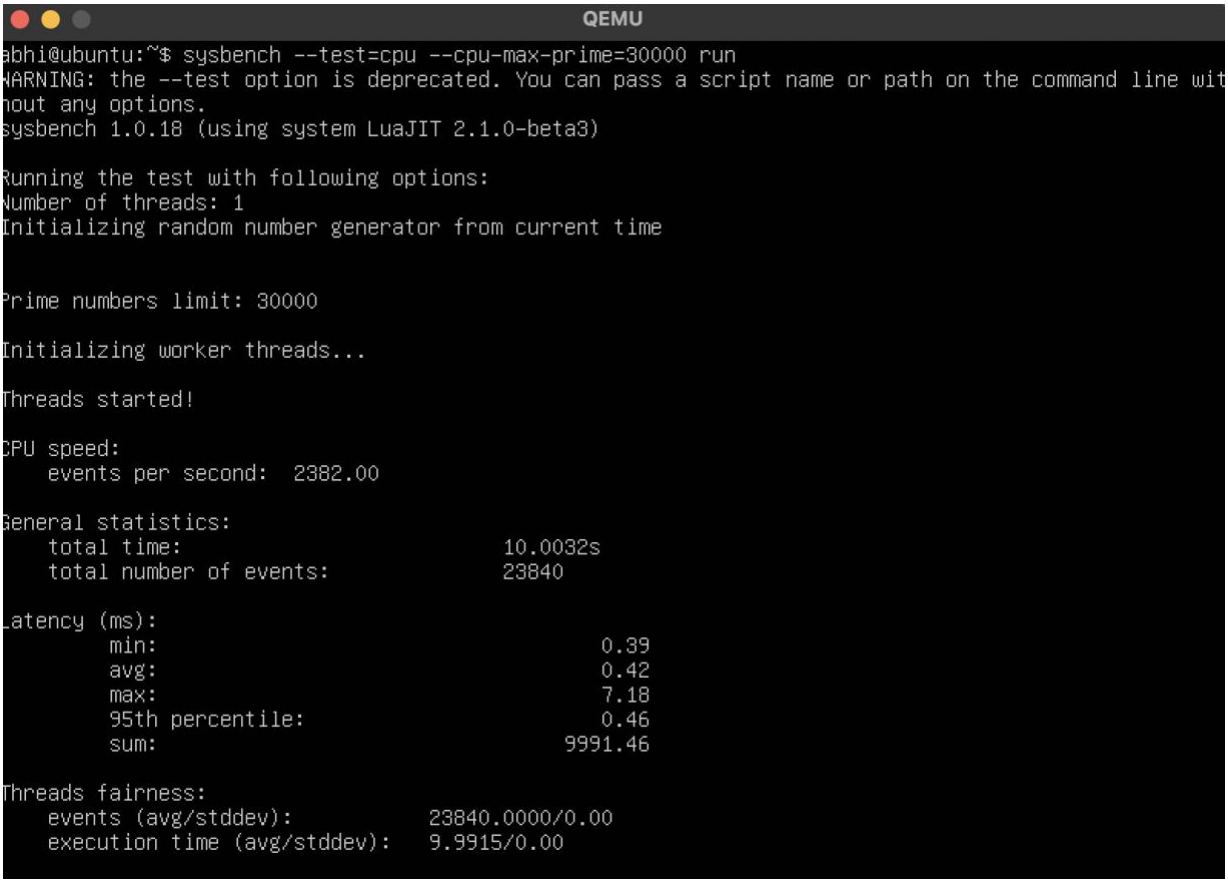
      The CPU is tested using the cpu-max-prime option which is used to find the max prime number under a given limit.

      Command used: CPU Time - *sysbench --test=cpu --cpu-max-prime=30000 run*

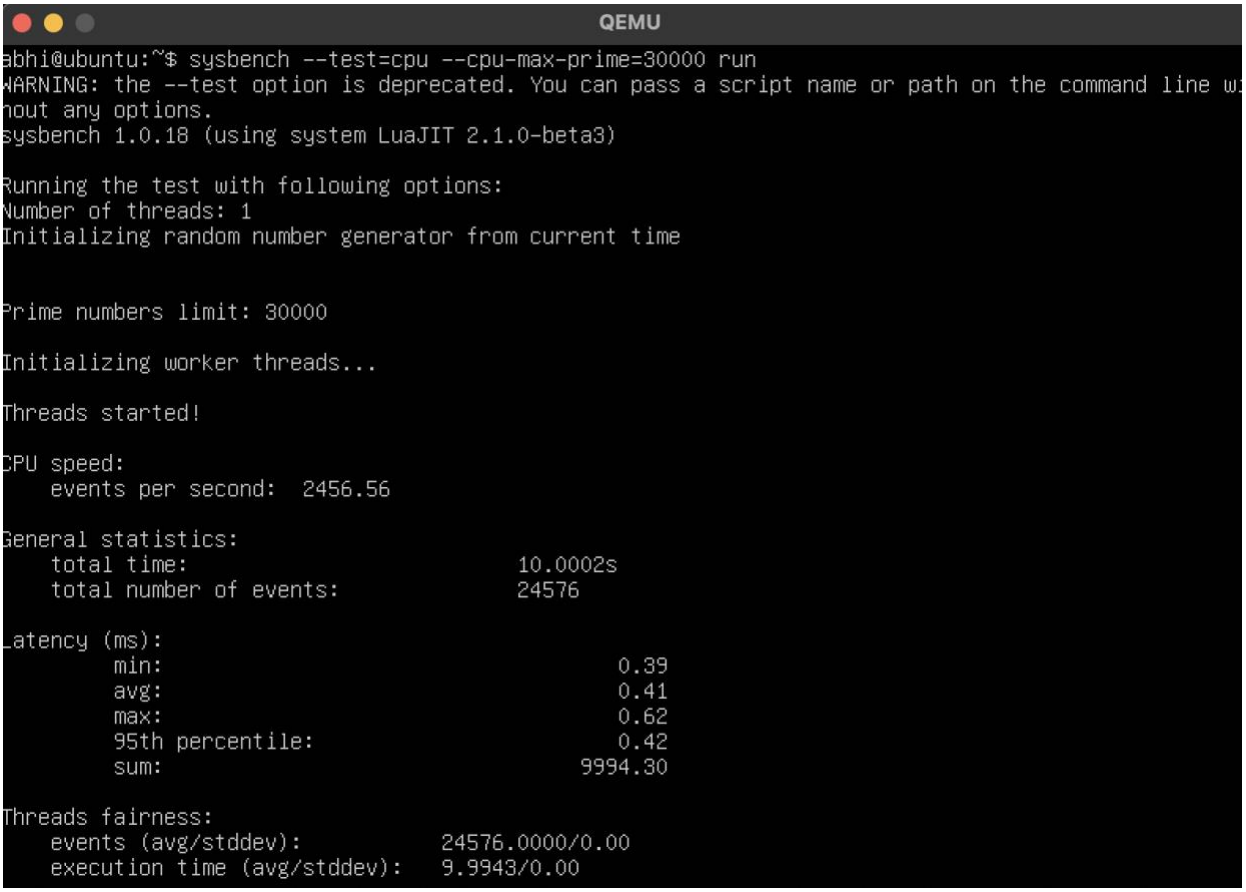
Test run - 1


QEMU
abhi@ubuntu:~$ sysbench --test=cpu --cpu-max-prime=30000 run
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 30000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 2459.70
General statistics:
total time: 10.0001s
total number of events: 24607
Latency (ms):
min: 0.39
avg: 0.41
max: 2.67
95th percentile: 0.42
sum: 9992.18
Threads fairness:
events (avg/stddev): 24607.0000/0.00
execution time (avg/stddev): 9.9922/0.00

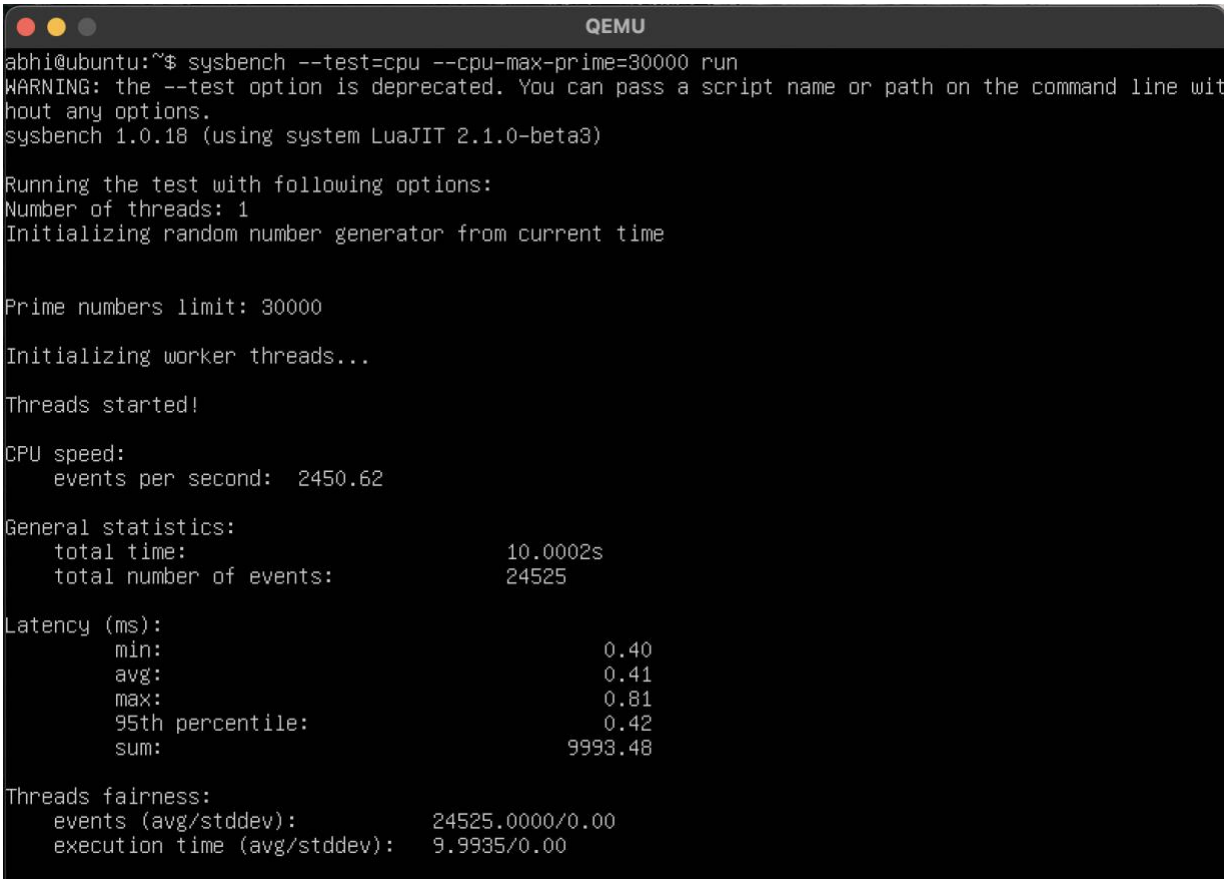
Test run – 2


QEMU
abhi@ubuntu:~$ sysbench --test=cpu --cpu-max-prime=30000 run
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 30000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 2382.00
General statistics:
total time: 10.0032s
total number of events: 23840
Latency (ms):
min: 0.39
avg: 0.42
max: 7.18
95th percentile: 0.46
sum: 9991.46
Threads fairness:
events (avg/stddev): 23840.0000/0.00
execution time (avg/stddev): 9.9915/0.00

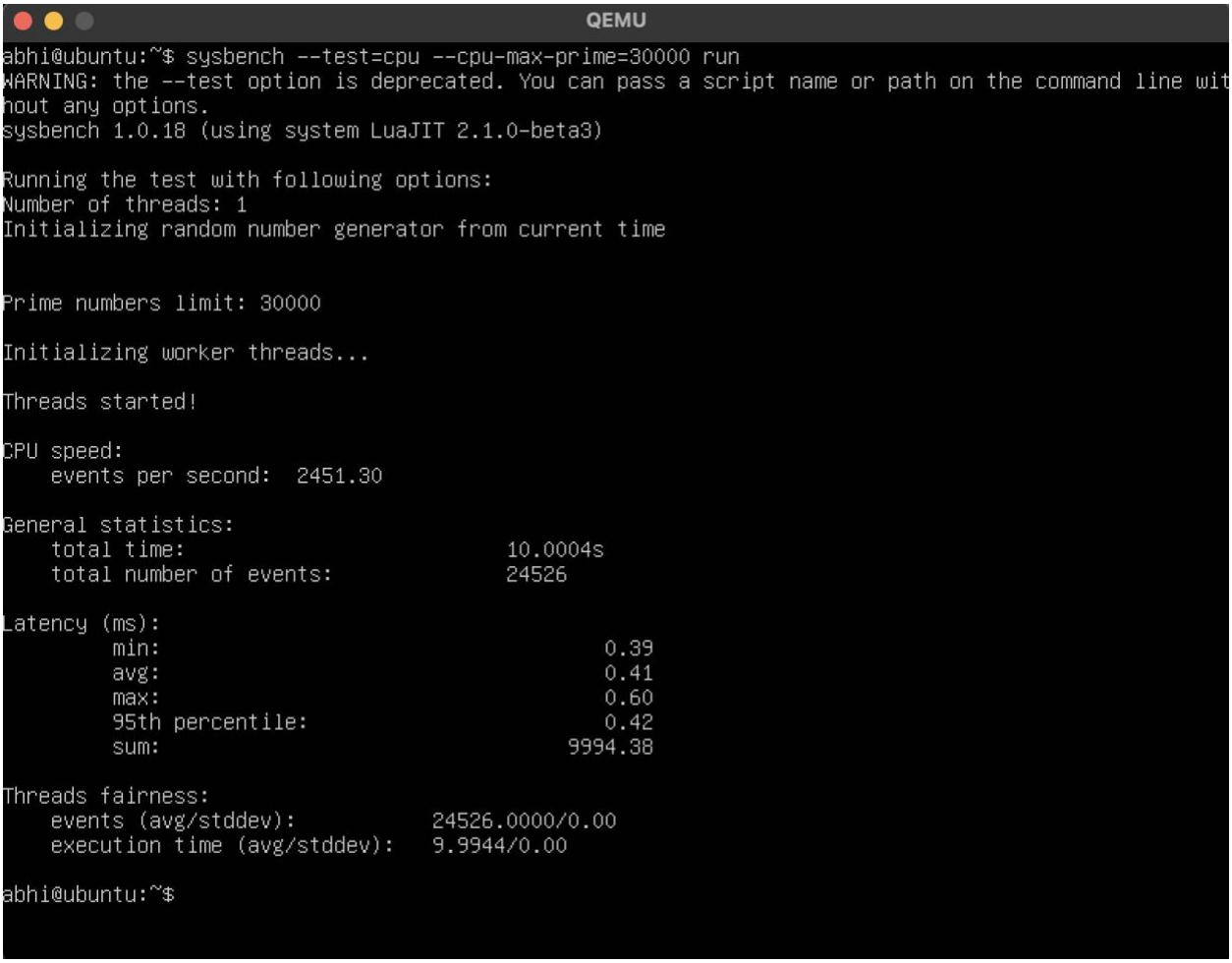
Test run – 3


QEMU
abhi@ubuntu:~$ sysbench --test=cpu --cpu-max-prime=30000 run
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wi
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 30000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 2456.56
General statistics:
total time: 10.0002s
total number of events: 24576
Latency (ms):
min: 0.39
avg: 0.41
max: 0.62
95th percentile: 0.42
sum: 9994.30
Threads fairness:
events (avg/stddev): 24576.0000/0.00
execution time (avg/stddev): 9.9943/0.00

Test run – 4


QEMU
abhi@ubuntu:~$ sysbench --test=cpu --cpu-max-prime=30000 run
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 30000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 2450.62
General statistics:
total time: 10.0002s
total number of events: 24525
Latency (ms):
min: 0.40
avg: 0.41
max: 0.81
95th percentile: 0.42
sum: 9993.48
Threads fairness:
events (avg/stddev): 24525.0000/0.00
execution time (avg/stddev): 9.9935/0.00

Test Run – 5


QEMU
abhi@ubuntu:~$ sysbench --test=cpu --cpu-max-prime=30000 run
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 30000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 2451.30
General statistics:
total time: 10.0004s
total number of events: 24526
Latency (ms):
min: 0.39
avg: 0.41
max: 0.60
95th percentile: 0.42
sum: 9994.38
Threads fairness:
events (avg/stddev): 24526.0000/0.00
execution time (avg/stddev): 9.9944/0.00
abhi@ubuntu:~$

- ## Experiment 2 – CPU Performance:

  The CPU is tested using the cpu-max-prime option which is used to find the max prime number under a given limit.

  Command used: CPU Time - *sysbench --test=cpu --cpu-max-prime=10000 run*

Test run - 1

```
abhi@ubuntu:~$ ./cputime2.sh
Test number : 1
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 10000

Initializing worker threads...

Threads started!

CPU speed:
    events per second: 10884.11

General statistics:
    total time:                          10.0001s
    total number of events:              108848

Latency (ms):
         min:                                    0.09
         avg:                                    0.09
         max:                                    5.96
         95th percentile:                        0.10
         sum:                                 9987.33

Threads fairness:
    events (avg/stddev):           108848.0000/0.00
    execution time (avg/stddev):   9.9873/0.00

-
```

Test run – 2

```
Threads started!

CPU speed:
    events per second: 10884.11

General statistics:
    total time:                          10.0001s
    total number of events:              108848

Latency (ms):
         min:                                    0.09
         avg:                                    0.09
         max:                                    5.96
         95th percentile:                        0.10
         sum:                                 9987.33

Threads fairness:
    events (avg/stddev):           108848.0000/0.00
    execution time (avg/stddev):   9.9873/0.00

Test number : 2
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 10000

Initializing worker threads...

Threads started!
```

Test run – 3

```
    execution time (avg/stddev):   9.9875/0.00

Test number : 3
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 10000

Initializing worker threads...

Threads started!

CPU speed:
    events per second: 10959.76

General statistics:
    total time:                          10.0001s
    total number of events:              109604

Latency (ms):
         min:                                    0.09
         avg:                                    0.09
         max:                                    0.49
         95th percentile:                        0.10
         sum:                                 9987.66

Threads fairness:
    events (avg/stddev):           109604.0000/0.00
    execution time (avg/stddev):   9.9877/0.00
```

Test run – 4

```
    execution time (avg/stddev):   9.9877/0.00

Test number : 4
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 10000

Initializing worker threads...

Threads started!

CPU speed:
    events per second: 10948.36

General statistics:
    total time:                          10.0002s
    total number of events:              109491

Latency (ms):
         min:                                    0.09
         avg:                                    0.09
         max:                                    0.24
         95th percentile:                        0.10
         sum:                                 9987.85

Threads fairness:
    events (avg/stddev):           109491.0000/0.00
    execution time (avg/stddev):   9.9878/0.00
```

Test Run – 5

```
    execution time (avg/stddev):   9.9878/0.00

Test number : 5
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 10000

Initializing worker threads...

Threads started!

CPU speed:
    events per second: 10941.77

General statistics:
    total time:                          10.0001s
    total number of events:              109424

Latency (ms):
         min:                                    0.09
         avg:                                    0.09
         max:                                    0.32
         95th percentile:                        0.10
         sum:                                 9988.07

Threads fairness:
    events (avg/stddev):           109424.0000/0.00
    execution time (avg/stddev):   9.9881/0.00
```

- ## Experiment 3 – CPU Performance:

  The CPU is tested using the cpu-max-prime option which is used to find the max prime number under a given limit.

  Command used: CPU Time - *sysbench --test=cpu --cpu-max-prime=50000 run*

Test run - 1

```
abhi@ubuntu:~$ ./cputime.sh
Test number : 1
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 50000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  1224.10

General statistics:
    total time:                          10.0002s
    total number of events:              12242

Latency (ms):
         min:                                    0.79
         avg:                                    0.82
         max:                                    1.35
         95th percentile:                        0.84
         sum:                                 9995.86

Threads fairness:
    events (avg/stddev):           12242.0000/0.00
    execution time (avg/stddev):   9.9959/0.00
```

Test run – 2

```
    execution time (avg/stddev):   9.9959/0.00

Test number : 2
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 50000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  1218.69

General statistics:
    total time:                          10.0003s
    total number of events:              12188

Latency (ms):
         min:                                    0.79
         avg:                                    0.82
         max:                                    1.41
         95th percentile:                        0.86
         sum:                                 9996.07

Threads fairness:
    events (avg/stddev):           12188.0000/0.00
    execution time (avg/stddev):   9.9961/0.00
```

Test run – 3

```
    execution time (avg/stddev):   9.9961/0.00

Test number : 3
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wi
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 50000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  1223.33

General statistics:
    total time:                          10.0001s
    total number of events:              12234

Latency (ms):
         min:                                    0.79
         avg:                                    0.82
         max:                                    1.38
         95th percentile:                        0.84
         sum:                                 9996.58

Threads fairness:
    events (avg/stddev):           12234.0000/0.00
    execution time (avg/stddev):   9.9966/0.00
```

Test run – 4

```
    execution time (avg/stddev):   9.9966/0.00

Test number : 4
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 50000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  1220.67

General statistics:
    total time:                          10.0006s
    total number of events:              12208

Latency (ms):
         min:                                    0.79
         avg:                                    0.82
         max:                                    1.40
         95th percentile:                        0.84
         sum:                                 9996.97

Threads fairness:
    events (avg/stddev):           12208.0000/0.00
    execution time (avg/stddev):   9.9970/0.00
```

Test Run – 5

```
    execution time (avg/stddev):   9.9970/0.00

Test number : 5
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 50000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  1222.89

General statistics:
    total time:                          10.0004s
    total number of events:              12230

Latency (ms):
         min:                                    0.79
         avg:                                    0.82
         max:                                    1.34
         95th percentile:                        0.84
         sum:                                 9996.77

Threads fairness:
    events (avg/stddev):           12230.0000/0.00
    execution time (avg/stddev):   9.9968/0.00
```

- ## Experiment - 4 File I/O Performance -

  The File I/O tests are used to determine the read and write throughput of the machines.

