

Homework-1-Cloud Computing

OS Configuration: MacOS BigSur with Intel processor

QEMU Installation: By using the Homebrew Command “brew install qemu”

Ubuntu installation for system virtualisation:

1. I downloaded the iso image with version 20.04.
2. After that I created 10GB hard disk by using the following command:
`qemu-img create -f qcow2 ~/QEMU/ubuntu-desktop-20.04.qcow2 10G`
3. Next, I created the following script for ubuntu vm creation:

```
qemu-system-x86_64 \
-m 4G \
-vga virtio \
-display default,show-cursor=on \
-usb \
-device usb-tablet \
-machine type=q35,accel=hvf \
-smp 2 \
-cdrom ubuntu-20.04.3-live-server-amd64.iso
-drive file=ubuntu-desktop-18.04.qcow2,if=virtio \
-cpu Nehalem
```

The -m tag specifies the size of virtual RAM used for the VM. I used 4G of Virtual RAM.

The -machine type flag specifies the type of emulated machine. I used the ‘q35’ which is a Standard PC(Q35 + ICH9, 2009). There are more options which I tested such as pc-q35-1.4.

The -drive file tag specifies the hard disk to be used for this VM.

The -cpu tag specifies the type of processor(CPU) model. This varies from one hardware to another.

The accel = hvf tag is used to install and run the ubuntu fast as it enables hardware acceleration by this flag. First, I tried to create a VM without using this flag and then by using it. There is a huge difference in the speed.

The -vga command is used to define the video card used to display VM guest graphical output. And I gave it virtio

a video card used to display VM Guest graphical output

The -cdrom specifies the iso image by using which the vm will be created.

The display and show cursor are for the UI, as I enabled the show-cursor as ‘on’ so it will show the cursor when I will be installing or using the ubuntu vm.

The -smp parameter specifies the number of cpu’s to be emulated, which I gave as 2.

Docker Installation for OS Virtualisation:

1. Download and install Docker desktop.
2. Pulled the “ubuntu-sysbench” image from docker hub by using the command “docker pull csmnpp/ubuntu-sysbench”.
3. Check if the image is pulled successfully by using command “docker images”, here you can see all the downloaded docker images.
4. Now, we have the sysbench image and we need to run and create a docker container from this image in interactive mode by using the command “docker container run -it 2787c5e16909 /bin/bash” where image-id = 2787c5e16909
5. Finally we have our docker container running with sysbench installed and we can start running our commands.
6. We can also check if our container is running successfully by using the command “docker ps” and it will list all the running docker containers.

Experiments:

CPU TESTS

1. **Command :** sysbench --num-threads=4 --test(cpu) --cpu-max-prime=9000 run

QEMU and Docker results after running the above command five times:

1.

Performance metrics	Docker	QEMU
Total time	3.9474s	10.0016s
Total events	10000	23505
events/second	2533 events/sec	2349.82 events/sec
min	0.68ms	0.71
max	15.78ms	24.30
avg	1.57ms	1.65

2.

Performance metrics	Docker	QEMU
Total time	3.9395s	10.0012s

Total events	10000	23414
events/sec	2538.39 events/sec	2340.79 events/sec
min	0.68ms	0.70ms
max	14.42ms	27.64ms
avg	1.55ms	1.66ms

3.

Performance metrics	Docker	QEMU
Total time	3.9990s	10.0011s
Total events	10000	23682
events/second	2500	2367.64 events/sec
min	0.68ms	0.70ms
max	13.99ms	18.30ms
avg	1.58ms	1.64ms

4.

Performance metrics	Docker	QEMU
Total time	3.9949s	10.0012s
Total events	10000	23574
events/second	2503	2356.82 events/sec
min	0.68ms	0.71ms
max	13.75ms	17.83ms
avg	1.58ms	1.64ms

5.

Performance metrics	Docker	QEMU
Total time	3.9857s	10.0009s
Total events	10,000	28574
events/second	2508	2356.82 events/sec
min	0.68ms	0.67ms
max	15.04ms	19.83ms
avg	1.58ms	1.84ms

Explanation: From the comparisons done above we can see that docker is giving better performance in terms of events/sec as compared to QEMU(system virtualisation) because we know it is less resource intensive as compared to VM. Docker is able to run more events per second as compared to QEMU VM.

Screenshots for the above experiments on Docker:

1.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=9000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 9000

Test execution summary:
  total time:          3.9474s
  total number of events: 10000
  total time taken by event execution: 15.6581
  per-request statistics:
    min:                0.68ms
    avg:                1.57ms
    max:                15.78ms
    approx. 95 percentile: 7.75ms

Threads fairness:
  events (avg/stddev): 2500.0000/8.22
  execution time (avg/stddev): 3.9145/0.01
```

2.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=9000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 9000

Test execution summary:
  total time:          3.9395s
  total number of events: 10000
  total time taken by event execution: 15.5090
  per-request statistics:
    min:                0.68ms
    avg:                1.55ms
    max:                14.42ms
    approx. 95 percentile: 7.74ms

Threads fairness:
  events (avg/stddev):   2500.0000/9.14
  execution time (avg/stddev): 3.8773/0.02
```

3.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=9000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 9000

Test execution summary:
  total time:          3.9990s
  total number of events: 10000
  total time taken by event execution: 15.8471
  per-request statistics:
    min:                0.68ms
    avg:                1.58ms
    max:               13.99ms
    approx. 95 percentile: 7.75ms

Threads fairness:
  events (avg/stddev): 2500.0000/7.81
  execution time (avg/stddev): 3.9618/0.00
```

4.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=9000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 9000

Test execution summary:
  total time:          3.9949s
  total number of events: 10000
  total time taken by event execution: 15.7805
  per-request statistics:
    min:                0.68ms
    avg:                1.58ms
    max:               13.75ms
    approx. 95 percentile: 7.74ms

Threads fairness:
  events (avg/stddev): 2500.0000/14.30
  execution time (avg/stddev): 3.9451/0.02
```

5.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=9000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 9000

Test execution summary:
  total time:          3.9857s
  total number of events: 10000
  total time taken by event execution: 15.7734
  per-request statistics:
    min:                0.68ms
    avg:                1.58ms
    max:                15.04ms
    approx. 95 percentile: 7.74ms

