System vs. OS Virtualization

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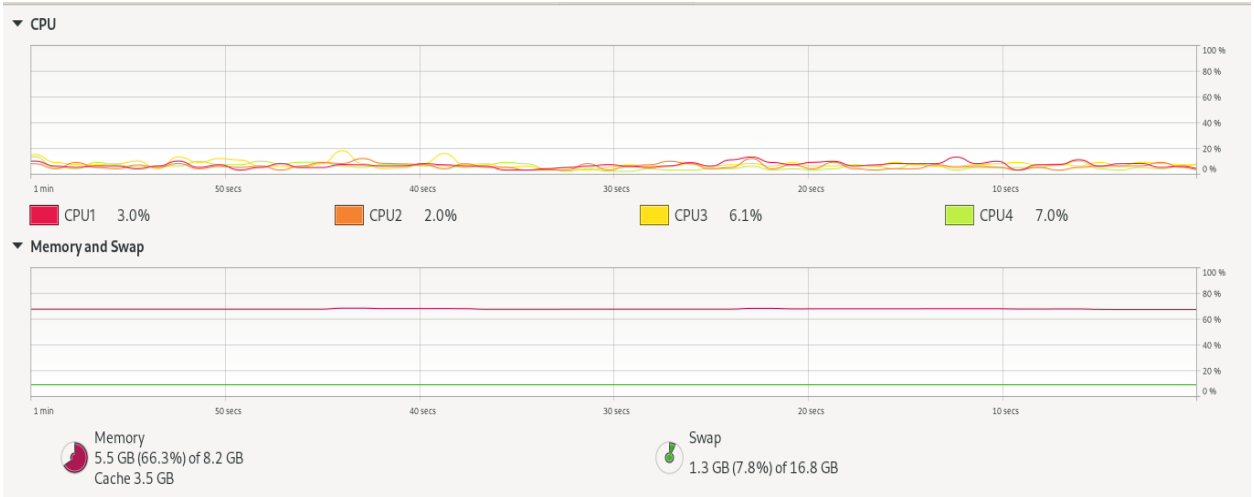
Environment Setup

Host System Configuration Details -

The host system used used to perform the execution of experiment has following configuration -

- CPU - x86_64 Intel(R) Core(TM) i5-5200U CPU @ 2.20GHz with 4 cores
- Memory - 8 GB RAM
- Disk Space -
  - 500 MB - EFI System
  - 8 GB - Linux Swap
  - 115 GB - Linux Filesystem
- OS - Linux fedora 5.19.15-201.fc36.x86_64

Detailed Host-System Configuration Screenshot -



Device	Directory	Type	Total	Available	Used	
/dev/sda7	/	ext4	121.0 GB	81.9 GB	32.9 GB	28%
/dev/sda5	/boot/efi	vfat	524.0 MB	509.3 MB	14.7 MB	2%

QEMU Ubuntu Virtual Machine Configuration Details -

The Ubuntu VM is created with QEMU by allocating 10 GB of disk space (qcow2 file format), 2 GB of RAM, and 2 CPU cores.

Docker Ubuntu Container Configuration Details -

The Ubuntu container in docker also allocated the same configuration as Ubuntu VM having 2 GB of RAM and 2 CPU cores.

System Virtualization Setup

QEMU Setup -

1. Install the QEMU on host (Fedora Linux) using following command -
   $ sudo dnf install qemu -y

   Command Output -

```
[pranav@fedora temp]$ sudo dnf install qemu
[sudo] password for pranav:
Last metadata expiration check: 0:55:26 ago on Sun 16 Oct 2022 04:05:34 PM PDT.
Dependencies resolved.
================================================================================
 Package                 Architecture        Version                 Repository
================================================================================
Installing:
 qemu                    x86_64              2:6.2.0-15.fc36         updates
Installing dependencies:
 SLOF                    noarch              20210217-4.git33a7322d.fc36 fedora
 edk2-aarch64            noarch              20220826gitba0e0e4c6a17-1.fc36 updates
 edk2-arm                noarch              20220826gitba0e0e4c6a17-1.fc36 updates
 openbios                noarch              1:20200725-4.git7f28286.fc36 fedora
 qemu-system-aarch64     x86_64              2:6.2.0-15.fc36         updates
 qemu-system-aarch64-core x86_64             2:6.2.0-15.fc36         updates
 qemu-system-alpha       x86_64              2:6.2.0-15.fc36         updates
 qemu-system-alpha-core  x86_64              2:6.2.0-15.fc36         updates
 qemu-system-arm         x86_64              2:6.2.0-15.fc36         updates
 qemu-system-arm-core    x86_64              2:6.2.0-15.fc36         updates
 qemu-system-avr         x86_64              2:6.2.0-15.fc36         updates
 qemu-system-avr-core    x86_64              2:6.2.0-15.fc36         updates
 qemu-system-cris        x86_64              2:6.2.0-15.fc36         updates
 qemu-system-cris-core   x86_64              2:6.2.0-15.fc36         updates
 qemu-system-m68k        x86_64              2:6.2.0-15.fc36         updates
 qemu-system-m68k-core   x86_64              2:6.2.0-15.fc36         updates
 qemu-system-microblaze  x86_64              2:6.2.0-15.fc36         updates
 qemu-system-microblaze-core x86_64          2:6.2.0-15.fc36         updates
 qemu-system-mips        x86_64              2:6.2.0-15.fc36         updates
 qemu-system-mips-core   x86_64              2:6.2.0-15.fc36         updates
 qemu-system-nios2       x86_64              2:6.2.0-15.fc36         updates
 qemu-system-nios2-core  x86_64              2:6.2.0-15.fc36         updates
 qemu-system-or1k        x86_64              2:6.2.0-15.fc36         updates
 qemu-system-or1k-core   x86_64              2:6.2.0-15.fc36         updates
 qemu-system-ppc         x86_64              2:6.2.0-15.fc36         updates
 qemu-system-ppc-core    x86_64              2:6.2.0-15.fc36         updates
 qemu-system-riscv       x86_64              2:6.2.0-15.fc36         updates
 qemu-system-riscv-core  x86_64              2:6.2.0-15.fc36         updates
```

2. Download ubuntu server image using following command -
   $ wget https://releases.ubuntu.com/focal/ubuntu-20.04.5-live-server-amd64.iso

   Command Output -

```
[pranav@fedora temp]$ wget wget https://releases.ubuntu.com/focal/ubuntu-20.04.5-live-server-amd64.iso
--2022-10-16 17:06:33--  http://wget/
Resolving wget (wget)... failed: Name or service not known.
wget: unable to resolve host address ‘wget’
--2022-10-16 17:06:37--  https://releases.ubuntu.com/focal/ubuntu-20.04.5-live-server-amd64.iso
Resolving releases.ubuntu.com (releases.ubuntu.com)... 185.125.190.37, 91.189.91.124, 91.189.91.123, ...
Connecting to releases.ubuntu.com (releases.ubuntu.com)|185.125.190.37|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 1406533632 (1.3G) [application/x-iso9660-image]
Saving to: ‘ubuntu-20.04.5-live-server-amd64.iso’

ubuntu-20.04.5-live-server-amd64.iso        4%[==>                                                                  ]  58.52M  5.94MB/s
```

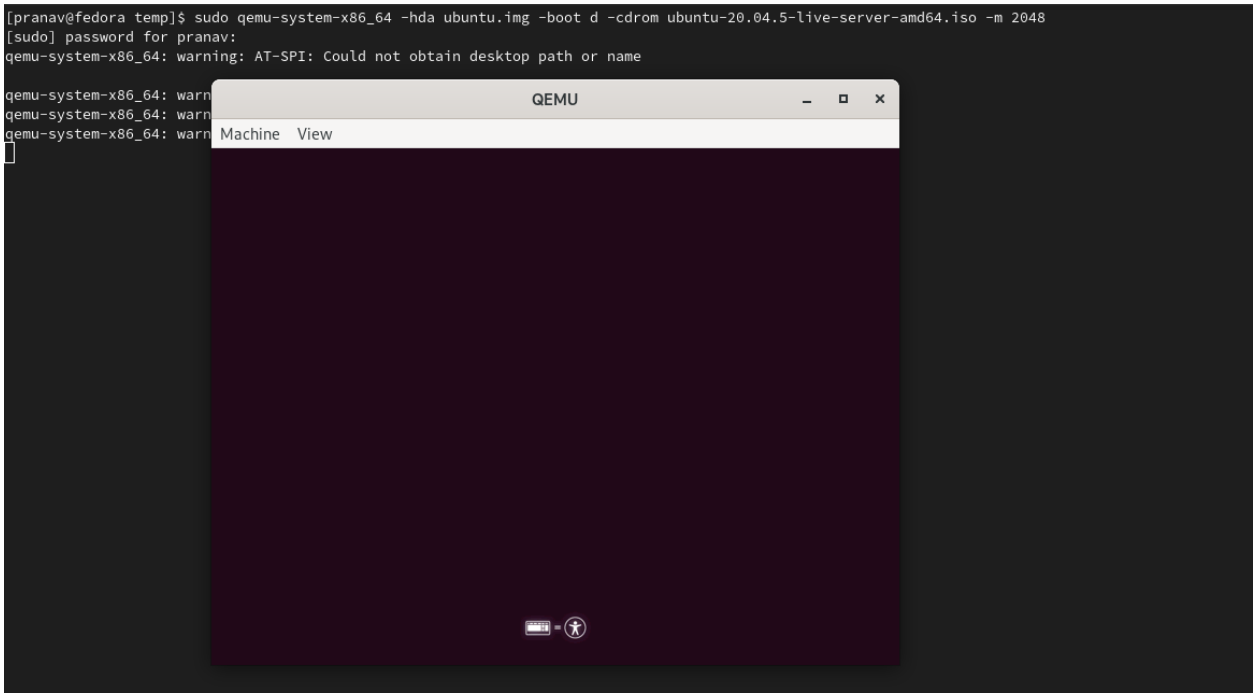
3. Create QEMU image of ubuntu in qcow2 file format using following command -
   $ qemu-img create -f qcow2 ubuntu.img 10G

Command Output -

```
[pranav@fedora temp]$ qemu-img create -f qcow2 ubuntu.img 10G
Formatting 'ubuntu.img', fmt=qcow2 cluster_size=65536 extended_l2=off compression_type=zlib size=10737418240 lazy_refcounts=off refcount_bits=16
[pranav@fedora temp]$ qemu-img info ubuntu.img
image: ubuntu.img
file format: qcow2
virtual size: 10 GiB (10737418240 bytes)
disk size: 196 KiB
cluster_size: 65536
Format specific information:
    compat: 1.1
    compression type: zlib
    lazy refcounts: false
    refcount bits: 16
    corrupt: false
    extended l2: false
```

4. After creating image, install the the Ubuntu VM using iso downloaded in 2nd step i.e. ubuntu-20.04.5-live-server-amd64.iso in the disk image created in 3rd step i.e. ubuntu.qcow2 using following command -
   $ sudo qemu-system-x86_64 -hda ubuntu.img -boot d -cdrom ubuntu-20.04.5-live-server-amd64.iso -m 2048

   Command Output -



In the above command the flags/option used have following meanings -

-hda : use file as a hard disk

-boot : this option specifies the boot order, for x86 architecture these drive letters are - a, b (for floppy drives), c (first hard-disk), d (first CD-ROM), n-p (Etherboot from network adapter 1-4). Hard-disk boot is the default option.

