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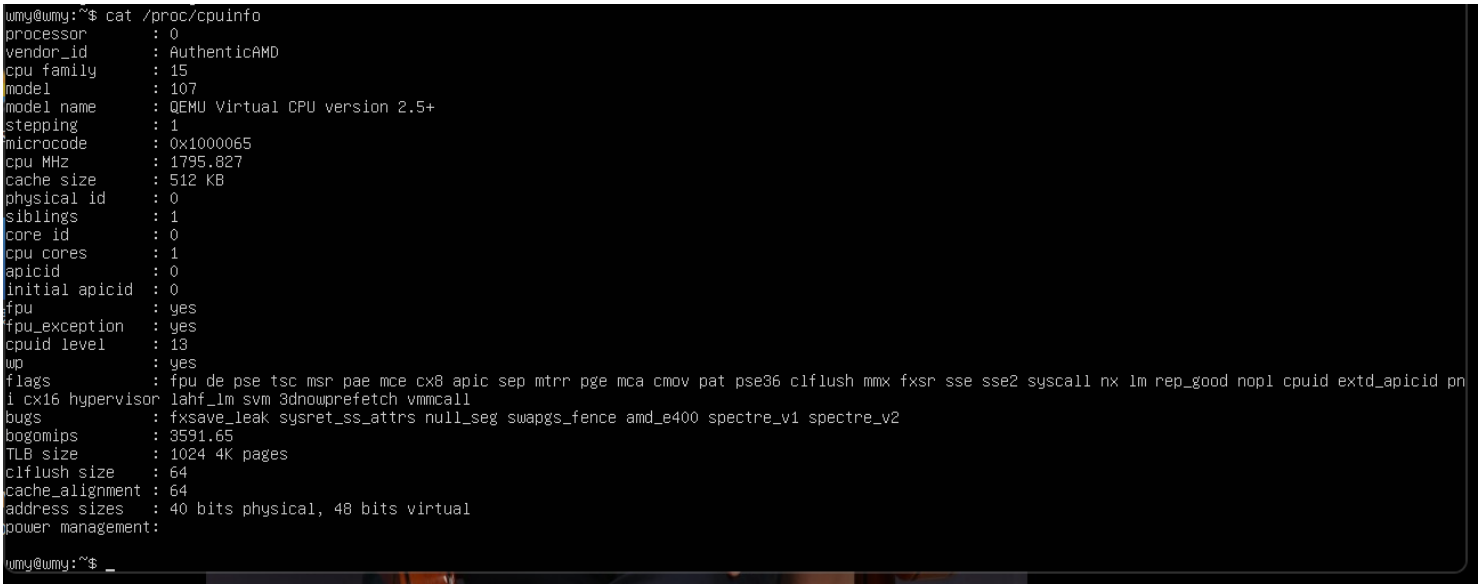
COEN 241 Cloud Computing

HW1

Detailed configurations:

Host System configuration:
Laptop name: ThinkPad T480
OS = Microsoft Windows 11
CPU = Intel(R) Core(TM) i5-8250U CPU @ 1.60GHz 1.80 GHz
Cores = 4
RAM = 8GB
Storage = 1TB

QEMU configuration:



OS = Ubuntu 20.04.5
CPU = QEMU
Core = 1
RAM = 2GB
Storage = 10GB

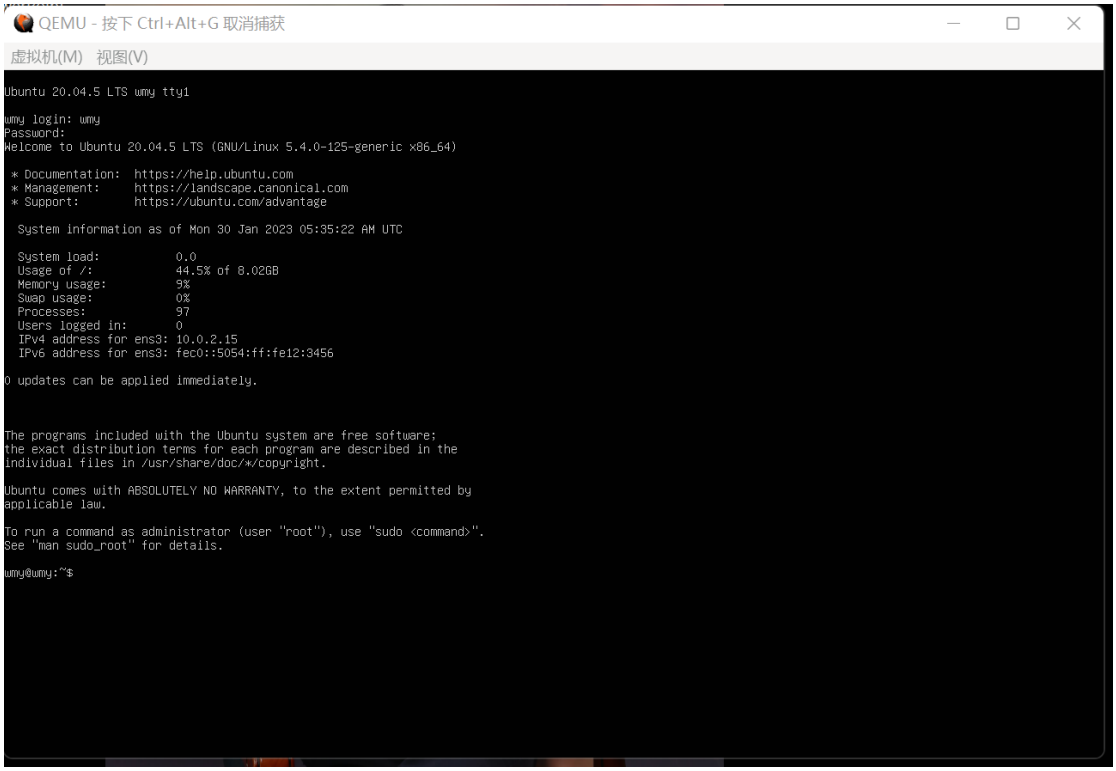
Docker configurations:
OS = Ubuntu 20.04.5
Core = 1
RAM = 2GB
Storage = 20GB

Main steps to enable a QEMU VM:

1. Go to Windows PowerShell and type the following command:
   $ sudo apt-get install qemu
2. We can then create the QEMU Image by running the following command:
   $ sudo qemu-img create ubuntu.img 10G -f qcow2

After created the image, we can use the command “ls” to check whether is was created successfully or not.

3. Given the QEMU image, we could install the VM using the command below:
   sudo qemu-system-x86_64 -m 2046 -hda ubuntu.img
4. Finally, we could find that the Ubuntu virtual machine run on HOST OS with Type1 Hypervisor as QEMU:



Now, we could type commands under this QEMU!

Detailed QEMU commands:
Source from QEMU Documentation: https://qemu.weilnetz.de/doc/6.0/

-h
Display help and exit

-version
Display version information and exit

-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.

