

# 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

```
hi@ubuntu:~$ inxi -fxz
System:    Kernel: 5.4.0-88-generic aarch64 bits: 64 compiler: gcc v: 9.3.0 
           Distro: Ubuntu 20.04.3 LTS (Focal Fossa)
Machine:   Model: Qemu System: QEMU product: QEMU Virtual Machine v: virt-6.2 serial: <filter>
CPU:       Topology: Single Core model: N/A bits: 64 type: UP arch: ARMv8 bogomips: 0
           Speed: N/A min/max: N/A Core speeds (MHz): No speed data found for 1 cores.
           Features: aes asimd asimdp cpuid crc32 dit evtstrm fp fpu pmlvl sha1 sha2
GPU:       Message: No ARM data found for this feature.
Display:   Server: No display server data found. Headless machine? tty: 100x37
           Message: Advanced graphics data unavailable in console. Try -G --display
Disk:      Message: No ARM data found for this feature.
Network:   Message: No ARM data found for this feature.
IP-Link:   ID-1: eth0 state: up speed: 1000 Mbps duplex: full mac: <filter>
           ID-2: ip6tnl0 state: down mac: <filter>
           ID-3: tunl0 state: down mac: <filter>
Drives:    Local Storage: total: 10.00 GiB used: 4.22 GiB (42.2%)
           ID-1: /dev/vda model: N/A size: 10.00 GiB
Partition: ID-1: / size: 8.30 GiB used: 4.12 GiB (49.6%) fs: ext4 dev: /dev/dm-0
           ID-2: /boot size: 975.9 MiB used: 107.4 MiB (11.0%) fs: ext4 dev: /dev/vda2
Sensors:   Message: No sensors data was found. Is sensors configured?
Info:      Processes: 90 Uptime: 23m Memory: 1.93 GiB used: 203.9 MiB (10.3%) Init: systemd
           VmSize: 5 GbVmRSS: 59 MiB VmHWM: 59 MiB Shell: bash v: 5.0.17 Inxi: 3.0.38
hi@ubuntu:~$
```

```
root@955aa1d0860a:/# inxi -Fxz
Use of uninitialized value $working in substitution ($//) at /usr/bin/inxi line 18559.
System:  Kernel: 5.10.47-linuskit aarch64 bits: 64 compiler: N/A Console: tty 0 Distro: Ubuntu 20.04.3 LTS (Focal Fossa)
Machine: Message: No machine data: try newer kernel. Is dmidecode installed? Try -M --dmidecode.
CPU:     Topology: Quad Core model: N/A variant: armv8 bits: 64 type: MCP arch: ARMv8
         features: Use -f option to see features bogomips: 0
         Speed: N/A min/max: N/A Core speeds (MHz): No speed data found for 4 cores.
Graphics: Message: No Device data found.
           Display: server: No display server data found. Headless machine? tty: 202x63
           Message: Advanced graphics data unavailable in console for root.
Audio:    Message: No Device data found.
Network:  Message: No ARM data found for this feature.
           IF-ID-1: eth0 state: up speed: 10000 Mbps duplex: full mac: <filter>
           IF-ID-2: ip6tnl0 state: down mac: <filter>
           IF-ID-3: tunl0 state: down mac: <filter>
Drives:   Local Storage: total: 59.60 GiB used: 11.22 GiB (18.8%)
           ID-1: /dev/vda model: N/A size: 59.60 GiB
Partition: ID-1: / size: 58.42 GiB used: 5.61 GiB (9.6%) fs: overlay source: ERR-102
Sensors:  Message: No sensors data was found. Is sensors configured?
Info:     Processes: 3 Uptime: 21m Memory: 1.94 GiB used: 381.1 MiB (19.2%) Init: N/A Compilers: gcc: N/A Shell: bash
           v: 5.0.17 inxi: 3.0.38
root@955aa1d0860a:/#
```

## 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/2021012022444.71840-1-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.