Threads fairness:
  events (avg/stddev): 2500.0000/10.39
  execution time (avg/stddev): 3.9433/0.01
```

Screenshots for the above experiments on QEMU:

1.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 9000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 2349.82  
  
General statistics:  
    total time:          10.0016s  
    total number of events: 23505  
  
Latency (ms):  
    min:                 0.71  
    avg:                 1.65  
    max:                 24.30  
    95th percentile:     8.90  
    sum:                38708.56  
  
Threads fairness:  
    events (avg/stddev): 5876.2500/29.22  
    execution time (avg/stddev): 9.6771/0.03
```

2.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 9000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 2340.79  
  
General statistics:  
    total time:          10.0012s  
    total number of events: 23414  
  
Latency (ms):  
    min:                 0.70  
    avg:                 1.66  
    max:                 27.64  
    95th percentile:     8.90  
    sum:                38801.06  
  
Threads fairness:  
    events (avg/stddev): 5853.5000/21.85  
    execution time (avg/stddev): 9.7003/0.03
```

3.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 9000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 2367.64  
  
General statistics:  
    total time:          10.0011s  
    total number of events: 23682  
  
Latency (ms):  
    min:                  0.70  
    avg:                 1.64  
    max:                 18.30  
    95th percentile:     8.90  
    sum:                38781.37  
  
Threads fairness:  
    events (avg/stddev): 5920.5000/31.23  
    execution time (avg/stddev): 9.6953/0.03
```

4.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 9000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 2356.82  
  
General statistics:  
    total time:          10.0012s  
    total number of events: 23574  
  
Latency (ms):  
    min:                  0.71  
    avg:                 1.64  
    max:                 17.83  
    95th percentile:     8.90  
    sum:                38773.12  
  
Threads fairness:  
    events (avg/stddev): 5893.5000/23.11  
    execution time (avg/stddev): 9.6933/0.01
```

2. Command : sysbench --num-threads=4 --test=cpu --cpu-max-prime=17000 run

QEMU and Docker results after running the above command five times:

1.

Performance metrics	Docker	QEMU
Total time	9.2053s	10.0017s
Total events	10,000	10159
events/second	1086.33 events/sec	1015.58 events/sec
min	1.66ms	1.74ms
max	15.85ms	18.61ms
avg	3.67ms	3.87ms

2.

Performance metrics	Docker	QEMU
Total time	9.0368s	10.0020s
Total events	10,000	10235
events/second	1106.58 events/sec	1023 events/sec
min	1.67ms	1.74ms
max	14.68ms	26.59ms
avg	3.60ms	3.85

3.

Performance metrics	Docker	QEMU
Total time	9.1046s	10.0026s

Total events	10,000	10186
events/second	1098	1018.19 events/sec
min	1.66ms	1.74ms
max	16.73ms	18.74ms
avg	3.62ms	3.87ms

4.

Performance metrics	Docker	QEMU
Total time	9.1686s	10.0016s
Total events	10,000	10068
events/second	1090	1006.51 events/sec
min	1.66ms	1.74
max	15.64ms	25.53
avg	3.65ms	3.91

5.

Performance metrics	Docker	QEMU
Total time	9.1466s	10.0022s
Total events	10,000	10106
events/second	1093	1010.22 events/sec
min	1.66ms	1.64ms
max	17.37ms	40.05ms
avg	3.64ms	3.91ms

Screenshots for the above experiments on Docker:

1.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=17000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 17000

Test execution summary:
  total time:          9.2053s
  total number of events: 10000
  total time taken by event execution: 36.6508
  per-request statistics:
    min:                1.66ms
    avg:                3.67ms
    max:                15.85ms
    approx. 95 percentile: 8.89ms

Threads fairness:
  events (avg/stddev): 2500.0000/1.00
  execution time (avg/stddev): 9.1627/0.01
```

2.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=17000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 17000

Test execution summary:
  total time:          9.0368s
  total number of events: 10000
  total time taken by event execution: 35.9988
  per-request statistics:
    min:                1.67ms
    avg:                3.60ms
    max:                14.68ms
    approx. 95 percentile: 8.84ms

Threads fairness:
  events (avg/stddev): 2500.0000/22.05
  execution time (avg/stddev): 8.9997/0.01
```

3.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test=cpu --cpu-max-prime=17000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 17000

Test execution summary:
  total time:          9.1046s
  total number of events: 10000
  total time taken by event execution: 36.2437
  per-request statistics:
    min:                1.66ms
    avg:                3.62ms
    max:                16.73ms
    approx. 95 percentile: 8.87ms

Threads fairness:
  events (avg/stddev): 2500.0000/4.95
  execution time (avg/stddev): 9.0609/0.01
```

4.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test=cpu --cpu-max-prime=17000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 17000

Test execution summary:
  total time:          9.1686s
  total number of events: 10000
  total time taken by event execution: 36.5085
  per-request statistics:
    min:                1.66ms
    avg:                3.65ms
    max:                15.64ms
    approx. 95 percentile: 8.89ms

Threads fairness:
  events (avg/stddev): 2500.0000/6.60
  execution time (avg/stddev): 9.1271/0.01
```

5.

```
root@28420f6b0a31:/# sysbench --num-threads=4 --test=cpu --cpu-max-prime=17000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 17000

Test execution summary:
  total time:          9.1466s
  total number of events: 10000
  total time taken by event execution: 36.3773
  per-request statistics:
    min:                1.66ms
    avg:                3.64ms
    max:                17.37ms
    approx. 95 percentile: 8.88ms

Threads fairness:
  events (avg/stddev): 2500.0000/3.74
  execution time (avg/stddev): 9.0943/0.01
```

Screenshots for the above experiments on QEMU:

1.

```
Running the test with following options:
Number of threads: 4
Initializing random number generator from current time

Prime numbers limit: 17000

Initializing worker threads...

Threads started!

CPU speed:
  events per second: 1015.58

General statistics:
  total time:          10.0017s
  total number of events: 10159

Latency (ms):
  min:                1.74
  avg:                3.87
  max:                18.61
  95th percentile:   10.84
  sum:                39319.49

Threads fairness:
  events (avg/stddev): 2539.7500/13.72
  execution time (avg/stddev): 9.8299/0.03
```

2.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 17000  
Initializing worker threads...  
Threads started!  
  
CPU speed:  
    events per second: 1023.13  
  
General statistics:  
    total time:          10.0020s  
    total number of events: 10235  
  
Latency (ms):  
    min:                  1.74  
    avg:                  3.85  
    max:                  26.59  
    95th percentile:     10.65  
    sum:                 39432.98  
  
Threads fairness:  
    events (avg/stddev): 2558.7500/12.21  
    execution time (avg/stddev): 9.8582/0.02
```

3.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 17000  
Initializing worker threads...  
Threads started!  
  