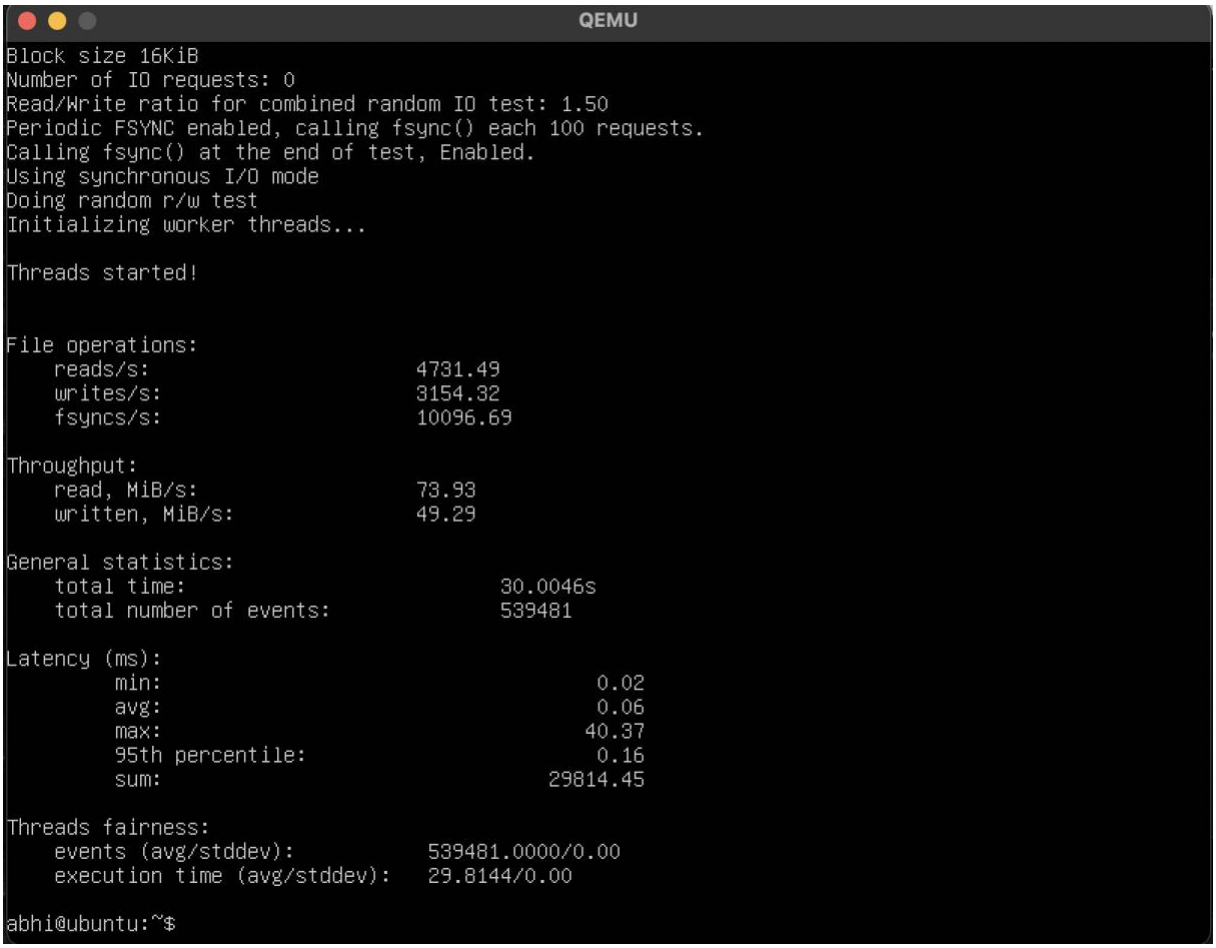
  - Command used: File I/O –
    sysbench --test=fileio --file-total-size=3G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags= direct prepare

    sysbench --test=fileio --file-total-size=3G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags= direct run

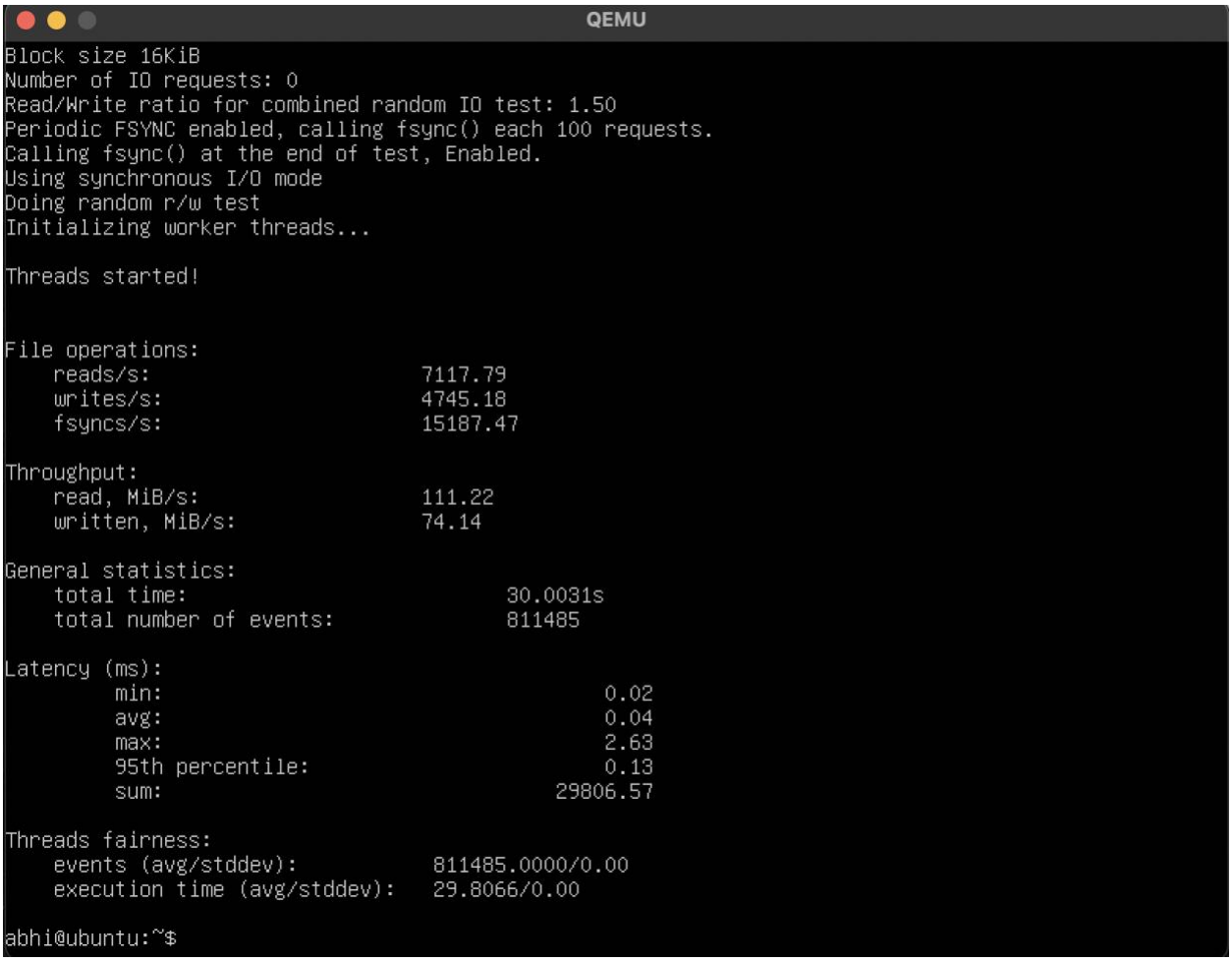
    sysbench --test=fileio --file-total-size=3G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags= direct cleanup

    The following command is run on the host machine to ensure files aren't cached – *sync && sudo purge*

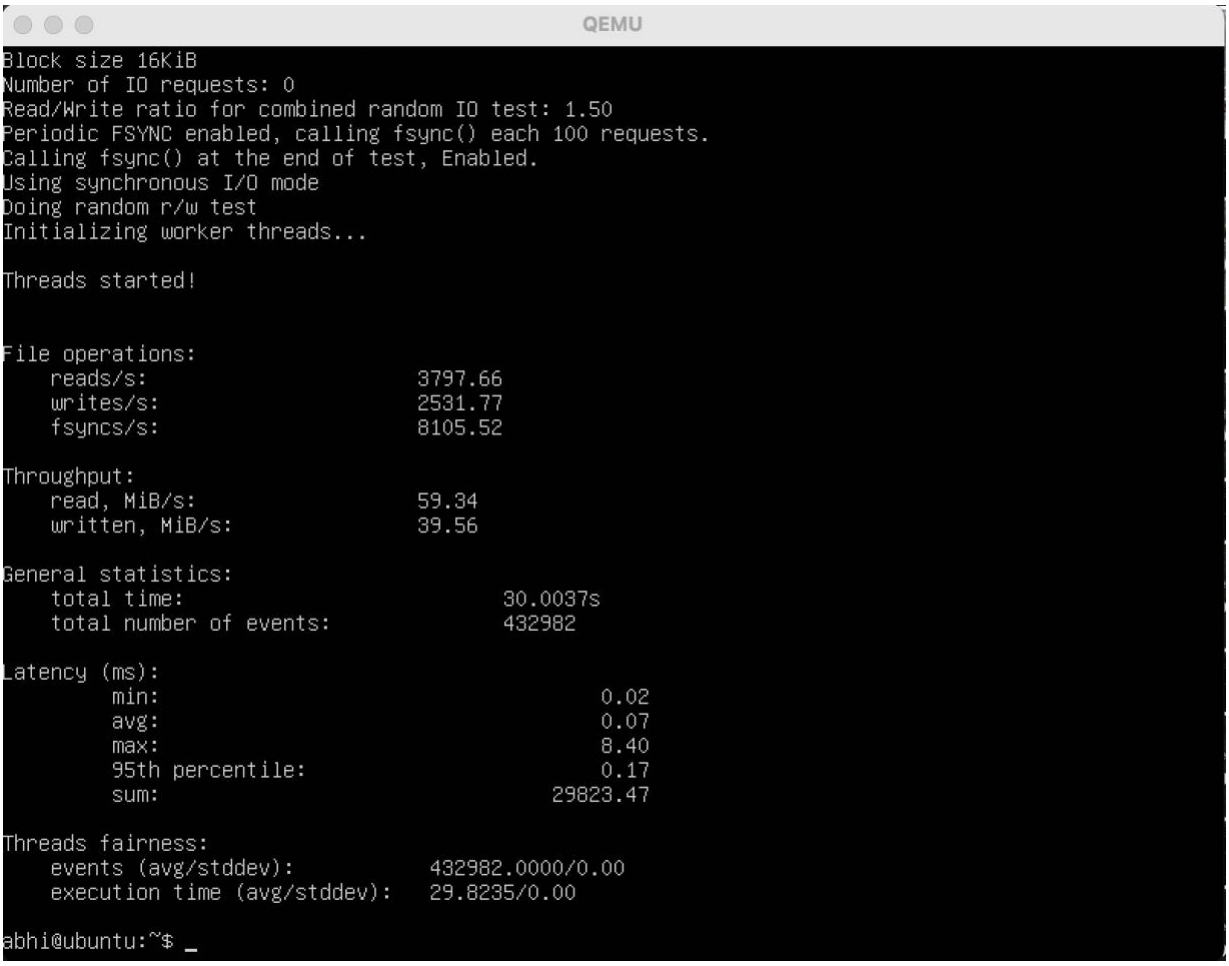
Test Run – 1


QEMU
Block size 16KiB
Number of IO requests: 0
Read/Write ratio for combined random IO test: 1.50
Periodic FSYNC enabled, calling fsync() each 100 requests.
Calling fsync() at the end of test, Enabled.
Using synchronous I/O mode
Doing random r/w test
Initializing worker threads...
Threads started!
File operations:
reads/s: 4731.49
writes/s: 3154.32
fsyncs/s: 10096.69
Throughput:
read, MiB/s: 73.93
written, MiB/s: 49.29
General statistics:
total time: 30.0046s
total number of events: 539481
Latency (ms):
min: 0.02
avg: 0.06
max: 40.37
95th percentile: 0.16
sum: 29814.45
Threads fairness:
events (avg/stddev): 539481.0000/0.00
execution time (avg/stddev): 29.8144/0.00
abhi@ubuntu:~$

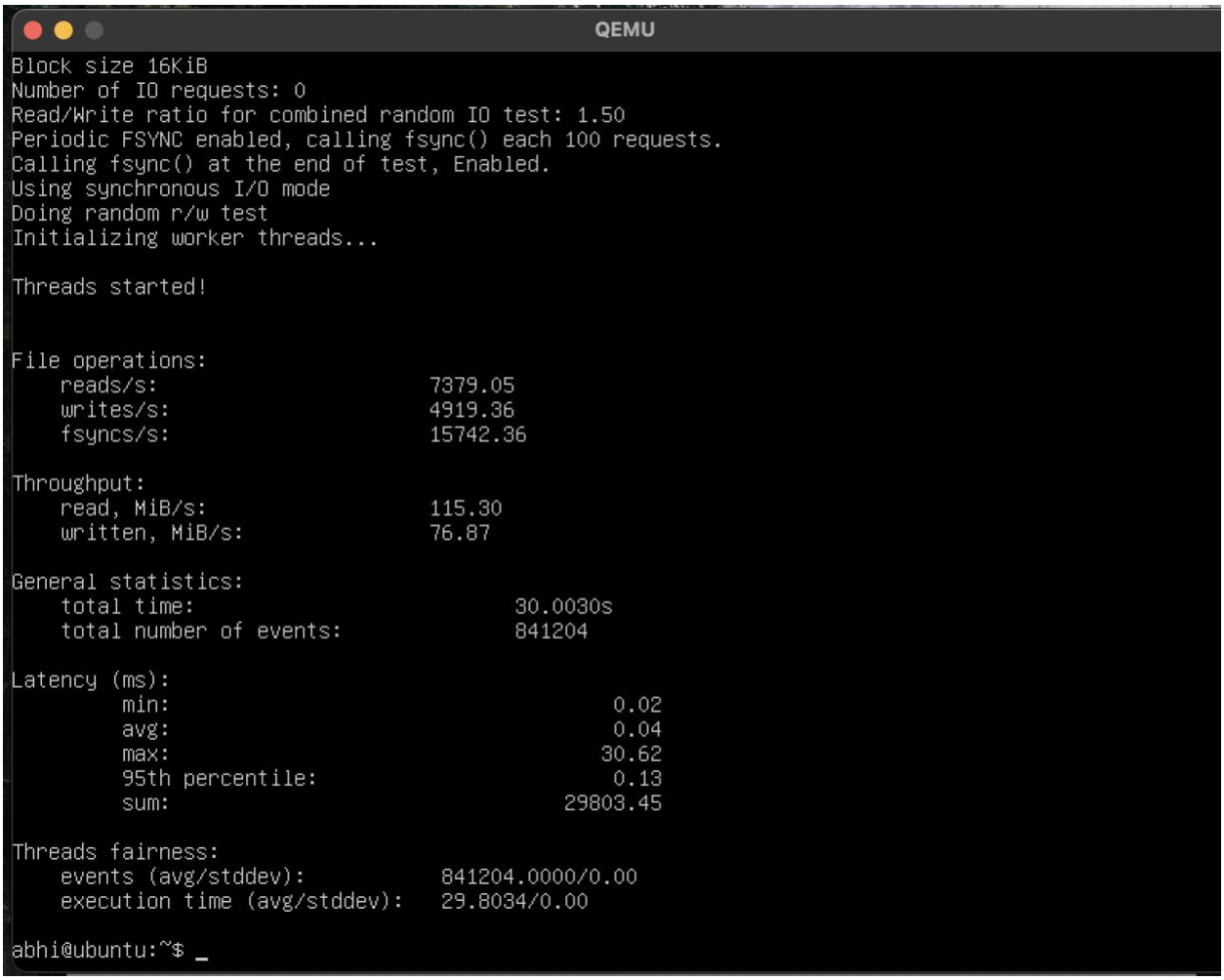
Test run – 2


QEMU
Block size 16KiB
Number of IO requests: 0
Read/Write ratio for combined random IO test: 1.50
Periodic FSYNC enabled, calling fsync() each 100 requests.
Calling fsync() at the end of test, Enabled.
Using synchronous I/O mode
Doing random r/w test
Initializing worker threads...
Threads started!
File operations:
reads/s: 7117.79
writes/s: 4745.18
fsyncs/s: 15187.47
Throughput:
read, MiB/s: 111.22
written, MiB/s: 74.14
General statistics:
total time: 30.0031s
total number of events: 811485
Latency (ms):
min: 0.02
avg: 0.04
max: 2.63
95th percentile: 0.13
sum: 29806.57
Threads fairness:
events (avg/stddev): 811485.0000/0.00
execution time (avg/stddev): 29.8066/0.00
abhi@ubuntu:~$

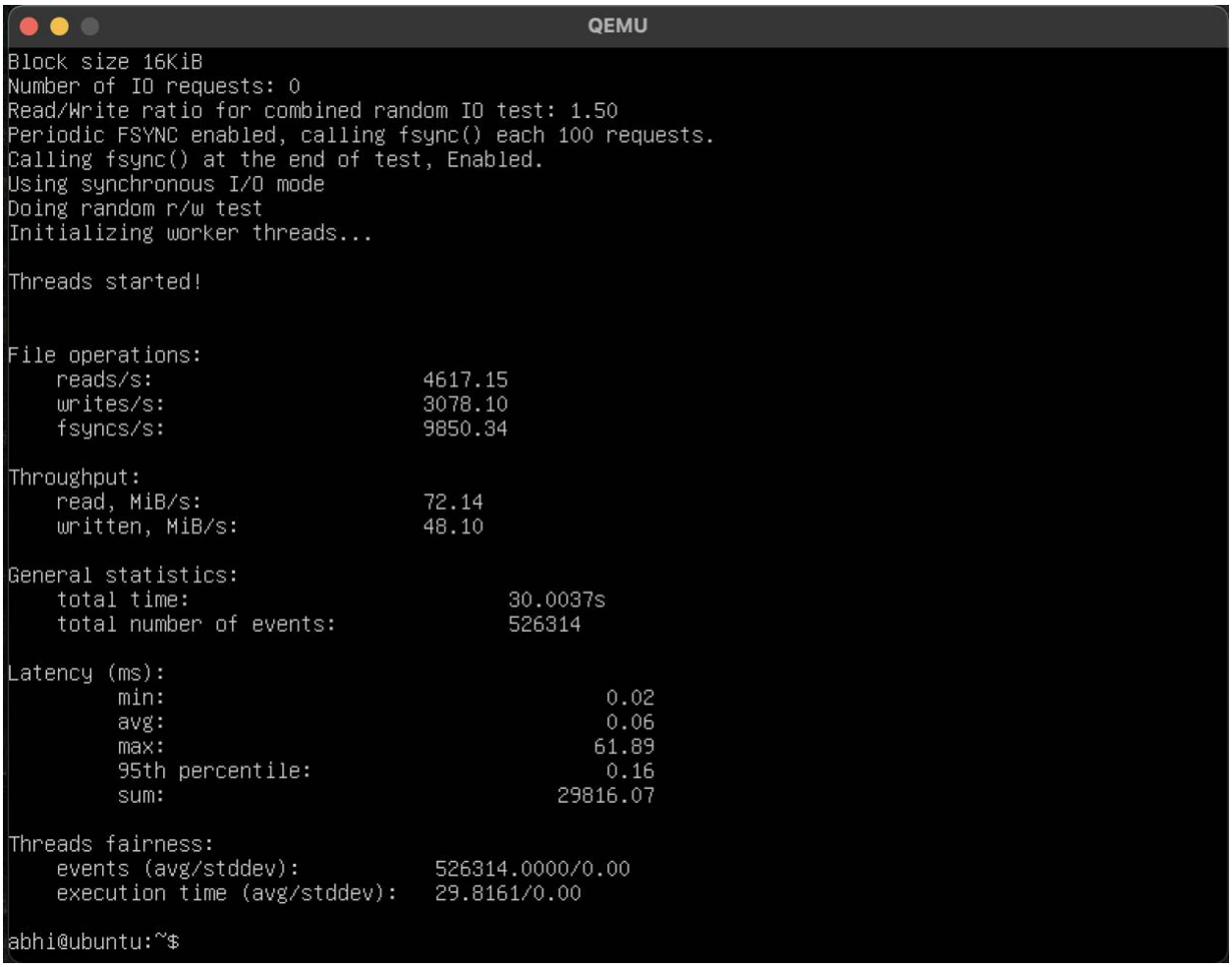
Test run – 3


QEMU
Block size 16KiB
Number of IO requests: 0
Read/Write ratio for combined random IO test: 1.50
Periodic FSYNC enabled, calling fsync() each 100 requests.
Calling fsync() at the end of test, Enabled.
Using synchronous I/O mode
Doing random r/w test
Initializing worker threads...
Threads started!
File operations:
reads/s: 3797.66
writes/s: 2531.77
fsyncs/s: 8105.52
Throughput:
read, MiB/s: 59.34
written, MiB/s: 39.56
General statistics:
total time: 30.0037s
total number of events: 432982
Latency (ms):
min: 0.02
avg: 0.07
max: 8.40
95th percentile: 0.17
sum: 29823.47
Threads fairness:
events (avg/stddev): 432982.0000/0.00
execution time (avg/stddev): 29.8235/0.00
abhi@ubuntu:~$

Test run – 4


QEMU
Block size 16KiB
Number of IO requests: 0
Read/Write ratio for combined random IO test: 1.50
Periodic FSYNC enabled, calling fsync() each 100 requests.
Calling fsync() at the end of test, Enabled.
Using synchronous I/O mode
Doing random r/w test
Initializing worker threads...
Threads started!
File operations:
reads/s: 7379.05
writes/s: 4919.36
fsyncs/s: 15742.36
Throughput:
read, MiB/s: 115.30
written, MiB/s: 76.87
General statistics:
total time: 30.0030s
total number of events: 841204
Latency (ms):
min: 0.02
avg: 0.04
max: 30.62
95th percentile: 0.13
sum: 29803.45
Threads fairness:
events (avg/stddev): 841204.0000/0.00
execution time (avg/stddev): 29.8034/0.00
abhi@ubuntu:~$ _

Test run – 5


QEMU
Block size 16KiB
Number of IO requests: 0
Read/Write ratio for combined random IO test: 1.50
Periodic FSYNC enabled, calling fsync() each 100 requests.
Calling fsync() at the end of test, Enabled.
Using synchronous I/O mode
Doing random r/w test
Initializing worker threads...
Threads started!
File operations:
reads/s: 4617.15
writes/s: 3078.10
fsyncs/s: 9850.34
Throughput:
read, MiB/s: 72.14
written, MiB/s: 48.10
General statistics:
total time: 30.0037s
total number of events: 526314
Latency (ms):
min: 0.02
avg: 0.06
max: 61.89
95th percentile: 0.16
sum: 29816.07
Threads fairness:
events (avg/stddev): 526314.0000/0.00
execution time (avg/stddev): 29.8161/0.00
abhi@ubuntu:~$

- ## Experiment - 5 File I/O Performance -

  The File I/O tests are used to determine the read and write throughput of the machines.