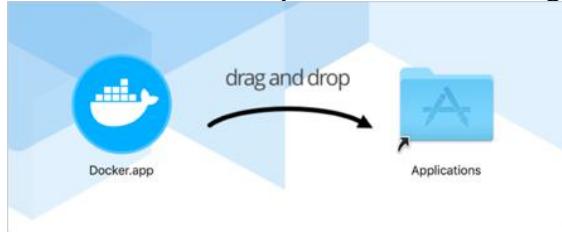
Use **monitor none** to disable the default monitor.

## 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 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: 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 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: 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 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: 2456.56

General statistics:
  total time:          10.00002s
  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 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: 2450.62

General statistics:
total time: 10.00002s
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 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: 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 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: 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:          10.00001s
  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 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!
```

### 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 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: 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 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: 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 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: 10941.77

General statistics:
  total time:          10.000is
  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
```

- o 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 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: 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 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: 1218.69

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 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: 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 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: 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 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: 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:        30.00037s
  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 without 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 without 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 without 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 without 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 without any options.
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.18 (using system LuaJIT 2.1.0-beta3)

Removing test files...
^-
```

- o 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 without 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 without 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 without 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 without 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 without 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

```
[root@955aa1d0860a:/# ./cpu-1.sh
./cpu-1.sh: line 1: i#!/bin/bash: No such file or directory
Test number: 1
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: 2452.83

General statistics:
total time: 10.0003s
total number of events: 24532

Latency (ms):
min: 0.40
avg: 0.41
max: 0.84
95th percentile: 0.43
sum: 9995.80

Threads fairness:
events (avg/stddev): 24532.0000/0.00
execution time (avg/stddev): 9.9958/0.00]
```

## 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
```

- o 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 number: 1
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: 1220.26

General statistics:
total time: 10.0002s
total number of events: 12206

Latency (ms):
min: 0.79
avg: 0.82
max: 3.17
95th percentile: 0.84
sum: 9996.59

Threads fairness:
events (avg/stddev): 12206.0000/0.00
execution time (avg/stddev): 9.9966/0.00
```

## 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
```

- o 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 number: 1
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: 10732.40

General statistics:
total time: 10.0015s
total number of events: 107450

Latency (ms):
min: 0.09
avg: 0.09
max: 7.97
95th percentile: 0.10
sum: 9980.31

Threads fairness:
events (avg/stddev): 107450.0000/0.00
execution time (avg/stddev): 9.9803/0.00
```

## 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
```