CPU speed:  
    events per second: 1018.19  
  
General statistics:  
    total time:          10.0026s  
    total number of events: 10186  
  
Latency (ms):  
    min:                  1.74  
    avg:                  3.87  
    max:                  18.74  
    95th percentile:     10.65  
    sum:                 39372.49  
  
Threads fairness:  
    events (avg/stddev): 2546.5000/14.17  
    execution time (avg/stddev): 9.8431/0.02
```

4.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 17000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 1006.51  
  
General statistics:  
    total time:          10.0016s  
    total number of events: 10068  
  
Latency (ms):  
    min:                  1.74  
    avg:                  3.91  
    max:                  25.53  
    95th percentile:      10.84  
    sum:                 39378.90  
  
Threads fairness:  
    events (avg/stddev): 2517.0000/10.12  
    execution time (avg/stddev): 9.8447/0.03
```

5.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 17000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 1010.22  
  
General statistics:  
    total time:          10.0022s  
    total number of events: 10106  
  
Latency (ms):  
    min:                  1.64  
    avg:                  3.91  
    max:                  40.05  
    95th percentile:      10.84  
    sum:                 39487.24  
  
Threads fairness:  
    events (avg/stddev): 2526.5000/12.11  
    execution time (avg/stddev): 9.8718/0.01
```

3. **Command :** sysbench --num-threads=4 --test(cpu) --cpu-max-prime=14000 run

QEMU and Docker results after running the above command five times:

1.

Performance metrics	Docker	QEMU
Total time	7.0865s	10.0018s
Total events	10000	13986
events/second	1411.1	1398.18 events/sec
min	1.25ms	1.34ms
max	19.69ms	24.29ms
avg	2.82ms	2.86ms

2.

Performance metrics	Docker	QEMU
Total time	6.9038s	10.0007s
Total events	10000	13926
events/second	1449	1392.33 events/sec
min	1.26ms	1.34ms
max	20.10ms	17.06ms
avg	2.75ms	2.87ms

3.

Performance metrics	Docker	QEMU
Total time	6.9262s	10.0008s

Total events	10000	14255
events/second	1443	1425.21 events/sec
min	1.25ms	1.30ms
max	16.35ms	17.71ms
avg	2.75ms	2.80ms

4.

Performance metrics	Docker	QEMU
Total time	7.0818s	10.0014s
Total events	10000	14218
events/second	1412	1421.39 events/sec
min	1.26ms	1.32ms
max	15.42ms	17.97ms
avg	2.82ms	2.81ms

5.

Performance metrics	Docker	QEMU
Total time	6.8390s	10.0021s
Total events	10000	14098
events/second	1462	1409.30 events/sec
min	1.25ms	1.33ms
max	15.03ms	22.03ms
avg	2.72ms	2.84ms

Screenshots for the above experiments on Docker:

1.

```
root@500773bf5a7a:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=14000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 14000

Test execution summary:
  total time:          7.0865s
  total number of events: 10000
  total time taken by event execution: 28.1865
  per-request statistics:
    min:                1.25ms
    avg:                2.82ms
    max:                19.69ms
    approx. 95 percentile: 8.40ms

Threads fairness:
  events (avg/stddev): 2500.0000/14.09
  execution time (avg/stddev): 7.0466/0.01
```

2.

```
root@500773bf5a7a:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=14000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 14000

Test execution summary:
  total time:          6.9038s
  total number of events: 10000
  total time taken by event execution: 27.4604
  per-request statistics:
    min:                1.26ms
    avg:                2.75ms
    max:                20.10ms
    approx. 95 percentile: 8.37ms

Threads fairness:
  events (avg/stddev): 2500.0000/9.03
  execution time (avg/stddev): 6.8651/0.02
```

3.

```
root@500773bf5a7a:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=14000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 14000

Test execution summary:
  total time:          6.9262s
  total number of events: 10000
  total time taken by event execution: 27.5200
  per-request statistics:
    min:                1.25ms
    avg:                2.75ms
    max:                16.35ms
    approx. 95 percentile: 8.37ms

Threads fairness:
  events (avg/stddev): 2500.0000/13.62
  execution time (avg/stddev): 6.8800/0.01
```

4.

```
root@500773bf5a7a:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=14000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 14000

Test execution summary:
  total time:          7.0818s
  total number of events: 10000
  total time taken by event execution: 28.1689
  per-request statistics:
    min:                1.26ms
    avg:                2.82ms
    max:                15.42ms
    approx. 95 percentile: 8.40ms

Threads fairness:
  events (avg/stddev): 2500.0000/13.44
  execution time (avg/stddev): 7.0422/0.00
```

5.

```
root@500773bf5a7a:/# sysbench --num-threads=4 --test(cpu) --cpu-max-prime=14000 run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 4

Doing CPU performance benchmark

Threads started!
Done.

Maximum prime number checked in CPU test: 14000

Test execution summary:
  total time:          6.8390s
  total number of events: 10000
  total time taken by event execution: 27.1780
  per-request statistics:
    min:                1.25ms
    avg:                2.72ms
    max:                15.03ms
    approx. 95 percentile: 8.36ms

Threads fairness:
  events (avg/stddev): 2500.0000/11.55
  execution time (avg/stddev): 6.7945/0.01
```

Screenshots for the above experiments on QEMU:

1.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 14000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 1398.18  
  
General statistics:  
    total time:          10.0018s  
    total number of events: 13986  
  
Latency (ms):  
    min:                  1.34  
    avg:                  2.86  
    max:                  24.29  
    95th percentile:      9.91  
    sum:                 39978.58  
  
Threads fairness:  
    events (avg/stddev): 3496.5000/2.96  
    execution time (avg/stddev): 9.9946/0.00  
  
my_ubuntu_vm@myubuntuvm:~$
```

2.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 14000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 1392.33  
  
General statistics:  
    total time:          10.0007s  
    total number of events: 13926  
  
Latency (ms):  
    min:                  1.34  
    avg:                  2.87  
    max:                  17.06  
    95th percentile:      9.91  
    sum:                 39959.79  
  
Threads fairness:  
    events (avg/stddev): 3481.5000/3.35  
    execution time (avg/stddev): 9.9899/0.01
```

3.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 14000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 1425.21  
  
General statistics:  
    total time:          10.0008s  
    total number of events: 14255  
  
Latency (ms):  
    min:                1.30  
    avg:                2.80  
    max:                17.71  
    95th percentile:   10.09  
    sum:               39974.90  
  
Threads fairness:  
    events (avg/stddev): 3563.7500/6.26  
    execution time (avg/stddev): 9.9937/0.00
```