  - Command used: File I/O –
    sysbench --test=fileio --file-total-size=2G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags= direct prepare

    sysbench --test=fileio --file-total-size=2G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags= direct run

    sysbench --test=fileio --file-total-size=2G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags= direct cleanup

    The following command is run on the host machine to ensure files aren't cached – *sync && sudo purge*

Test Run – 1

```
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      14394.11
    writes/s:                     9596.40
    fsyncs/s:                     30901.17

Throughput:
    read, MiB/s:                  224.91
    written, MiB/s:               149.94

General statistics:
    total time:                          10.0244s
    total number of events:              548230

Latency (ms):
         min:                                    0.00
         avg:                                    0.29
         max:                                   21.25
         95th percentile:                        1.27
         sum:                               159351.76

Threads fairness:
    events (avg/stddev):           34264.3750/494.96
    execution time (avg/stddev):   9.9595/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on the command line wi
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

Test run – 2

```
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      15117.72
    writes/s:                     10077.65
    fsyncs/s:                     32445.05

Throughput:
    read, MiB/s:                  236.21
    written, MiB/s:               157.46

General statistics:
    total time:                          10.0212s
    total number of events:              575606

Latency (ms):
         min:                                    0.00
         avg:                                    0.28
         max:                                   30.88
         95th percentile:                        1.27
         sum:                               159322.01

Threads fairness:
    events (avg/stddev):           35975.3750/748.98
    execution time (avg/stddev):   9.9576/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

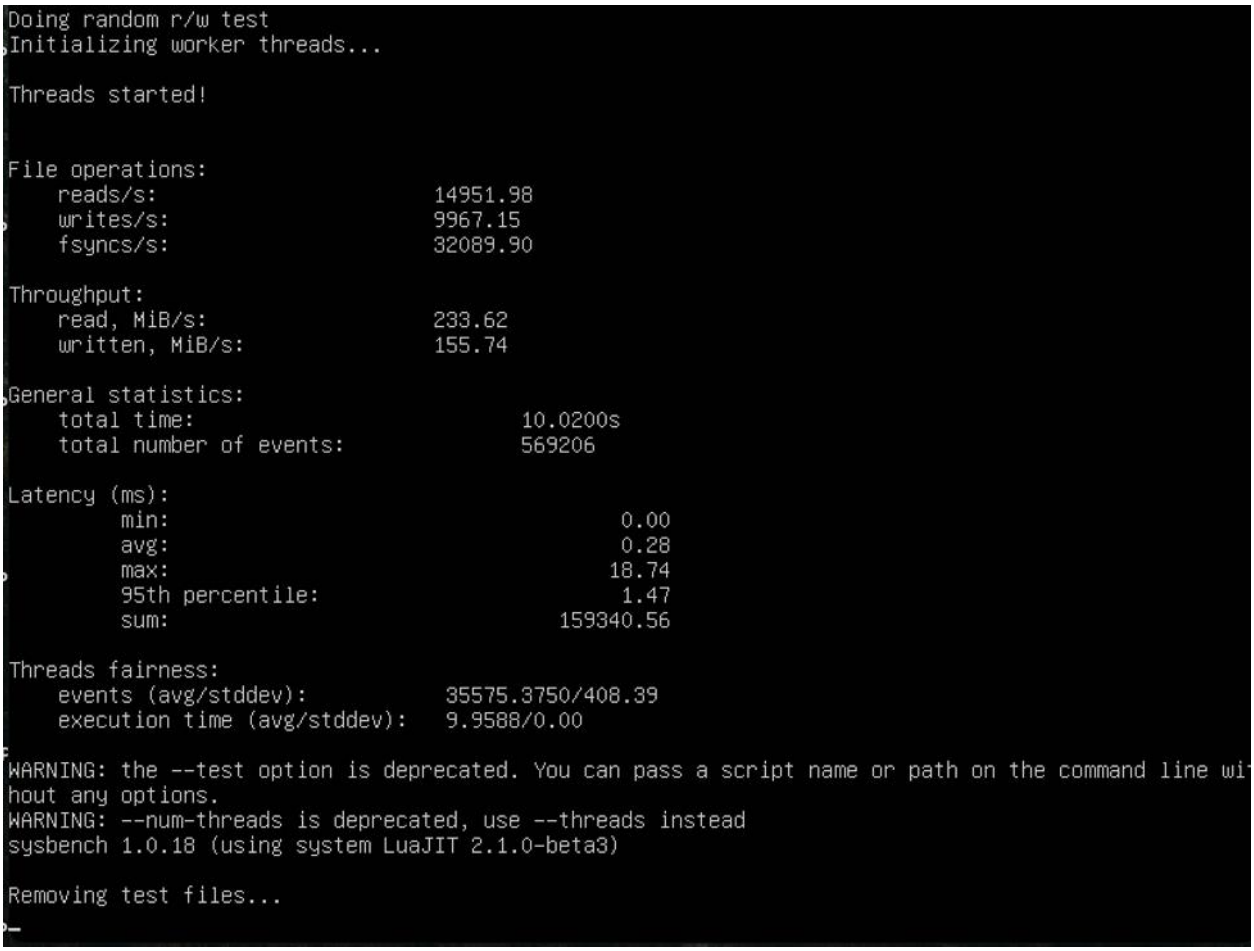
Test run – 3

```
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      15949.83
    writes/s:                     10632.55
    fsyncs/s:                     34217.93

Throughput:
    read, MiB/s:                  249.22
    written, MiB/s:               166.13

General statistics:
    total time:                          10.0212s
    total number of events:              607273

Latency (ms):
         min:                                    0.00
         avg:                                    0.26
         max:                                   48.40
         95th percentile:                        1.14
         sum:                               159289.96

Threads fairness:
    events (avg/stddev):           37954.5625/703.36
    execution time (avg/stddev):   9.9556/0.01

WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

Test run – 4

```
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      13202.48
    writes/s:                     8801.16
    fsyncs/s:                     28366.43

Throughput:
    read, MiB/s:                  206.29
    written, MiB/s:               137.52

General statistics:
    total time:                          10.0207s
    total number of events:              502714

Latency (ms):
         min:                                    0.00
         avg:                                    0.32
         max:                                   30.99
         95th percentile:                        1.96
         sum:                               159384.75

Threads fairness:
    events (avg/stddev):           31419.6250/624.25
    execution time (avg/stddev):   9.9615/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

Test run – 5


Doing random r/w test
Initializing worker threads...
Threads started!
File operations:
reads/s: 14951.98
writes/s: 9967.15
fsyncs/s: 32089.90
Throughput:
read, MiB/s: 233.62
written, MiB/s: 155.74
General statistics:
total time: 10.0200s
total number of events: 569206
Latency (ms):
min: 0.00
avg: 0.28
max: 18.74
95th percentile: 1.47
sum: 159340.56
Threads fairness:
events (avg/stddev): 35575.3750/408.39
execution time (avg/stddev): 9.9588/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line wi
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

Experiment - 6 File I/O Performance -

The File I/O tests are used to determine the read and write throughput of the machines.

- Command used: File I/O –
  sysbench --test=fileio --file-total-size=1G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags= direct prepare

  sysbench --test=fileio --file-total-size=1G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags= direct run

  sysbench --test=fileio --file-total-size=1G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags= direct cleanup

  The following command is run on the host machine to ensure files aren't cached – *sync && sudo purge*

Test Run – 1

```
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      27914.88
    writes/s:                     18610.02
    fsyncs/s:                     59752.28

Throughput:
    read, MiB/s:                  436.17
    written, MiB/s:               290.78

General statistics:
    total time:                          10.0206s
    total number of events:              1062967

Latency (ms):
         min:                                    0.00
         avg:                                    0.15
         max:                                   20.71
         95th percentile:                        0.62
         sum:                               159095.15

Threads fairness:
    events (avg/stddev):           66435.4375/716.74
    execution time (avg/stddev):   9.9434/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on the command line wi
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

Test run – 2

```
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      31389.66
    writes/s:                     20926.50
    fsyncs/s:                     67164.08

Throughput:
    read, MiB/s:                  490.46
    written, MiB/s:               326.98

General statistics:
    total time:                          10.0201s
    total number of events:              1195215

Latency (ms):
         min:                                    0.00
         avg:                                    0.13
         max:                                    4.70
         95th percentile:                        0.57
         sum:                               158831.85

Threads fairness:
    events (avg/stddev):           74700.9375/848.63
    execution time (avg/stddev):   9.9270/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

Test run – 3

```
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      31478.15
    writes/s:                     20985.44
    fsyncs/s:                     67357.78

Throughput:
    read, MiB/s:                  491.85
    written, MiB/s:               327.90

General statistics:
    total time:                          10.0198s
    total number of events:              1198596

Latency (ms):
         min:                                    0.00
         avg:                                    0.13
         max:                                   15.50
         95th percentile:                        0.54
         sum:                               158877.39

Threads fairness:
    events (avg/stddev):           74912.2500/835.17
    execution time (avg/stddev):   9.9298/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

Test run – 4

```
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      23958.81
    writes/s:                     15972.54
    fsyncs/s:                     51307.14

Throughput:
    read, MiB/s:                  374.36
    written, MiB/s:               249.57

General statistics:
    total time:                          10.0292s
    total number of events:              913048

Latency (ms):
         min:                                    0.00
         avg:                                    0.17
         max:                                   17.10
         95th percentile:                        0.65
         sum:                               159534.14

Threads fairness:
    events (avg/stddev):           57065.5000/396.78
    execution time (avg/stddev):   9.9709/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

Test run – 5

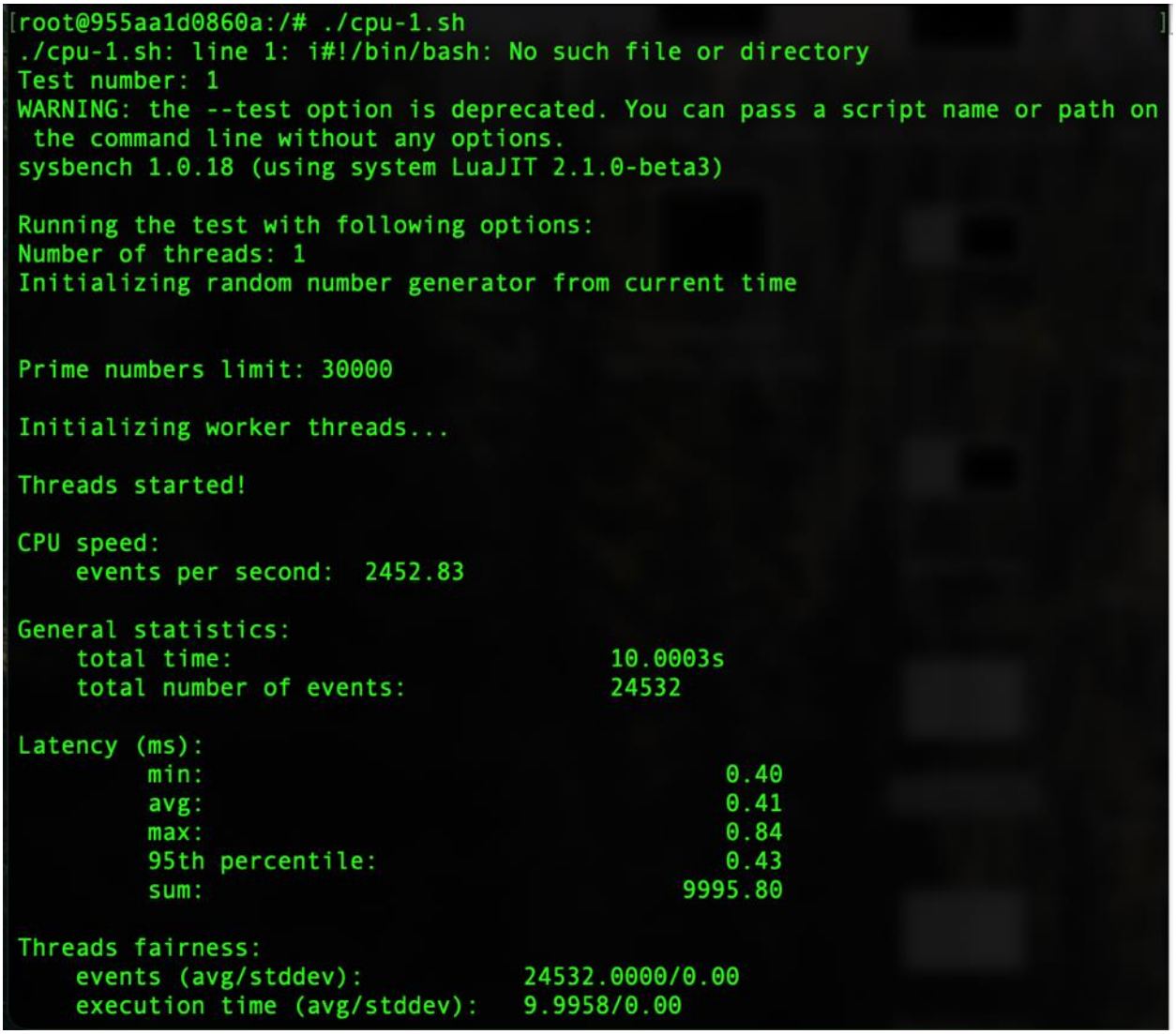
```
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      18101.97
    writes/s:                     12067.98
    fsyncs/s:                     38819.26

Throughput:
    read, MiB/s:                  282.84
    written, MiB/s:               188.56

General statistics:
    total time:                          10.0228s
    total number of events:              689446

Latency (ms):
         min:                                    0.00
         avg:                                    0.23
         max:                                  193.36
         95th percentile:                        0.92
         sum:                               159336.13

Threads fairness:
    events (avg/stddev):           43090.3750/501.82
    execution time (avg/stddev):   9.9585/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on the command line wit
hout any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

- Testing on Docker (OS Virtualization)
  - Experiment 1 – CPU Performance:

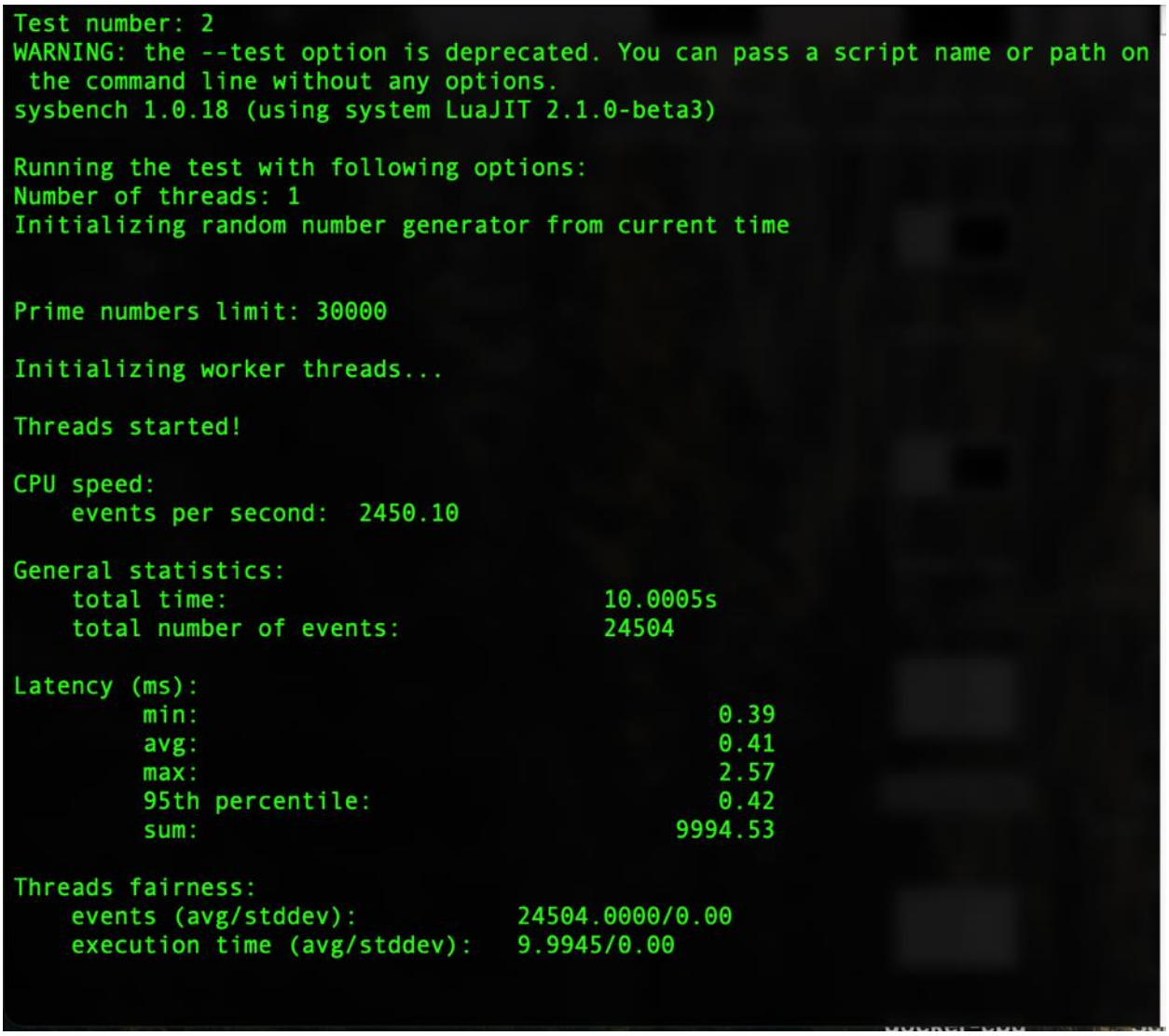
    The CPU is tested using the cpu-max-prime option which is used to find the max prime number under a given limit.

    Command used: CPU Time - *sysbench --test=cpu --cpu-max-prime=30000 run*

Test run – 1

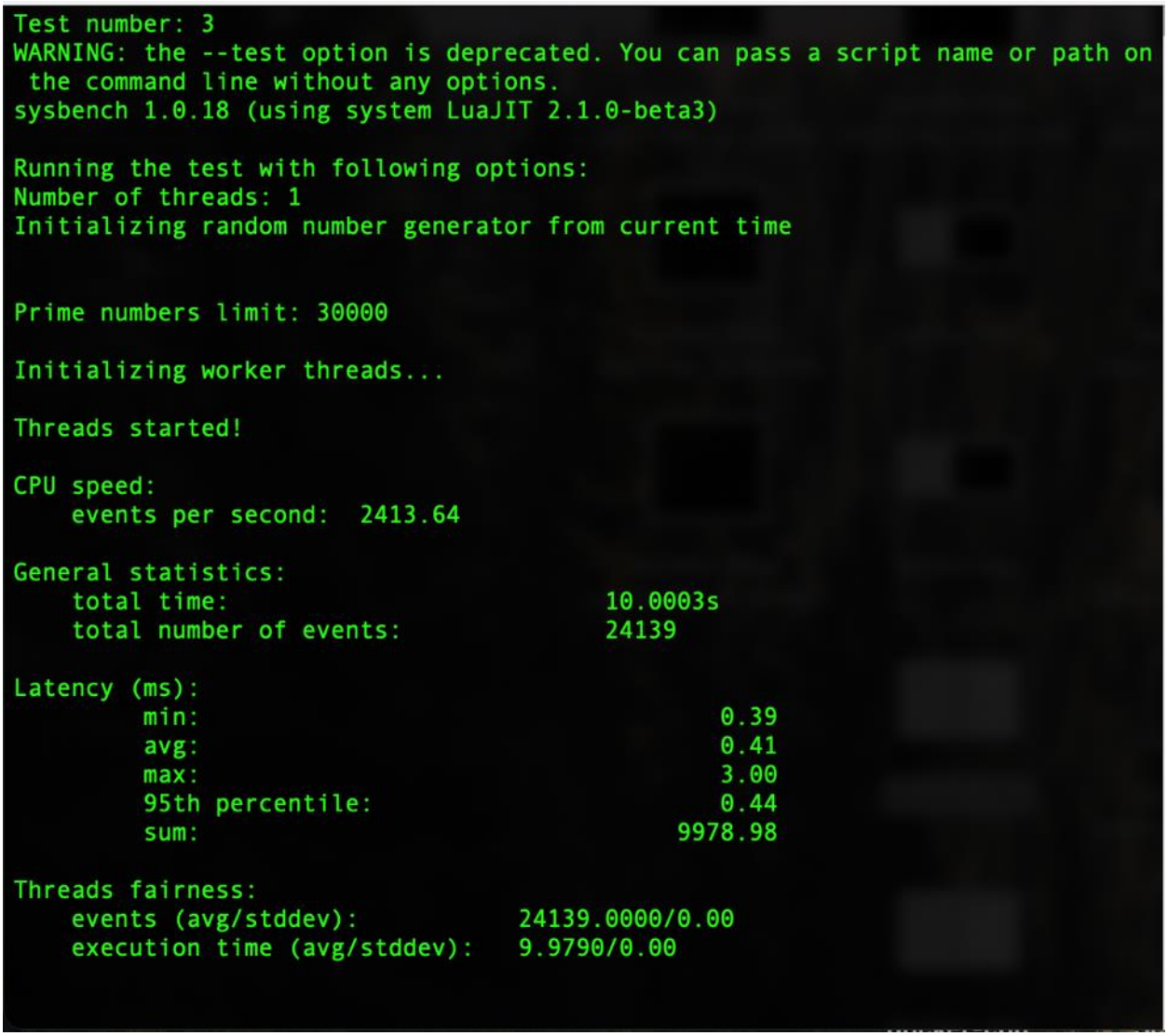


Test run – 2



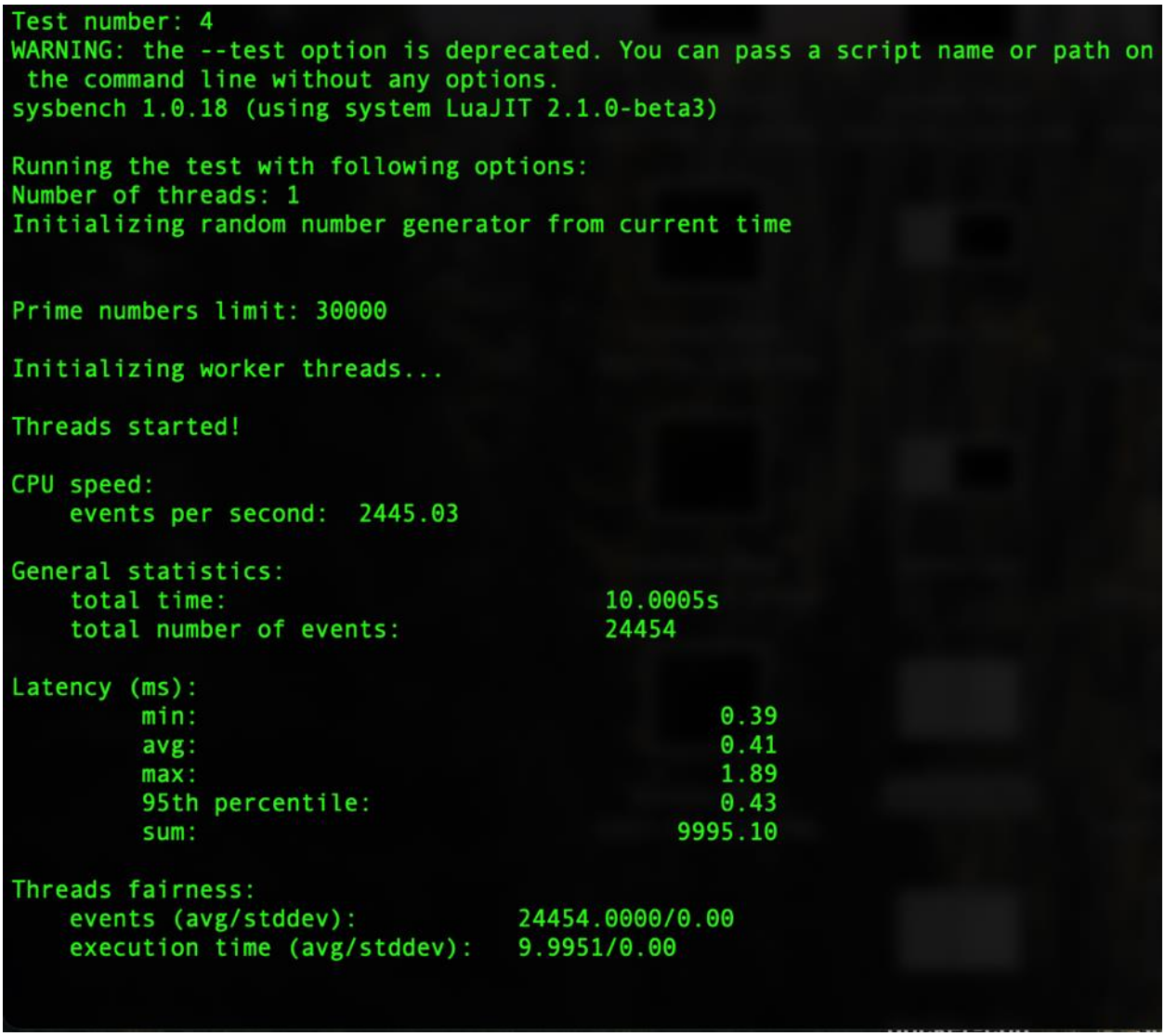
```
Test number: 2
WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 30000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  2450.10