- o 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...
[]
```

- o 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
<b>Minimum</b>	10.0001	2382	0.41
<b>Maximum</b>	10.0032	2459.7	0.42
<b>Average</b>	10.00082	2440.036	0.412
<b>StdDev</b>	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
<b>Minimum</b>	10.0001	10884.11	0.09
<b>Maximum</b>	10.0002	10959.76	0.09
<b>Average</b>	10.00012	10923.622	0.09
<b>StdDev</b>	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
<b>Minimum</b>	10.0001	1218.69	0.82
<b>Maximum</b>	10.0006	1224.1	0.82
<b>Average</b>	10.00032	1221.936	0.82
<b>StdDev</b>	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
<b>Minimum</b>	10.0003	2413.64	0.41
<b>Maximum</b>	10.0005	2452.83	0.41
<b>Average</b>	10.00038	2441.468	0.41
<b>StdDev</b>	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
<b>Minimum</b>	10.0002	10732.4	0.09
<b>Maximum</b>	10.0015	10938.43	0.09
<b>Average</b>	10.00046	10878.644	0.09
<b>StdDev</b>	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
<b>Minimum</b>	10.0002	1212.62	0.82
<b>Maximum</b>	10.0009	1220.26	0.82
<b>Average</b>	10.00054	1217.298	0.82
<b>StdDev</b>	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
<b>Minimum</b>	59.34	39.56	30.003
<b>Maximum</b>	115.3	76.87	30.0046
<b>Average</b>	86.386	57.592	30.00362
<b>StdDev</b>	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
<b>Minimum</b>	206.29	137.52	10.02
<b>Maximum</b>	249.22	166.13	10.0244
<b>Average</b>	230.05	153.358	10.0215
<b>StdDev</b>	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
<b>Minimum</b>	282.84	188.56	10.0198
<b>Maximum</b>	491.85	327.9	10.0292
<b>Average</b>	415.136	276.758	10.0225
<b>StdDev</b>	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
<b>Minimum</b>	43.4	28.93	30.0047
<b>Maximum</b>	66.71	44.47	30.0113
<b>Average</b>	58.418	38.944	30.00656
<b>StdDev</b>	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
<b>Minimum</b>	54.23	36.15	30.005
<b>Maximum</b>	96.66	64.44	30.0073
<b>Average</b>	72.416	48.278	30.0057
<b>StdDev</b>	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
<b>Minimum</b>	30.005	37.49	30.0048
<b>Maximum</b>	86.2	57.47	30.0065
<b>Average</b>	62.659	46.85	30.00586
<b>StdDev</b>	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

Process	ID	COMMAND	PPID	TIME	#TH	FWD	APORT	MEN	PURG	CMRPS	PGRP	PPID	STATE
Load Avg: 1.76, 1.62, 1.69 CPU usage: 5.6% user, 17.85% sys, 77.18% idle													
SharedLibs	1	/bin/sh -c /etc/init.d/3216m restart	44M	0:00	1					9088K	1	1	running
Memcached	2	/usr/local/bin/memcached -l 127.0.0.1 -p 11211 -m 16384 -u memcached -t 1000000	1	0:00	1					16384K	1	1	running
PhyMem	3	6439M used (1589W wired), 980M unused	1	0:00	1					1589K	1	1	running
Networks:	4	14087 vsz, 3216m framework vsz	93808533(1616)	swapsin, 94348000(0)	swapsout.								
VMS	5	219985443(756k) read, 219980877(1866k) written.											
Disk	6												
PID	7	COMMAND	8	PPID	9	TIME	10	#TH	11	FWD	12	APORT	13
79788	8	Windscribe 21.8	8	1829715 2271	9	5:552	1828M	81M	24M	385	1	1	running
79788	10	screencapture 8.9	1	0:08:42	2	5:56	5858K	752K	88	649	649	1	running
79788	12	kernel_task	8	0:53:513 589/8	1	0	68	62M	0B	0B	0B	0B	running
79865	14	top	8	0:00:00:00:00:00	1	5:58	538M	1024K	1024K	1024K	1024K	1024K	running
79865	16	top	8	0:16:25 1/1	1	0:53	712K	0B	1984K	7945	7947	1	running
79815	18	PerfPowerer 2.1	8	0:15:56 6	2	6:264	129M	0B	374K	7918	1	1	sleeping
79815	20	airplayd	8	0:00:00:00:00:00	1	7:00	1024K	0B	7872K	1	1	sleeping	
79792	22	com.apple.We 1.7	8	0:13:15 8	1	1:53	314M	0B	1024K	5729	1	1	sleeping
79819	24	com.apple.Ap 0.7	13	0:13:13 92	3	2:77	2161K	0B	1168K	7905	1	1	sleeping