4.

```
Running the test with following options:  
Number of threads: 4  
Initializing random number generator from current time  
  
Prime numbers limit: 14000  
  
Initializing worker threads...  
  
Threads started!  
  
CPU speed:  
    events per second: 1421.39  
  
General statistics:  
    total time:          10.0014s  
    total number of events: 14218  
  
Latency (ms):  
    min:                1.32  
    avg:                2.81  
    max:                17.97  
    95th percentile:   10.09  
    sum:               39980.18  
  
Threads fairness:  
    events (avg/stddev): 3554.5000/2.87  
    execution time (avg/stddev): 9.9950/0.00
```

5.

```

Running the test with following options:
Number of threads: 4
Initializing random number generator from current time

Prime numbers limit: 14000

Initializing worker threads...

Threads started!

CPU speed:
  events per second: 1409.30

General statistics:
  total time:          10.0021s
  total number of events: 14098

Latency (ms):
  min:                 1.33
  avg:                 2.84
  max:                 22.03
  95th percentile:    10.09
  sum:                39971.49

Threads fairness:
  events (avg/stddev): 3524.5000/8.90
  execution time (avg/stddev): 9.9929/0.00

```

Experiment 2: FILEIO TESTS

1. Command : sysbench --num-threads=16 --test=fileio --file-total-size=3G
--file-test-mode=rndrw run

Explanation: From the comparison of experiments mentioned below we can see that docker is giving better performance in terms of reads and writes per second. The number of CPU's in docker and qemu are 2, which is same for both. Although the RAM in QEMU is 4G and in docker it is 2G, docker gives better IO performance as compared to VM. The processor of my local machine which is Intel processor might degrade the performance of QEMU.

QEMU and Docker results after running the above command five times:

1.

Performance metrics	Docker	QEMU
Reads(mb/s)	43.369 mb/s	22.21 mb/s

Writes(mb/s)	28.848 mb/s	14.82 mb/s
Total transferred(mb/s)	72.218 mb/s	37.03 mb/s
Total time(s)	2.1714 s	10.42 s
events/sec	4621.9	5403.5
avg	1.08ms	2.62 ms

2.

Performance metrics	Docker	QEMU
Reads(mb/s)	68.07 mb/s	18.11 mb/s
Writes(mb/s)	45.26 mb/s	12.06 mb/s
Total transferred(mb/s)	113.33 mb/s	30.17 mb/s
Total time(s)	1.38 s	10.356 s
events/sec	7253 events/sec	4395.13
avg	1.05 ms	3.33 ms

3.

Performance metrics	Docker	QEMU
Reads(mb/s)	176.07 mb/s	18.26 mb/s
Writes(mb/s)	117.31 mb/s	12.16 mb/s
Total transferred(mb/s)	293.37 mb/s	30.42 mb/s
Total time(s)	0.5337 s	10.347 s
events/sec	18776.4 events/sec	4434.03
avg	0.02 ms	3.31 ms

4.

Performance metrics	Docker	QEMU
Reads(mb/s)	125.9 mb/s	18.48mb/s
Writes(mb/s)	83.98 mb/s	12.31 mb/s
Total transferred(mb/s)	209.95 mb/s	30.79 mb/s
Total time(s)	0.744 s	10.349 s
events/sec	13437.6 events/sec	4490 events/sec
avg	0.04 ms	3.25 ms

5.

Performance metrics	Docker	QEMU
Reads(mb/s)	77.41 mb/s	18.82 mb/s
Writes(mb/s)	51.47 mb/s	12.53 mb/s
Total transferred(mb/s)	128.89 mb/sec	31.35 mb/s
Total time(s)	1.2135 s	10.366 s
events/sec	8248.86 events/sec	4570.03 events/sec
avg	0.78 ms	3.19 ms

Screenshots for Docker:

1.

```
root@28420f6b0a31:/# sysbench --num-threads=16 --test=fileio --file-total-size=3G --file-test-mode=rndrw run
sysbench 0.4.12: multi-threaded system evaluation benchmark

Running the test with following options:
Number of threads: 16

Extra file open flags: 0
128 files, 24Mb each
3Gb total file size
Block size 16Kb
Number of random requests for random IO: 10000
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
Threads started!
Done.

Operations performed: 6027 Read, 4009 Write, 12801 Other = 22837 Total
Read 94.172Mb Written 62.641Mb Total transferred 156.81Mb (72.218Mb/sec)
4621.95 Requests/sec executed

Test execution summary:
    total time:          2.1714s
    total number of events: 10036
    total time taken by event execution: 10.8485
    per-request statistics:
        min:           0.02ms
        avg:           1.08ms
        max:          17.45ms
        approx. 95 percentile: 3.68ms

Threads fairness:
    events (avg/stddev):   627.2500/26.45
    execution time (avg/stddev): 0.6780/0.02
```

2.

```
3Gb total file size
Block size 16Kb
Number of random requests for random IO: 10000
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
Threads started!
Done.

Operations performed: 6012 Read, 3998 Write, 12800 Other = 22810 Total
Read 93.938Mb Written 62.469Mb Total transferred 156.41Mb (113.33Mb/sec)
7253.12 Requests/sec executed

Test execution summary:
    total time:          1.3801s
    total number of events: 10010
    total time taken by event execution: 10.5094
    per-request statistics:
        min:           0.00ms
        avg:           1.05ms
        max:          26.20ms
        approx. 95 percentile: 2.97ms

Threads fairness:
    events (avg/stddev):   625.6250/32.54
    execution time (avg/stddev): 0.6568/0.02
```

3.

```
3Gb total file size
Block size 16Kb
Number of random requests for random IO: 10000
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
Threads started!
Done.

Operations performed: 6014 Read, 4007 Write, 12801 Other = 22822 Total
Read 93.969Mb Written 62.609Mb Total transferred 156.58Mb (293.37Mb/sec)
18775.54 Requests/sec executed

Test execution summary:
    total time:          0.5337s
    total number of events: 10021
    total time taken by event execution: 0.1836
    per-request statistics:
        min:            0.00ms
        avg:            0.02ms
        max:            1.23ms
        approx. 95 percentile: 0.03ms

Threads fairness:
    events (avg/stddev): 626.3125/165.19
    execution time (avg/stddev): 0.0115/0.00
```