-cdrom : this option specifies the .iso file to be used as a base for image we are creating

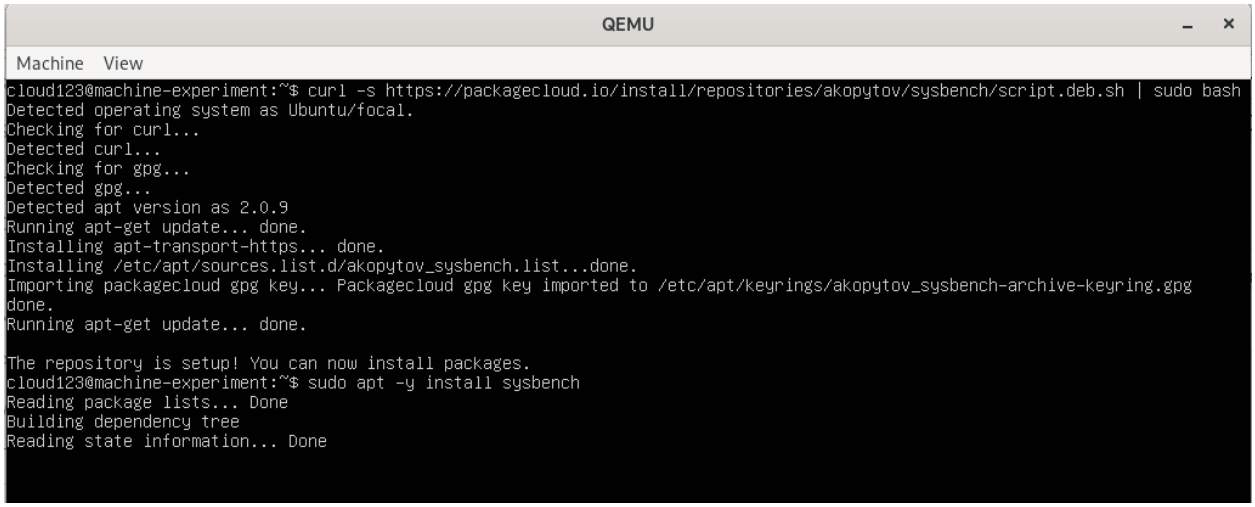
-m : this option sets guest OS's startup RAM to specified value i.e. 2048 MB

Sysbench Setup on QEMU VM -

1. Once VM is launched after finishing the above QEMU setup steps, we are now ready to install sysbench on the Ubuntu VM using following command -

   $ curl -s https://packagecloud.io/install/repositories/akopytov/sysbench/script.deb.sh | sudo bash
   $ apt -y install sysbench

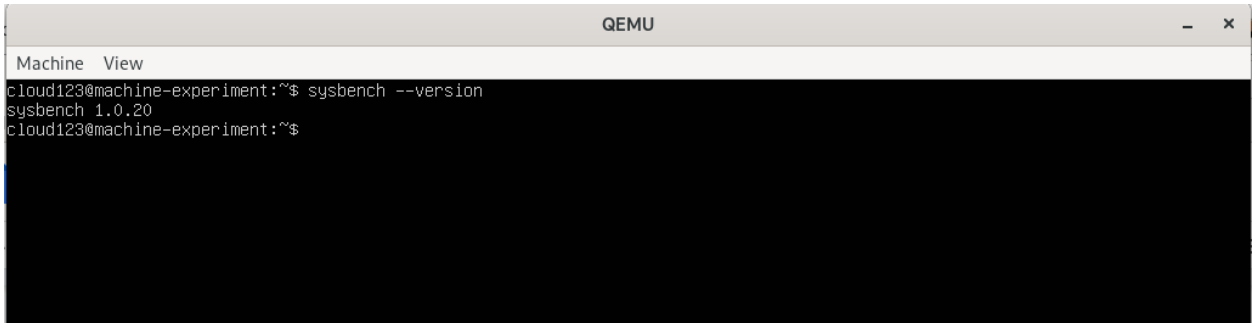
   Command Output -



2. Check the version of sysbench installed using following command -

   $ sysbench –version

   Command Output -



Going In-Depth of QEMU

We can launch the Ubuntu OS from above created ubuntu.img by providing a lot of options. For example we can provide options to give it memory, cpu, network, block device, accelerators etc.

Following are some of the examples of launching Ubuntu VM using extra options -

1. We can start Ubuntu VM by using -accel option to accelerate the machine using paravirtualized hypervisors such as kvm, xen, tcg (default) inside them. For example below command uses 'kvm' accelerator to start -

   ```
   $ sudo qemu-system-x86_64 -hda ubuntu1.qcow2 -accel kvm -boot c -m 2048
   ```

2. We can use -smp option to mention the number of cores the Guest OS can use and -cpu to provide an option for choosing from supported CPUs by QEMU. For example, below command uses 2 cores and for cpu type 'host' option which emulates host OS's cpu -

   ```
   $ sudo qemu-system-x86_64 -hda ubuntu1.qcow2 -accel kvm -boot c -m 2048 -smp 2 -cpu host
   ```

3. We can use the -drive option to set the drive for guest os to use. For example, below command sets the ubuntu.img drive and uses virt-io interface -

   ```
   $ sudo qemu-system-x86_64 -drive file=ubuntu1.img,if=virtio -accel kvm -boot c -m 2048 -smp 2 -cpu host
   ```

4. We can use the '-netdev user' option to configure the user mode host network backend which requires no administrator privilege to run. Below is command uses the '-netdev user' -

   ```
   $ sudo qemu-system-x86_64 -drive file=ubuntu1.img,if=virtio -accel kvm -boot c -m 2048 -smp 2 -cpu host -netdev user,id=net0
   ```

5. Combinedly, below is the more advanced command using various options and their values to launch the guest operating system -

   ```
   $ sudo qemu-system-x86_64 -accel kvm \
           -cpu host \
           -m 2048 \
           -smp 2 \
           -hda ubuntu.img \
           -boot c \
           -device virtio-net,netdev=vm \
           -netdev user,id=vm,hostfwd=tcp:127.0.0.1:9001-:22
   ```

Operating System (OS) Virtualization Setup

Docker Setup -

1. Install the Docker on host (Fedora Linux) using following commands -

   $ sudo dnf -y install dnf-plugins-core

   $ sudo dnf config-manager \
   --add-repo \
   https://download.docker.com/linux/fedora/docker-ce.repo

   $ sudo dnf install docker-ce docker-ce-cli containerd.io docker-compose-plugin

2. The above command installs the components required for docker and creates a group called docker. Now, to start the docker use following command -

   $ sudo systemctl start docker

3. To verify installation is proper, run a hello world container -

   $ sudo docker run hello-world

   Command Output -

```
[pranav@fedora hw1]$ sudo docker run hello-world
Unable to find image 'hello-world:latest' locally
latest: Pulling from library/hello-world
2db29710123e: Pull complete
Digest: sha256:18a657d0cc1c7d0678a3fbea8b7eb4918bba25968d3e1b0adebfa71caddbc346
Status: Downloaded newer image for hello-world:latest

Hello from Docker!
This message shows that your installation appears to be working correctly.

To generate this message, Docker took the following steps:
 1. The Docker client contacted the Docker daemon.
 2. The Docker daemon pulled the "hello-world" image from the Docker Hub.
    (amd64)
 3. The Docker daemon created a new container from that image which runs the
    executable that produces the output you are currently reading.
 4. The Docker daemon streamed that output to the Docker client, which sent it
    to your terminal.

To try something more ambitious, you can run an Ubuntu container with:
 $ docker run -it ubuntu bash

Share images, automate workflows, and more with a free Docker ID:
 https://hub.docker.com/

For more examples and ideas, visit:
 https://docs.docker.com/get-started/
```

4. Now, pull the ubuntu:latest image from docker hub using following command -

   $ docker pull ubuntu:latest

   Command Output -

```
[pranav@fedora hw1]$ docker pull ubuntu:latest
latest: Pulling from library/ubuntu
cf92e523b49e: Pull complete
Digest: sha256:35fb073f9e56eb84041b0745cb714eff0f7b225ea9e024f703cab56aaa5c7720
Status: Downloaded newer image for ubuntu:latest
docker.io/library/ubuntu:latest
```

5. Run the docker container with ubuntu:latest base image using following command -

   $ docker container run -it --memory="2g" --cpus="2" pranav2306/sysbench-ubuntu:version1 /bin/bash

   Command Output -

```
[pranav@fedora cloud-computing-course]$ docker container run -it --memory="2g" --cpus="2" pranav2306/sysbench-ubuntu:version1 /bin/bash
root@44cfe525fbb4:/#
```

6. Check and update the Ubuntu OS running inside the container using the following command -

   $ apt install update

7. Check the cpu and memory the container is using using following command -
   $ docker stats 44cfe525fbb4

   Command Output:

```
CONTAINER ID   NAME           CPU %     MEM USAGE / LIMIT   MEM %     NET I/O       BLOCK I/O     PIDS
44cfe525fbb4   busy_pasteur   0.00%     1.918MiB / 2GiB     0.09%     4.35kB / 0B   1.78MB / 0B   1
```

Sysbench Setup in Docker Container -

1. Now, since the ubuntu container is running, we can now install the sysbench in container using following commands -

   $ $ curl -s
   https://packagecloud.io/install/repositories/akopytov/sysbench/script.deb.sh | sudo bash
   $ apt -y install sysbench

2. Check the version of sysbench installed using the following command -

   $ sysbench –version

   Command Output -

```
root@44cfe525fbb4:/# sysbench --version
sysbench 1.0.20
```

3. After setting up sysbench on docker, we need to create an image out of this container to use it in future test cases. Create image using following command -

   $ docker commit 44cfe525fbb4 panu2306/sysbench-ubuntu:version1

4. Now, lets check the created image and its history using following commands -

   $ docker image ls
   $ docker image history 30dd295e0a5b

   Command Output -

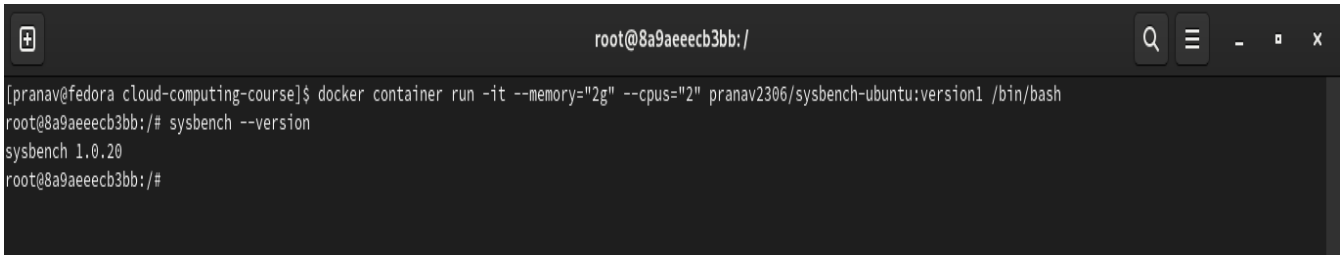
```
[pranav@fedora cloud-computing-course]$ docker image ls
REPOSITORY                  TAG        IMAGE ID       CREATED      SIZE
pranav2306/sysbench-ubuntu  version1   30dd295e0a5b   3 days ago   139MB
[pranav@fedora cloud-computing-course]$ docker image history 30dd295e0a5b
IMAGE          CREATED       CREATED BY                                      SIZE      COMMENT
30dd295e0a5b   3 days ago    /bin/bash                                       61.6MB
<missing>      13 days ago   /bin/sh -c #(nop)  CMD ["bash"]                 0B
<missing>      13 days ago   /bin/sh -c #(nop) ADD file:6cd2e13356aa5339c…   77.8MB
[pranav@fedora cloud-computing-course]$
```

NOTE - Make sure the RAM, CPU allocation and the version of sysbench is same in both System Virtualization (QEMU) and OS Virtualization (Docker) setup.