79846	26	gamecontrol 1.0	8	0:02:16 3	2	5:9	372K	0B	1488K	7948	1	1	sleeping
79846	28	git 0.29.0-10-g9e9	8	0:00:00:00:00:00	1	5:58	1024K	1024K	1024K	1024K	1024K	1024K	running
445	30	mDNSResponder 0.2	1	0:14:48 38 4	2	1:87	6370K	0B	1780K	445	1	1	sleeping
444	32	awdd	1	0:00:04 7	3	1:22	4546K	64K	2656K	444	1	1	sleeping
79823	34	com.apple.Ap 0.7	13	0:00:00:00:00:00	1	7:00	1024K	0B	938K	7923	1	1	sleeping
585	36	Notification 1.0	1	0:00:00:00:00:00	2	1:347	43M	0B	28M	585	1	1	sleeping
584	38	WiFIagent	1	0:00:05:67 7	4	1:069	129M	0B	6168K	584	1	1	sleeping
79789	40	screencapture 1.0	8	0:08:16 11	3	1:81	17M	0B	88	79789	1	1	sleeping
79828	42	com.apple.Ap 0.7	13	0:13:13 93	2	1:53	2161K	0B	1388K	7905	1	1	sleeping
559	44	sharingd	0.7	0:13:13 93 5	2	2:83	27M	0B	18M	559	1	1	sleeping
79815	46	com.apple.Ap 0.7	0:04:22 27	3	2:78	217K	0B	1152K	7905	1	1	sleeping	
348	48	AirPlayXPoE 0.7	0.8	0:15:16 3	4	2:50	598K	0B	322M	348	1	1	sleeping
544	50	com.apple.xbsd 1.7	1	0:00:00:00:00:00	3	3:65	1024K	1024K	1024K	1024K	1024K	1024K	running
63571	52	WirelessRadi 0.5	0.6	0:08:06 8	5	7:11	3873K	0B	1888K	63571	1	1	sleeping
611	54	Terminal 0.5	0.5	0:34:27 73	9	3:452	144M	48M	58M	611	1	1	sleeping
611	56	com.apple.xbsd 1.7	1	0:00:00:00:00:00	2	7:00	1024K	0B	2072K	611	1	1	sleeping
684	58	CalendarAgent 0.4	0.2	0:05:24 24 4	2	2:73	191M	0B	47M	684	1	1	sleeping
79818	60	com.apple.Ap 0.8	0:08:26 9	2	1:75	195M	0B	944M	79018	1	1	sleeping	
79822	62	com.apple.Ap 0.8	0:08:21 0	1	1:75	228K	0B	1248K	79022	1	1	sleeping	
79874	64	com.apple.xbsd 1.7	1	0:00:00:00:00:00	2	4:87	1024K	0B	208K	79074	1	1	sleeping
79764	66	dm	0.3	0:08:09 12	3	5:8	468K	0B	313K	79674	1	1	sleeping
536	68	distributed 0.3	0.1	0:15:56 64	1	3:54	432K	0B	1648K	533	1	1	sleeping
79264	70	dyld 0.0	0.0	0:00:00:00:00:00	1	3:54	1024K	0B	1780K	79264	1	1	sleeping
331	72	locationd 0.2	0.2	12:19:15 7	5	2:27	13M	0B	6648K	331	1	1	sleeping
1851	74	Messages 0.2	0.0	0:02:52 59	1	1:342	217M	0B	284M	1851	1	1	sleeping
62882	76	AppleSpell 0.8	0.0	0:15:73 2	1	1:26	32M	0B	31M	62882	1	1	sleeping
62882	78	com.apple.xbsd 1.7	1	0:00:00:00:00:00	2	7:00	1024K	0B	2072K	62882	1	1	sleeping
64431	80	contactsd 0.2	0.0	0:08:06 78	2	1:72	11M	0B	18M	64431	1	1	sleeping
658	82	Finder 0.2	0.2	0:34:71 5	2	1:864	249M	0B	158M	658	1	1	sleeping
79827	84	com.apple.Chrome 1.0	0.1	0:02:18 0	3	1:383	758M	0B	214M	79827	1	1	sleeping
344	86	bluetoothd 0.1	0.0	0:02:18 0	3	1:383	758M	0B	214M	344	1	1	sleeping
57477	88	LocationMenu 0.1	0.0	0:04:46 77 4	2	1:62	984K	0B	344K	57477	1	1	sleeping
79369	90	com.apple.We 0.1	0.0	0:33:09 0	2	1:65	557K	0B	394K	79369	1	1	sleeping
343	92	com.apple.xbsd 1.7	0.1	0:00:00:00:00:00	1	3:54	1024K	0B	334K	343	1	1	sleeping
79767	94	netbiosd 0.1	0.0	0:23:79 6	5	3:38	332K	0B	1952K	79767	1	1	sleeping
469	96	sympmed 0.1	0.1	0:18:42 2	2	1:39+	669K	0B	281K	469	1	1	sleeping
288	98	com.apple.xbsd 1.7	1	0:00:00:00:00:00	1	3:54	1024K	0B	332K	288	1	1	sleeping
79338	100	cupid 0.1	0.0	0:08:00 13	1	1:52	480K	0B	2432K	79338	1	1	sleeping
79738	102	com.apple.We 0.1	0.0	0:22:39 17	2	2:28	868M	1M	847M	57938	1	1	sleeping
77384	104	com.apple.We 0.0	0.0	0:32:42 6	2	1:15	67M	0B	55M	77384	1	1	sleeping
43377	106	com.apple.xbsd 1.7	0.1	0:00:00:00:00:00	1	3:54	1024K	0B	13M	43377	1	1	sleeping
554	108	UserEventAgent 0.1	0.1	0:29:54 3	2	1:824	717K	0B	3584K	554	1	1	sleeping
689	110	Safari 0.8	0.8	38:33:09 8	1	3:69	584M	0B	572M	689	1	1	sleeping

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

The screenshot shows two terminal windows running QEMU tests. Both windows display memory usage statistics and swap activity.

**Top Window (QEMU - top - 87x54):**