4.

```
3Gb total file size
Block size 16Kb
Number of random requests for random IO: 10000
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
Threads started!
Done.

Operations performed: 6004 Read, 4003 Write, 12800 Other = 22807 Total
Read 93.812Mb Written 62.547Mb Total transferred 156.36Mb (209.95Mb/sec)
13436.85 Requests/sec executed

Test execution summary:
    total time:          0.7447s
    total number of events: 10007
    total time taken by event execution: 0.4143
    per-request statistics:
        min:            0.00ms
        avg:            0.04ms
        max:            5.85ms
        approx. 95 percentile: 0.06ms

Threads fairness:
    events (avg/stddev): 625.4375/122.29
    execution time (avg/stddev): 0.0259/0.00
```

5.

```
3Gb total file size
Block size 16Kb
Number of random requests for random IO: 10000
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
Threads started!
Done.

Operations performed: 6012 Read, 3998 Write, 12800 Other = 22810 Total
Read 93.938Mb Written 62.469Mb Total transferred 156.41Mb (128.89Mb/sec)
8248.80 Requests/sec executed

Test execution summary:
    total time:          1.2135s
    total number of events: 10010
    total time taken by event execution: 7.7604
    per-request statistics:
        min:            0.00ms
        avg:            0.78ms
        max:            8.82ms
        approx. 95 percentile: 2.53ms

    Threads fairness:
        events (avg/stddev): 625.6250/59.31
        execution time (avg/stddev): 0.4850/0.02
```

QEMU Screenshots:

1.

```
Initializing worker threads...
Threads started!

File operations:
    reads/s:           1421.18
    writes/s:          948.57
    fsyncs/s:          3228.71

Throughput:
    read, MiB/s:      22.21
    written, MiB/s:   14.82

General statistics:
    total time:        10.4213s
    total number of events: 56305

Latency (ms):
    min:              0.01
    avg:              2.62
    max:             101.43
    95th percentile:  9.22
    sum:            147559.66

Threads fairness:
    events (avg/stddev): 3519.0625/144.05
    execution time (avg/stddev): 9.2225/0.07
```

2.

```
Initializing worker threads...
Threads started!

File operations:
  reads/s:          1159.14
  writes/s:         771.79
  fsyncs/s:        2661.20

Throughput:
  read, MiB/s:      18.11
  written, MiB/s:   12.06

General statistics:
  total time:       10.8561s
  total number of events: 45516

Latency (ms):
  min:              0.01
  avg:             3.83
  max:            72.22
  95th percentile: 8.13
  sum:           151531.26

Threads fairness:
  events (avg/stddev): 2844.7500/78.79
  execution time (avg/stddev): 9.4707/0.03
```

3.

```
Initializing worker threads...
Threads started!

File operations:
  reads/s:          1168.82
  writes/s:         778.34
  fsyncs/s:        2683.96

Throughput:
  read, MiB/s:      18.26
  written, MiB/s:   12.16

General statistics:
  total time:       10.3475s
  total number of events: 45879

Latency (ms):
  min:              0.01
  avg:             3.31
  max:            102.24
  95th percentile: 8.28
  sum:           151960.38

Threads fairness:
  events (avg/stddev): 2867.4375/71.53
  execution time (avg/stddev): 9.4975/0.02
```

4.

```
Initializing worker threads...
Threads started!

File operations:
    reads/s:          1182.97
    writes/s:         787.84
    fsyncs/s:        2716.73

Throughput:
    read, MiB/s:      18.48
    written, MiB/s:   12.31

General statistics:
    total time:       10.3498s
    total number of events: 46473

Latency (ms):
    min:              0.01
    avg:             3.25
    max:            115.09
    95th percentile:  8.43
    sum:           151237.03

Threads fairness:
    events (avg/stddev): 2904.5625/56.97
    execution time (avg/stddev): 9.4523/0.05
```

5.

```

Initializing worker threads...

Threads started!

File operations:
    reads/s:          1204.29
    writes/s:         801.89
    fsyncs/s:        2760.52

Throughput:
    read, MiB/s:     18.82
    written, MiB/s:  12.53

General statistics:
    total time:      10.3667s
    total number of events: 47373

Latency (ms):
    min:              0.01
    avg:             3.19
    max:            47.61
    95th percentile: 8.58
    sum:           151099.30

Threads fairness:
    events (avg/stddev): 2960.8125/63.77
    execution time (avg/stddev): 9.4437/0.04

```

2. Command: sysbench --num-threads=1 --test=fileio --file-total-size=1G --file-test-mode=rndrd --max-time=30 --max-requests=0 --file-extra-flags=direct run

QEMU and Docker results after running the above command five times:

1.

Performance metrics	Docker	QEMU
Reads(mb/s)	45.5 mb/s	47.22mb/s
Writes(mb/s)	0mb/s	0 mb/s
Total transferred(mb/s)	45.5 mb/s	47.22mb/s
Total time(s)	30.0015 s	30.0002 s
events/sec	2914.5 s	3022 s
avg	0.33 ms	0.33 ms

2.

Performance metrics	Docker	QEMU
Reads(mb/s)	49.2 mb/s	52.05 mb/s
Writes(mb/s)	0 mb/s	0 mb/s
Total transferred(mb/s)	49.2 mb/s	52.05 mb/s
Total time(s)	30.0003 s	30.0004 s
events/sec	3149 events/sec	3331
avg	0.30 ms	0.30 ms

3.

Performance metrics	Docker	QEMU
Reads(mb/s)	56.86 mb/s	68.11 mb/s
Writes(mb/s)	0 mb/s	0 mb/s
Total transferred(mb/s)	56.86 mb/s	68.11 mb/s
Total time(s)	30.0003 s	30.0002 s
events/sec	3639 events/sec	4359 events/sec
avg	0.26 ms	0.23

4.

Performance metrics	Docker	QEMU
Reads(mb/s)	61.90 mb/s	59 mb/sec
Writes(mb/s)	0 mb/s	0 mb/sec
Total transferred(mb/s)	61.90 mb/s	59 mb/sec
Total time(s)	30.0004 s	30.0003 s
events/sec	3962 events/s	3781 events/s
avg	0.24 ms	0.26

5.