Proof of Experiment

1. QEMU Running Environment -

2. Docker Running Environment -



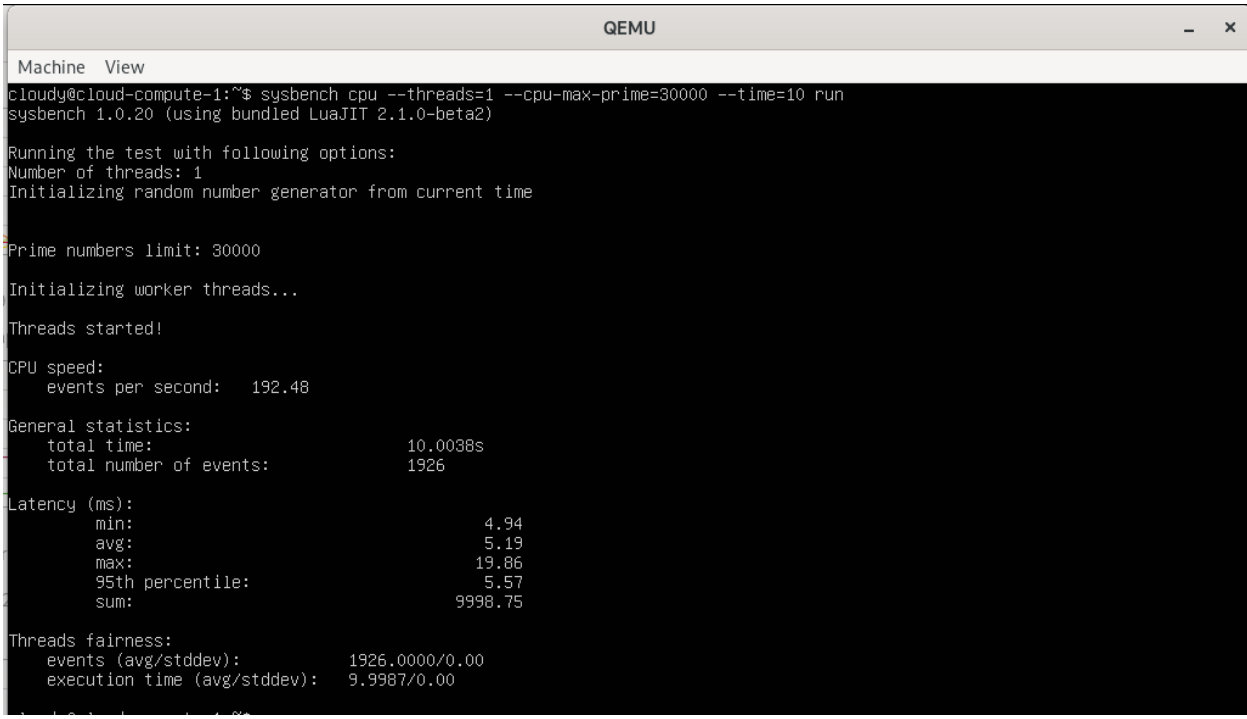
Sysbench Experiment

CPU Test -

1. CPU Test in QEMU VM -

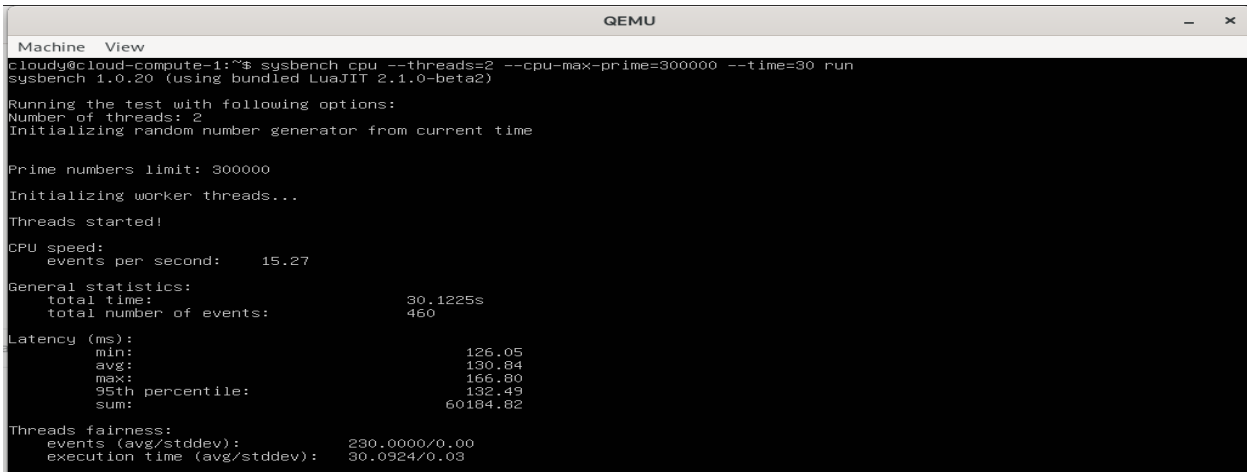
a. Test 1:
$ sysbench cpu --threads=1 --cpu-max-prime=30000 --time=10 run

Command O/P Screenshot -



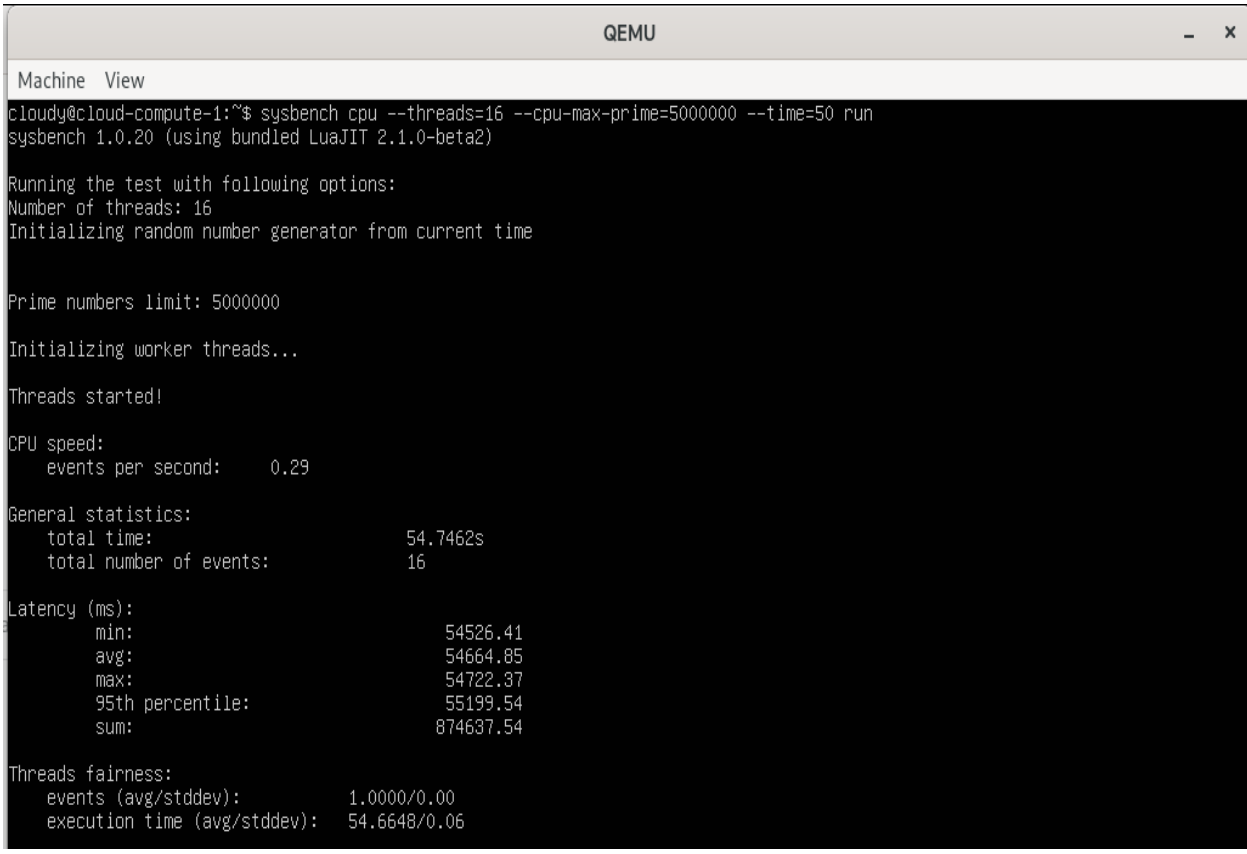
b. Test 2:
$ sysbench cpu --threads=2 --cpu-max-prime=300000 --time=30 run

Command O/P Screenshot -



c. Test 3:
$ sysbench cpu --threads=16 --cpu-max-prime=5000000 --time=50 run

Command O/P Screenshot -

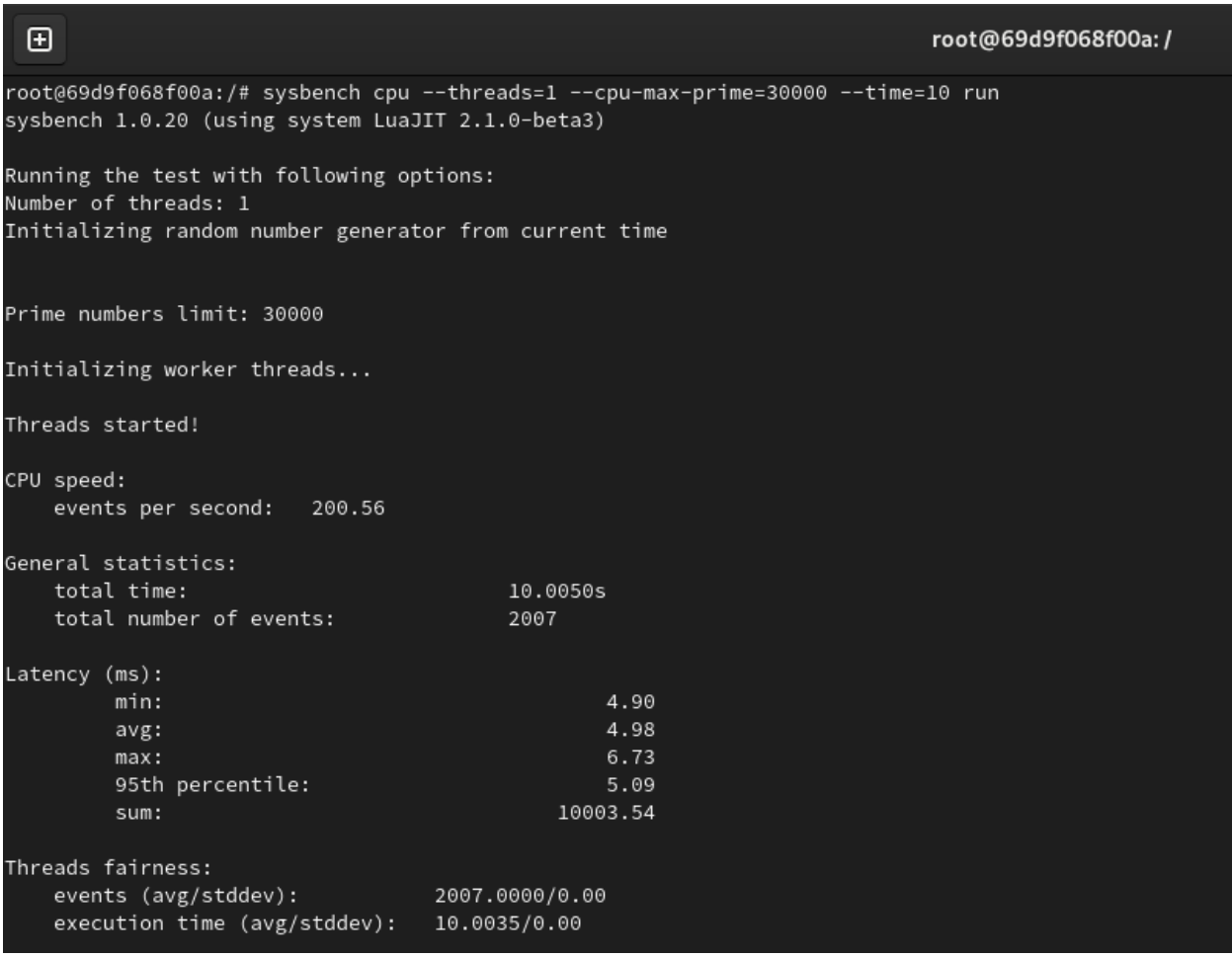


2. CPU Test in Docker Container -

a. Test 1:

$ sysbench cpu --threads=1 --cpu-max-prime=30000 --time=10 run

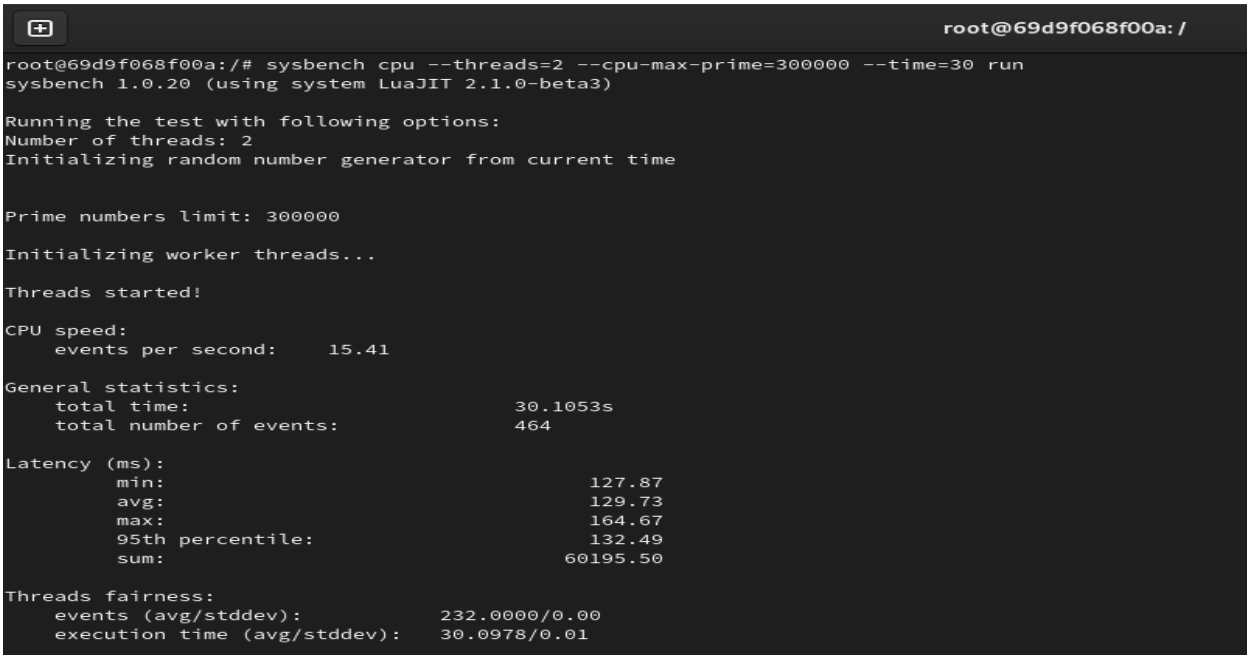
Command O/P Screenshot -



b. Test 2:

$ sysbench cpu --threads=2 --cpu-max-prime=300000 --time=30 run

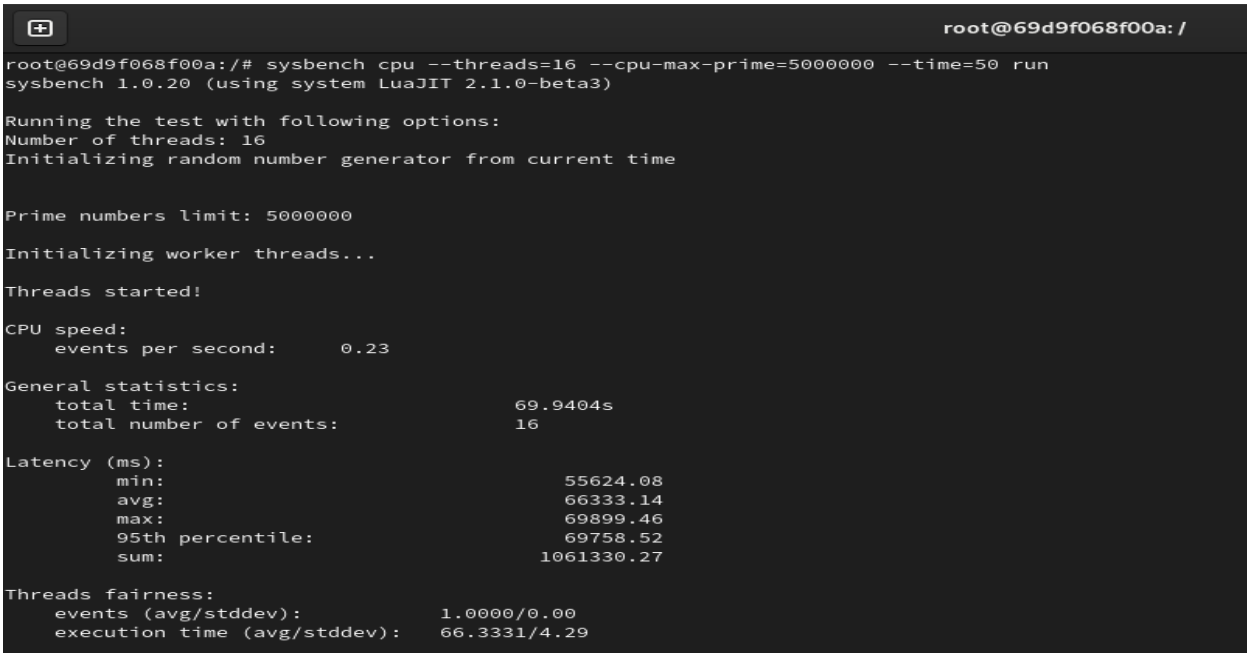
Command O/P Screenshot -



c. Test 3:

$ sysbench cpu --threads=16 --cpu-max-prime=5000000 --time=50 run

Command O/P Screenshot -



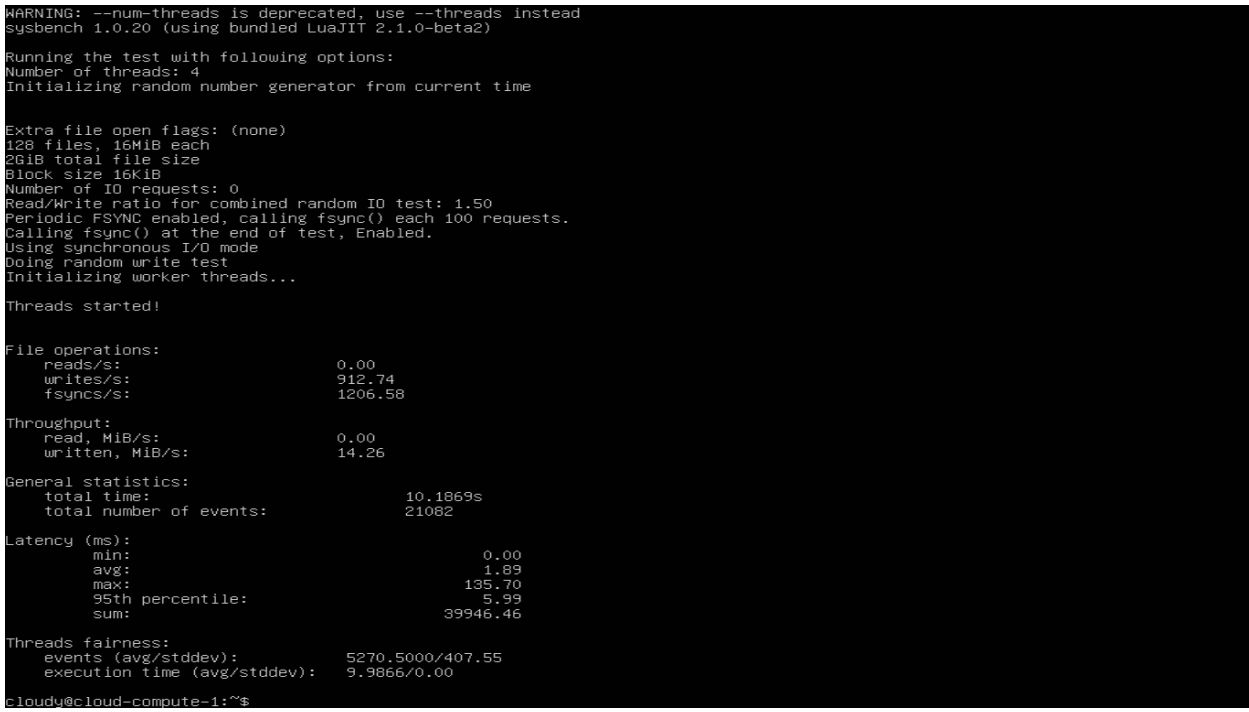
FILEIO Test -

1. FILE-IO Test in QEMU VM -

a. Test 1:

$ sysbench --num-threads=4 fileio --file-total-size=2G --file-test-mode=rndwr prepare
$ sysbench --num-threads=4 fileio --file-total-size=2G --file-test-mode=rndwr run
$ $ sysbench --num-threads=4 fileio --file-total-size=2G --file-test-mode=rndwr cleanup

Run Command O/P Screenshot -



b. Test 2:

$ sysbench --num-threads=16 fileio --file-total-size=5G --file-test-mode=seqrewr prepare
$ sysbench --num-threads=16 fileio --file-total-size=5G --file-test-mode=seqrewr run
$ $ sysbench --num-threads=16 fileio --file-total-size=5G --file-test-mode=seqrewr cleanup

Run Command O/P Screenshot -

```
cloudy@cloud-compute-1:~$ sysbench --num-threads=16 fileio --file-total-size=5G --file-test-mode=seqrewr run
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.20 (using bundled LuaJIT 2.1.0-beta2)

Running the test with following options:
Number of threads: 16
Initializing random number generator from current time


Extra file open flags: (none)
128 files, 40MiB each
5GiB total file size
Block size 16KiB
Periodic FSYNC enabled, calling fsync() each 100 requests.
Calling fsync() at the end of test, Enabled.
Using synchronous I/O mode
Doing sequential rewrite test
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      0.00
    writes/s:                     2315.72
    fsyncs/s:                     3154.30

Throughput:
    read, MiB/s:                  0.00
    written, MiB/s:               36.18

General statistics:
    total time:                          10.3618s
    total number of events:              54643

Latency (ms):
         min:                                    0.01
         avg:                                    2.93
         max:                                  190.80
         95th percentile:                        9.22
         sum:                               159908.26

Threads fairness:
    events (avg/stddev):           3415.1875/163.00
    execution time (avg/stddev):   9.9943/0.00

cloudy@cloud-compute-1:~$
```

c. <u>Test 3:</u>

$ sysbench --num-threads=8 fileio --file-total-size=4G --file-test-mode=rndrw prepare
$ sysbench --num-threads=8 fileio --file-total-size=4G --file-test-mode=rndrw run
$ $ sysbench --num-threads=8 fileio --file-total-size=4G --file-test-mode=rndrw cleanup