General statistics:
    total time:                          10.0005s
    total number of events:              24504

Latency (ms):
         min:                                    0.39
         avg:                                    0.41
         max:                                    2.57
         95th percentile:                        0.42
         sum:                                 9994.53

Threads fairness:
    events (avg/stddev):           24504.0000/0.00
    execution time (avg/stddev):   9.9945/0.00
```

Test Run – 3



```
Test number: 3
WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 30000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  2413.64

General statistics:
    total time:                          10.0003s
    total number of events:              24139

Latency (ms):
         min:                                    0.39
         avg:                                    0.41
         max:                                    3.00
         95th percentile:                        0.44
         sum:                                 9978.98

Threads fairness:
    events (avg/stddev):           24139.0000/0.00
    execution time (avg/stddev):   9.9790/0.00
```

Test run – 4


Test number: 4
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 30000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 2445.03
General statistics:
total time: 10.0005s
total number of events: 24454
Latency (ms):
min: 0.39
avg: 0.41
max: 1.89
95th percentile: 0.43
sum: 9995.10
Threads fairness:
events (avg/stddev): 24454.0000/0.00
execution time (avg/stddev): 9.9951/0.00

Test run – 5

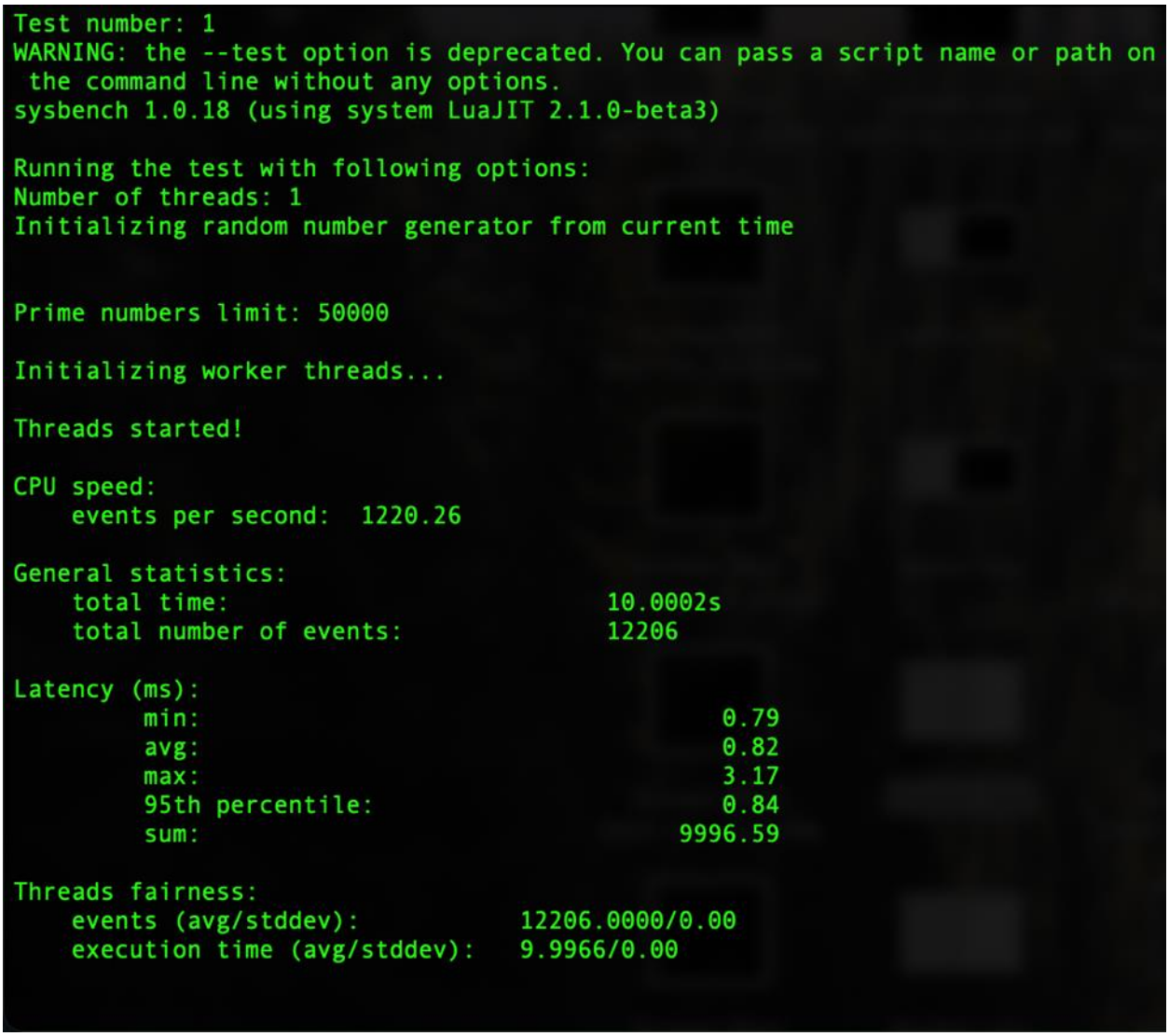
```
Test number: 5
WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 30000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  2445.74

General statistics:
    total time:                          10.0003s
    total number of events:              24460

Latency (ms):
         min:                                    0.39
         avg:                                    0.41
         max:                                    2.55
         95th percentile:                        0.42
         sum:                                 9995.30

Threads fairness:
    events (avg/stddev):           24460.0000/0.00
    execution time (avg/stddev):   9.9953/0.00
```

- Experiment 2 – CPU Performance:

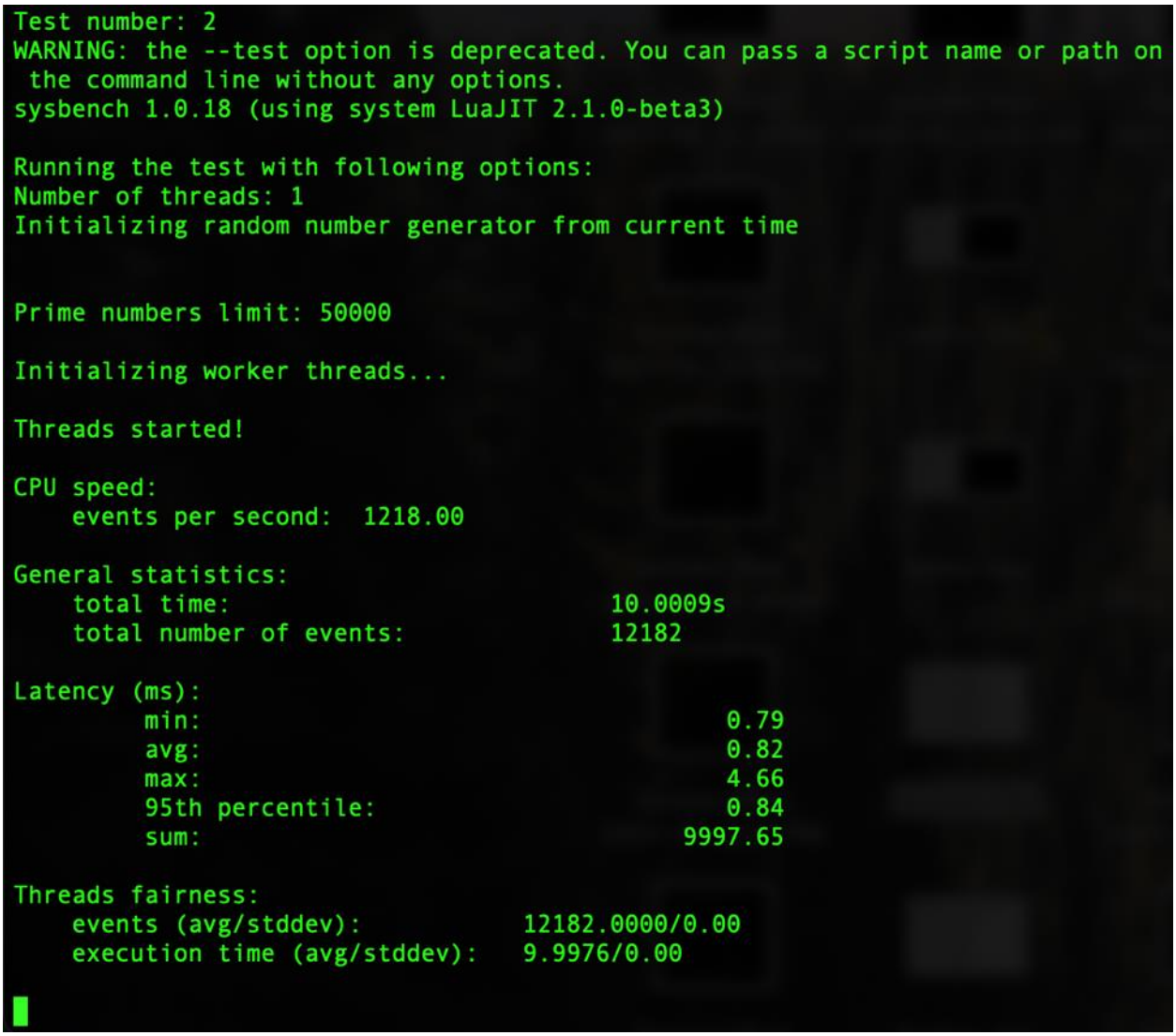
  The CPU is tested using the cpu-max-prime option which is used to find the max prime number under a given limit.

  Command used: CPU Time - *sysbench --test=cpu --cpu-max-prime=50000 run*

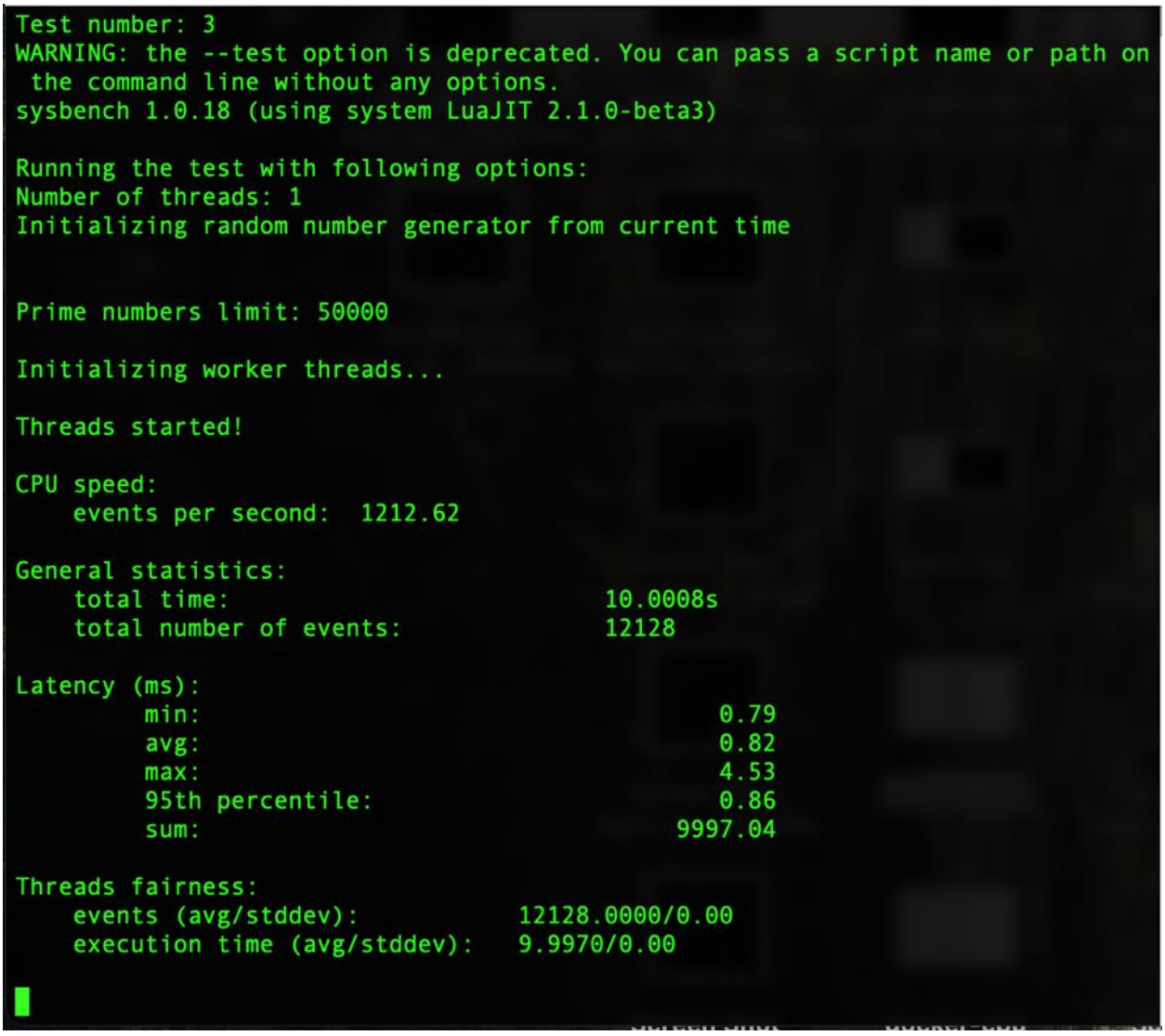
Test run – 1



Test run – 2


Test number: 2
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 50000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 1218.00
General statistics:
total time: 10.0009s
total number of events: 12182
Latency (ms):
min: 0.79
avg: 0.82
max: 4.66
95th percentile: 0.84
sum: 9997.65
Threads fairness:
events (avg/stddev): 12182.0000/0.00
execution time (avg/stddev): 9.9976/0.00

Test Run – 3



```
Test number: 3
WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 50000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  1212.62

General statistics:
    total time:                          10.0008s
    total number of events:              12128

Latency (ms):
         min:                                    0.79
         avg:                                    0.82
         max:                                    4.53
         95th percentile:                        0.86
         sum:                                 9997.04

Threads fairness:
    events (avg/stddev):           12128.0000/0.00
    execution time (avg/stddev):   9.9970/0.00
```

Test run – 4

```
Test number: 4
WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 50000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  1218.62

General statistics:
    total time:                          10.0006s
    total number of events:              12188

Latency (ms):
         min:                                    0.79
         avg:                                    0.82
         max:                                    3.85
         95th percentile:                        0.84
         sum:                                 9996.95

Threads fairness:
    events (avg/stddev):           12188.0000/0.00
    execution time (avg/stddev):   9.9970/0.00
```

Test run – 5

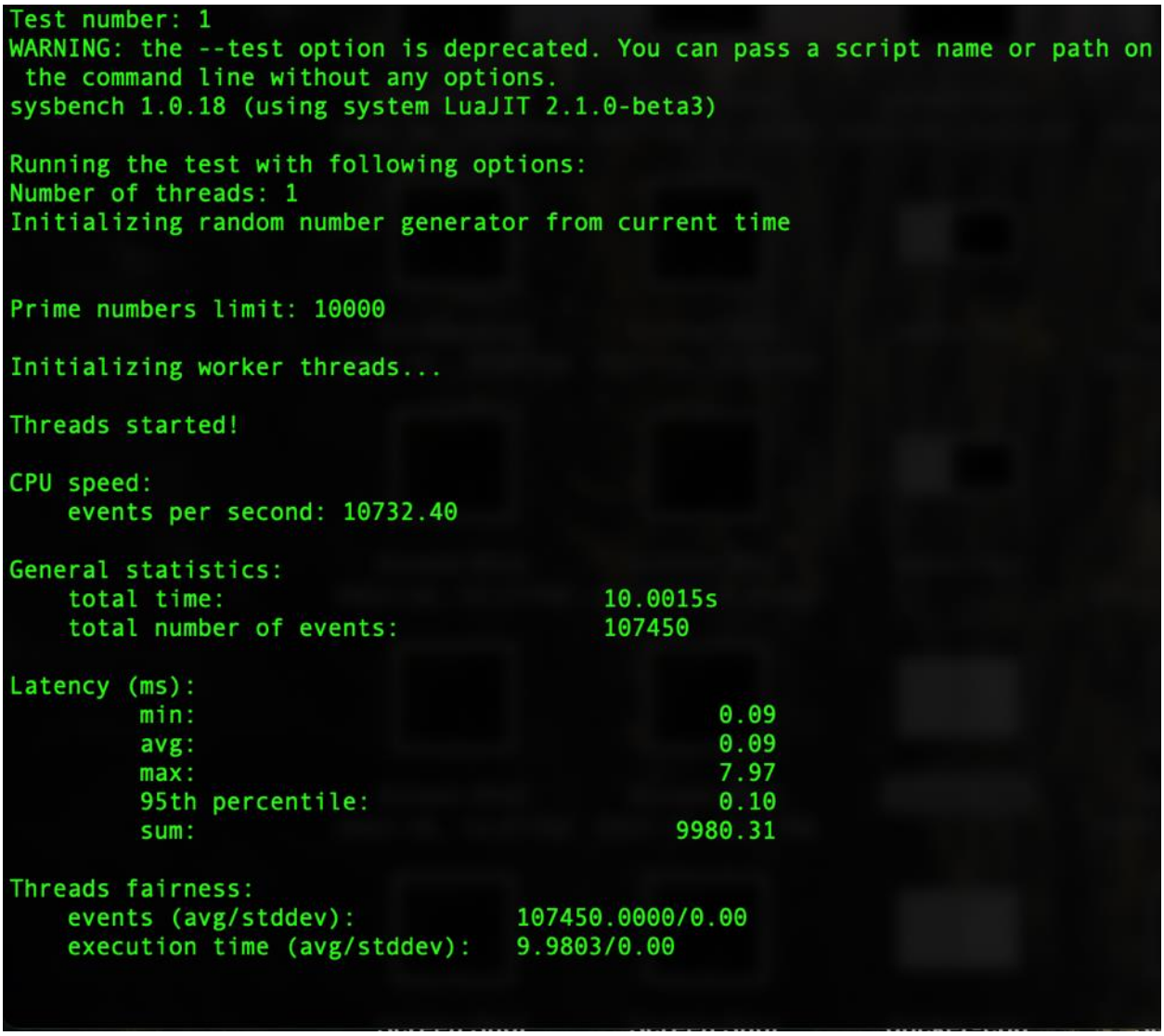
```
Test number: 5
WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 50000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:  1216.99

General statistics:
    total time:                          10.0002s
    total number of events:              12171

Latency (ms):
         min:                                    0.79
         avg:                                    0.82
         max:                                    4.70
         95th percentile:                        0.84
         sum:                                 9996.68