Performance metrics	Docker	QEMU
Reads(mb/s)	69.37 mb/sec	68.11 mb/s
Writes(mb/s)	0 mb/sec	0 mb/sec
Total transferred(mb/s)	69.37 mb/sec	68.11 mb/s
Total time(s)	30.0001 s	30.0002 s
events/sec	4439	4359
avg	0.21 ms	0.23 ms

Screenshots for Docker:

1.

```
Operations performed: 87441 Read, 0 Write, 0 Other = 87441 Total
Read 1.3342Gb Written 0b Total transferred 1.3342Gb (45.54Mb/sec)
2914.59 Requests/sec executed

Test execution summary:
total time:                      30.0011s
total number of events:          87441
total time taken by event execution: 28.6916
per-request statistics:
    min:                          0.09ms
    avg:                          0.33ms
    max:                          18446744073676.01ms
    approx. 95 percentile:         0.45ms

Threads fairness:
events (avg/stddev):            87441.0000/0.00
execution time (avg/stddev):     28.6916/0.00
```

2.

```
Operations performed: 94477 Read, 0 Write, 0 Other = 94477 Total
Read 1.4416Gb Written 0b Total transferred 1.4416Gb (49.206Mb/sec)
3149.20 Requests/sec executed

Test execution summary:
    total time:                      30.0003s
    total number of events:           94477
    total time taken by event execution: 28.6021
    per-request statistics:
        min:                           0.09ms
        avg:                           0.30ms
        max:                           37.77ms
        approx. 95 percentile:          0.48ms

Threads fairness:
    events (avg/stddev):            94477.0000/0.00
    execution time (avg/stddev):     28.6021/0.00
```

3.

```
Operations performed: 109175 Read, 0 Write, 0 Other = 109175 Total
Read 1.6659Gb Written 0b Total transferred 1.6659Gb (56.861Mb/sec)
3639.13 Requests/sec executed

Test execution summary:
    total time:                      30.0003s
    total number of events:           109175
    total time taken by event execution: 28.3874
    per-request statistics:
        min:                           0.09ms
        avg:                           0.26ms
        max:                           18446744073677.57ms
        approx. 95 percentile:          0.44ms

Threads fairness:
    events (avg/stddev):            109175.0000/0.00
    execution time (avg/stddev):     28.3874/0.00
```

4.

```
Operations performed: 118865 Read, 0 Write, 0 Other = 118865 Total  
Read 1.8137Gb Written 0b Total transferred 1.8137Gb (61.908Mb/sec)  
3962.12 Requests/sec executed
```

Test execution summary:

total time:	30.0004s
total number of events:	118865
total time taken by event execution:	28.2541
per-request statistics:	
min:	0.08ms
avg:	0.24ms
max:	18446744073682.81ms
approx. 95 percentile:	0.42ms

Threads fairness:

events (avg/stddev):	118865.0000/0.00
execution time (avg/stddev):	28.2541/0.00

5.

```
Operations performed: 133198 Read, 0 Write, 0 Other = 133198 Total  
Read 2.0324Gb Written 0b Total transferred 2.0324Gb (69.374Mb/sec)  
4439.91 Requests/sec executed
```

Test execution summary:

total time:	30.0001s
total number of events:	133198
total time taken by event execution:	28.0297
per-request statistics:	
min:	0.08ms
avg:	0.21ms
max:	18446744073676.00ms
approx. 95 percentile:	0.43ms

Threads fairness:

events (avg/stddev):	133198.0000/0.00
execution time (avg/stddev):	28.0297/0.00

Screenshots from QEMU:

1.

```
Threads started!

File operations:
  reads/s:          3021.98
  writes/s:         0.00
  fsyncs/s:         0.00

Throughput:
  read, MiB/s:      47.22
  written, MiB/s:   0.00

General statistics:
  total time:       30.0002s
  total number of events: 90665

Latency (ms):
  min:              0.08
  avg:              0.33
  max:              9.92
  95th percentile:  0.43
  sum:              29911.27

Threads fairness:
  events (avg/stddev): 90665.0000/0.00
  execution time (avg/stddev): 29.9113/0.00
```

2.

```
Threads started!

File operations:
  reads/s:          3331.32
  writes/s:         0.00
  fsyncs/s:         0.00

Throughput:
  read, MiB/s:      52.05
  written, MiB/s:   0.00

General statistics:
  total time:       30.0004s
  total number of events: 99946

Latency (ms):
  min:              0.08
  avg:              0.30
  max:              21.84
  95th percentile:  0.47
  sum:              29899.44

Threads fairness:
  events (avg/stddev): 99946.0000/0.00
  execution time (avg/stddev): 29.8994/0.00
```

3.

```
Threads started!

File operations:
  reads/s:          4358.98
  writes/s:         0.00
  fsyncs/s:         0.00

Throughput:
  read, MiB/s:      68.11
  written, MiB/s:   0.00

General statistics:
  total time:       30.0002s
  total number of events: 130776

Latency (ms):
  min:              0.08
  avg:              0.23
  max:              32.70
  95th percentile:  0.42
  sum:              29869.10

Threads fairness:
  events (avg/stddev): 130776.0000/0.00
  execution time (avg/stddev): 29.8691/0.00
```

4.

```
Threads started!

File operations:
  reads/s:          3781.67
  writes/s:         0.00
  fsyncs/s:         0.00

Throughput:
  read, MiB/s:      59.09
  written, MiB/s:   0.00

General statistics:
  total time:       30.0003s
  total number of events: 113456

Latency (ms):
  min:              0.08
  avg:              0.26
  max:              17.26
  95th percentile:  0.45
  sum:              29874.95

Threads fairness:
  events (avg/stddev): 113456.0000/0.00
  execution time (avg/stddev): 29.8750/0.00
```

5.

```
Threads started!

File operations:
  reads/s:          4358.98
  writes/s:         0.00
  fsyncs/s:         0.00

Throughput:
  read, MiB/s:      68.11
  written, MiB/s:   0.00

General statistics:
  total time:        30.0002s
  total number of events: 130776

Latency (ms):
  min:                0.08
  avg:                0.23
  max:               32.70
  95th percentile:    0.42
  sum:              29869.10

Threads fairness:
  events (avg/stddev): 130776.0000/0.00
  execution time (avg/stddev): 29.8691/0.00
```

3. **Command:** sysbench --num-threads=2 --test=fileio --file-total-size=2G --file-test-mode=seqrd --max-time=30 run

QEMU and Docker results after running the above command five times:

1.

Performance metrics	Docker	QEMU
Reads(mb/s)	237 mb/s	670.42 mb/s
Writes(mb/s)	0 mb/s	0 mb/s
Total transferred(mb/s)	237 mb/s	670.42 mb/s
Total time(s)	8.8 s	30.0027 s
events/sec	14892.5	42911

avg	0.11 ms	0.02
-----	---------	------

2.