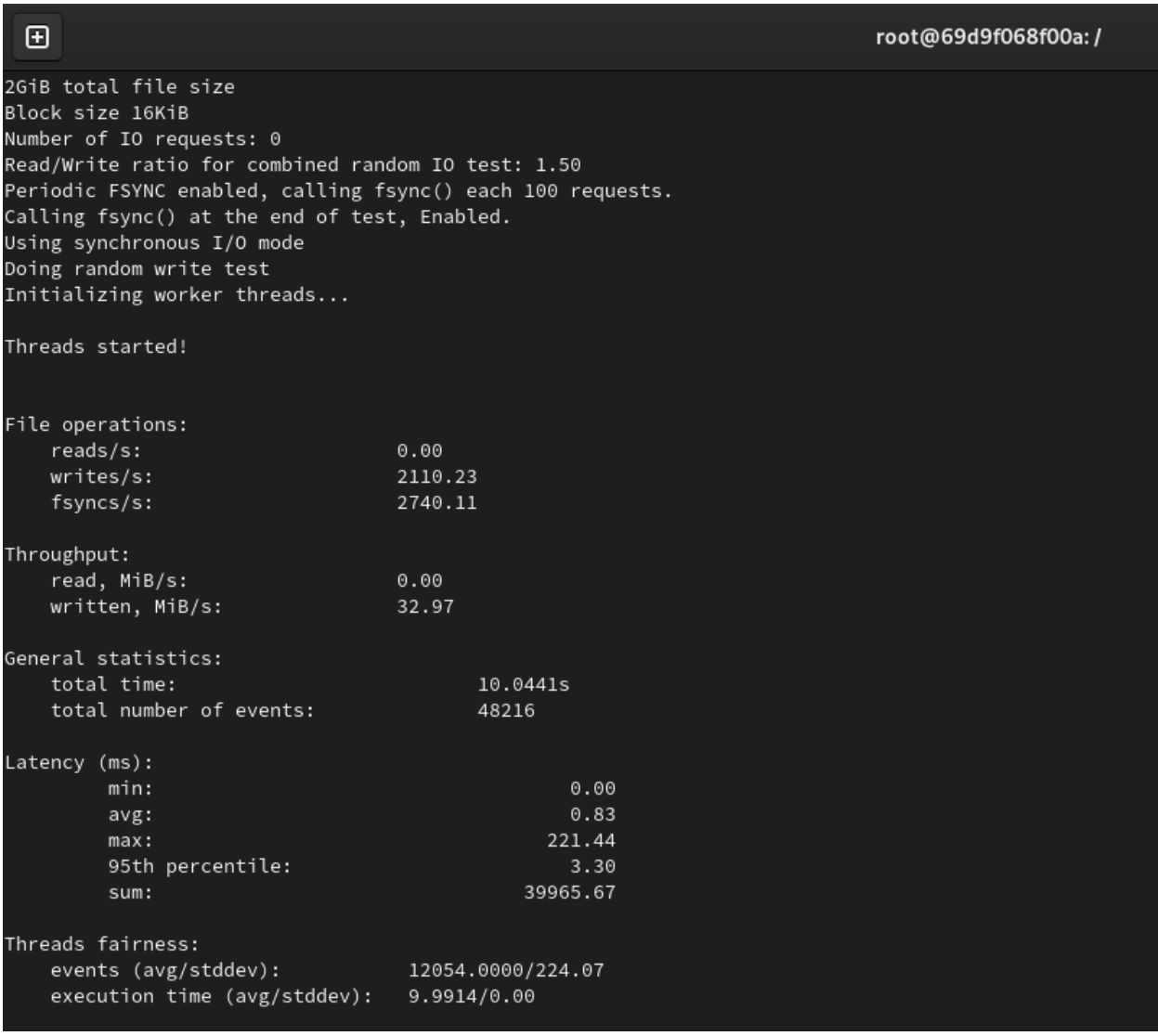
Run Command O/P Screenshot -

```
WARNING: --num-threads is deprecated, use --threads instead
sysbench 1.0.20 (using bundled LuaJIT 2.1.0-beta2)

Running the test with following options:
Number of threads: 8
Initializing random number generator from current time


Extra file open flags: (none)
128 files, 32MiB each
4GiB total file size
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:                      618.72
    writes/s:                     412.32
    fsyncs/s:                     1420.18

Throughput:
    read, MiB/s:                  9.67
    written, MiB/s:               6.44

General statistics:
    total time:                          10.1818s
    total number of events:              23939

Latency (ms):
         min:                                    0.00
         avg:                                    3.34
         max:                                   65.25
         95th percentile:                        9.22
         sum:                                79928.41

Threads fairness:
    events (avg/stddev):           2992.3750/248.65
    execution time (avg/stddev):   9.9911/0.00

cloudy@cloud-compute-1:~$
```

2. **FILE-IO Test in Docker Container -**
    a. Test 1:

$ sysbench --threads=4 fileio --file-total-size=2G --file-test-mode=rndwr prepare
$ sysbench --threads=4 fileio --file-total-size=2G --file-test-mode=rndwr run
$ sysbench --threads=4 fileio --file-total-size=2G --file-test-mode=rndwr cleanup

Run Command O/P Screenshot-



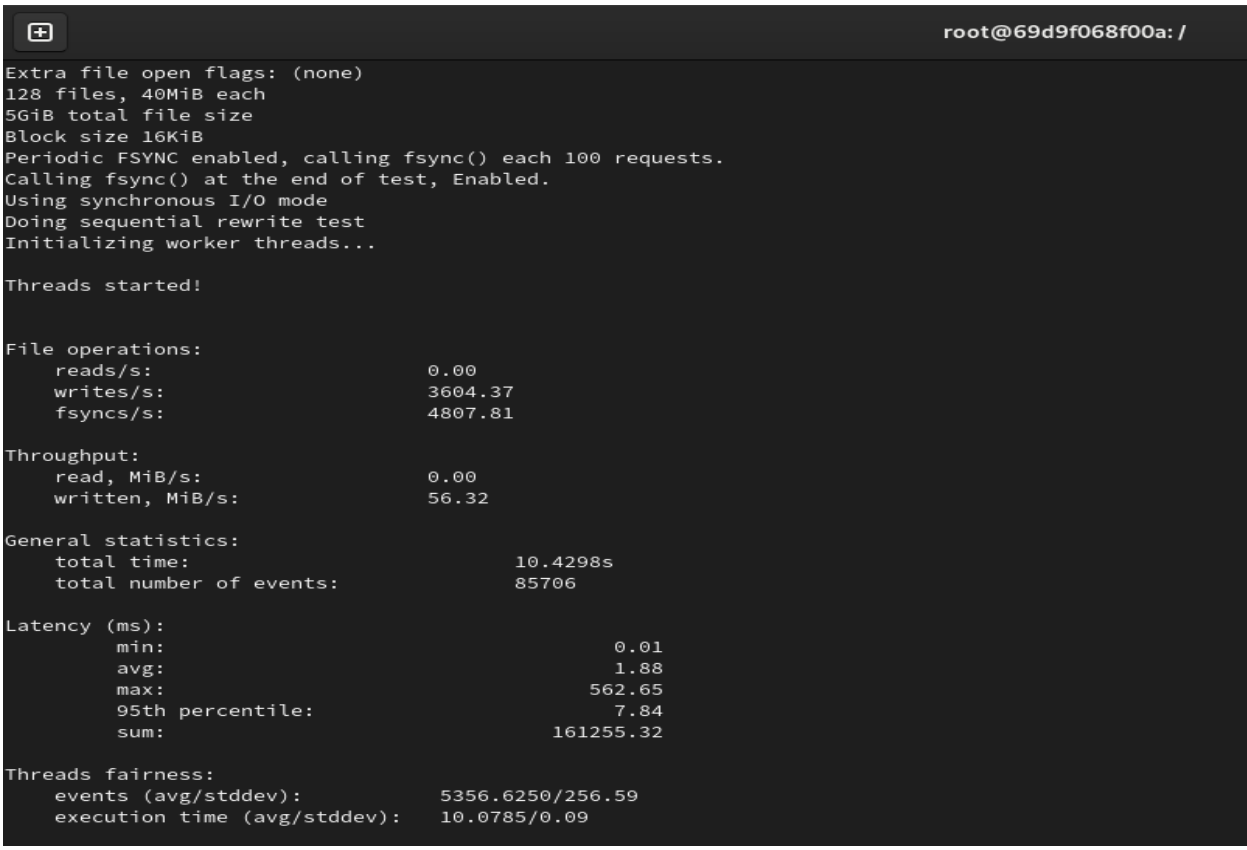
b. Test 2:

$ sysbench --num-threads=16 fileio --file-total-size=5G --file-test-mode=seqrewr prepare

$ sysbench --num-threads=16 fileio --file-total-size=5G --file-test-mode=seqrewr run

$ $ sysbench --num-threads=16 fileio --file-total-size=5G --file-test-mode=seqrewr cleanup

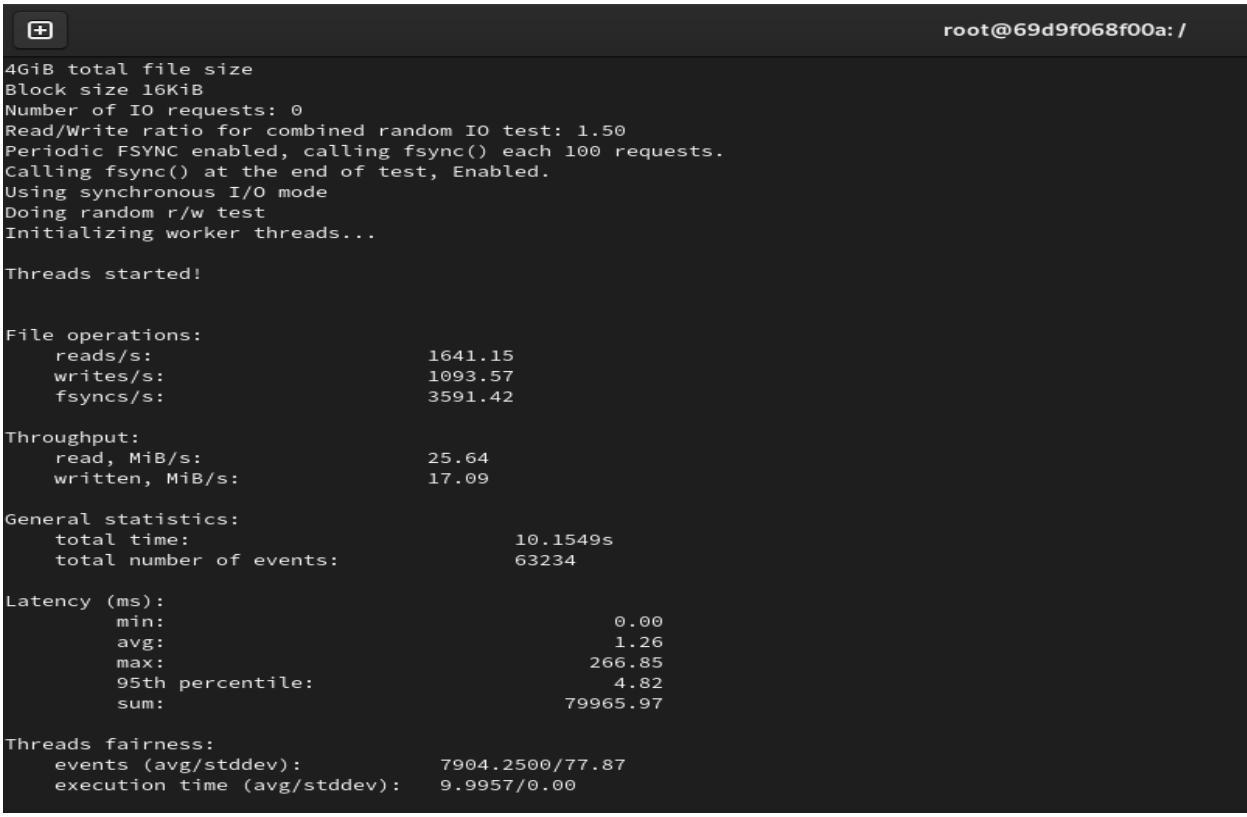
Run Command O/P Screenshot-



c. Test 3:

$ sysbench --threads=8 fileio --file-total-size=4G --file-test-mode=rndrw prepare
$ sysbench --threads=8 fileio --file-total-size=4G --file-test-mode=rndrw run
$ sysbench --threads=8 fileio --file-total-size=4G --file-test-mode=rndrw cleanup