Threads fairness:
    events (avg/stddev):           12171.0000/0.00
    execution time (avg/stddev):   9.9967/0.00
```

- ## Experiment 3 – CPU Performance:

  The CPU is tested using the cpu-max-prime option which is used to find the max prime number under a given limit.

  Command used: CPU Time - *sysbench --test=cpu --cpu-max-prime=10000 run*

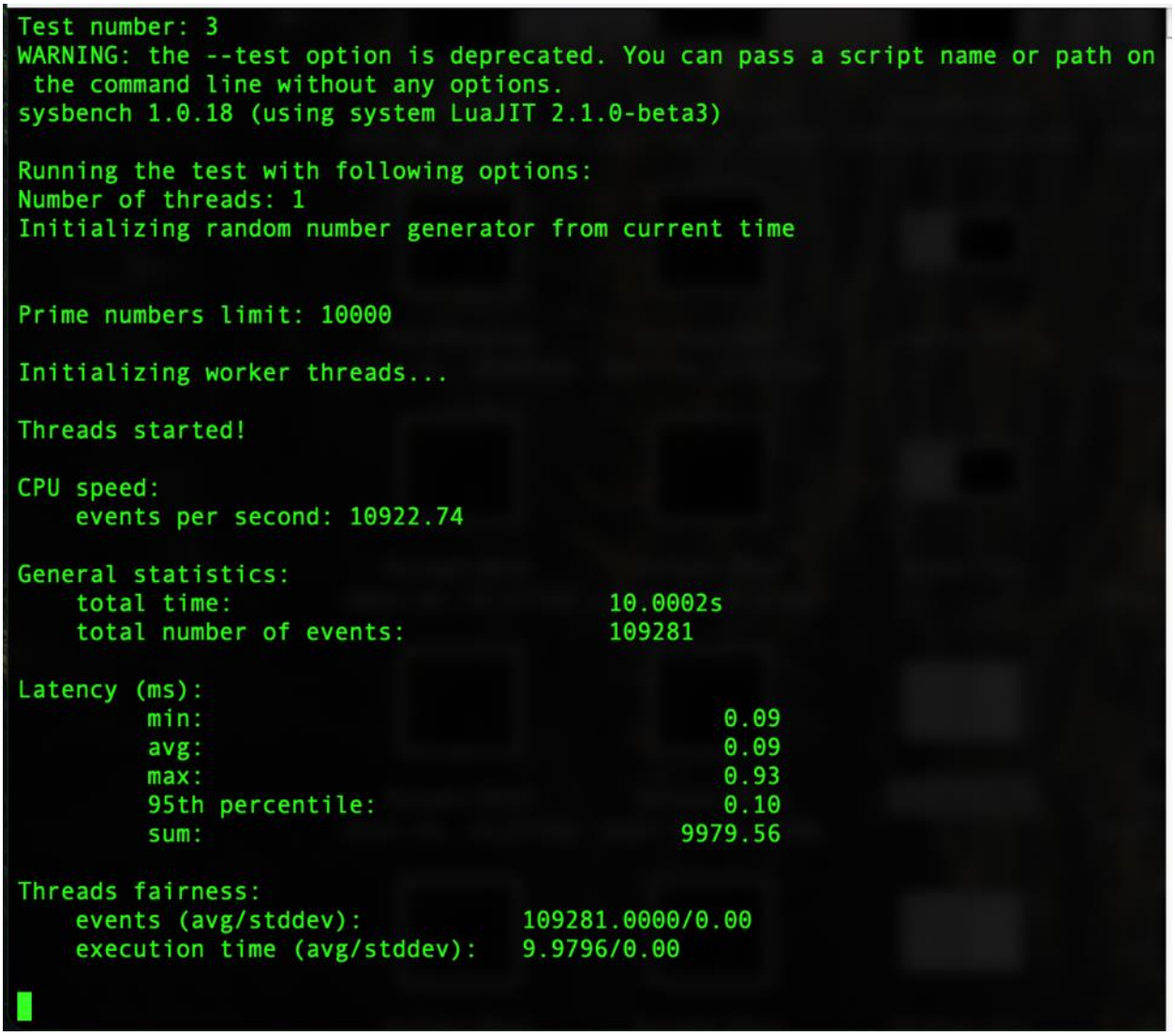
Test run – 1



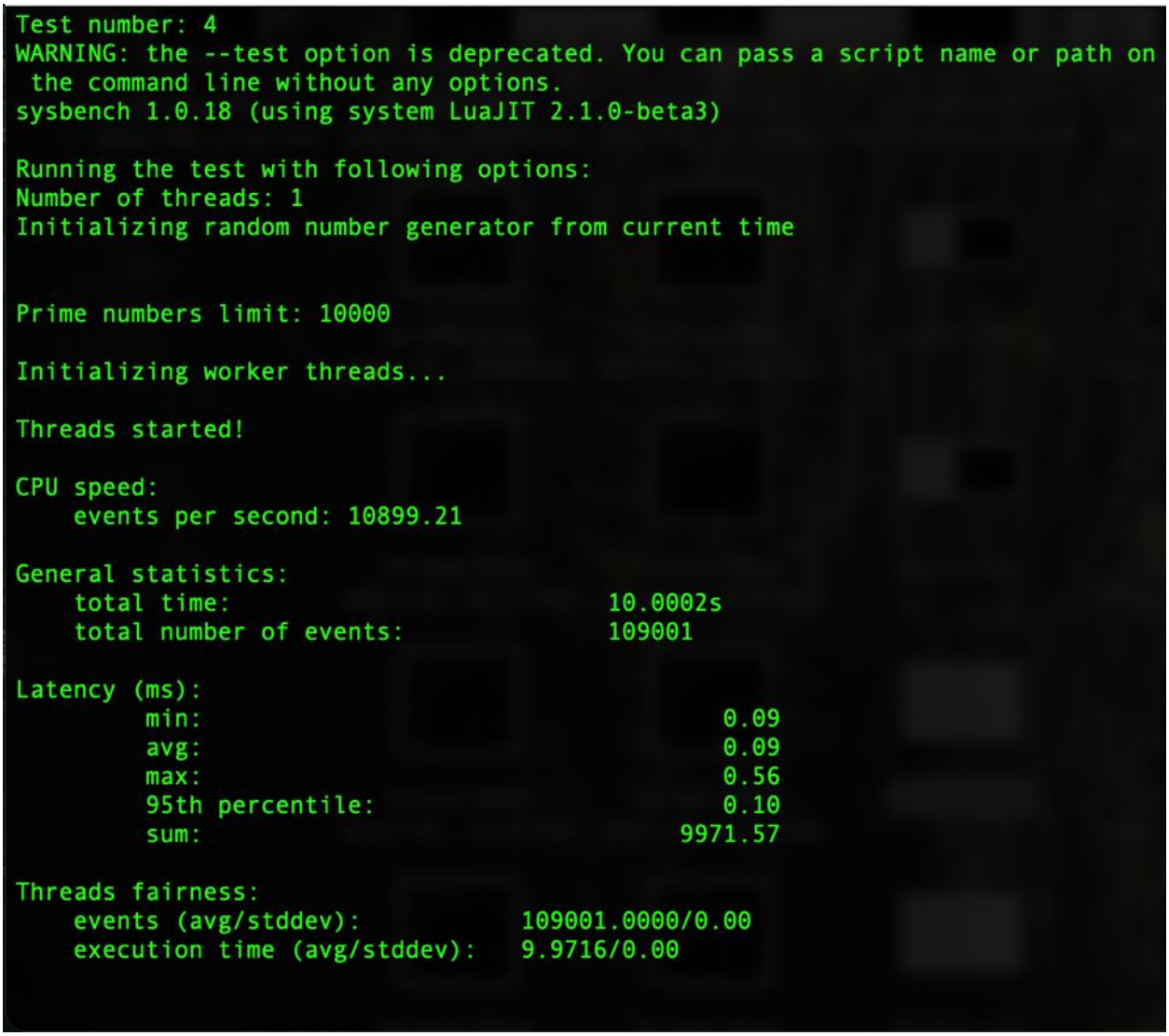
Test run – 2

```
Test number: 2
WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 10000

Initializing worker threads...

Threads started!

CPU speed:
    events per second: 10938.43

General statistics:
    total time:                          10.0002s
    total number of events:              109442

Latency (ms):
         min:                                    0.09
         avg:                                    0.09
         max:                                    0.42
         95th percentile:                        0.10
         sum:                                 9988.34

Threads fairness:
    events (avg/stddev):           109442.0000/0.00
    execution time (avg/stddev):   9.9883/0.00
```

Test Run – 3


Test number: 3
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 10000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 10922.74
General statistics:
total time: 10.0002s
total number of events: 109281
Latency (ms):
min: 0.09
avg: 0.09
max: 0.93
95th percentile: 0.10
sum: 9979.56
Threads fairness:
events (avg/stddev): 109281.0000/0.00
execution time (avg/stddev): 9.9796/0.00

Test run – 4



```
Test number: 4
WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 10000

Initializing worker threads...

Threads started!

CPU speed:
    events per second: 10899.21

General statistics:
    total time:                          10.0002s
    total number of events:              109001

Latency (ms):
         min:                                    0.09
         avg:                                    0.09
         max:                                    0.56
         95th percentile:                        0.10
         sum:                                 9971.57

Threads fairness:
    events (avg/stddev):           109001.0000/0.00
    execution time (avg/stddev):   9.9716/0.00
```

Test run – 5

```
Test number: 5
WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Prime numbers limit: 10000

Initializing worker threads...

Threads started!

CPU speed:
    events per second: 10900.44

General statistics:
    total time:                          10.0002s
    total number of events:              109018

Latency (ms):
         min:                                    0.09
         avg:                                    0.09
         max:                                    0.68
         95th percentile:                        0.10
         sum:                                 9979.84

Threads fairness:
    events (avg/stddev):           109018.0000/0.00
    execution time (avg/stddev):   9.9798/0.00
```

- Experiment - 4 File I/O Performance -

  The File I/O tests are used to determine the read and write throughput of the machines.

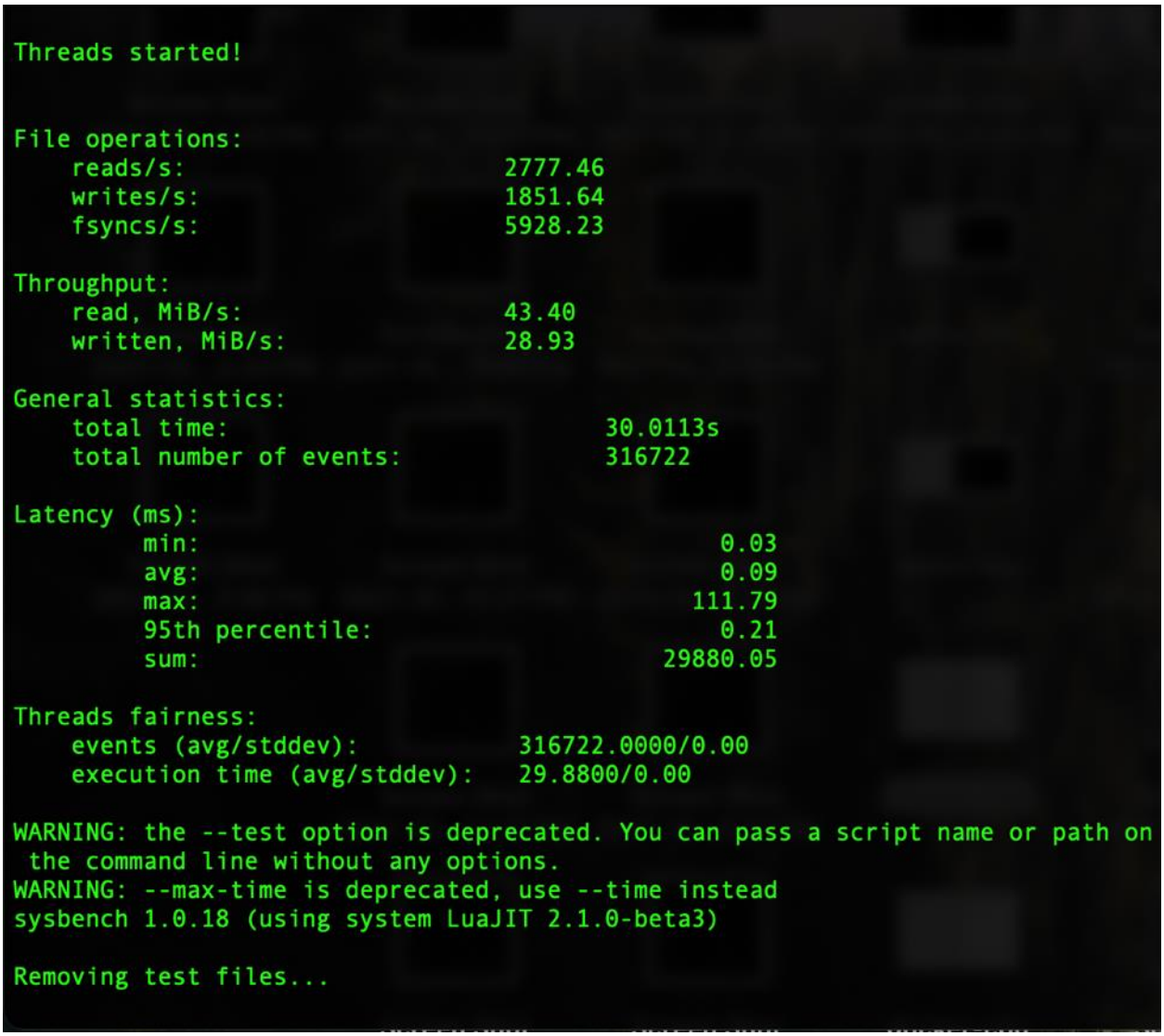
  - Command used: File I/O –
    sysbench --test=fileio --file-total-size=3G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags=direct prepare

    sysbench --test=fileio --file-total-size=3G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags=direct run

    sysbench --test=fileio --file-total-size=3G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags=direct cleanup

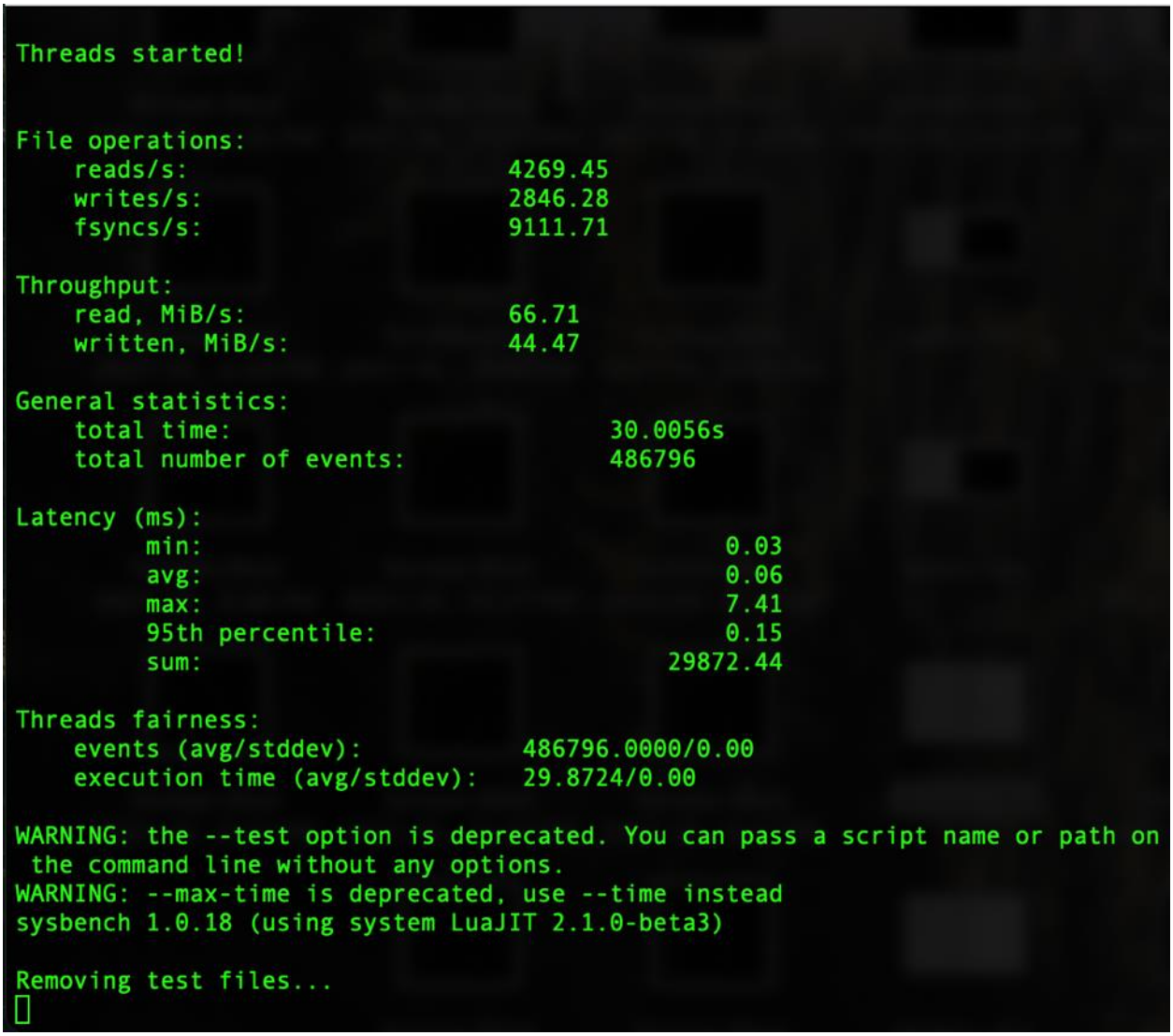
    The following command is run on the host machine to ensure files aren't cached – *sync && sudo purge*

Test run – 1



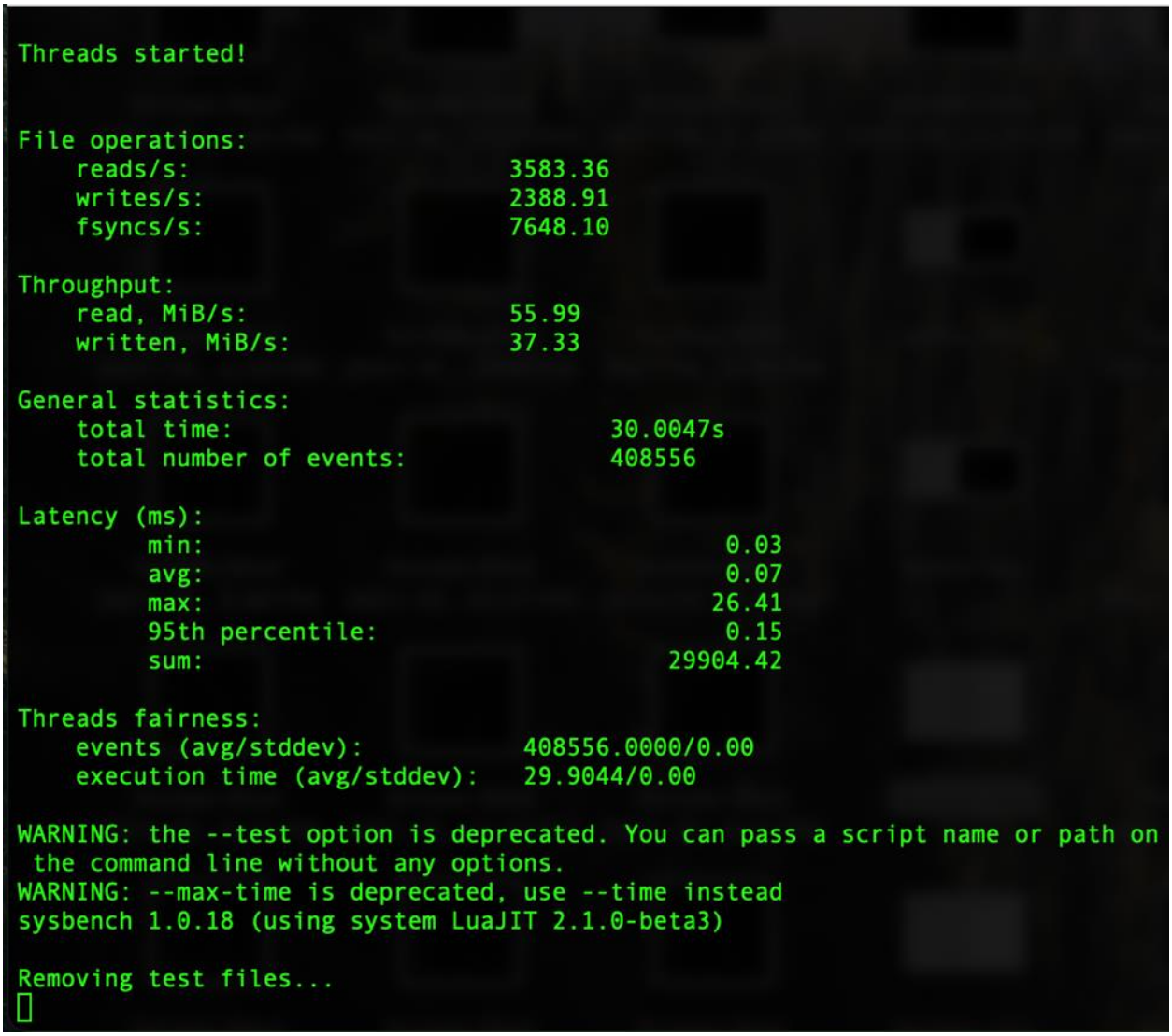
```
Threads started!


