

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

```
abhilubuntu:~$ inxi -fxz
CPU:    Topology: Single Core model: N/A bits: 64 type: UP arch: ARMv8 bogomips: 0
        Speed: N/A min/max: N/A Core speed (MHz): No speed data found for 1 cores.
        Features: aes asimd asimdrnd cpuid crc32 dit evtstrm fp fphp pmull sha1 sha2
Machine: Type: Qemu System: QEMU product: QEMU Virtual Machine v: virt-6.2 serial: <filter>
        Hobo: N/A model: N/A serial: N/A UEFI: EFI Development Kit II / OVMF v: 0.0.0
        date: 02/06/2015
CPU:    Topology: Single Core model: N/A bits: 64 type: UP arch: ARMv8
        features: Use -f option to see features bogomips: 0
        Speed: N/A min/max: N/A Core speed (MHz): No speed data found for 1 cores.
Graphics: 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
Audio:   Message: No ARM data found for this feature.
Network: Message: No ARM data found for this feature.
IF-ID-1: eth0 state: up speed: -1 duplex: unknown 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
        runlevel: 5 Compilers: gcc: N/A Shell: bash v: 5.0.17 inxi: 3.0.38
abhilubuntu:~$ _
```

```
root@955aaid0860a:~# inxi -Fxz
Use of uninitialized value $working in substitution ($//) at /usr/bin/inxi line 18559.
System:  Kernel: 5.10.47-linuxkit 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: tun10 state: down mac: <filter>
Drives:  Local Storage: total: 59.68 GiB used: 11.22 GiB (18.8%)
        ID-1: /dev/vda model: N/A size: 59.68 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@955aaid0860a:~#
```

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**

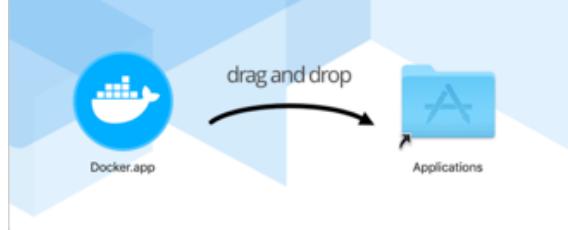
Redirect the monitor to host device dev (same devices as the serial port). The default device is **vc** in graphical mode and **stdio** in non graphical mode. Use **-monitor none** to disable the default monitor.

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:          10.00032s
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

```
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:~$
```

- 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=10000 run`

Test run - 1

```
abhi@ubuntu:~$ ./cpitime2.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:          10.0000is
  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:          10.0001s
  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
```

- 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:~/Documents$ ./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: 10.00003s
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:          10.00001s
  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:        30.0037s
  total number of events: 432982

Latency (ms):
  min:                0.02
  avg:                0.07
  max:                8.40
  95th percentile:    0.17
  sum:               29623.47

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:       30.00037s
  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:            43.48
    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:   48.91