```

Processes: 334 total, 2 running, 1 stuck, 331 sleeping, 1753 threads          13:39:56
Load Avg: 1.93, 1.82, 1.88 CPU usage: 6.34% user, 8.53% sys, 85.12% idle
SharedLibs: 218M resident, 49M data, 7520K linked.
MemRegions: 144982 total, 2728M resident, 115M private, 976M shared.
PhysMem: 7238M used (1557M wired), 271M free
VM: 198T max, 3218M free
Netwrk: 1 packets: 32082446/199 in, 14242785/9413M out.
Disk: 2278826/17390 written.

```

ID	COMMAND	STATE	TIME	#TH	#WQ	#PORT	MEM	PURS	CPMHS	PCPBM	PPID
79458	Qemu-system-i86_64 -monitor stdio	running	13:39:56	1	1	1	104M	114M	459M	79457	79457
354	WindowsServer 16.0	running	08:28:14	23	5	3581	971M	72M	318M-	354	1
0	kernel_task	running	08:09:34	2	1	65-	6242K	752K	0B	0B	0
79647	screencaptur 3.6	running	08:09:34	2	1	55-	292K	0B	649	649	649
79645	Notification 0.8	running	08:09:34	2	1	59-	5489K	0B	79645	79674	79674
886	Notification 0.8	running	25:04:47	1	2	1346-	292K	0B	585	585	1
79606	gamecontrol 0.7	running	08:09:48	3	5	3499K	0B	1424K	79686	1	1
79819	com.apple.Ap.0	running	08:13:06	3	2	77-	2161K	0B	115K	79819	1
79828	com.apple.Ap.0	running	08:14:49	75	3	2-	2241K	0B	1296K	79828	1
79831	com.apple.Ap.0	running	08:14:50	3	2	77-	2161K	0B	1296K	79828	1
79823	com.apple.Ap.0	running	08:09:32	2	1	77-	2193K	0B	123K	79823	1
79648	screencaptur 0.4	running	08:09:16	5	3	184-	17M	0B	0B	79648	1
611	Terminal 0.4	running	08:28:18	7	1	43B	125M	16M	611	611	1
79818	com.apple.Ap.0	running	08:19:18	2	2	195	958K	0B	928K	79818	1
79822	com.apple.Ap.0	running	08:19:18	2	2	195-	224K	0B	928K	79818	1
78627	Google Chrome 0.2	running	08:19:54	11	2	158-	180M	0B	58M	78614	78614
79369	com.apple.Ws.0	running	08:31:88	7	2	165-	61M	2944K	377K	79369	1
62364	com.apple.Ws.0	running	08:26:15	19	1	216-	928M	0B	62364	1	1
77384	com.apple.Ws.0	running	08:32:05	5	1	115-	67M	0B	55M	77384	1
344	Notification 0.8	running	08:09:32	5	3	2-	2161K	0B	1296K	79828	1
63465	com.apple.Ws.0	running	08:21:29	11	1	193-	799M	0B	533M	64345	1
331	locationd 0.1	running	12:19:41	6	4	217+	13M	0B	7712K	331	1
58428	com.apple.Ws.0	running	08:21:18	9	1	192-	985M	716K	346M	58428	1
58854	com.apple.Ws.0	running	08:22:33	16	1	214-	123M	244K	997M	58854	1
1179	com.apple.Ws.0	running	08:26:42	12	1	1243-	12M	0B	84-	1179	1
488	TouchBarServ 0.1	running	14:14:14	93	5	378-	26M	5440K	15M	488	1
58832	com.apple.Ws.0	running	08:15:35	4	1	118-	11M	0B	189M	58832	1
1317	com.apple.Ws.0	running	08:36:59	6	1	312-	32M	0B	297K	1317	1
836	diston 0.1	running	08:15:18	5	2	344-	24M	0B	1296K	836	1
57938	com.apple.Ws.0	running	08:21:46	16	1	228-	85M	11M	782K	57938	1
1198	com.apple.Ws.0	running	08:24:59	5	1	248-	184M	0B	178M	1198	1
1196	com.apple.Ws.0	running	08:27:27	5	1	116-	31M	0B	254M	1196	1

**Bottom Window (QEMU - top - 87x54):**