Run Command O/P Screenshot



Experiment Result Analysis

CPU Test - QEMU VM vs. Docker Container -

To perform CPU Test, I have taken following three main parameters into consideration -

1. --threads: number of threads to be used to perform test
2. --cpu-max-prime: the maximum number upto which numbers to be tested if they are prime
3. –time: maximum time process can take to finish

By altering above parameters, following three CPU Tests are performed and the result of them in various measures are shown below in respective test tables -

Test 1:
$ sysbench cpu –threads=1 –cpu-max-prime=30000 –time=10 run

	min	average	max	no. of events
QEMU VM	**4.94**	**5.19**	**19.86**	**1926**
Docker	**4.90**	**4.98**	**6.73**	**2007**

Test 2:
$ sysbench cpu –threads=2 –cpu-max-prime=300000 –time=30 run

	min	average	max	no. of events
QEMU VM	**126.05**	**130.84**	**166.80**	**460**
Docker	**127.87**	**129.73**	**164.67**	**464**

Test 3:
$ sysbench cpu –threads=16 –cpu-max-prime=5000000 –time=50 run

	min	average	max	no. of events
QEMU VM	**54526.41**	**54664.84**	**54722.37**	**16**
Docker	**55624.08**	**66333.14**	**69899.46**	**16**

FILEIO Test - QEMU VM vs. Docker Container

To perform FILE-IO Test, I have taken following three main parameters into consideration-

1. --threads: number of threads to be used to perform test
2. --file-total-size: total size of file/files to be created
3. --file-test-mode: mode of of file test, there are five modes of file-io -
    a. rndrd
    b. rndrw
    c. rndwr
    d. seqrd
    e. seqrewr
    f. seqwr

By altering above parameters, following three File-IO Tests are performed and the result of them in various measures are shown below in respective test tables -

Test 1:
$ sysbench --num-threads=4 fileio --file-total-size=2G --file-test-mode=rndwr run

	min	**average**	**max**	**no. of events**
QEMU VM	**0.00**	**1.89**	**135.70**	**21082**
Docker	**0.00**	**0.83**	**221.44**	**48216**

Test 2:
$ sysbench --num-threads=16 fileio --file-total-size=5G --file-test-mode=seqrewr run

	min	**average**	**max**	**no. of events**
QEMU VM	**0.01**	**2.93**	**190.80**	**54643**
Docker	**0.01**	**1.88**	**562.65**	**85706**

Test 3:
$ sysbench --num-threads=8 fileio --file-total-size=4G --file-test-mode=rndrw run

	min	**average**	**max**	**no. of events**
QEMU VM	**0.00**	**3.34**	**65.25**	**23939**
Docker	**0.00**	**1.26**	**266.85**	**63234**

Findings and Conclusion of CPU and FILEIO Tests-

The above analysis has been based on three different cases for each CPU test and File-IO test. Moreover, each test is run five times to see if the result of each test is consistent with the other case. Following are some of the findings which can be drawn from the results mentioned -

1. The performance of docker containers is faster than the QEMU VM given that they have been provided with the same resources such as CPU and RAM.

2. In all three test cases of CPU tests, the docker container was found to be faster than the QEMU VM.

3. In all three test cases of File-IO tests, the docker container was found to be faster than the QEMU VM.

4. For CPU Tests, the number of events decreases as the thread numbers increase.

5. For CPU Tests, as the number of threads and time given to perform a case is increased, the latency values, min, max, and the average also increases.

6. For File-IO Tests, the number of events performed in both docker container and QEMU VM is more in sequential order than the random order operation for all read, write, or read-write operations.

7. When the number of threads increases in both, for docker containers the max latency parameter value increases as thread numbers increase while the QEMU VMs same parameter value decreases as thread number increases.

Experiment Shell Scripts

Shell Scripts for CPU and FILE-IO Test -

1. **Shell Script for CPU Tests -**

   $ ./cpu_test.sh

```
#! /bin/bash

echo "Hey, you are in $0, and about to test cpu!"

PRIMES_UPTO=("30000" "300000" "5000000")
MAX_TIME=("10" "30" "50")
THREADS=("1" "2" "16")
TEST_RUNS=5
TEST_CASES=3

for ((i=0; i<$TEST_CASES;i++))
do
   echo "*****************************Starting ${i+1}st Test
Case*************************************"
   for (( j=1; j <=$TEST_RUNS; j++ ))
   do
         echo "Running ${j}st run of Test Case ${i+1}"
         sysbench cpu --threads=${THREADS[$i]}
--cpu-max-prime=${PRIMES_UPTO[$i]} --time=${MAX_TIME[$i]} run
         echo "Completed ${j}st run of Test Case ${i+1}"
   done
   echo "*****************************Completed ${i}st Test
Case*************************************"
done
```

2. **Shell Script for FileIO Tests -**

$ ./fileio_test.sh

```
#! /bin/bash

echo "Hey, you are in $0, and about to test fileio"

THREADS=("4" "16" "8")
FILE_TOTAL_SIZES=("2G" "5G" "4G")
TEST_MODE=("rndwr" "seqrewr" "rndrw")
TEST_RUNS=5
TEST_CASES=3

for ((i=0; i<$TEST_CASES;i++))
do
   echo "*****************************Starting ${i+1}st Test
Case************************************"
   for (( j=1; j <=$TEST_RUNS; j++ ))
   do
         echo "Running ${j}st run of Test Case ${i+1}"
         sysbench --threads=${THREADS[$i]} fileio
--file-total-size=${FILE_TOTAL_SIZES[$i]} --file-test-mode=${TEST_MODE[i]}
prepare
         sysbench --threads=${THREADS[$i]} fileio
--file-total-size=${FILE_TOTAL_SIZES[$i]} --file-test-mode=${TEST_MODE[i]} run
         sysbench --threads=${THREADS[$i]} fileio
--file-total-size=${FILE_TOTAL_SIZES[$i]} --file-test-mode=${TEST_MODE[i]}
cleanup
         echo "Completed ${j}st run of Test Case ${i+1}"
   done
   echo "*****************************Completed ${i}st Test
Case************************************"
done
```