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
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

```

Processes: 304 total, 9 running, 303 sleeping, 2788 threads          23:43:11
Load Avg.: 1.81, 1.73, 1.76 CPU usage: 4.2% user, 14.88% sys, 85.33% idle
SharedLibs: 229M resident, 49M data, 746M shared.
Memory: 148181 total, 2770K free, 1255M private, 9808M shared.
Swap: 129T visible, 3216M framework write, 9193384(12) swapins, 93801921(0) swapouts.
Networks: packets: 320847563/199 in, 142034297430 out.
Networks: 227647563/37490 netin, 23847563/378730 netout.

PID COMMAND      RSS   VMR  %CPU %MEM  NI   PRR  PRIO STATE
2958 gnu-system-  139,7  141,3  38,8%  2  260-  530984  7108-  445K  79673  294393
  8  WindowsDriver  13,7  84,2  28,4%  25  5  3588  878M  720-  588K  354  1
  8  kernel_task  4,4  93,3  23,8  54976  0  8  62K  68-  88  8  8
  79648 top       2,8  99,9  45,3%  573  0  31  6457K  68-  79648  79474
  330  Terminal  0,7  89,1  10,3  4,2%  573  0  31  6457K  68-  79648  79474
  585 Notification  2,7  28,4  49,9%  2  3345  62K  68-  208  885  1
  79653 screenscraper  0,6  88,9  35,2  1  56-  6864K  73K  68-  449  849
  79628 com.apple.Ap  0,5  88,1  21,2  3  2  78  2361K  68-  128K  79628  1
  79615 com.apple.Ap  0,5  88,1  48,8  5  28  2177K  68-  134K  79615  1
  411 Terminal  0,5  88,1  10,3  4,2%  573  0  31  6457K  68-  79648  79474
  79618 com.apple.Ap  0,2  88,1  28,4  2  1  78  2953K  68-  92K  79618  1
  79622 com.apple.Ap  0,2  88,1  28,4  2  1  78  2289K  68-  133K  79622  1
  64265 com.apple.Wo  0,2  83,1  21,6  12  2  293  299K  68-  57K  62635  1
  79627 Google Chrome  0,2  88,1  39,7  31  2  588  188K  68-  508  78814  78814
  79676 com.apple.Wo  0,1  88,1  39,7  31  2  588  188K  68-  508  78814
  79629 com.apple.Wo  0,1  88,1  32,2  6  2  192  985K  71,6K  32K  58428  1
  79630 com.apple.Wo  0,1  88,1  32,2  6  2  192  985K  71,6K  32K  58428  1
  79631 com.apple.Wo  0,1  88,1  32,2  6  2  192  985K  71,6K  32K  58428  1
  79632 com.apple.Wo  0,1  88,1  32,2  6  2  192  985K  71,6K  32K  58428  1
  554 UserInterface  0,2  88,1  22,2  23  2  281  7284K  68-  352K  554  1
  488 TouchbarServer  0,1  88,1  25,5  3  3  378  268  15K  488  1
  77984 com.apple.Wo  0,1  88,1  22,8  5  1  315  67K  68-  508  77984  1
  64264 com.apple.Wo  0,1  88,1  22,8  5  1  315  67K  68-  508  77984  1
  342 Terminal  0,1  88,1  10,3  4,2%  573  0  31  6457K  68-  79648  79474
  58684 com.apple.Wo  0,1  88,1  23,9  34  1  214  529P  432K  188K  58684  1
  58628 com.apple.Wo  0,1  87,8  31,9  34  1  214  529P  432K  188K  58684  1
  312 connectbot  0,1  92,1  48,8  3  2  539  744K  32K  393K  322  1
  317 com.apple.Wo  0,1  88,1  35,6  9  1  312  334K  68-  412K  331  1
  58630 com.apple.Wo  0,1  88,1  35,6  9  1  312  334K  68-  412K  331  1
  79633 com.apple.Wo  0,1  88,1  21,4  3  1  228  85K  11K  65K  57958  1
  5186 com.apple.Wo  0,1  88,1  27,8  5  1  316  318K  68-  297K  314K  1
  5188 com.apple.Wo  0,1  88,1  49,7  5  1  245  184K  68-  178K  318K  1
  996 com.apple.Wo  0,1  88,1  45,5  7  1  245  184K  68-  178K  318K  1
  3187 com.apple.Wo  0,1  88,1  32,2  12  1  315  128K  68-  89K  3187  1
  79618 com.apple.Ap  0,1  88,1  13,8  3  2  77  2161K  68-  132K  79618  1

```

```

Processes: 394 total, 0 running, 391 sleeping, 27918 threads          23:48:22
Load Avg.: 2.76, 1.62, 1.49 CPU usage: 5.4% user, 17.83% sys, 77.18% idle
SharedLibs: 228M resident, 48M data, 9888M shared.
Memory: 147947 total, 289M private, 2843M shared.
Swap: 129T visible, 3216M framework write, 9193384(12) swapins, 93801921(0) swapouts.
Networks: packets: 320847563/199 in, 142034297430 out.
Networks: 227647563/37490 netin, 23847563/378730 netout.

PID COMMAND      RSS   VMR  %CPU %MEM  NI   PRR  PRIO STATE
29798 gnu-system-  139,8  141,8  38,9%  0  34  2739K  68  639K  79678  29718 running
  8  WindowsDriver  12,8  84,2  28,4%  275  5  3512  388K  720-  445K  347  1
  79788 com.apple.Wo  0,1  88,1  21,4  3  2  345  404K  68-  128K  79788  1
  8  kernel_task  4,4  93,3  23,8  54976  0  8  62K  68-  88  8  8
  295 config  4,4  88,1  21,4  3  2  345  7378K  68-  348K  395  1
  79648 top       2,8  99,9  45,3%  573  0  31  6457K  68-  79648  79474
  79618 PerfPowerSer  2,5  88,1  15,6  6  4  244P  529K  68-  374K  79185  1
  427 airport  3,7  88,1  42,4  15  1  387P  529K  68-  7972K  427  1
  57923 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79622 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79629 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79630 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79631 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79632 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79633 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79634 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79635 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79636 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79637 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79638 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79639 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79640 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79641 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79642 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79643 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79644 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79645 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79646 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79647 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79648 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79649 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79650 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79651 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79652 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79653 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79654 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79655 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79656 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79657 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79658 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79659 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79660 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79661 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79662 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79663 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79664 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79665 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79666 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79667 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79668 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79669 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79670 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79671 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79672 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79673 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79674 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79675 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79676 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79677 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79678 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79679 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79680 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79681 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79682 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79683 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79684 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79685 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79686 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79687 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79688 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79689 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79690 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79691 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79692 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79693 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79694 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79695 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79696 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79697 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79698 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79699 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79700 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79701 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79702 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79703 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79704 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79705 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79706 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79707 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79708 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79709 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79710 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79711 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79712 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79713 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79714 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79715 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79716 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79717 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79718 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79719 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79720 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79721 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79722 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79723 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79724 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79725 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79726 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79727 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79728 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79729 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79730 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79731 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79732 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79733 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79734 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79735 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79736 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79737 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79738 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79739 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79740 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79741 com.apple.Wo  0,1  88,1  48,8  3  5  383  314K  68-  62K  57923  1
  79742 com.apple.Wo  0,1  88
```

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.