File operations:
    reads/s:                      2777.46
    writes/s:                     1851.64
    fsyncs/s:                     5928.23

Throughput:
    read, MiB/s:                  43.40
    written, MiB/s:               28.93

General statistics:
    total time:                          30.0113s
    total number of events:              316722

Latency (ms):
         min:                                    0.03
         avg:                                    0.09
         max:                                  111.79
         95th percentile:                        0.21
         sum:                                29880.05

Threads fairness:
    events (avg/stddev):           316722.0000/0.00
    execution time (avg/stddev):   29.8800/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

Test run – 2

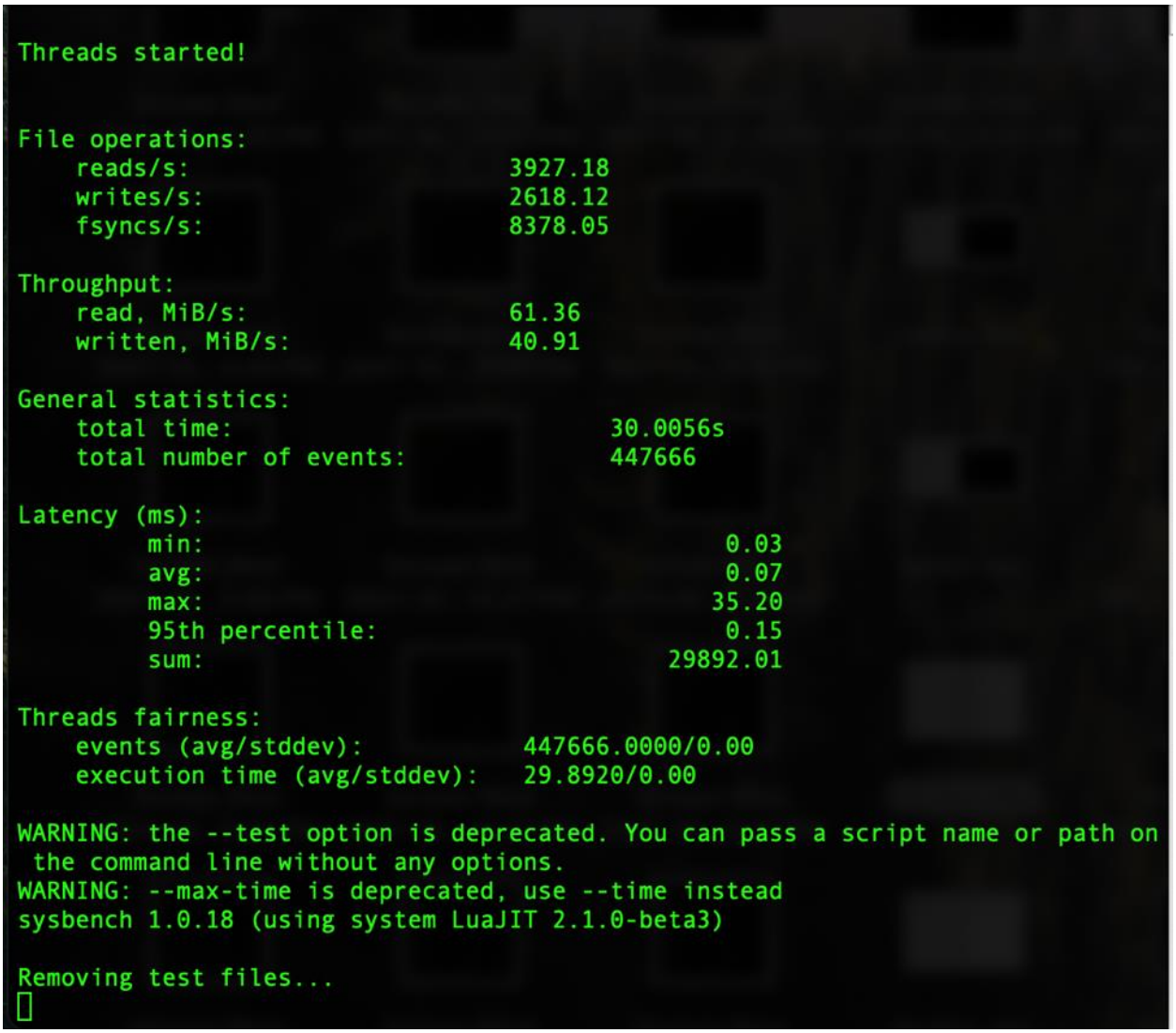


```
Threads started!


File operations:
    reads/s:                      4269.45
    writes/s:                     2846.28
    fsyncs/s:                     9111.71

Throughput:
    read, MiB/s:                  66.71
    written, MiB/s:               44.47

General statistics:
    total time:                          30.0056s
    total number of events:              486796

Latency (ms):
         min:                                    0.03
         avg:                                    0.06
         max:                                    7.41
         95th percentile:                        0.15
         sum:                                29872.44

Threads fairness:
    events (avg/stddev):           486796.0000/0.00
    execution time (avg/stddev):   29.8724/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

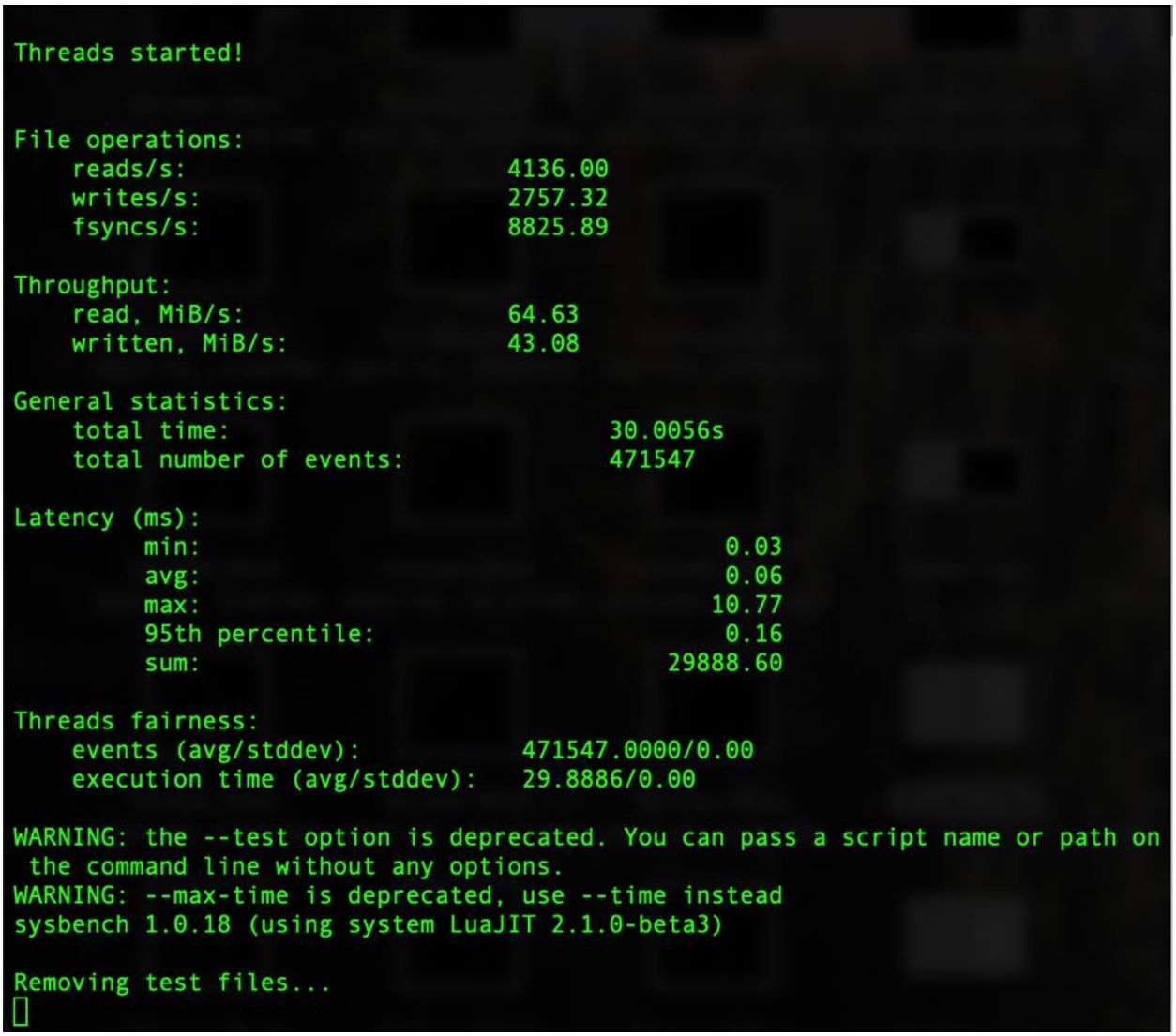
Test run – 3


Threads started!
File operations:
reads/s: 3583.36
writes/s: 2388.91
fsyncs/s: 7648.10
Throughput:
read, MiB/s: 55.99
written, MiB/s: 37.33
General statistics:
total time: 30.0047s
total number of events: 408556
Latency (ms):
min: 0.03
avg: 0.07
max: 26.41
95th percentile: 0.15
sum: 29904.42
Threads fairness:
events (avg/stddev): 408556.0000/0.00
execution time (avg/stddev): 29.9044/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

Test run – 4


Threads started!
File operations:
reads/s: 3927.18
writes/s: 2618.12
fsyncs/s: 8378.05
Throughput:
read, MiB/s: 61.36
written, MiB/s: 40.91
General statistics:
total time: 30.0056s
total number of events: 447666
Latency (ms):
min: 0.03
avg: 0.07
max: 35.20
95th percentile: 0.15
sum: 29892.01
Threads fairness:
events (avg/stddev): 447666.0000/0.00
execution time (avg/stddev): 29.8920/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

Test run – 5


Threads started!
File operations:
reads/s: 4136.00
writes/s: 2757.32
fsyncs/s: 8825.89
Throughput:
read, MiB/s: 64.63
written, MiB/s: 43.08
General statistics:
total time: 30.0056s
total number of events: 471547
Latency (ms):
min: 0.03
avg: 0.06
max: 10.77
95th percentile: 0.16
sum: 29888.60
Threads fairness:
events (avg/stddev): 471547.0000/0.00
execution time (avg/stddev): 29.8886/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

- ## Experiment - 5 File I/O Performance -

  The File I/O tests are used to determine the read and write throughput of the machines.

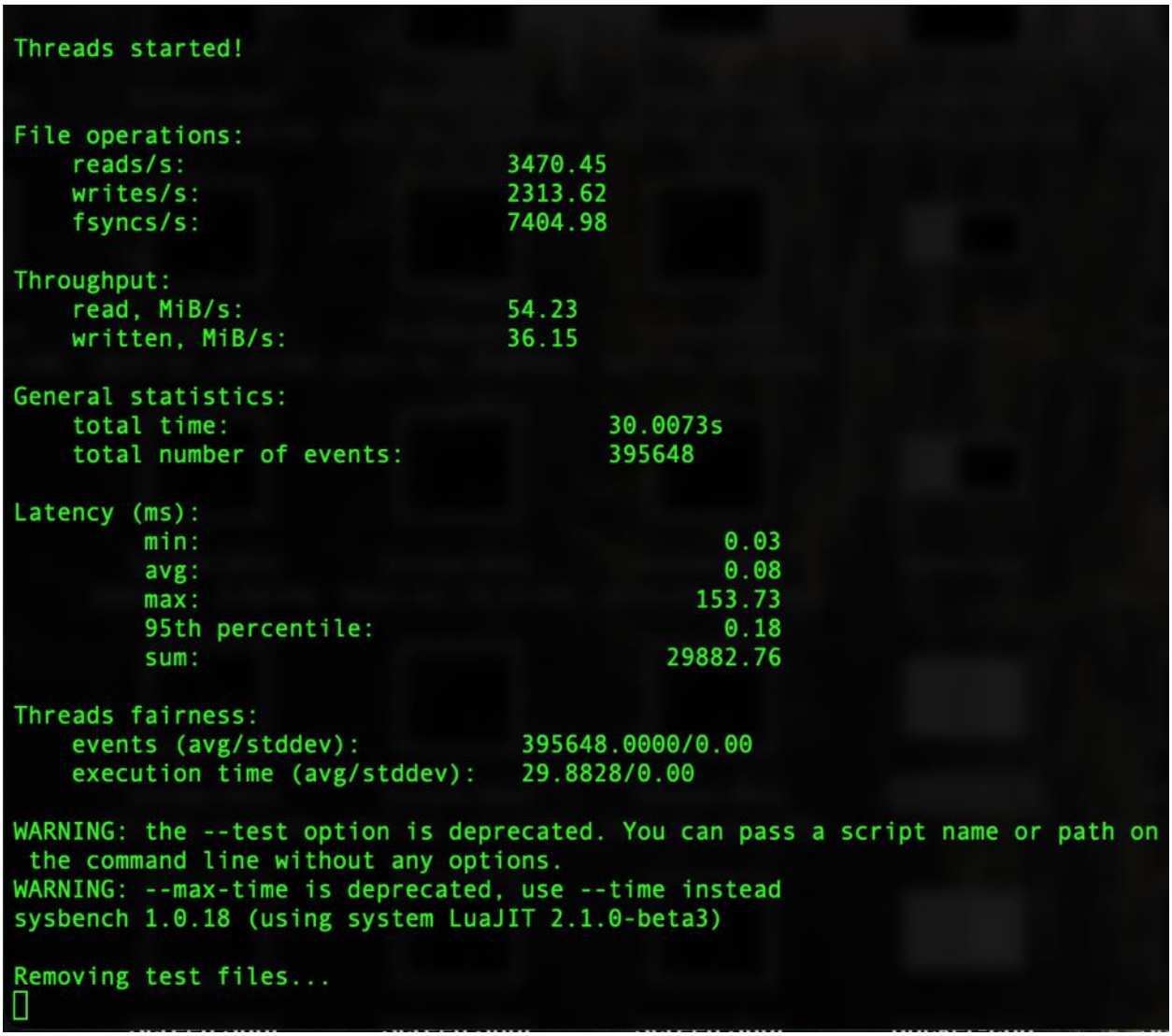
  - Command used: File I/O –
    sysbench --test=fileio --file-total-size=2G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags=direct prepare

    sysbench --test=fileio --file-total-size=2G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags=direct run

    sysbench --test=fileio --file-total-size=2G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags=direct cleanup

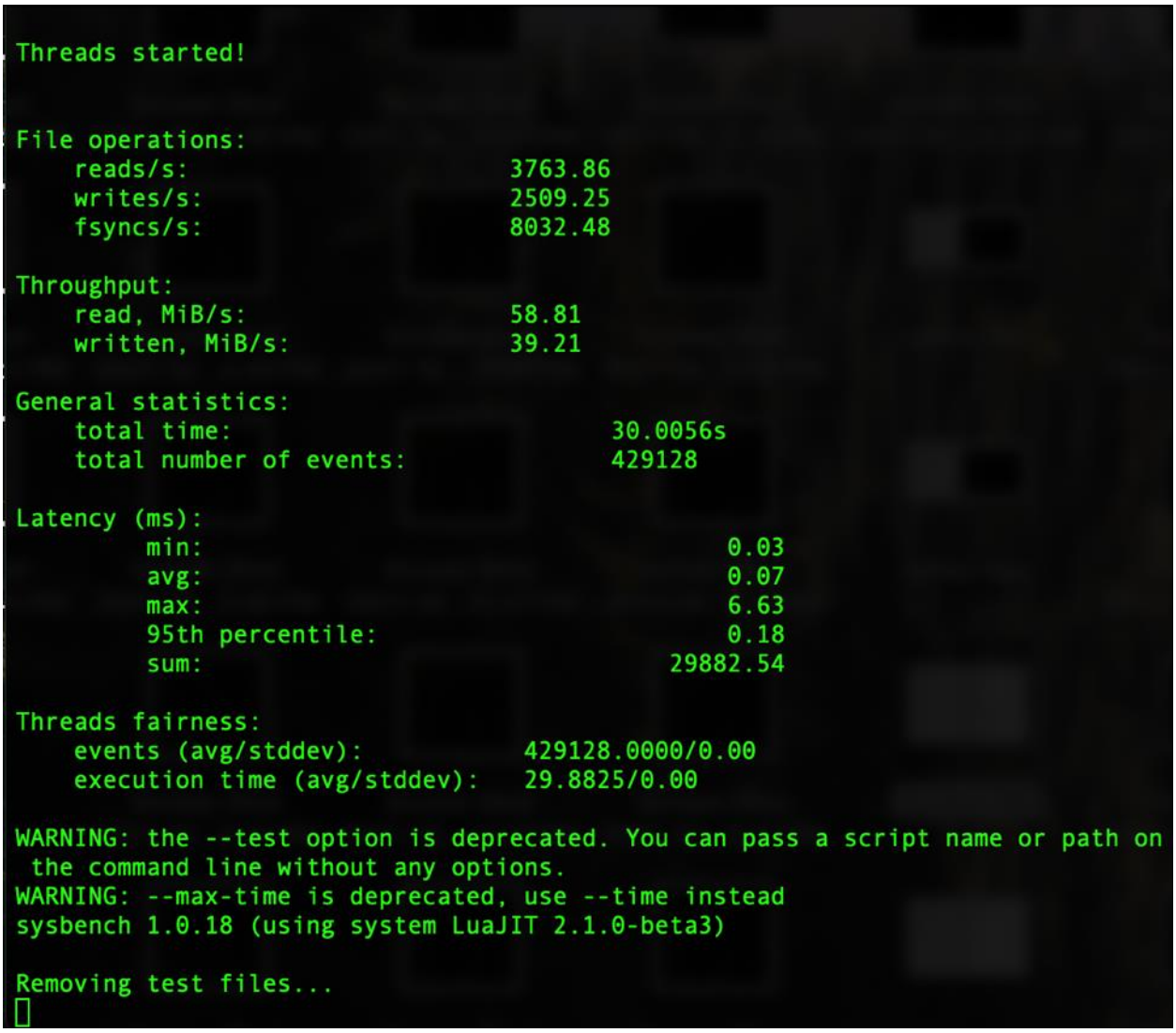
    The following command is run on the host machine to ensure files aren't cached – *sync && sudo purge*

Test run – 1

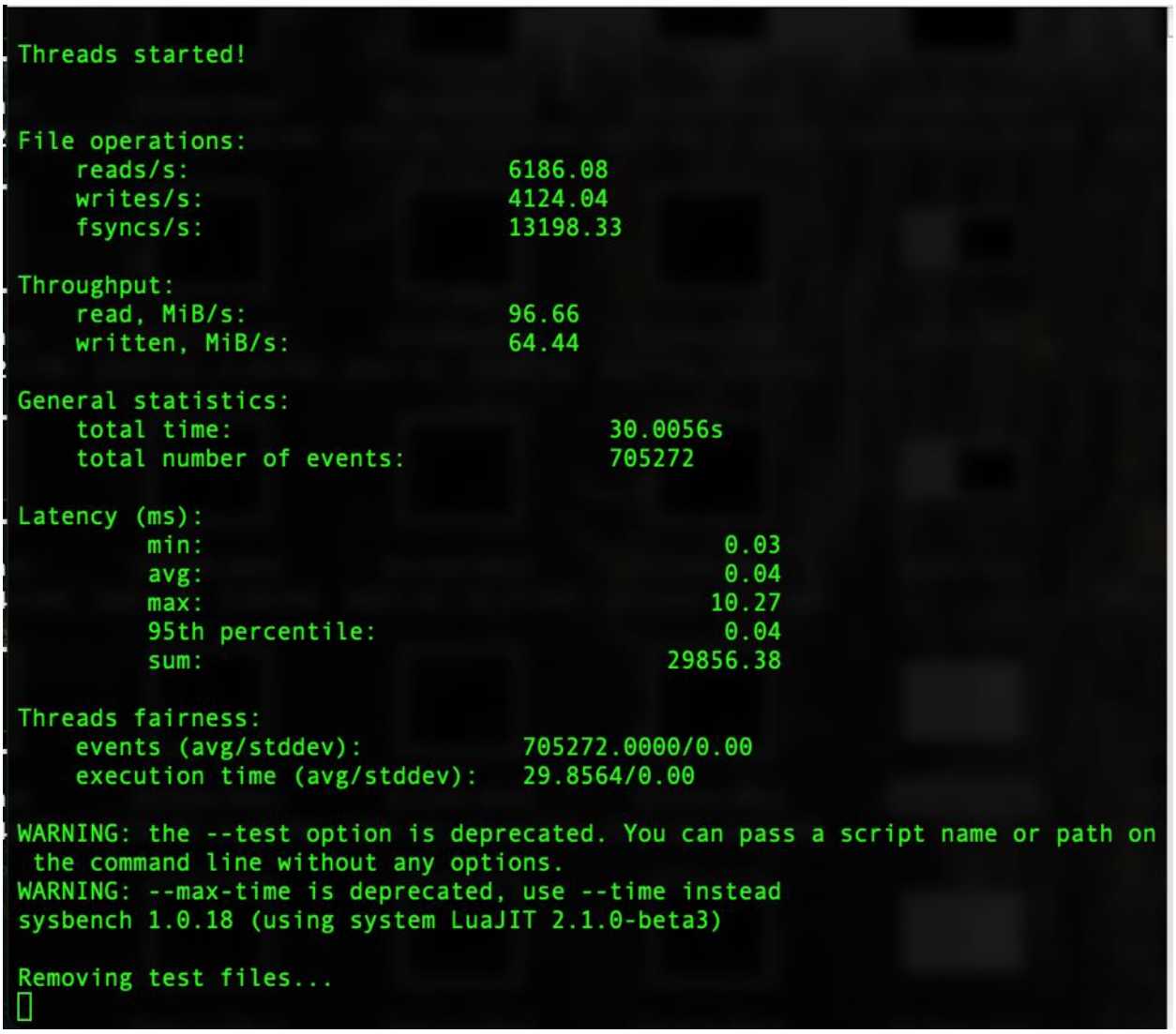


```
Threads started!