```

Processes: 363 total, 3 running, 360 sleeping, 1929 threads          13:45:28
Load Avg: 1.46, 1.56, 1.67 CPU usage: 2.48% user, 7.33% sys, 90.26% idle
SharedLibs: 2420M resident, 48M data, 7520K linked.
MemRegions: 144982 total, 2728M resident, 115M private, 976M shared.
PhysMem: 7238M used (1557M wired), 224M unused.
VM: 1397M valise, 3218M free
Netwrk: 1 packets: 929322383(16) swapins, 9420783(8) swapouts.
Disk: 22897798/17485 read, 2195768/18830 written.

```

ID	COMMAND	STATE	TIME	#TH	#WQ	#PORT	MEM	PURS	CPMHS	PCPBM	PPID
79728	qemu-system-i86_64 -monitor stdio	running	08:15:35	24	1	0	39-	273M	89	573M	79728
0	kernel_task	running	08:13:47	9	1	62M	0B	88	88	0B	running
79645	top	running	08:14:03	17	1	64-	7121K	0B	2832K	79645	79747
256	WindowsServer 16.0	running	08:14:03	17	1	308-	3019K	0B	2919K	256	256
611	Terminal 0.4	running	08:14:03	17	1	70-	292K	0B	1296K	611	611
344	bluetoothd	running	08:01:08	55	3	1036-	7602K	288K	344	1	sleeping
62361	Notification 0.8	running	08:14:03	17	2	1444-	26M	561	611	1	sleeping
58832	com.apple.Ws.0	running	08:15:35	4	1	118-	32M	0B	189M	58832	1
347	corebrightness 0.1	running	08:19:48	3	2	1821-	7218K	0B	4864K	5884	1
79705	PerfPowerSet 0.2	running	07:51:11	61	3	134-	5794K	3368K	347	1	sleeping
58832	com.apple.Ws.0	running	08:15:41	4	2	258-	12M	0B	4416K	79705	1
58777	locationd 0.1	running	08:22:06	5	2	216-	13M	0B	1296K	58777	1
57477	LocationMenu 0.8	running	08:14:46	73	2	161-	9826K	3472K	57477	1	sleeping
64345	com.apple.Ws.0	running	08:12:42	12	2	193-	88M	542K	64345	1	sleeping
79787	com.apple.Ws.0	running	08:14:46	73	2	177-	2177K	0B	1296K	79787	1
981	sharingd 0.1	running	08:13:47	37	2	288-	27M	18M	559	1	sleeping
559	sharingd 0.1	running	08:13:55	7	2	288-	27M	18M	559	1	sleeping
79818	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
79822	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
554	UserEventAge 0.1	running	08:19:48	3	2	1821-	7218K	0B	4864K	5884	1
347	corebrightness 0.1	running	08:11:51	61	3	134-	5794K	3368K	347	1	sleeping
79705	PerfPowerSet 0.2	running	08:15:41	4	2	258-	12M	0B	4416K	79705	1
58832	com.apple.Ws.0	running	08:15:41	4	2	258-	12M	0B	1296K	58832	1
57477	LocationMenu 0.8	running	08:14:46	73	2	161-	9826K	3472K	57477	1	sleeping
64345	com.apple.Ws.0	running	08:12:42	12	2	193-	88M	542K	64345	1	sleeping
79787	com.apple.Ws.0	running	08:14:46	73	2	177-	2177K	0B	1296K	79787	1
981	com.apple.Ap.0	running	08:14:47	37	1	75-	3793K	0B	2512K	981	1
559	sharingd 0.1	running	08:13:55	7	2	288-	27M	18M	559	1	sleeping
79818	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
79822	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
554	UserEventAge 0.1	running	08:19:48	3	2	1821-	7218K	0B	4864K	5884	1