Performance metrics	Docker	QEMU
Reads(mb/s)	179.17 mb/s	719.92 mb/s
Writes(mb/s)	0 mb/s	0 mb/s
Total transferred(mb/s)	179.17 mb/s	719.92 mb/s
Total time(s)	11.4307 s	30.0005 mb/s
events/sec	11467.3	46077
avg	0.15 ms	0.02

3.

Performance metrics	Docker	QEMU
Reads(mb/s)	120.03 mb/s	690.51 mb/s
Writes(mb/s)	0 mb/s	0 mb/s
Total transferred(mb/s)	120.03 mb/s	690.51 mb/s
Total time(s)	17.061 s	30.0005 s
events/sec	7682.5	44195
avg	0.23 ms	0.02 ms

4.

Performance metrics	Docker	QEMU
Reads(mb/s)	238.7 mb/s	655.92 mb/s

Writes(mb/s)	0 mb/s	0 mb/s
Total transferred(mb/s)	238.7 mb/s	655.93 mb/s
Total time(s)	8.57 s	30.0005 s
events/sec	15294	41984
avg	0.11 ms	0.02 ms

5.

Performance metrics	Docker	QEMU
Reads(mb/s)	180.7 mb/s	664.68 mb/s
Writes(mb/s)	0 mb/s	0 mb/s
Total transferred(mb/s)	180.7 mb/s	664.68 mb/s
Total time(s)	11.33 s	30.0003 s
events/sec	11568	42542
avg	0.15 ms	0.02 ms

Screenshots of Docker:

1.

```

Running the test with following options:
Number of threads: 2

Extra file open flags: 0
128 files, 16Mb each
2Gb total file size
Block size 16Kb
Periodic FSYNC enabled, calling fsync() each 100 requests.
Calling fsync() at the end of test, Enabled.
Using synchronous I/O mode
Doing sequential read test
Threads started!
Done.

Operations performed: 131072 Read, 0 Write, 0 Other = 131072 Total
Read 2Gb Written 0b Total transferred 2Gb (232.7Mb/sec)
14892.56 Requests/sec executed

Test execution summary:
total time: 8.8012s
total number of events: 131072
total time taken by event execution: 14.7746
per-request statistics:
    min: 0.01ms
    avg: 0.11ms
    max: 85.06ms
    approx. 95 percentile: 0.11ms

Threads fairness:
events (avg/stddev): 65536.0000/394.00
execution time (avg/stddev): 7.3873/0.02

```

2.

```

Operations performed: 131072 Read, 0 Write, 0 Other = 131072 Total
Read 2Gb Written 0b Total transferred 2Gb (179.17Mb/sec)
11466.65 Requests/sec executed

Test execution summary:
total time: 11.4307s
total number of events: 131072
total time taken by event execution: 19.8839
per-request statistics:
    min: 0.01ms
    avg: 0.15ms
    max: 15.26ms
    approx. 95 percentile: 0.17ms

Threads fairness:
events (avg/stddev): 65536.0000/3492.00
execution time (avg/stddev): 9.9419/0.05

```

3.

```
Operations performed: 131072 Read, 0 Write, 0 Other = 131072 Total
Read 2Gb Written 0b Total transferred 2Gb (120.03Mb/sec)
7682.17 Requests/sec executed

Test execution summary:
    total time:          17.0619s
    total number of events: 131072
    total time taken by event execution: 30.5960
    per-request statistics:
        min:                0.02ms
        avg:                0.23ms
        max:           18446744073679.57ms
        approx. 95 percentile: 0.31ms

Threads fairness:
    events (avg/stddev): 65536.0000/77.00
    execution time (avg/stddev): 15.2980/0.02
```

4.

```
Operations performed: 131072 Read, 0 Write, 0 Other = 131072 Total
Read 2Gb Written 0b Total transferred 2Gb (238.77Mb/sec)
15281.45 Requests/sec executed

Test execution summary:
    total time:          8.5772s
    total number of events: 131072
    total time taken by event execution: 14.4507
    per-request statistics:
        min:                0.02ms
        avg:                0.11ms
        max:           26.26ms
        approx. 95 percentile: 0.15ms

Threads fairness:
    events (avg/stddev): 65536.0000/6897.00
    execution time (avg/stddev): 7.2254/0.05
```

5.

```
Operations performed: 131072 Read, 0 Write, 0 Other = 131072 Total
Read 2Gb Written 0b Total transferred 2Gb (180.7Mb/sec)
11564.99 Requests/sec executed

Test execution summary:
    total time:                      11.3335s
    total number of events:           131072
    total time taken by event execution: 19.6986
    per-request statistics:
        min:                           0.02ms
        avg:                           0.15ms
        max:                           24.35ms
        approx. 95 percentile:          0.24ms

Threads fairness:
    events (avg/stddev):           65536.0000/2932.00
    execution time (avg/stddev):    9.8493/0.02
```

Screenshots of QEMU:

1.

```
Initializing worker threads...
Threads started!

File operations:
    reads/s:                      42906.93
    writes/s:                      0.00
    fsyncs/s:                      0.00

Throughput:
    read, MiB/s:                  670.42
    written, MiB/s:                0.00

General statistics:
    total time:                   30.0027s
    total number of events:        1287457

Latency (ms):
    min:                           0.00
    avg:                           0.02
    max:                           13.80
    95th percentile:              0.03
    sum:                           23715.02

Threads fairness:
    events (avg/stddev):         643728.5000/141.50
    execution time (avg/stddev):  11.8575/0.04
```

2.

```
Initializing worker threads...
Threads started!

File operations:
  reads/s:          46074.70
  writes/s:         0.00
  fsyncs/s:         0.00

Throughput:
  read, MiB/s:     719.92
  written, MiB/s:  0.00

General statistics:
  total time:      30.0003s
  total number of events: 1382327

Latency (ms):
  min:              0.00
  avg:              0.02
  max:              5.54
  95th percentile: 0.02
  sum:              22439.25

Threads fairness:
  events (avg/stddev):   691163.5000/487.50
  execution time (avg/stddev): 11.2196/0.01
```

3.

```
Initializing worker threads...
Threads started!

File operations:
  reads/s:          44192.88
  writes/s:         0.00
  fsyncs/s:         0.00

Throughput:
  read, MiB/s:     690.51
  written, MiB/s:  0.00

General statistics:
  total time:      30.0005s
  total number of events: 1325878

Latency (ms):
  min:              0.00
  avg:              0.02
  max:              28.58
  95th percentile: 0.02
  sum:              22609.59

Threads fairness:
  events (avg/stddev):   662939.0000/111.00
  execution time (avg/stddev): 11.3048/0.02
```