File operations:
    reads/s:                      3470.45
    writes/s:                     2313.62
    fsyncs/s:                     7404.98

Throughput:
    read, MiB/s:                  54.23
    written, MiB/s:               36.15

General statistics:
    total time:                          30.0073s
    total number of events:              395648

Latency (ms):
         min:                                    0.03
         avg:                                    0.08
         max:                                  153.73
         95th percentile:                        0.18
         sum:                                29882.76

Threads fairness:
    events (avg/stddev):           395648.0000/0.00
    execution time (avg/stddev):   29.8828/0.00

WARNING: the --test option is deprecated. You can pass a script name or path on
 the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
```

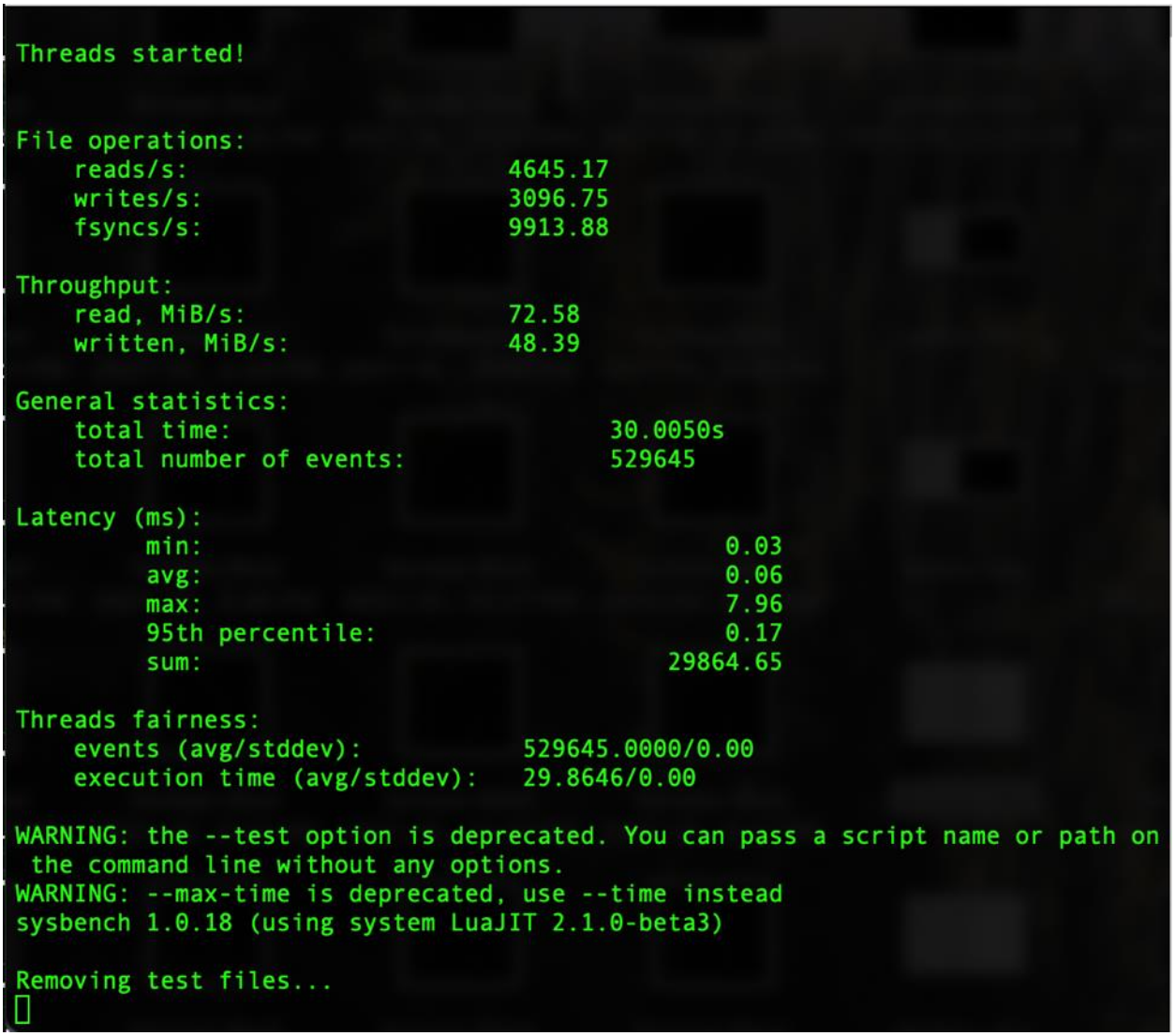
Test run – 2


Threads started!
File operations:
reads/s: 3763.86
writes/s: 2509.25
fsyncs/s: 8032.48
Throughput:
read, MiB/s: 58.81
written, MiB/s: 39.21
General statistics:
total time: 30.0056s
total number of events: 429128
Latency (ms):
min: 0.03
avg: 0.07
max: 6.63
95th percentile: 0.18
sum: 29882.54
Threads fairness:
events (avg/stddev): 429128.0000/0.00
execution time (avg/stddev): 29.8825/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

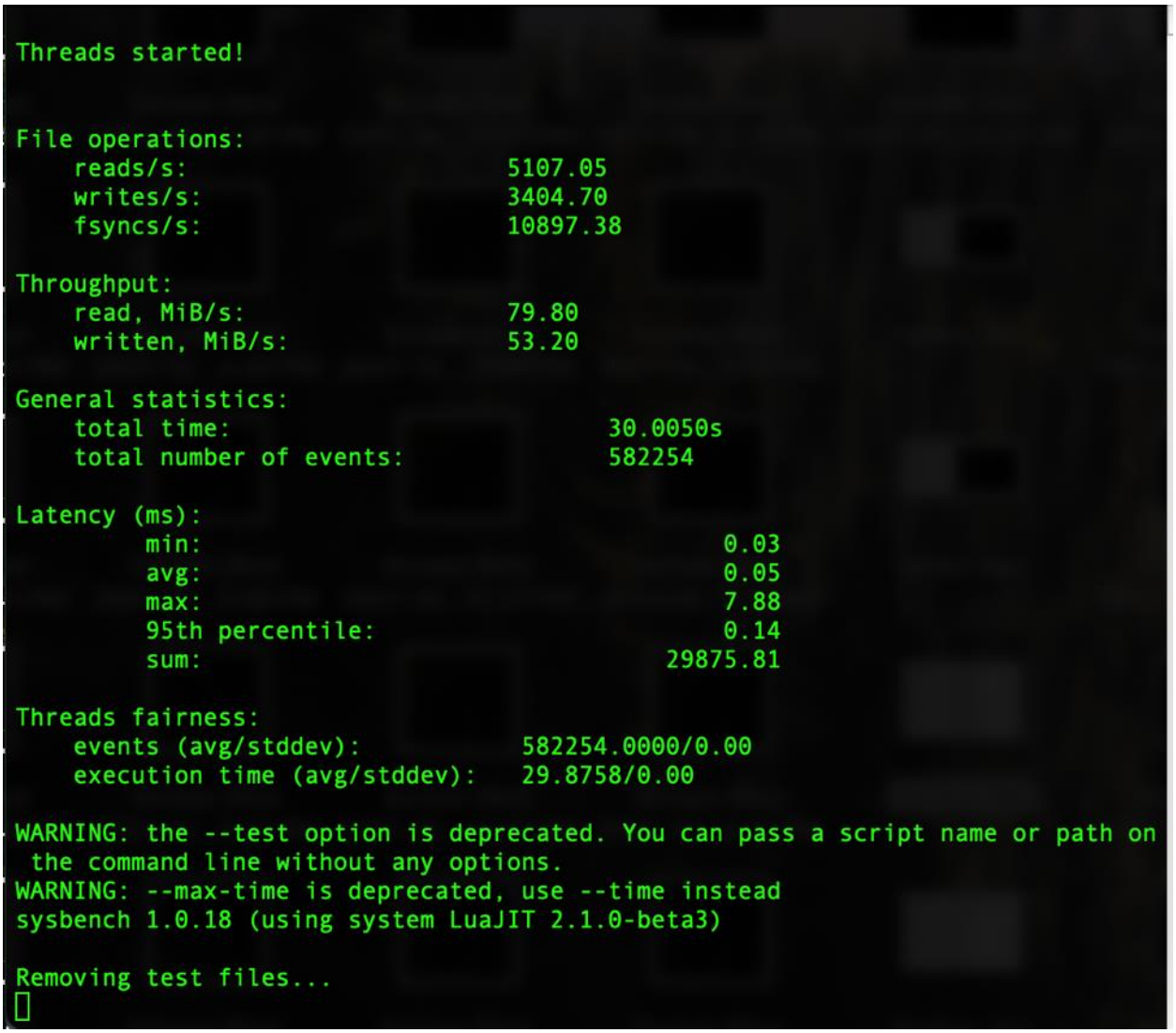
Test run – 3


Threads started!
File operations:
reads/s: 6186.08
writes/s: 4124.04
fsyncs/s: 13198.33
Throughput:
read, MiB/s: 96.66
written, MiB/s: 64.44
General statistics:
total time: 30.0056s
total number of events: 705272
Latency (ms):
min: 0.03
avg: 0.04
max: 10.27
95th percentile: 0.04
sum: 29856.38
Threads fairness:
events (avg/stddev): 705272.0000/0.00
execution time (avg/stddev): 29.8564/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

Test run – 4


Threads started!
File operations:
reads/s: 4645.17
writes/s: 3096.75
fsyncs/s: 9913.88
Throughput:
read, MiB/s: 72.58
written, MiB/s: 48.39
General statistics:
total time: 30.0050s
total number of events: 529645
Latency (ms):
min: 0.03
avg: 0.06
max: 7.96
95th percentile: 0.17
sum: 29864.65
Threads fairness:
events (avg/stddev): 529645.0000/0.00
execution time (avg/stddev): 29.8646/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

Test run – 5


Threads started!
File operations:
reads/s: 5107.05
writes/s: 3404.70
fsyncs/s: 10897.38
Throughput:
read, MiB/s: 79.80
written, MiB/s: 53.20
General statistics:
total time: 30.0050s
total number of events: 582254
Latency (ms):
min: 0.03
avg: 0.05
max: 7.88
95th percentile: 0.14
sum: 29875.81
Threads fairness:
events (avg/stddev): 582254.0000/0.00
execution time (avg/stddev): 29.8758/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

- ## Experiment - 6 File I/O Performance -

  The File I/O tests are used to determine the read and write throughput of the machines.

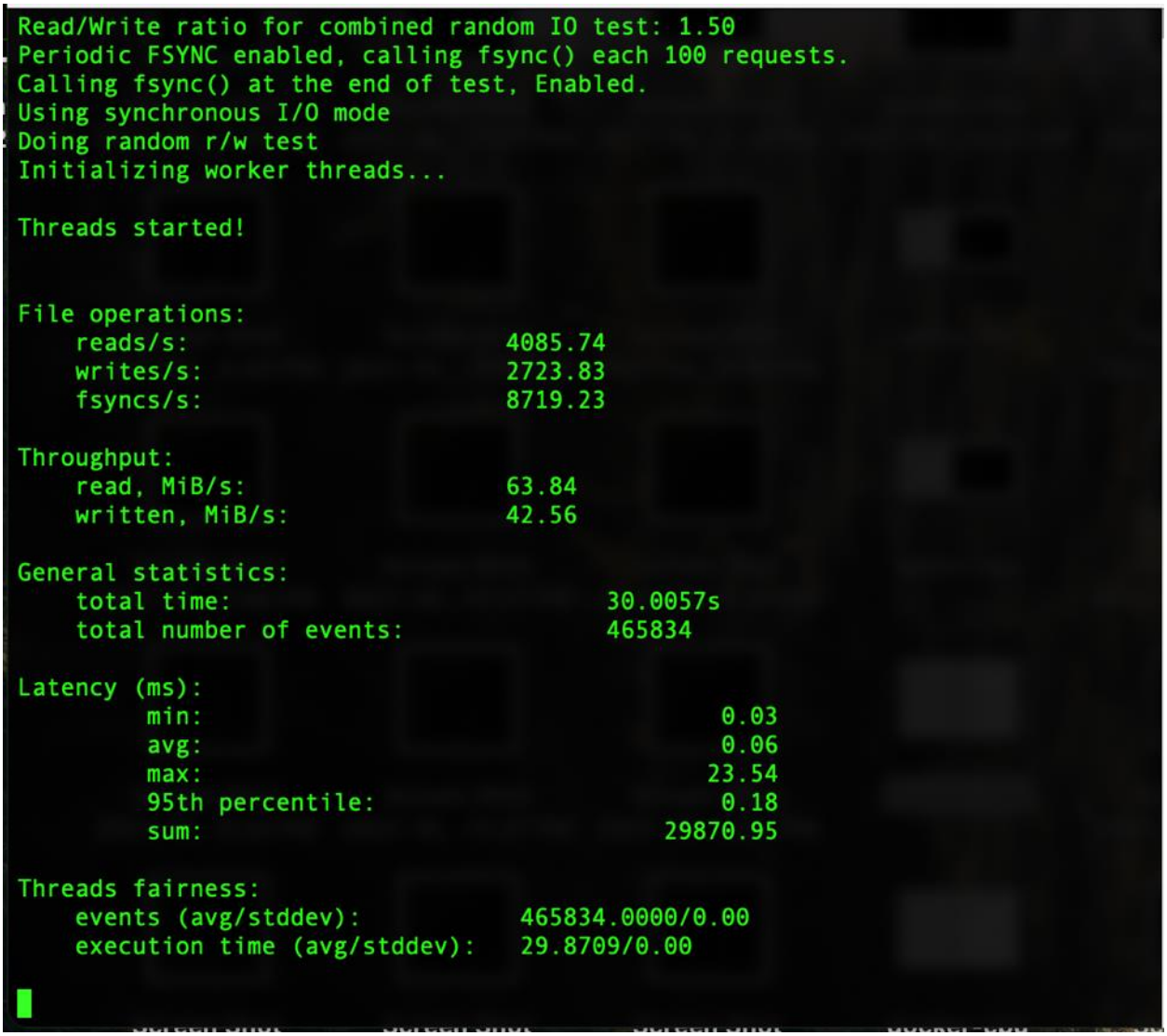
  - Command used: File I/O –
    sysbench --test=fileio --file-total-size=4G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags=direct prepare

    sysbench --test=fileio --file-total-size=4G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags=direct run

    sysbench --test=fileio --file-total-size=4G --file-test-mode=rndrw --max-time=30 --max-requests=0 --file-extra-flags=direct cleanup

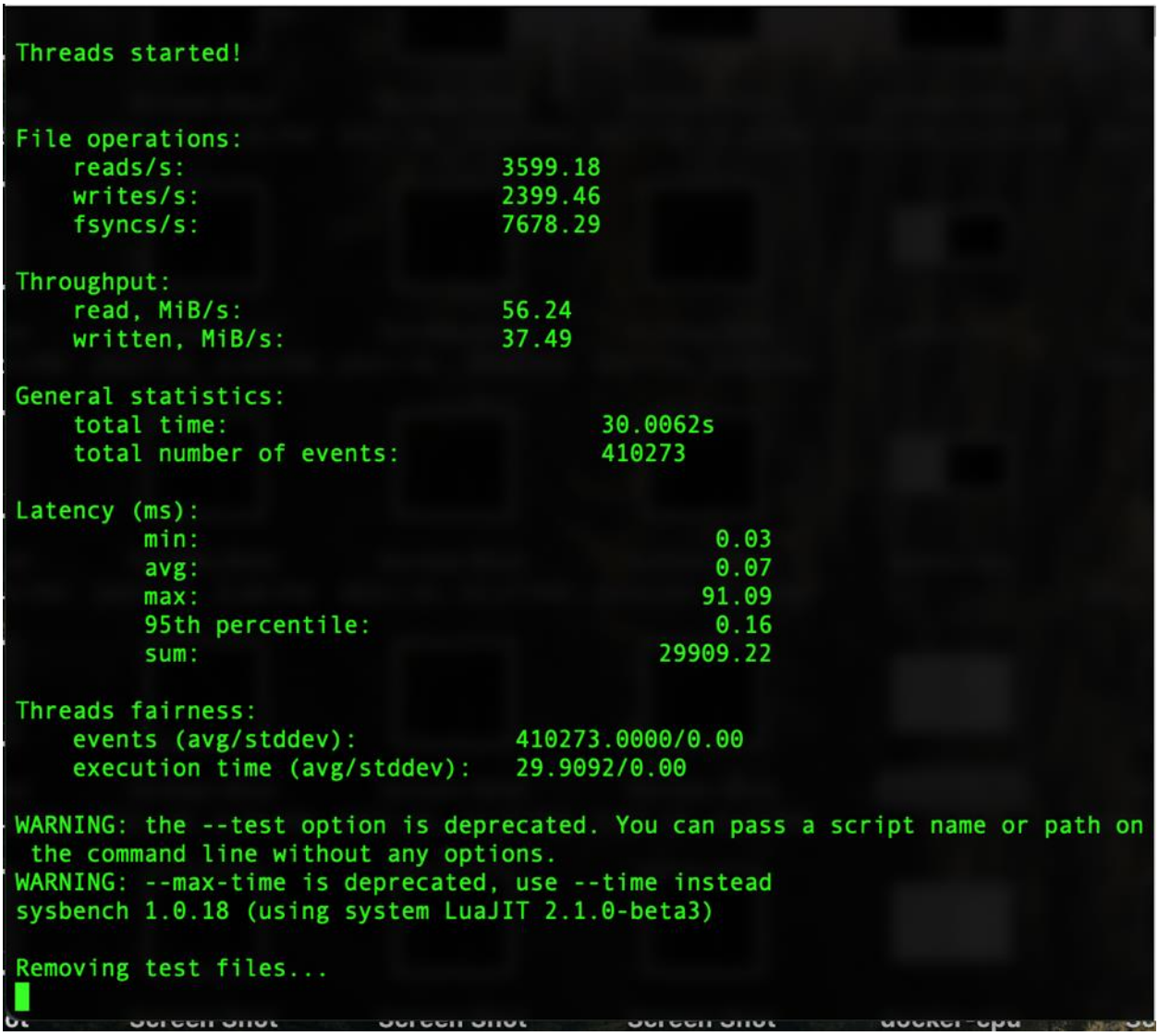
    The following command is run on the host machine to ensure files aren't cached – *sync && sudo purge*

Test run – 1

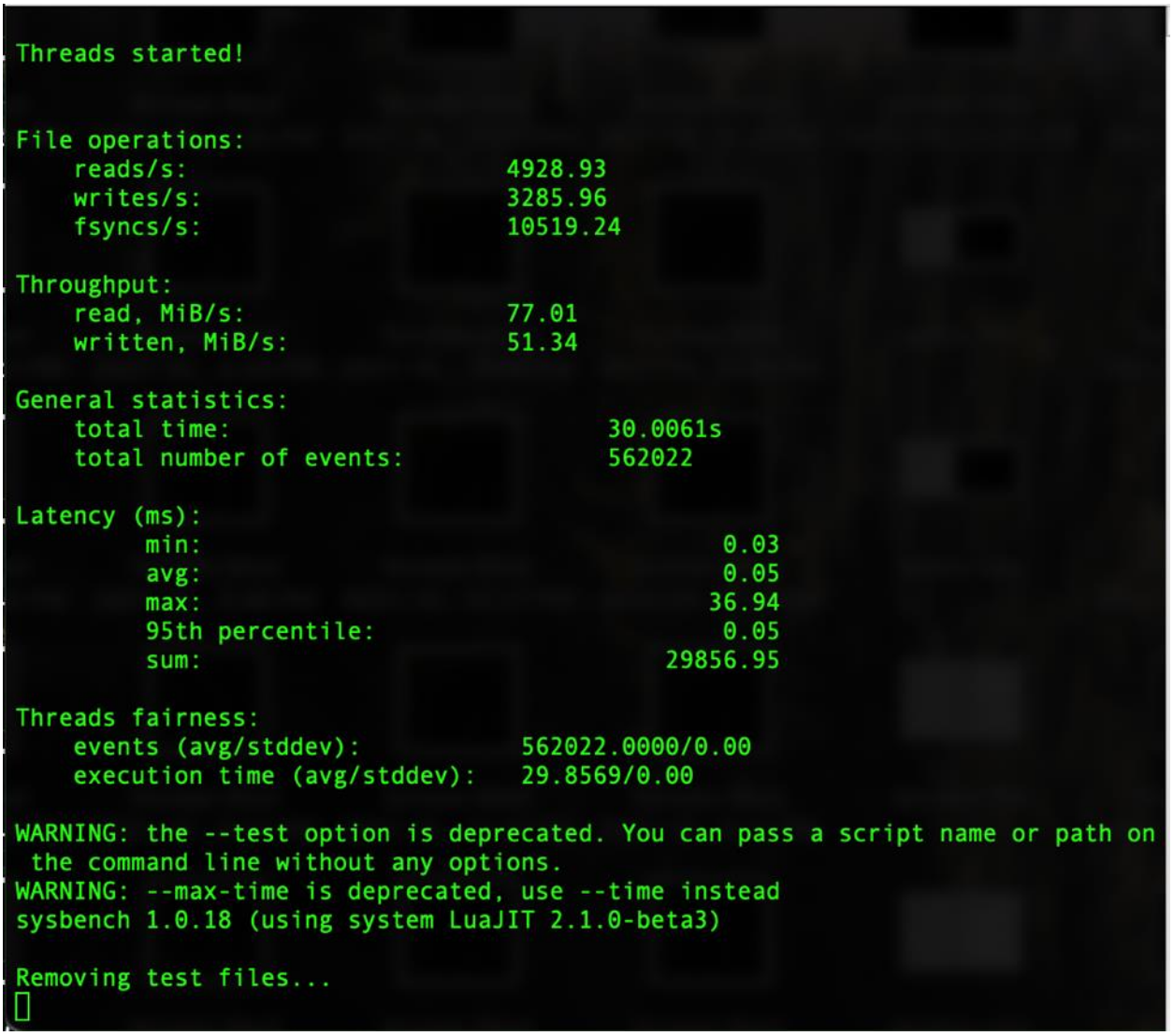


```
Read/Write ratio for combined random IO test: 1.50
Periodic FSYNC enabled, calling fsync() each 100 requests.
Calling fsync() at the end of test, Enabled.
Using synchronous I/O mode
Doing random r/w test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      4085.74
    writes/s:                     2723.83
    fsyncs/s:                     8719.23

Throughput:
    read, MiB/s:                  63.84
    written, MiB/s:               42.56

General statistics:
    total time:                          30.0057s
    total number of events:              465834

Latency (ms):
         min:                                    0.03
         avg:                                    0.06
         max:                                   23.54
         95th percentile:                        0.18
         sum:                                29870.95