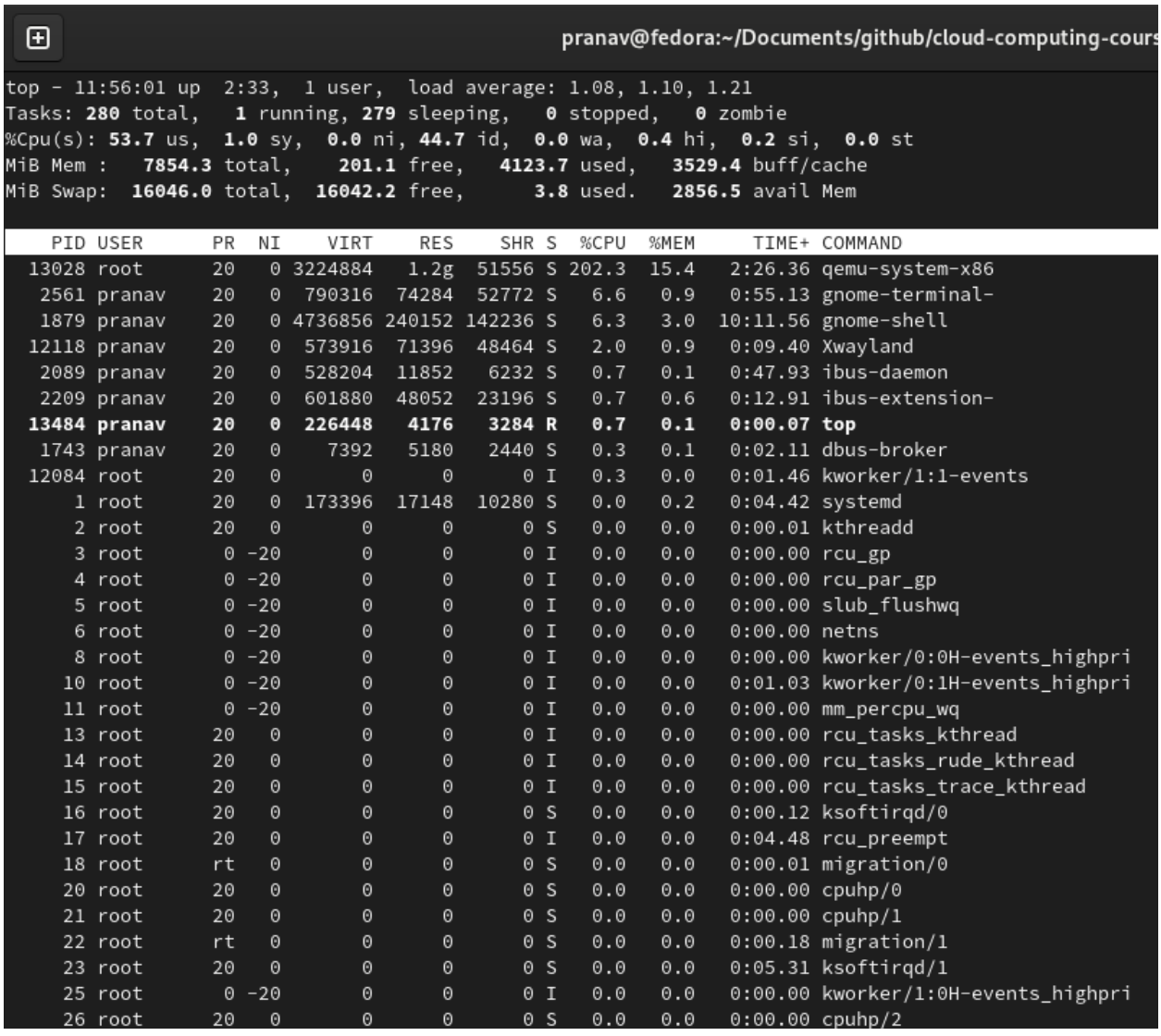
System Performance Tools and Analysis

CPU Utilization -

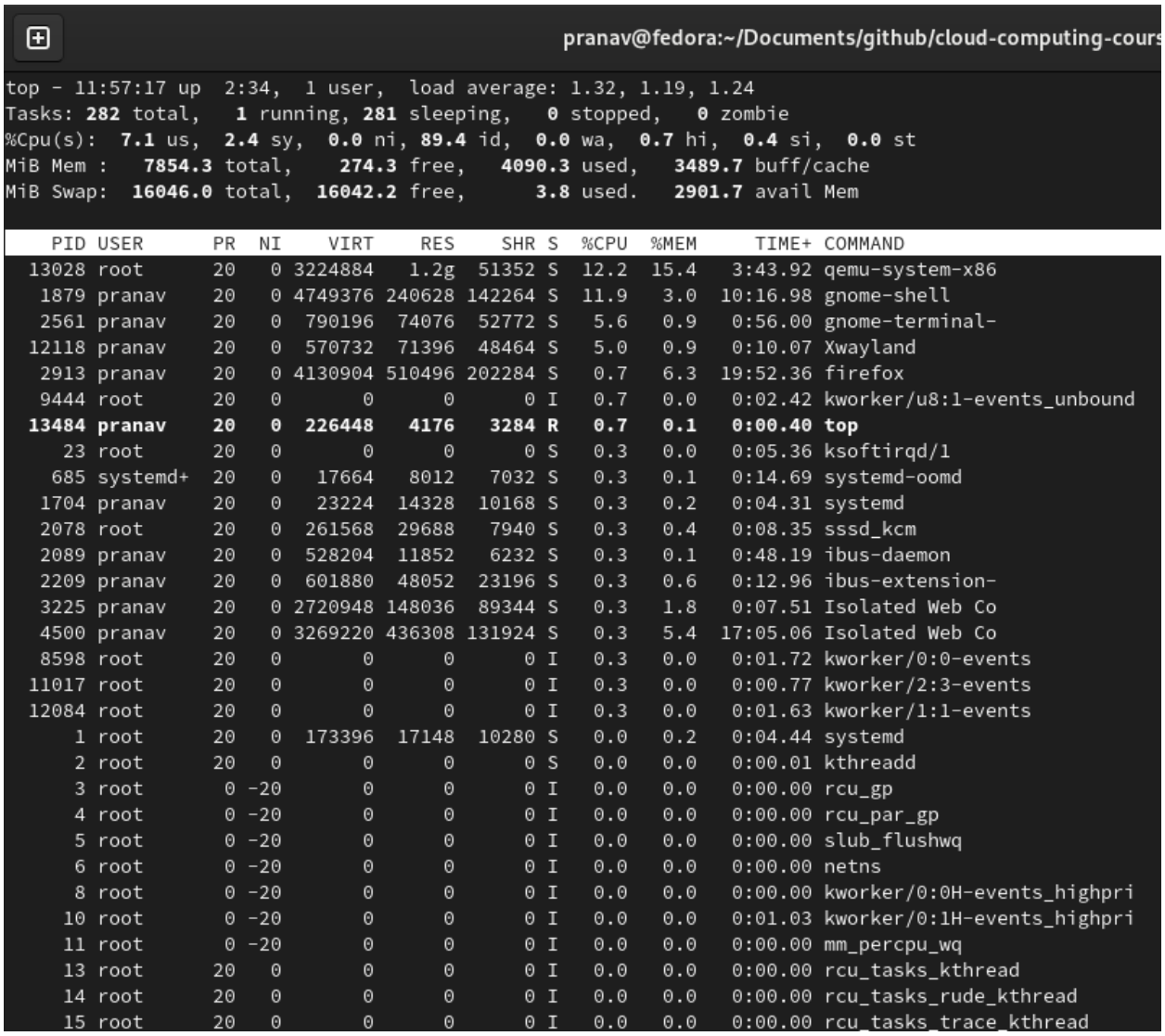
By making use of ‘top’ command in linux we can see the cpu usage in User Mode, System Mode and Idle Mode.

The CPU Utilization is observed in following cases -

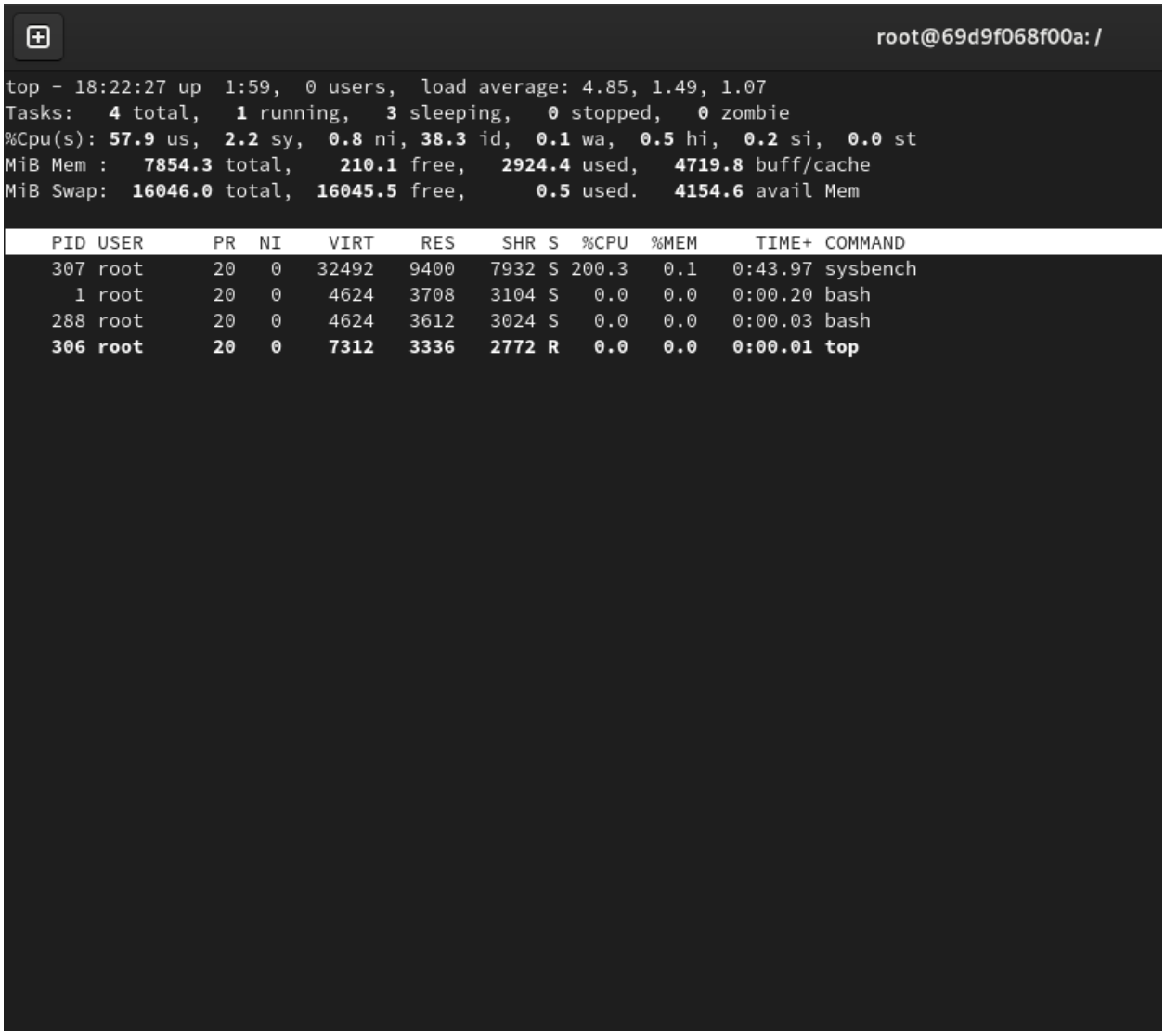
1. QEMU VM Running Sysbench CPU Test Case -



2. QEMU VM Not-Running Sysbench CPU Test Case -



3. Docker Container Running Sysbench CPU Test Case -



4. Docker Container Not-Running Sysbench CPU Test Case -

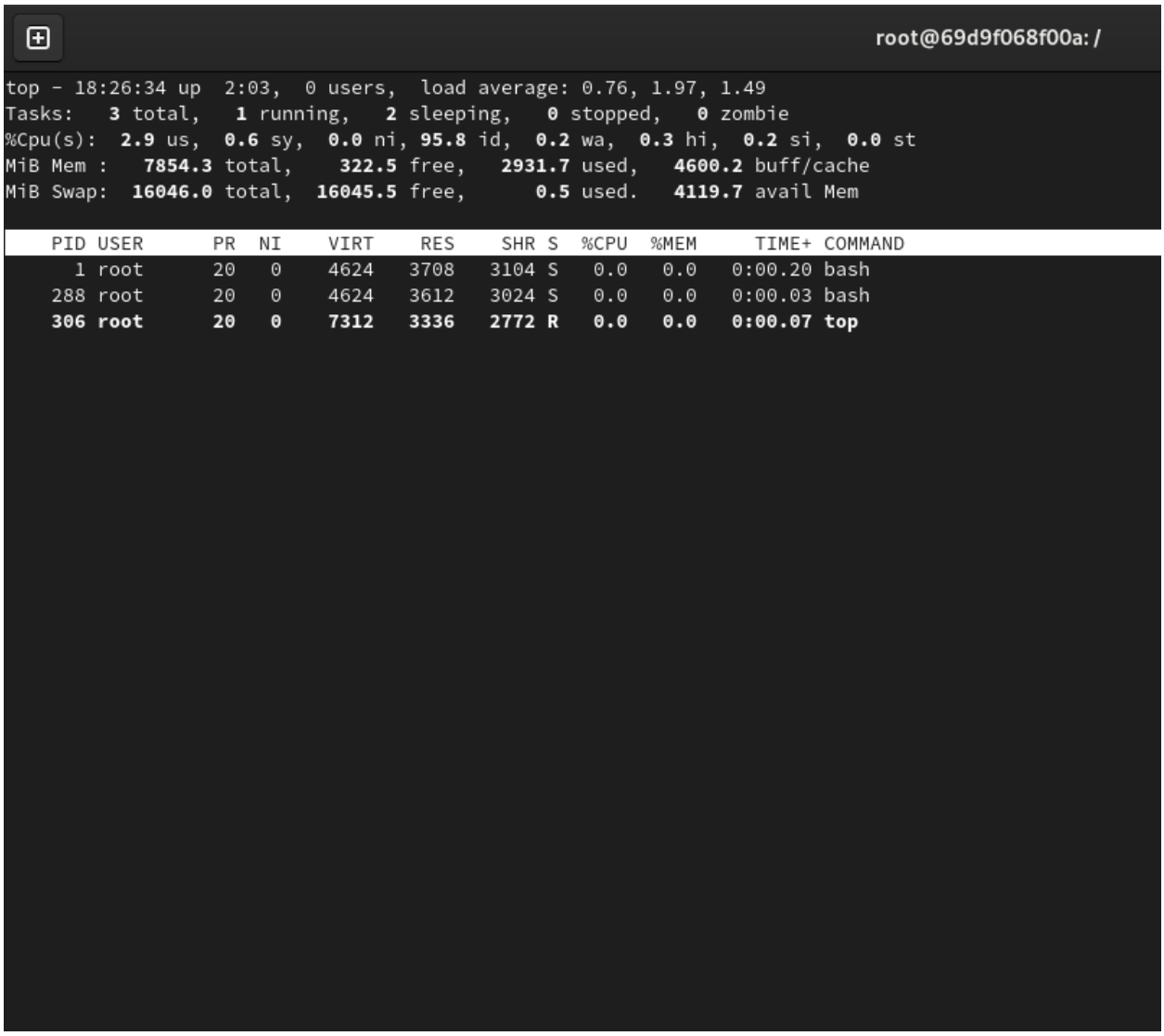


Table of comparison between above four cases -

1. **Docker Container CPU -**

	Sysbench Running	Sysbench Not-Running
User level CPU usage %	57.9	2.9
Kernel level CPU usage %	2.2	0.6
Idle CPU %	38.3	95.8

2. **Host OS CPU Usage - Docker Container -**

	Sysbench Running	Sysbench Not-Running
User level CPU usage %	57.1	0.2
Kernel level CPU usage %	1.2	0.3
Idle CPU %	40.9	99.3

3. **Host OS CPU Usage - QEMU VM -**

	Sysbench Running	Sysbench Not-Running
User level CPU usage %	53.7	7.1
Kernel level CPU usage %	1.0	2.4
Idle CPU %	44.7	89.4

Findings and Conclusion -

1. When the sysbench test is running inside a docker container, the user level cpu usage and kernel level cpu usage increases more than when the sysbench is not running. Moreover, the idle time decreases when sysbench is running in a docker container.

2. When the sysbench test is running in a docker container, the host os cpu usage goes up. The kernel level cpu usage goes from 0.3 to 1.2 when docker container starts running sysbench test and also the idle time decreases. This shows that the docker containers use the kernel level CPUs of host os.

3. When the sysbench test is running in a qemu vm, the host OS kernel-level cpu usage doesn't go up, but user-level goes up. This shows that the qemu vm does not use the kernel level CPUs of host os.