347	corebrightness 0.1	running	08:11:51	61	3	134-	5794K	3368K	347	1	sleeping
79705	PerfPowerSet 0.2	running	08:15:41	4	2	258-	12M	0B	4416K	79705	1
58832	com.apple.Ws.0	running	08:15:41	4	2	258-	12M	0B	1296K	58832	1
57477	LocationMenu 0.8	running	08:14:46	73	2	161-	9826K	3472K	57477	1	sleeping
64345	com.apple.Ws.0	running	08:12:42	12	2	193-	88M	542K	64345	1	sleeping
79787	com.apple.Ws.0	running	08:14:46	73	2	177-	2177K	0B	1296K	79787	1
981	com.apple.Ap.0	running	08:14:47	37	1	75-	3793K	0B	2512K	981	1
559	sharingd 0.1	running	08:13:55	7	2	288-	27M	18M	559	1	sleeping
79818	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
79822	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
554	UserEventAge 0.1	running	08:19:48	3	2	1821-	7218K	0B	4864K	5884	1
347	corebrightness 0.1	running	08:11:51	61	3	134-	5794K	3368K	347	1	sleeping
79705	PerfPowerSet 0.2	running	08:15:41	4	2	258-	12M	0B	4416K	79705	1
58832	com.apple.Ws.0	running	08:15:41	4	2	258-	12M	0B	1296K	58832	1
57477	LocationMenu 0.8	running	08:14:46	73	2	161-	9826K	3472K	57477	1	sleeping
64345	com.apple.Ws.0	running	08:12:42	12	2	193-	88M	542K	64345	1	sleeping
79787	com.apple.Ws.0	running	08:14:46	73	2	177-	2177K	0B	1296K	79787	1
981	com.apple.Ap.0	running	08:14:47	37	1	75-	3793K	0B	2512K	981	1
559	sharingd 0.1	running	08:13:55	7	2	288-	27M	18M	559	1	sleeping
79818	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
79822	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
554	UserEventAge 0.1	running	08:19:48	3	2	1821-	7218K	0B	4864K	5884	1
347	corebrightness 0.1	running	08:11:51	61	3	134-	5794K	3368K	347	1	sleeping
79705	PerfPowerSet 0.2	running	08:15:41	4	2	258-	12M	0B	4416K	79705	1
58832	com.apple.Ws.0	running	08:15:41	4	2	258-	12M	0B	1296K	58832	1
57477	LocationMenu 0.8	running	08:14:46	73	2	161-	9826K	3472K	57477	1	sleeping
64345	com.apple.Ws.0	running	08:12:42	12	2	193-	88M	542K	64345	1	sleeping
79787	com.apple.Ws.0	running	08:14:46	73	2	177-	2177K	0B	1296K	79787	1
981	com.apple.Ap.0	running	08:14:47	37	1	75-	3793K	0B	2512K	981	1
559	sharingd 0.1	running	08:13:55	7	2	288-	27M	18M	559	1	sleeping
79818	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
79822	com.apple.Ap.0	running	08:19:54	2	1	75-	195M	0B	944K	79818	1
554	UserEventAge 0.1	running	08:19:48	3	2	1821-	7218K	0B	4864K	5884	1
347	corebrightness 0.1	running	08:11:51	61	3	134-	5794K	3368K	347	1	sleeping
79705	PerfPowerSet 0.2	running	08:15:41	4	2	258-	12M	0B	4416K	79705	1
58832	com.apple.Ws.0	running	08:15:41	4	2	258-	12M	0B	1296K	58832	1
57477	LocationMenu 0.8	running	08:14:46	73	2	161-	9826K	3472K	57477	1	sleeping
64345	com.apple.Ws.0	running	08:12:42	12	2	193-	88M</td				

## 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.