Threads fairness:
    events (avg/stddev):           465834.0000/0.00
    execution time (avg/stddev):   29.8709/0.00
```

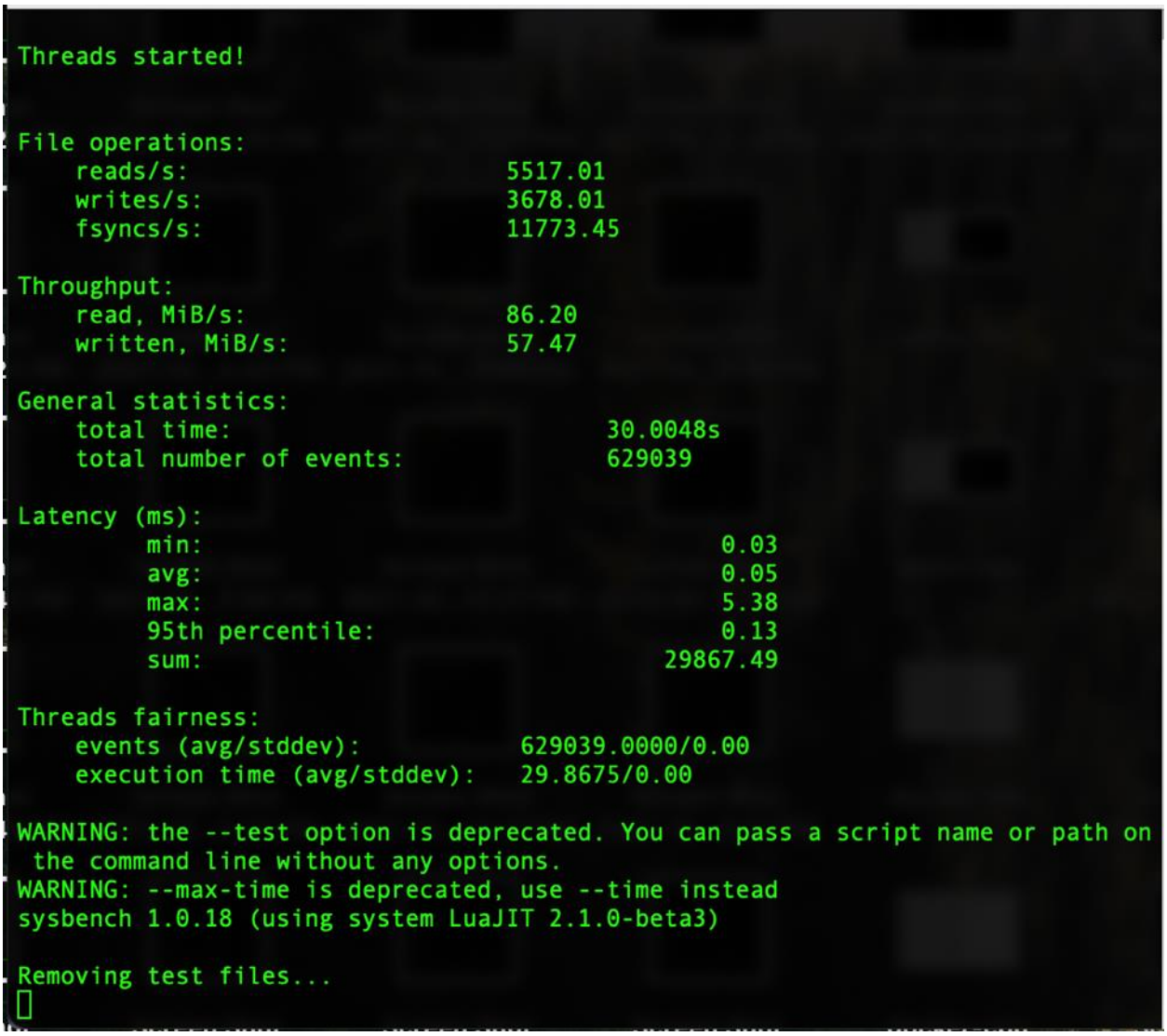
Test run – 2


Threads started!
File operations:
reads/s: 3599.18
writes/s: 2399.46
fsyncs/s: 7678.29
Throughput:
read, MiB/s: 56.24
written, MiB/s: 37.49
General statistics:
total time: 30.0062s
total number of events: 410273
Latency (ms):
min: 0.03
avg: 0.07
max: 91.09
95th percentile: 0.16
sum: 29909.22
Threads fairness:
events (avg/stddev): 410273.0000/0.00
execution time (avg/stddev): 29.9092/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

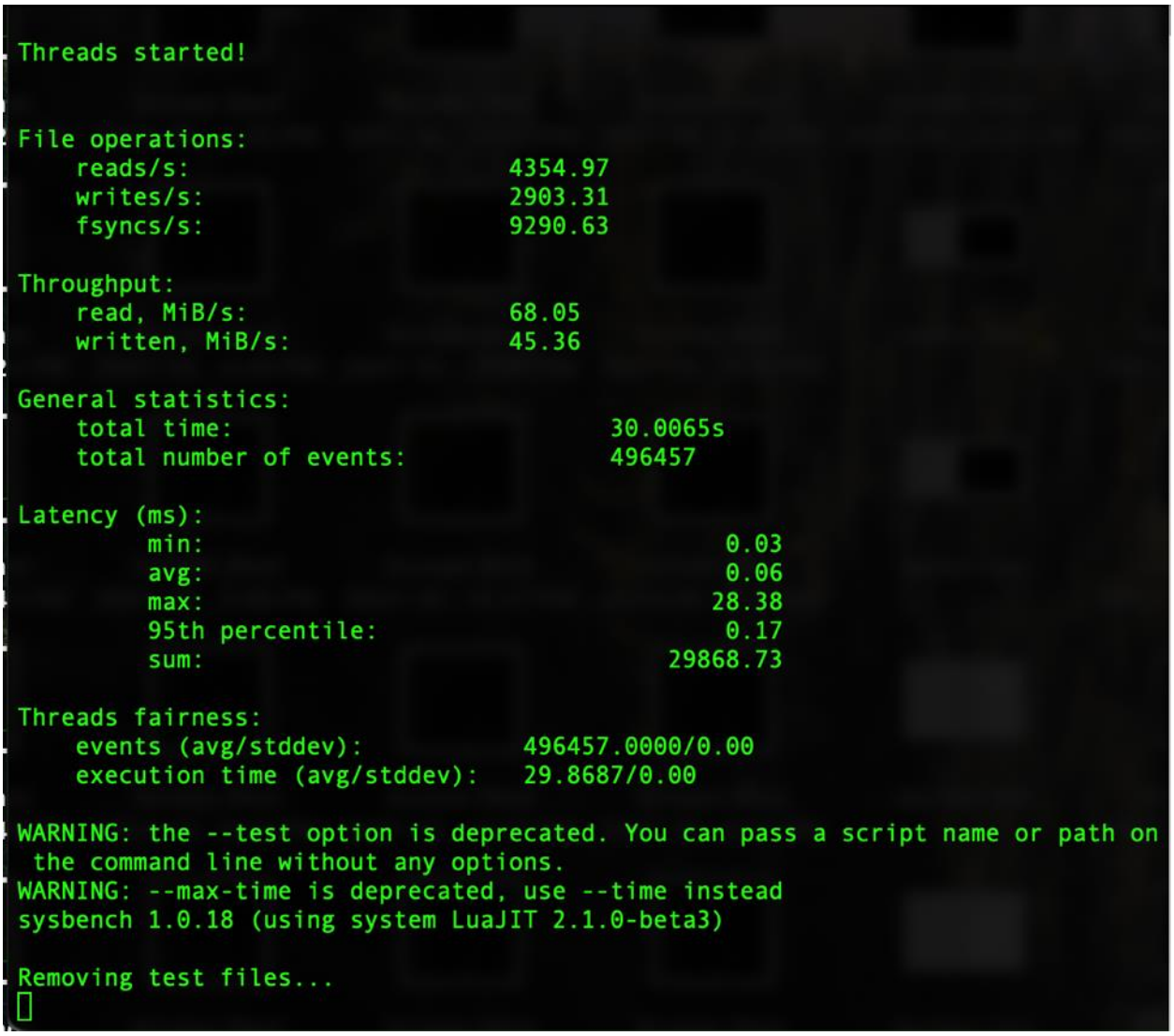
Test run – 3


Threads started!
File operations:
reads/s: 4928.93
writes/s: 3285.96
fsyncs/s: 10519.24
Throughput:
read, MiB/s: 77.01
written, MiB/s: 51.34
General statistics:
total time: 30.0061s
total number of events: 562022
Latency (ms):
min: 0.03
avg: 0.05
max: 36.94
95th percentile: 0.05
sum: 29856.95
Threads fairness:
events (avg/stddev): 562022.0000/0.00
execution time (avg/stddev): 29.8569/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

Test run – 4


Threads started!
File operations:
reads/s: 5517.01
writes/s: 3678.01
fsyncs/s: 11773.45
Throughput:
read, MiB/s: 86.20
written, MiB/s: 57.47
General statistics:
total time: 30.0048s
total number of events: 629039
Latency (ms):
min: 0.03
avg: 0.05
max: 5.38
95th percentile: 0.13
sum: 29867.49
Threads fairness:
events (avg/stddev): 629039.0000/0.00
execution time (avg/stddev): 29.8675/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

Test run – 5


Threads started!
File operations:
reads/s: 4354.97
writes/s: 2903.31
fsyncs/s: 9290.63
Throughput:
read, MiB/s: 68.05
written, MiB/s: 45.36
General statistics:
total time: 30.0065s
total number of events: 496457
Latency (ms):
min: 0.03
avg: 0.06
max: 28.38
95th percentile: 0.17
sum: 29868.73
Threads fairness:
events (avg/stddev): 496457.0000/0.00
execution time (avg/stddev): 29.8687/0.00
WARNING: the --test option is deprecated. You can pass a script name or path on the command line without any options.
WARNING: --max-time is deprecated, use --time instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)
Removing test files...

OS virtualization and System Virtualization performances results and comparisons

- CPU Performance Experiments
  - QEMU Ubuntu Virtual Machine
    - Experiment – 1 –cpu-max-prime=30000

Test Run	Total Time (s)	CPU Speed (Events/s)	Average Latency (ms)
1	10.0001	2459.70	0.41
2	10.0032	2382.00	0.42
3	10.0002	2456.56	0.41
4	10.0002	2450.62	0.41
5	10.0004	2451.30	0.41
Minimum	10.0001	2382	0.41
Maximum	10.0032	2459.7	0.42
Average	10.00082	2440.036	0.412
StdDev	0.001334915728	32.66034109	0.004472135955

    - Experiment – 2 –cpu-max-prime=10000

Test Run	Total Time (s)	CPU Speed (Events/s)	Average Latency (ms)
1	10.0001	10884.11	0.09
2	10.0001	10884.11	0.09
3	10.0001	10959.76	0.09
4	10.0002	10948.36	0.09
5	10.0001	10941.77	0.09
Minimum	10.0001	10884.11	0.09
Maximum	10.0002	10959.76	0.09
Average	10.00012	10923.622	0.09
StdDev	0.00004472135955	36.63901568	0

- Experiment – 3 –cpu-max-prime=50000

Test Run	Total Time (s)	CPU Speed (Events/s)	Average Latency (ms)
1	10.0002	1224.10	0.82
2	10.0003	1218.69	0.82
3	10.0001	1223.33	0.82
4	10.0006	1220.67	0.82
5	10.0004	1222.89	0.82
Minimum	10.0001	1218.69	0.82
Maximum	10.0006	1224.1	0.82
Average	10.00032	1221.936	0.82
StdDev	0.0001923538406	2.217854819	0

- Docker Ubuntu Virtual Machine
  - Experiment – 1 –cpu-max-prime=30000

Test Run	Total Time (s)	CPU Speed (Events/s)	Average Latency (ms)
1	10.0003	2452.83	0.41
2	10.0005	2450.10	0.41
3	10.0003	2413.64	0.41
4	10.0005	2445.03	0.41
5	10.0003	2445.74	0.41
Minimum	10.0003	2413.64	0.41
Maximum	10.0005	2452.83	0.41
Average	10.00038	2441.468	0.41
StdDev	0.0001095445115	15.88192274	0

- Experiment – 2 –cpu-max-prime=10000

Test Run	Total Time (s)	CPU Speed (Events/s)	Average Latency (ms)
1	10.0015	10732.40	0.09
2	10.0002	10938.43	0.09
3	10.0002	10922.74	0.09
4	10.0002	10899.21	0.09
5	10.0002	10900.44	0.09
Minimum	10.0002	10732.4	0.09
Maximum	10.0015	10938.43	0.09
Average	10.00046	10878.644	0.09
StdDev	0.0005813776742	83.37289206	0

- Experiment – 3 –cpu-max-prime=50000

Test Run	Total Time (s)	CPU Speed (Events/s)	Average Latency (ms)
1	10.0002	1220.26	0.82
2	10.0009	1218.00	0.82
3	10.0008	1212.62	0.82
4	10.0006	1218.62	0.82
5	10.0002	1216.99	0.82
Minimum	10.0002	1212.62	0.82
Maximum	10.0009	1220.26	0.82
Average	10.00054	1217.298	0.82
StdDev	0.0003286335345	2.871954039	0

- File I/O Performance Experiments
  - QEMU Ubuntu Virtual Machine
    - Experiment – 4 –file-size=3G

Test Run	Read Throughput (MiB/s)	Write Throughput (MiB/s)	Total Time (s)
1	73.93	49.29	30.0046
2	111.22	74.14	30.0031
3	59.34	39.56	30.0037
4	115.30	76.87	30.0030
5	72.14	48.10	30.0037
Minimum	59.34	39.56	30.003
Maximum	115.3	76.87	30.0046
Average	86.386	57.592	30.00362
StdDev	25.21077904	16.80514713	0.0006379655163

    - Experiment – 5 –file-size=2G

Test Run	Read Throughput (MiB/s)	Write Throughput (MiB/s)	Total Time (s)
1	224.91	149.94	10.0244
2	236.21	157.46	10.0212
3	249.22	166.13	10.0212
4	206.29	137.52	10.0207
5	233.62	155.74	10.0200
Minimum	206.29	137.52	10.02
Maximum	249.22	166.13	10.0244
Average	230.05	153.358	10.0215
StdDev	15.88345523	10.5847683	0.001694107435

- Experiment – 6 –file-size=1G

Test Run	Read Throughput (MiB/s)	Write Throughput (MiB/s)	Total Time (s)
1	436.17	290.78	10.0206
2	490.46	326.98	10.0201
3	491.85	327.90	10.0198
4	374.36	249.57	10.0292
5	282.84	188.56	10.0228
Minimum	282.84	188.56	10.0198
Maximum	491.85	327.9	10.0292
Average	415.136	276.758	10.0225
StdDev	88.26959516	58.84820405	0.003925557285

- Docker Ubuntu Virtual Machine
  - Experiment – 4 –file-size=3G

Test Run	Read Throughput (MiB/s)	Write Throughput (MiB/s)	Total Time (s)
1	43.40	28.93	30.0113
2	66.71	44.47	30.0056
3	55.99	37.33	30.0047
4	61.36	40.91	30.0056
5	64.63	43.08	30.0056
Minimum	43.4	28.93	30.0047
Maximum	66.71	44.47	30.0113
Average	58.418	38.944	30.00656
StdDev	9.31983208	6.212759451	0.002678245694

- Experiment – 5 –file-size=2G

Test Run	Read Throughput (MiB/s)	Write Throughput (MiB/s)	Total Time (s)
1	54.23	36.15	30.0073
2	58.81	39.21	30.0056
3	96.66	64.44	30.0056
4	72.58	48.39	30.0050
5	79.80	53.20	30.0050
Minimum	54.23	36.15	30.005
Maximum	96.66	64.44	30.0073
Average	72.416	48.278	30.0057
StdDev	17.01599042	11.34422628	0.0009433981132

- Experiment – 6 –file-size=1G

Test Run	Read Throughput (MiB/s)	Write Throughput (MiB/s)	Total Time (s)
1	63.84	42.56	30.0057
2	56.24	37.49	30.0062
3	77.01	51.34	30.0061
4	86.20	57.47	30.0048
5	68.05	45.39	30.0065
Minimum	30.005	37.49	30.0048
Maximum	86.2	57.47	30.0065
Average	62.659	46.85	30.00586
StdDev	21.61603525	7.763533345	0.0006580273551

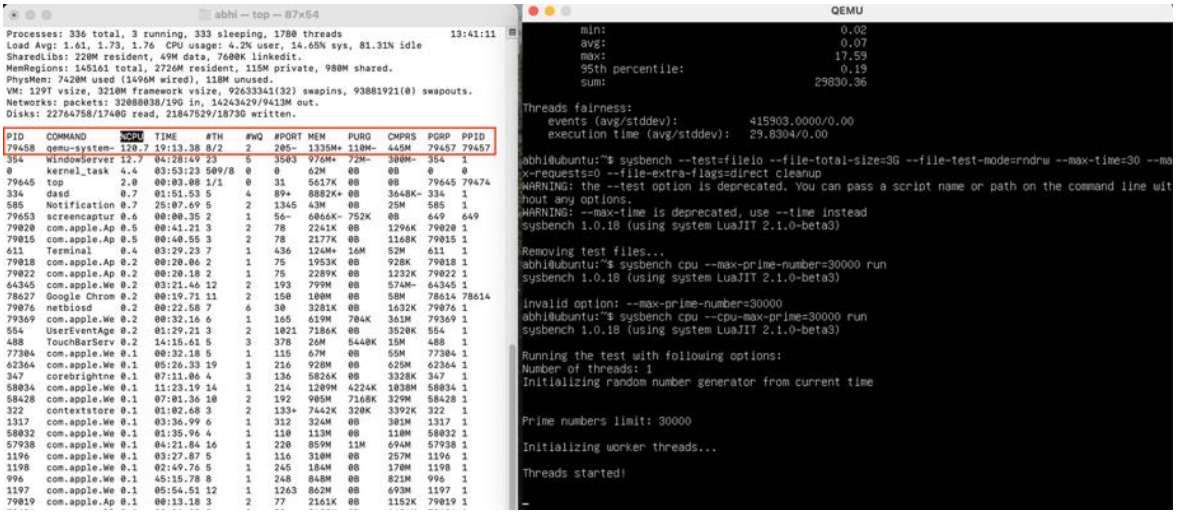
Comparison:

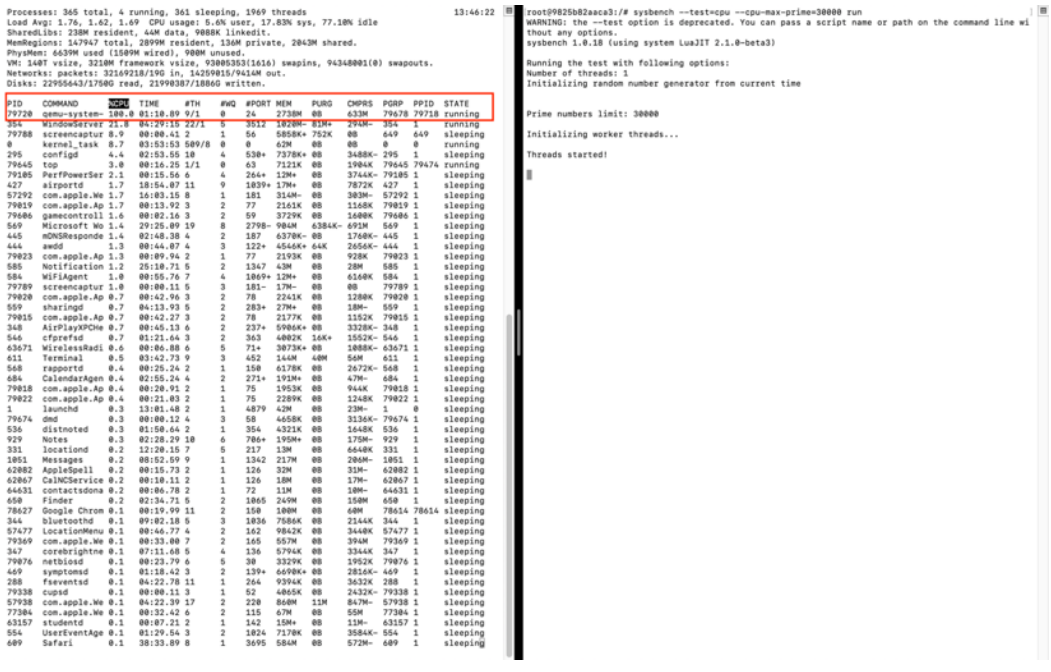
Comparing results, we can see that QEMU and Docker both perform almost equally in the CPU max prime test in all three scenarios. In the file I/O tests, QEMU outperforms Docker by a big margin in all the three scenarios.

Performance Data of Host Machine

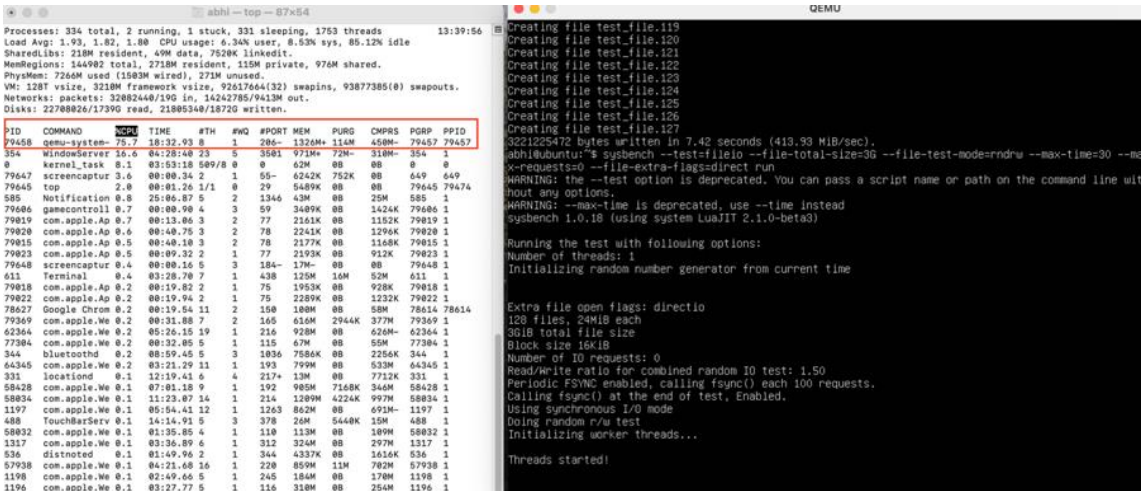
The performance data of the Host machine was recorded by running the top command in the host terminal, while the experiments were being performed in the Virtual Machine and the Container.

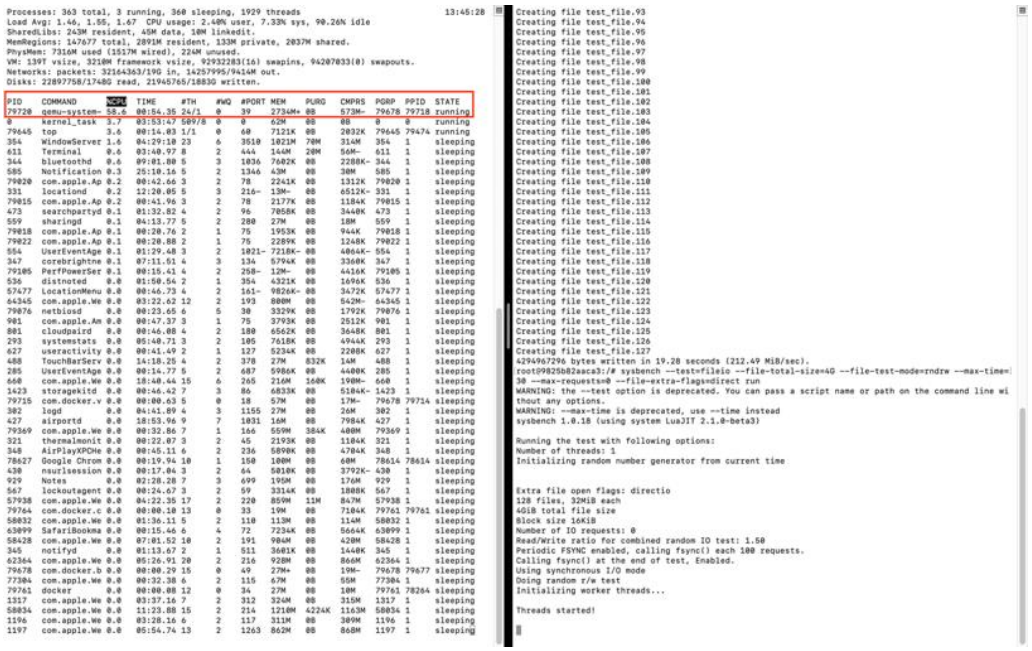
The CPU utilization % of the host machine was 100+ during CPU tests for both Docker and QEMU





Based on the observations, the Memory Utilization in the Host system depended more on the type of virtualization rather than the tests performed





Conclusion

In terms of CPU performance, Docker containers should perform better than virtual machines as containers are lighter than VMs. But in the above experiments we found almost equal performance for the different scenarios. This is probably due to system configurations of the machines. In terms of file I/O, QEMU performed better than Docker. Given these performance benefits, it looks like containers are always a better choice. In most cases, they are. However, there are a few cases where VMs are a better choice. For example, It is difficult to ensure that an untrusted process will not escape containers. Hence, in terms of security, VMs would be a better fit.