IO Utilization -

Real-time disk utilization is observed using the `iotop` tool. The installation of iotop requires to run below command in both docker container and qemu vm -

$ sudo apt install systat

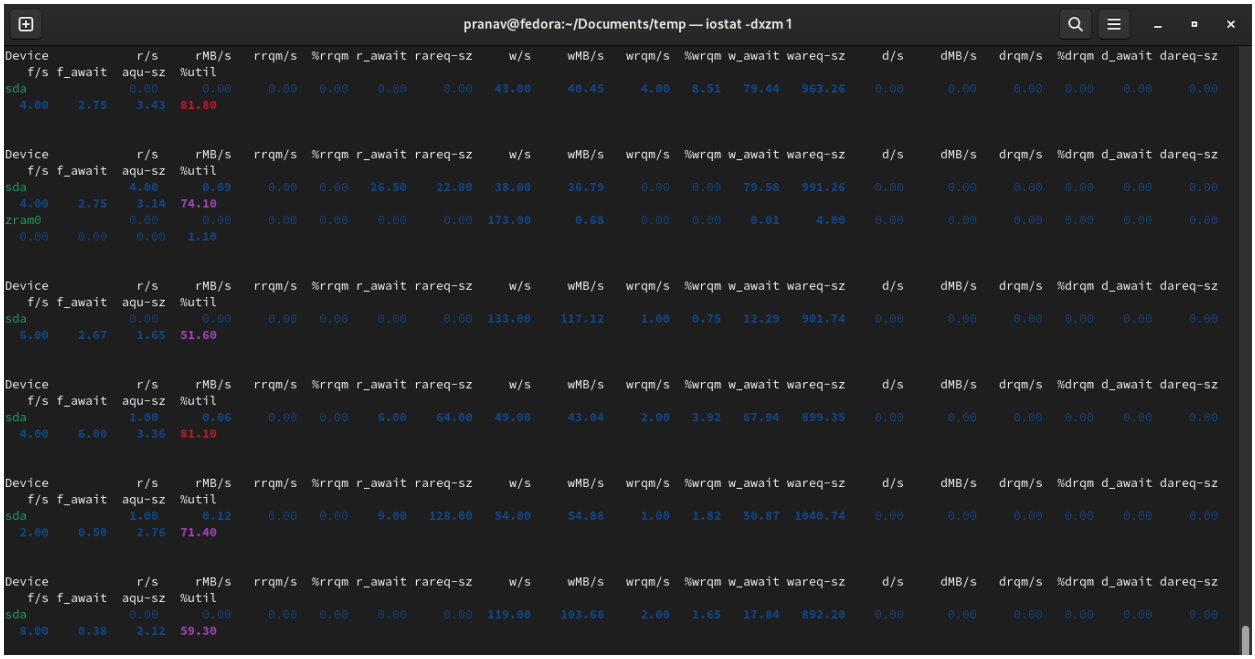
Using this tool, the disk utilization of Host OS while running Docker Container and QEMU VM is observed during fileio test in docker container using following command -

$ sudo iostat -dxzm 1

Test Case Commands for fileio -

1. **Prepare Stage -**
   $ sysbench --threads=16 fileio --file-total-size=4G --file-test-mode=rndrw prepare

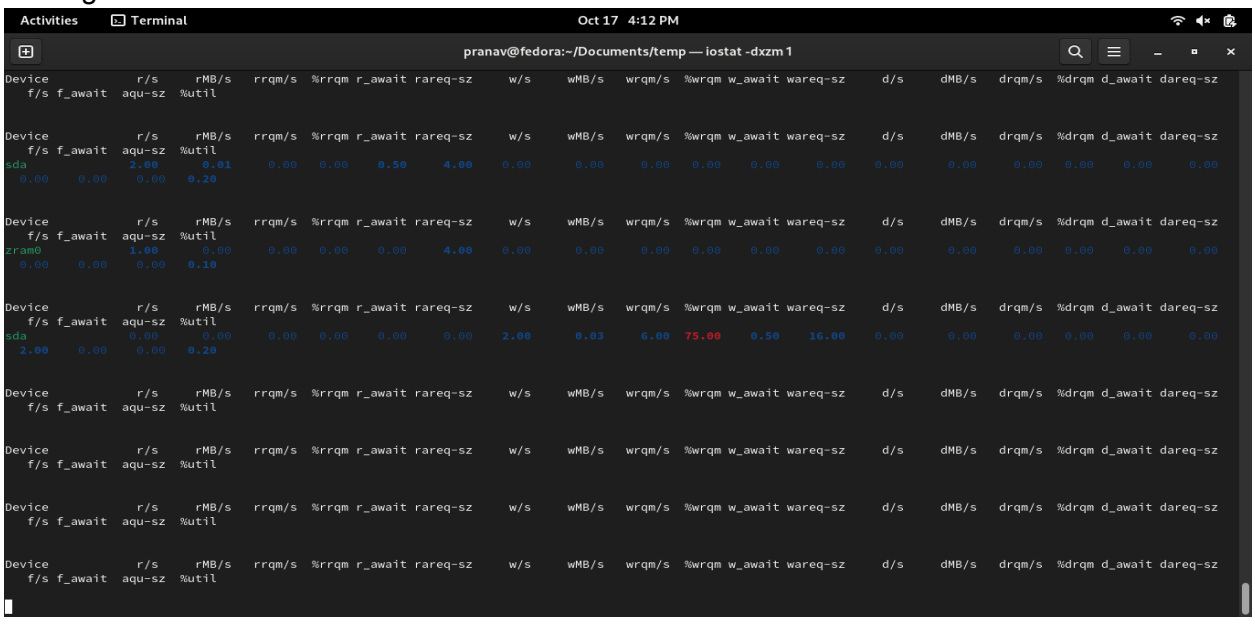
   Screenshot of Disk IO Utilization, latency, throughput of host os when above command is running in QEMU VM -



Screenshot of Disk IO Utilization, latency, throughput of host os when above command is running in Docker Container -

2. **Run Stage -**
$ sysbench --threads=16 fileio --file-total-size=4G --file-test-mode=rndrw run

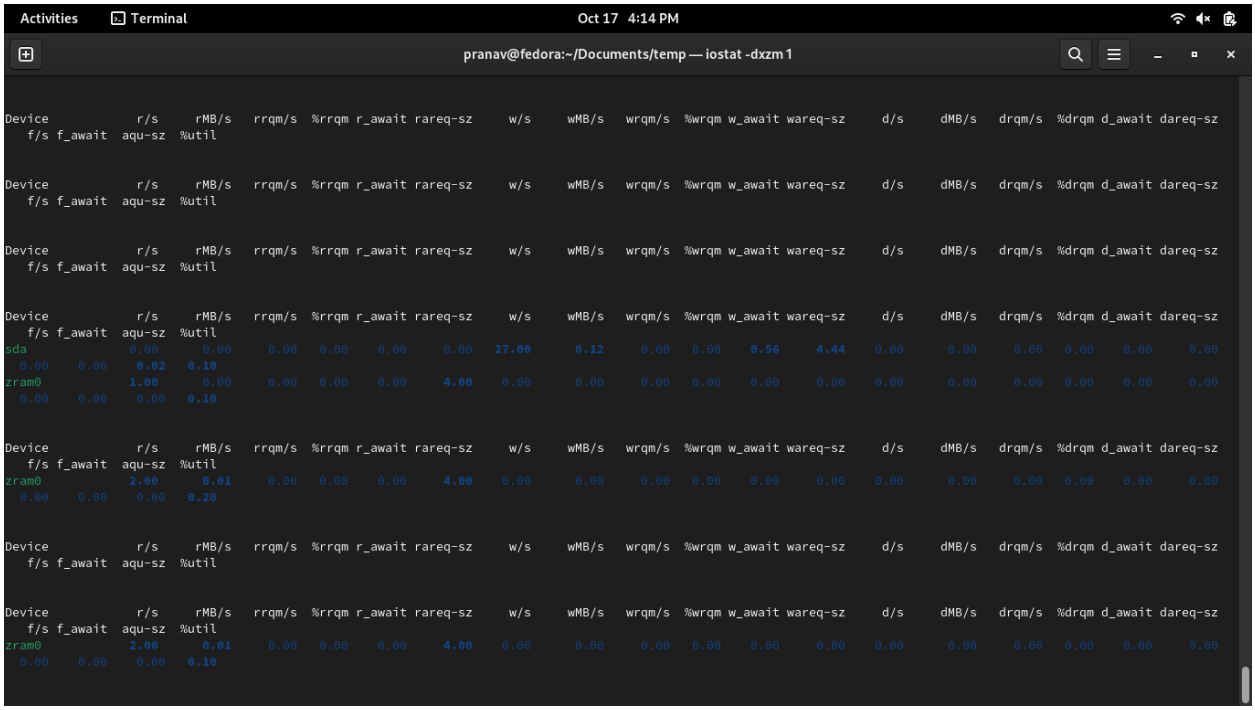
Screenshot of Disk IO Utilization, latency, throughput of host os when above command is running in QEMU VM -



Screenshot of Disk IO Utilization, latency, throughput of host os when above command is running in Docker Container -

3. **Cleanout Stage -**
   $ sysbench --threads=16 fileio --file-total-size=4G --file-test-mode=rndrw cleanup

Screenshot of Disk IO Utilization, latency, throughput of host os when above command is running in QEMU VM -



Screenshot of Disk IO Utilization, latency, throughput of host os when above command is running in Docker Container -

Table of I/O Throughput, I/O Latency, and I/O Disk Utilization Host OS in case of Docker Container based on above screenshots -

	I/O Throughput	I/O Latency	I/O Disk Utilization
Prepare Stage	43.04	6.00	81.10
Run Stage	0.03	0.00	0.20
Cleanup Stage	0.12	0.56	0.10

Table of I/O Throughput, I/O Latency, and I/O Disk Utilization Host OS in case of QEMU VM based on above screenshots -

	I/O Throughput	I/O Latency	I/O Disk Utilization
Prepare Stage	98.23	8.00	93.20
Run Stage	0.50	0.05	0.20
Cleanup Stage	0.00	0.00	0.20

Findings and Conclusion -

1. The host OS disk utilization while running FILEIO test cases of containers was higher than that of QEMU VM.

2. The I/O Throughput, I/O Latency, and I/O Disk Utilization vary based on which stage of test they are captured. The Prepare Stage has the highest value for all three parameters, then comes the Run Stage, and then the Cleanup Stage.

Automation

Vagrant File -

```
Vagrant.configure("2") do |config|
  # The most common configuration options are documented and commented below.
  # For a complete reference, please see the online documentation at
  # https://docs.vagrantup.com.

  # Every Vagrant development environment requires a box. You can search for
  # boxes at https://vagrantcloud.com/search.
  config.vm.box = "bento/ubuntu-20.04-live"

  # Provider Settings
  config.vm.provider "virtualbox" do |vb|
          vb.memory = 2048
          vb.cpus = 2
  end

  # Folder Settings
  config.vm.synced_folder ".", "/vagrant_data"

  # Provision Settings
  config.vm.provision "shell", path: "vagrant_script.sh"

end
```

Dockerfile -

```
FROM pranav2306/sysbench-ubuntu:version1

COPY docker_script.sh /docker_script.sh
COPY cpu_test.sh /cpu_test.sh
COPY fileio_test.sh /fileio_test.sh

RUN chmod +x docker_script.sh
RUN chmod +x cpu_test.sh
RUN chmod +x fileio_test.sh

ENTRYPOINT bash docker_script.sh
```

Resources

- **[MAIN LINK]** The link to the GitHub repository to access the homework - https://github.com/panu2306/cloud-computing-course/tree/main/homeworks/hw1

- The link to the docker image of created image in this experiment - https://hub.docker.com/repository/docker/pranav2306/sysbench-ubuntu/
  Or
  simply pull using -
  $ docker pull pranav2306/sysbench-ubuntu:version1

- The link for Vagrantfile - https://github.com/panu2306/cloud-computing-course/blob/main/homeworks/hw1/qemu/Vagrantfile

- The link for Dockerfile - https://github.com/panu2306/cloud-computing-course/blob/main/homeworks/hw1/docker/Dockerfile

- The link for CPU Tests shell script - https://github.com/panu2306/cloud-computing-course/blob/main/homeworks/hw1/shell_scripts/cpu_test.sh

- The link for FILEIO Tests shell script - https://github.com/panu2306/cloud-computing-course/blob/main/homeworks/hw1/shell_scripts/fileio_test.sh