4.

```
Initializing worker threads...
Threads started!

File operations:
  reads/s:          41978.70
  writes/s:         0.00
  fsyncs/s:         0.00

Throughput:
  read, MiB/s:     655.92
  written, MiB/s:  0.00

General statistics:
  total time:      30.00005s
  total number of events: 1259566

Latency (ms):
  min:              0.00
  avg:              0.02
  max:              81.26
  95th percentile: 0.02
  sum:              23131.69

Threads fairness:
  events (avg/stddev): 629783.0000/365.00
  execution time (avg/stddev): 11.5658/0.05
```

5.

```
Initializing worker threads...
Threads started!

File operations:
  reads/s:          42539.80
  writes/s:         0.00
  fsyncs/s:         0.00

Throughput:
  read, MiB/s:     664.68
  written, MiB/s:  0.00

General statistics:
  total time:      30.00003s
  total number of events: 1276283

Latency (ms):
  min:              0.00
  avg:              0.02
  max:              10.91
  95th percentile: 0.04
  sum:              24279.72

Threads fairness:
  events (avg/stddev): 638141.5000/555.50
  execution time (avg/stddev): 12.1399/0.02
```

4. **Title:** Present how you use performance tools to collect performance data. For CPU utilization, you should at least divide them into two parts including user-level and kernel-level. For I/O, you should present I/O throughput, latency, and disk utilization

Explanation: On host PC

As we can see below that user level system utilization is 10.25% and system level is 24.05% where qemu system is using 51.3% of CPU.

```

Processes: 554 total, 3 running, 551 sleeping, 1992 threads          15:30:48
Load Avg: 1.92, 1.95, 2.19  CPU usage: 10.25% user, 24.0% sys, 65.73% idle
SharedLibs: 293M resident, 37M data, 20M linkedit.
MemRegions: 101899 total, 451M resident, 40M private, 2855M shared.
PhysMem: 8011M used (2505M wired), 180M unused.
VM: 4065G vsize, 2322M framework vsize, 161149950(1280) swapins, 165235199(0) sw
Networks: packets: 33688263/29G in, 18698439/3794M out.
Disks: 29063156/998G read, 12780313/838G written.

      PID   COMMAND    %CPU TIME      #TH  #WQ  #PORTS MEM     PURG    CMPRS    PGRP
  77947  qemu-system- 51.3 01:27.96 11/2   2    197  4043M+ 15M-  623M+  77946
        0   kernel_task 32.6 12:33:07 208/4  0     0  446M-  0B    0B      0
        141  WindowServer 17.6 14:23:28 12    5   3553+ 1084M- 0B    318M-  141
  77952  iTerm2       6.0  00:31.91 10    7   273   52M    0B-   30M+  77952
  78031  top          5.7  00:26.93 1/1   0    28   4708K  0B    916K-  78031
  77859  qemu-system- 5.1  01:19.70 16    1   200  1331M+ 17M-  255M+  77858
  78042  screencaptur 4.0  00:00.22 3     2    55  3360K+ 600K  1800K  60826
  75258  com.docker.h 3.6  28:37.85 11   0    34   3614M  0B    1145M+ 75213
  76575  gamecontrol 1.4  01:00.90 5     4    62  1408K+ 0B    764K-  76575
  135   AirPlayXPCH  0.7  34:05.27 12   8    264  5428K+ 0B    4020K- 135
  69573  com.apple.We 0.7  03:58.00 11   1    231  396M+  0B    337M-  69573
  78041  screencaptur 0.5  00:00.08 4     2    152  3428K  0B    2624K- 78041
  131   bluetoothd    0.3  60:17.00 4     2   14028  12M    0B    10M-   131
  144   runningboard 0.2  05:57.70 6     5    761  6980K+ 0B    3564K- 144
  61002  assistantd   0.2  00:14.14 2     1   245  6816K  0B    6608K- 61002

```

On QEMU: After running the ‘top’ command on QEMU, the CPU utilisation is 0.3%

On Docker: After running the ‘top’ command on Docker, the CPU utilisation for user level 1.6% and kernel level is 6.5%

Extra-Credits:

I created the docker file for sysbench. I took the base image of ubuntu and installed sysbench on it.

Screenshots for the docker-file creation, build the docker image from the same docker file and running the docker container:

```
rinkle@Karanbirs-MacBook-Pro Cloud Computing % cat Dockerfile
#getting base image ubuntu
FROM ubuntu

MAINTAINER rinkle rani

RUN apt-get -y update && apt-get install -y sysbench

CMD ["echo", "This is sysbench image"]
rinkle@Karanbirs-MacBook-Pro Cloud Computing % docker build -t mysysbenchimage:1.0 .
[+] Building 21.4s (7/7) FINISHED
=> [internal] load build definition from Dockerfile
=> => transferring dockerfile: 202B
=> [internal] load .dockerignore
=> => transferring context: 2B
=> [internal] load metadata for docker.io/library/ubuntu:latest
=> [auth] library/ubuntu:pull token for registry-1.docker.io
=> CACHED [1/2] FROM docker.io/library/ubuntu@sha256:a0d9e826ab87bd665cf640598a871b748b4b70a01a4f3d174d4fb02adad07a9
=> [2/2] RUN apt-get -y update && apt-get install -y sysbench
=> exporting to image
=> => exporting layers
=> => writing image sha256:161995ab79fcde40c96318387700fa3c26cdf1db71d3866eb38d36cfcaad2023
=> => naming to docker.io/library/mysysbenchimage:1.0

Use 'docker scan' to run Snyk tests against images to find vulnerabilities and learn how to fix them
rinkle@Karanbirs-MacBook-Pro Cloud Computing % docker images
REPOSITORY          TAG      IMAGE ID      CREATED       SIZE
mysysbenchimage     1.0      161995ab79fc  19 seconds ago  124MB
simple-node         latest   0b67cfb585de  9 days ago    943MB
isjustintime/debug-me  latest   b9c1dbfcdd8e  18 months ago   942MB
csmminpp/ubuntu-sysbench  latest   2787c5e16909  5 years ago    336MB
rinkle@Karanbirs-MacBook-Pro Cloud Computing % docker container run -it 161995ab79fc /bin/bash
root@4e0fc752d78f:/# sysbench --version
sysbench 1.0.18
root@4e0fc752d78f:/# []
```