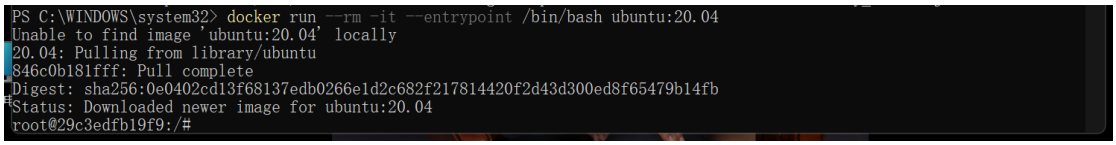
-cpu model
Select CPU model (-cpu help for list and additional feature selection)

-accel name[,prop=value[,...]]
This is used to enable an accelerator. Depending on the target architecture, kvm, xen, hax, hvf, 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.

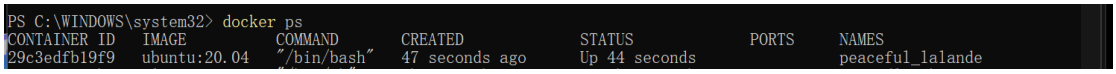
-smp
[cpus=]n[,cores=cores][,threads=threads][,dies=dies][,sockets=sockets][,maxcpus=maxcpus]
Simulate an SMP system with n CPUs. On the PC target, up to 255 CPUs are supported. On Sparc32 target, Linux limits the number of usable CPUs to 4. For the PC target, the number of cores per die, the number of threads per cores, the number of dies per packages and the total number of sockets can be specified. Missing values will be computed. If any on the three values is given, the total number of CPUs n can be omitted. maxcpus specifies the maximum number of hotpluggable CPUs.

Main steps to enable the Docker container:

1. Download the Docker Desktop from website https://docs.docker.com/desktop/windows/install/
2. Install the Docker Desktop on the host machine
3. After the installation, run the Docker application to start the Docker engine
4. Install Sysbench on Ubuntu:
   $ sudo apt update
   $ sudo apt install sysbench
   Create a new image:
   $ docker run --rm -it --entrypoint /bin/sh ubuntu:20.04

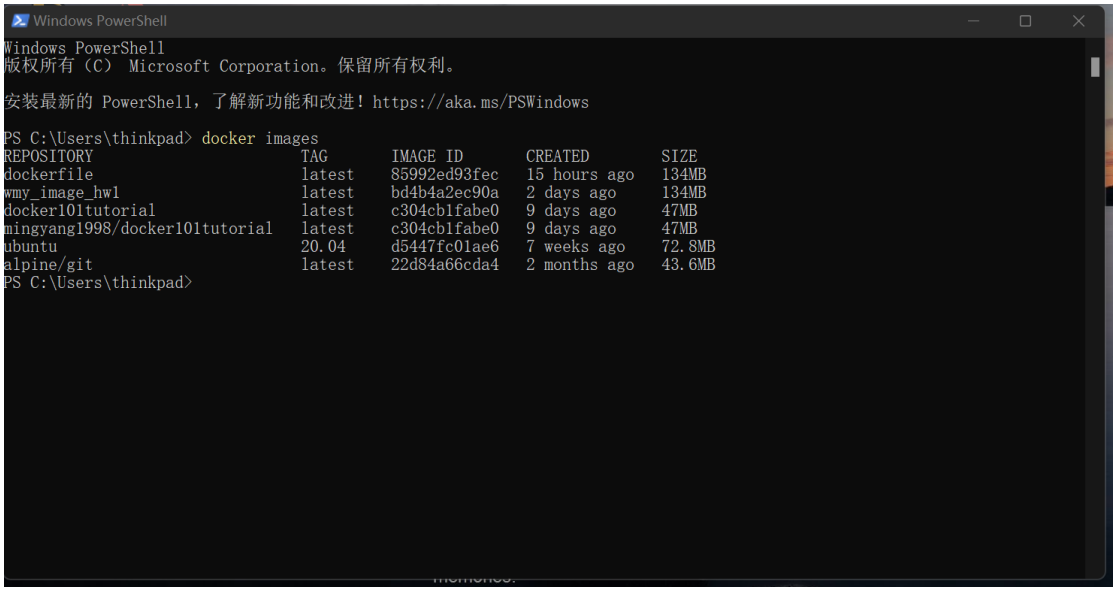


5. On another window:
   $ docker ps



$ docker commit <container_id> wmy_image_hw1

6. Check the Docker image and container history:



Docker Operations:

(1)create:

Create a Docker container from an image

(2)run:

Create a new Docker container and run it

(3)docker search + name:

Search the images that you want to find

(4)docker ps -a:

Show the containers and their ID, name and when they were created

(5)docker images:

Show the images you have and their ID

(6)build

Build Docker image from a Dockerfile

(7)docker version:

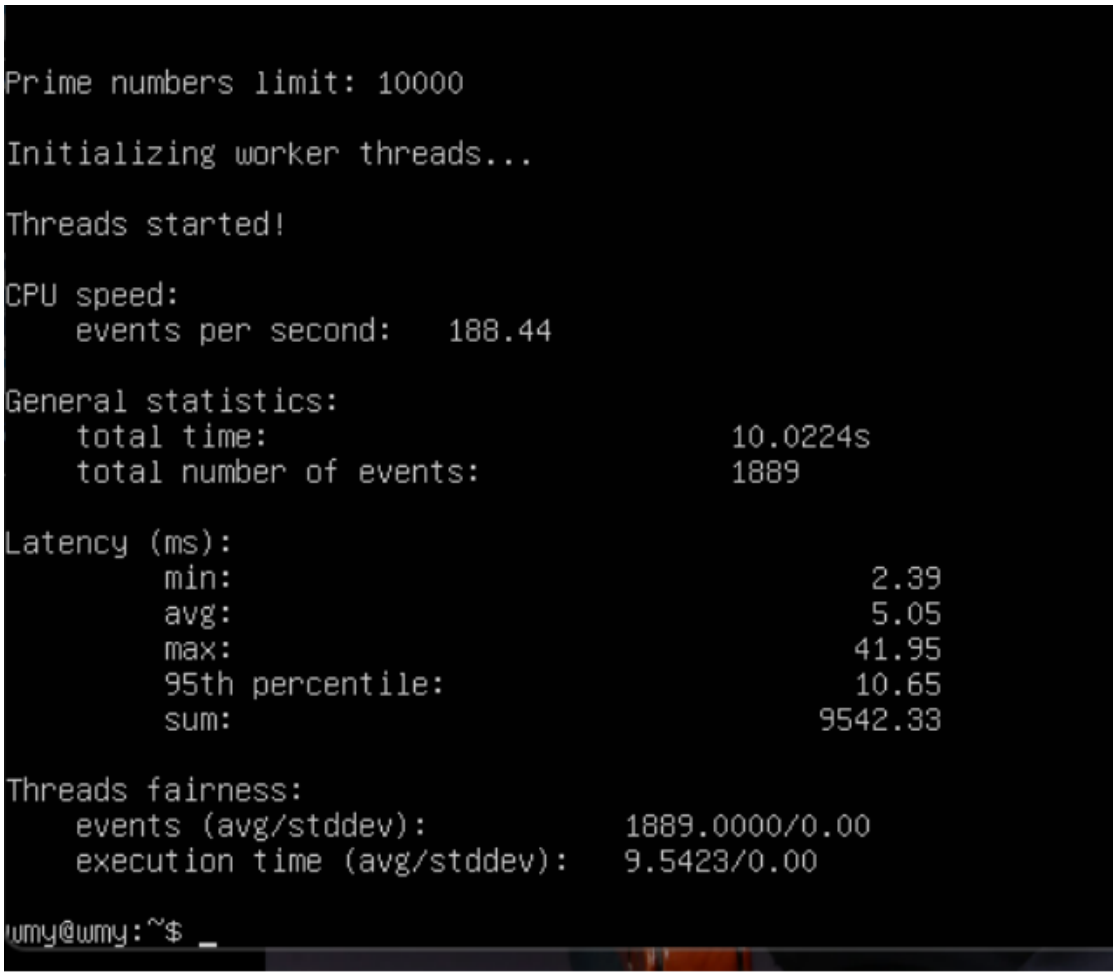
Check the version of your docker

(8)cat /etc/issue:

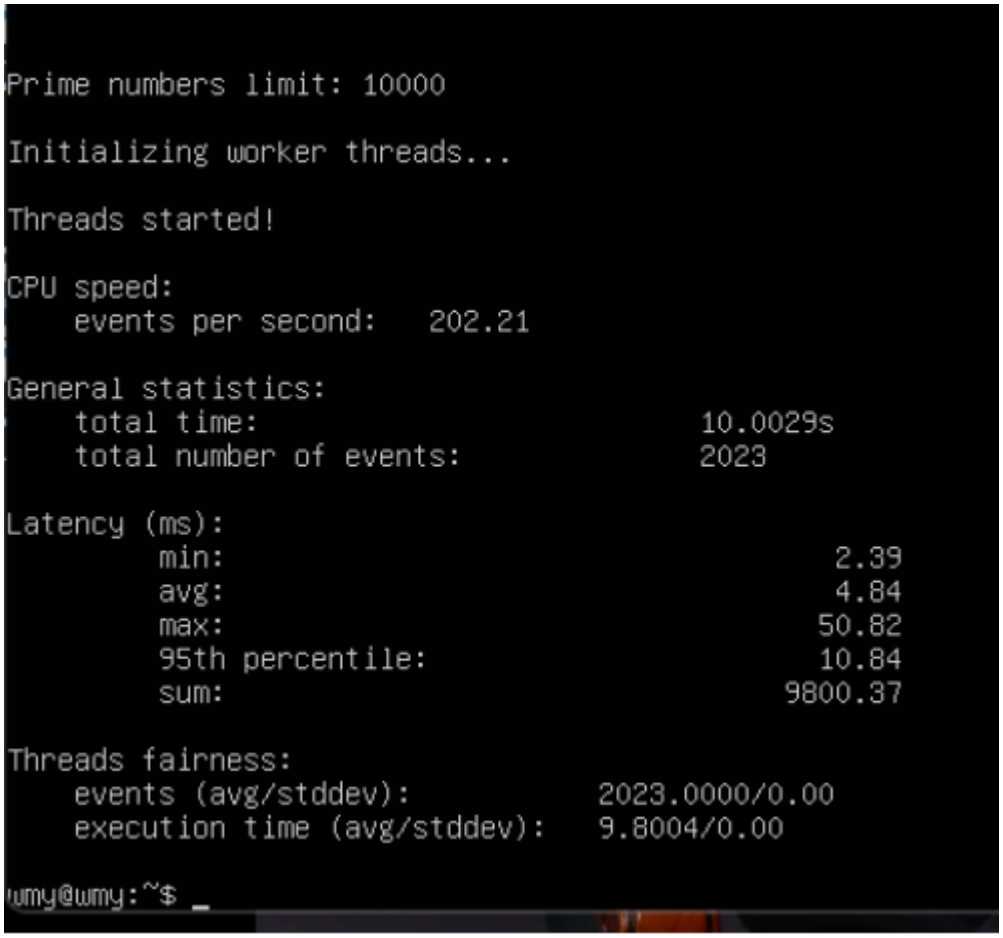
Check the Ubuntu version in the docker

CPU Experiments on QEMU:
Testing command: $ sysbench cpu --cpu-max-prime=10000 run

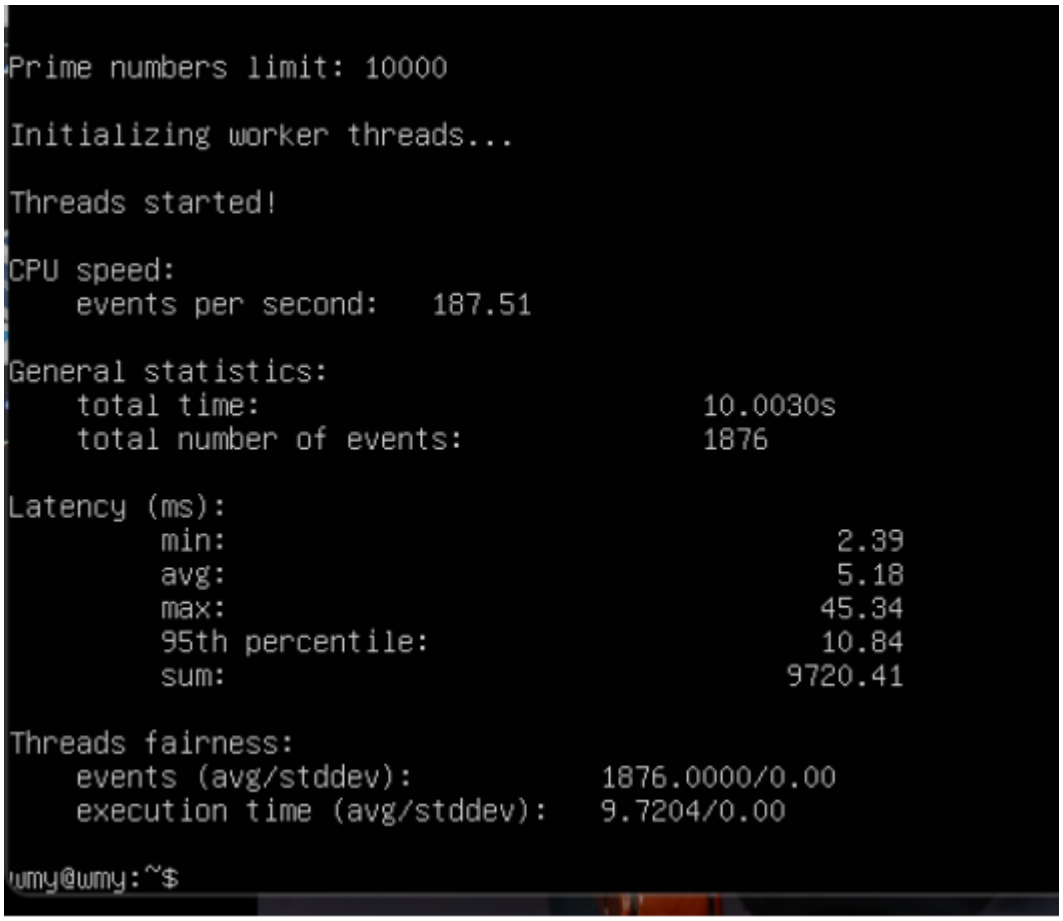
Test 1:



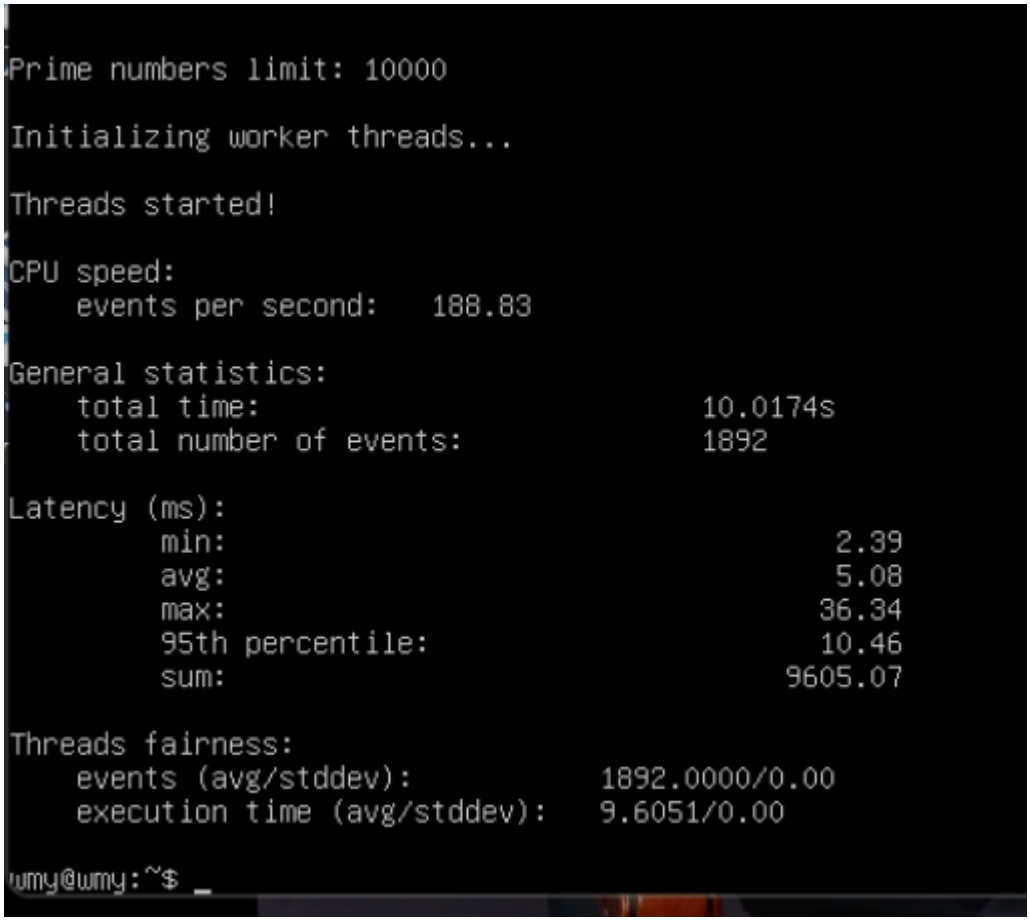
Test 2:


Prime numbers limit: 10000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 202.21
General statistics:
total time: 10.0029s
total number of events: 2023
Latency (ms):
min: 2.39
avg: 4.84
max: 50.82
95th percentile: 10.84
sum: 9800.37
Threads fairness:
events (avg/stddev): 2023.0000/0.00
execution time (avg/stddev): 9.8004/0.00
wmy@wmy:~$

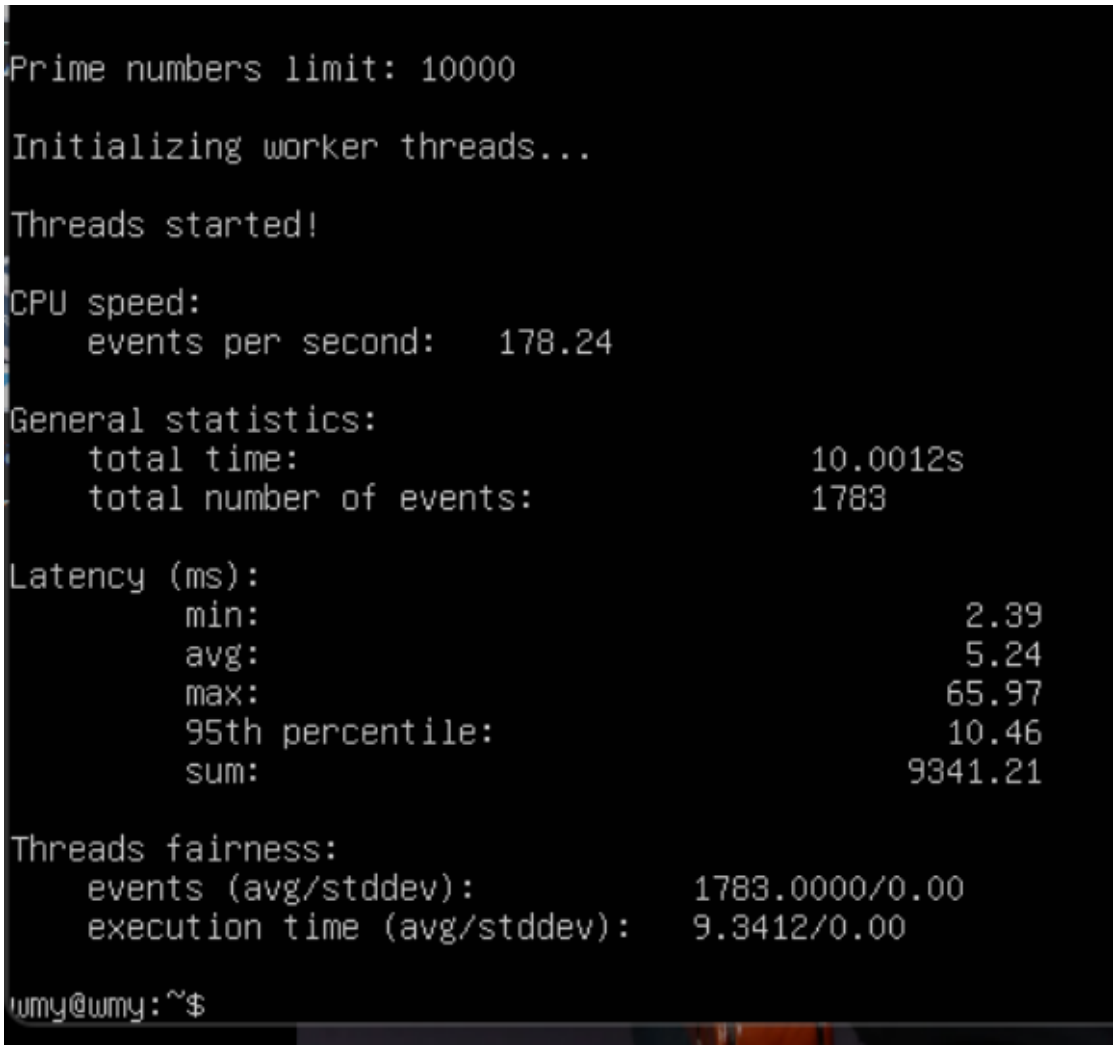
Test 3:


Prime numbers limit: 10000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 187.51
General statistics:
total time: 10.0030s
total number of events: 1876
Latency (ms):
min: 2.39
avg: 5.18
max: 45.34
95th percentile: 10.84
sum: 9720.41
Threads fairness:
events (avg/stddev): 1876.0000/0.00
execution time (avg/stddev): 9.7204/0.00
wmy@wmy:~$

Test 4:

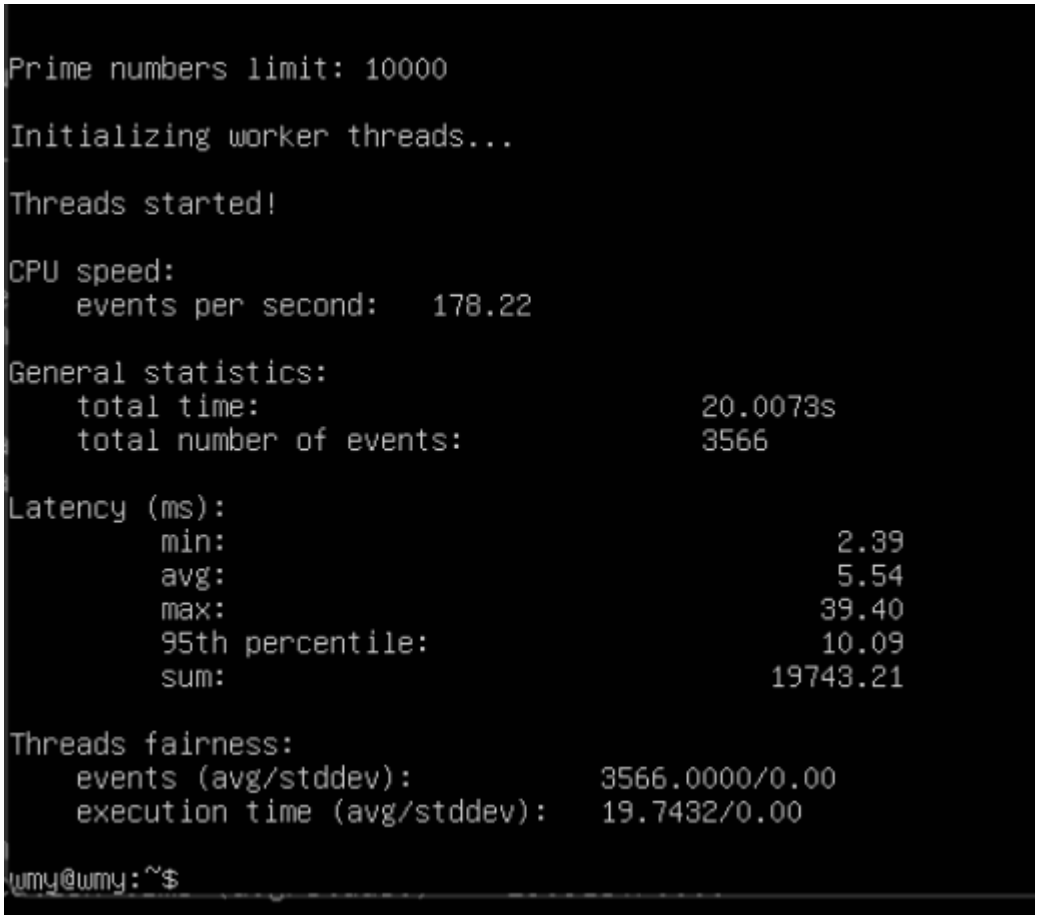

Prime numbers limit: 10000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 188.83
General statistics:
total time: 10.0174s
total number of events: 1892
Latency (ms):
min: 2.39
avg: 5.08
max: 36.34
95th percentile: 10.46
sum: 9605.07
Threads fairness:
events (avg/stddev): 1892.0000/0.00
execution time (avg/stddev): 9.6051/0.00
umy@umy:~$

Test 5:

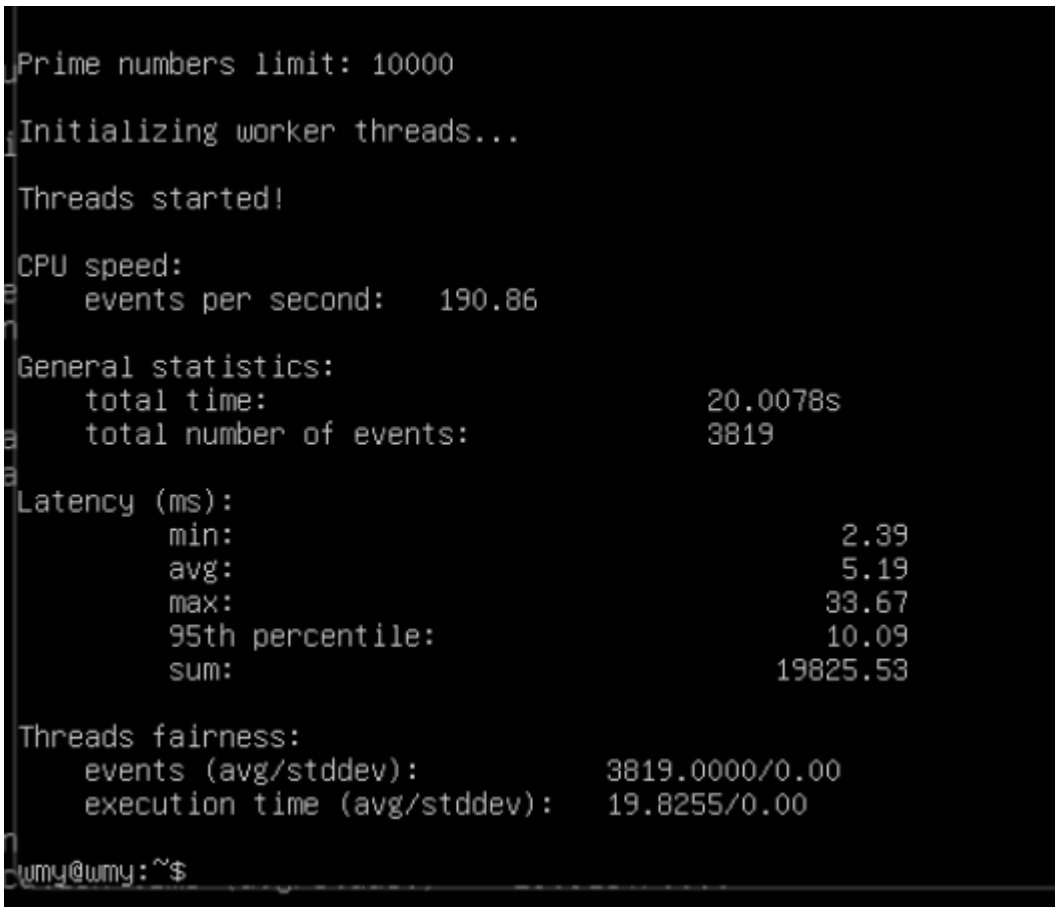

Prime numbers limit: 10000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 178.24
General statistics:
total time: 10.0012s
total number of events: 1783
Latency (ms):
min: 2.39
avg: 5.24
max: 65.97
95th percentile: 10.46
sum: 9341.21
Threads fairness:
events (avg/stddev): 1783.0000/0.00
execution time (avg/stddev): 9.3412/0.00
wmy@wmy:~$

Testing command: $ sysbench cpu --cpu-max-prime=10000 --max-time=20 run

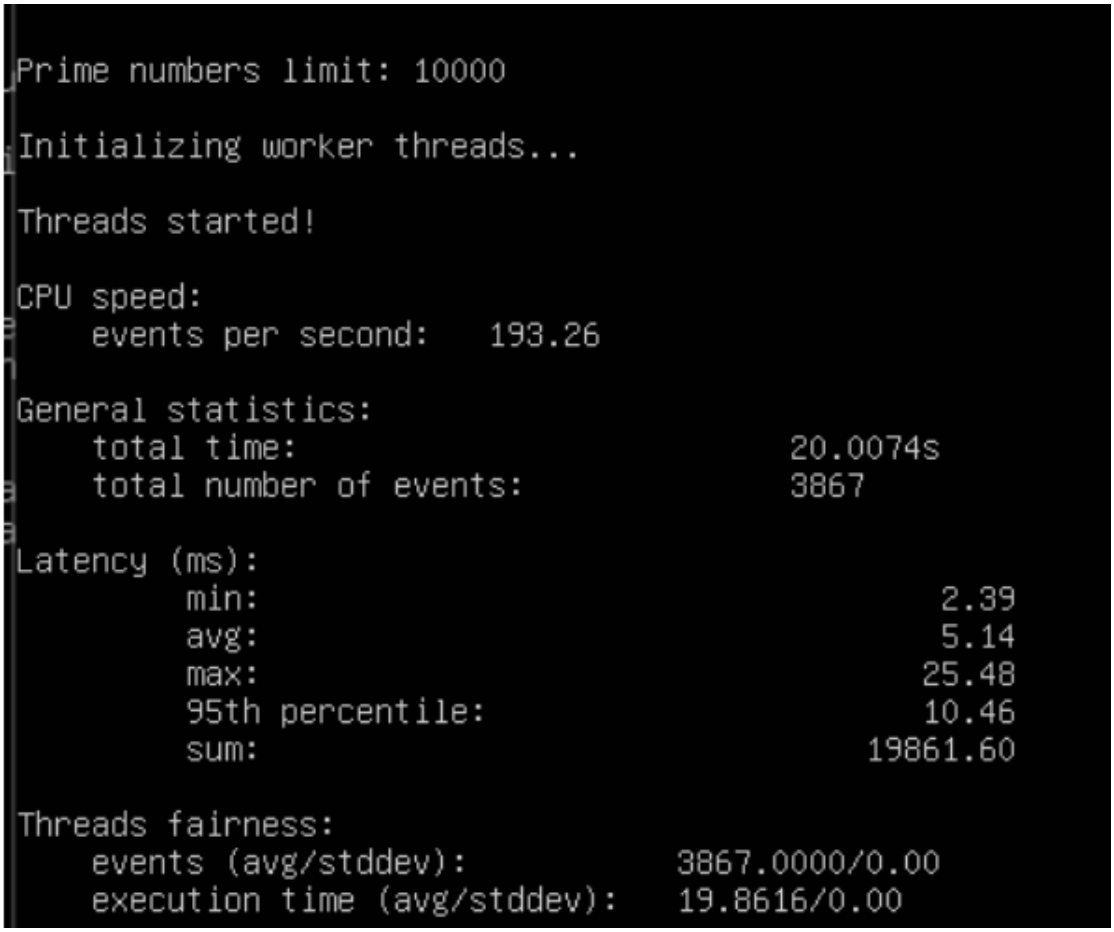
Test 1:



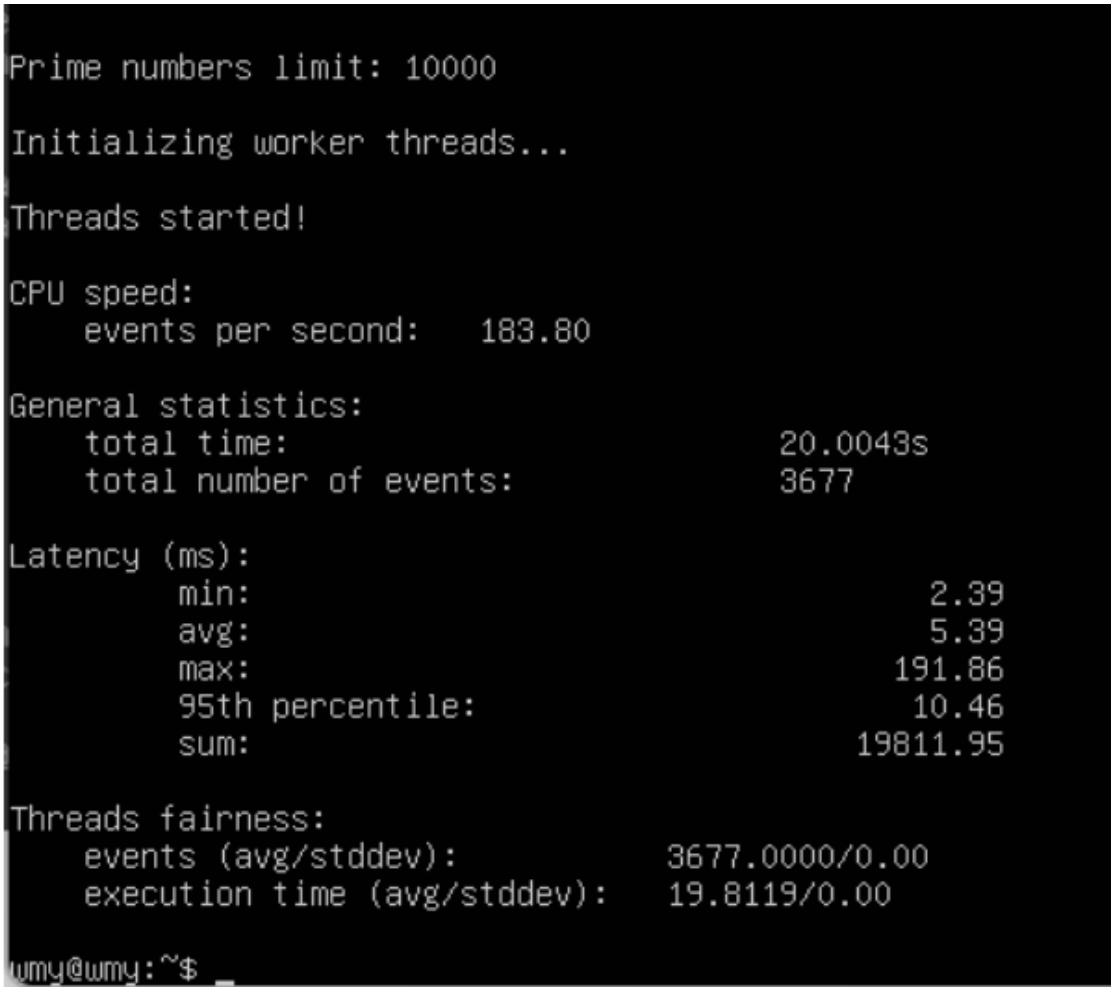
Test 2:


Prime numbers limit: 10000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 190.86
General statistics:
total time: 20.0078s
total number of events: 3819
Latency (ms):
min: 2.39
avg: 5.19
max: 33.67
95th percentile: 10.09
sum: 19825.53
Threads fairness:
events (avg/stddev): 3819.0000/0.00
execution time (avg/stddev): 19.8255/0.00
wmy@wmy:~$

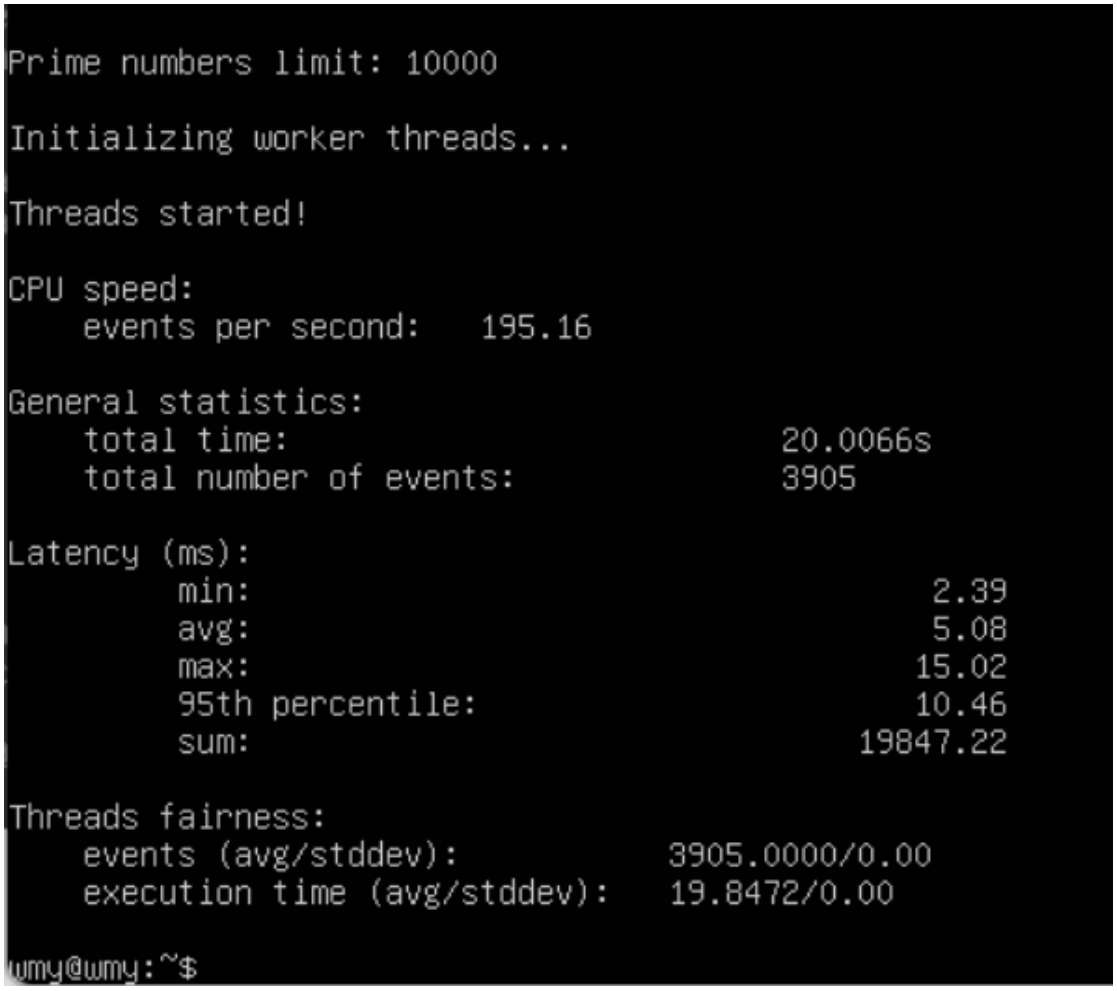
Test 3:


Prime numbers limit: 10000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 193.26
General statistics:
total time: 20.0074s
total number of events: 3867
Latency (ms):
min: 2.39
avg: 5.14
max: 25.48
95th percentile: 10.46
sum: 19861.60
Threads fairness:
events (avg/stddev): 3867.0000/0.00
execution time (avg/stddev): 19.8616/0.00

Test 4:

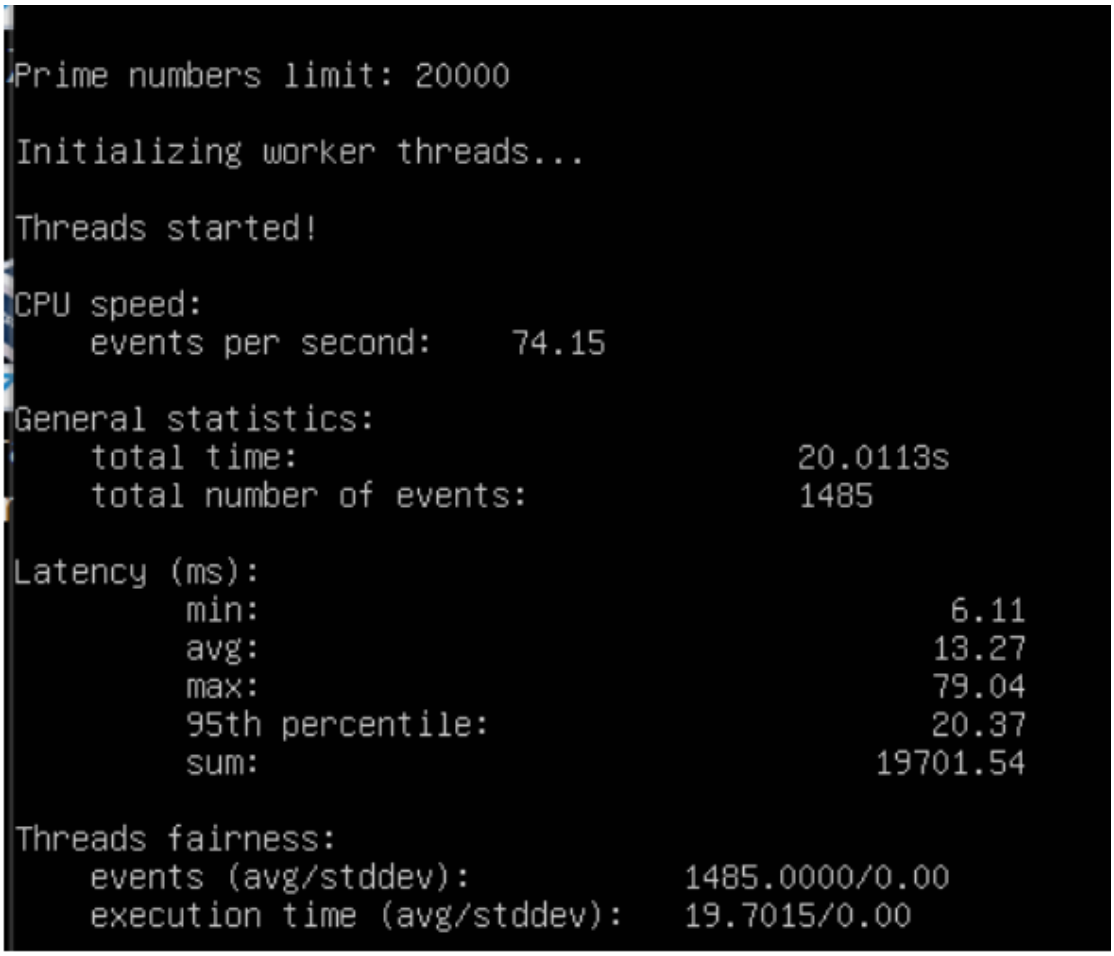

Prime numbers limit: 10000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 183.80
General statistics:
total time: 20.0043s
total number of events: 3677
Latency (ms):
min: 2.39
avg: 5.39
max: 191.86
95th percentile: 10.46
sum: 19811.95
Threads fairness:
events (avg/stddev): 3677.0000/0.00
execution time (avg/stddev): 19.8119/0.00
wmy@wmy:~$

Test 5:

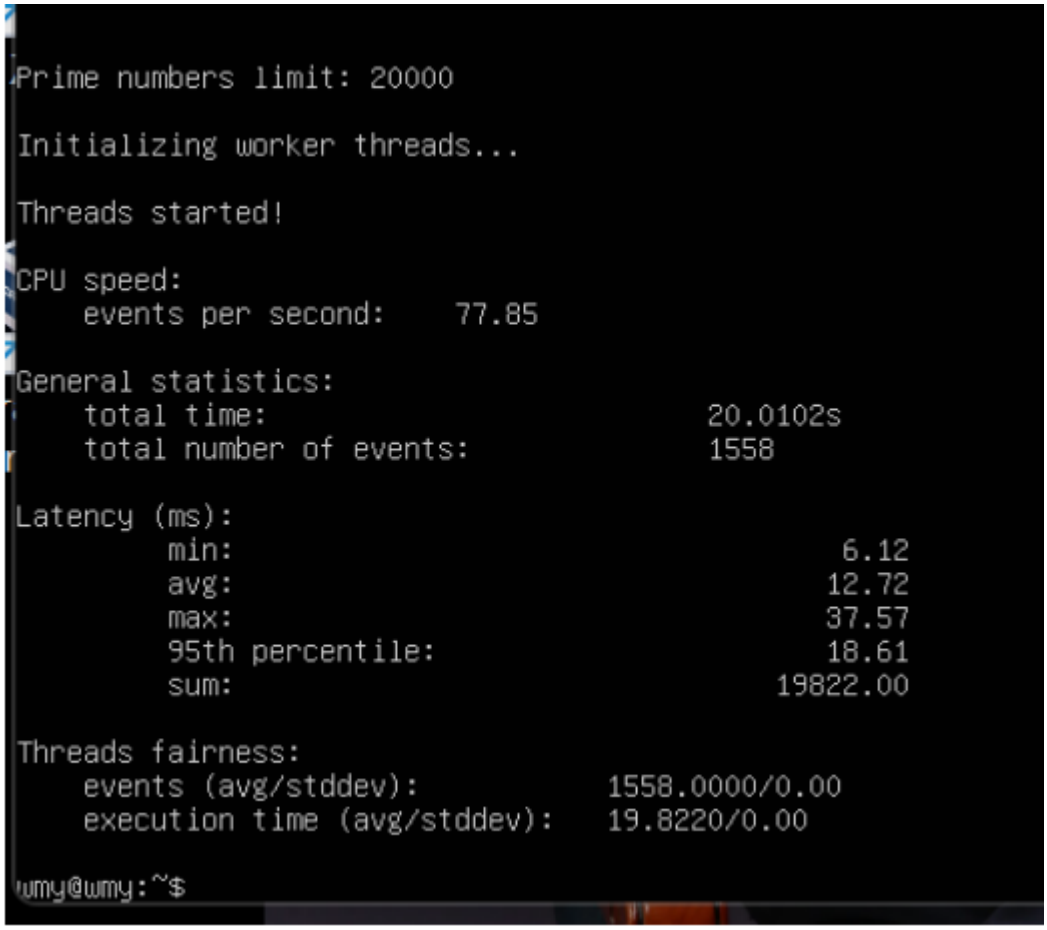

Prime numbers limit: 10000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 195.16
General statistics:
total time: 20.0066s
total number of events: 3905
Latency (ms):
min: 2.39
avg: 5.08
max: 15.02
95th percentile: 10.46
sum: 19847.22
Threads fairness:
events (avg/stddev): 3905.0000/0.00
execution time (avg/stddev): 19.8472/0.00
wmy@wmy:~$

Testing command: $ sysbench cpu --cpu-max-prime=20000 --max-time=20 run

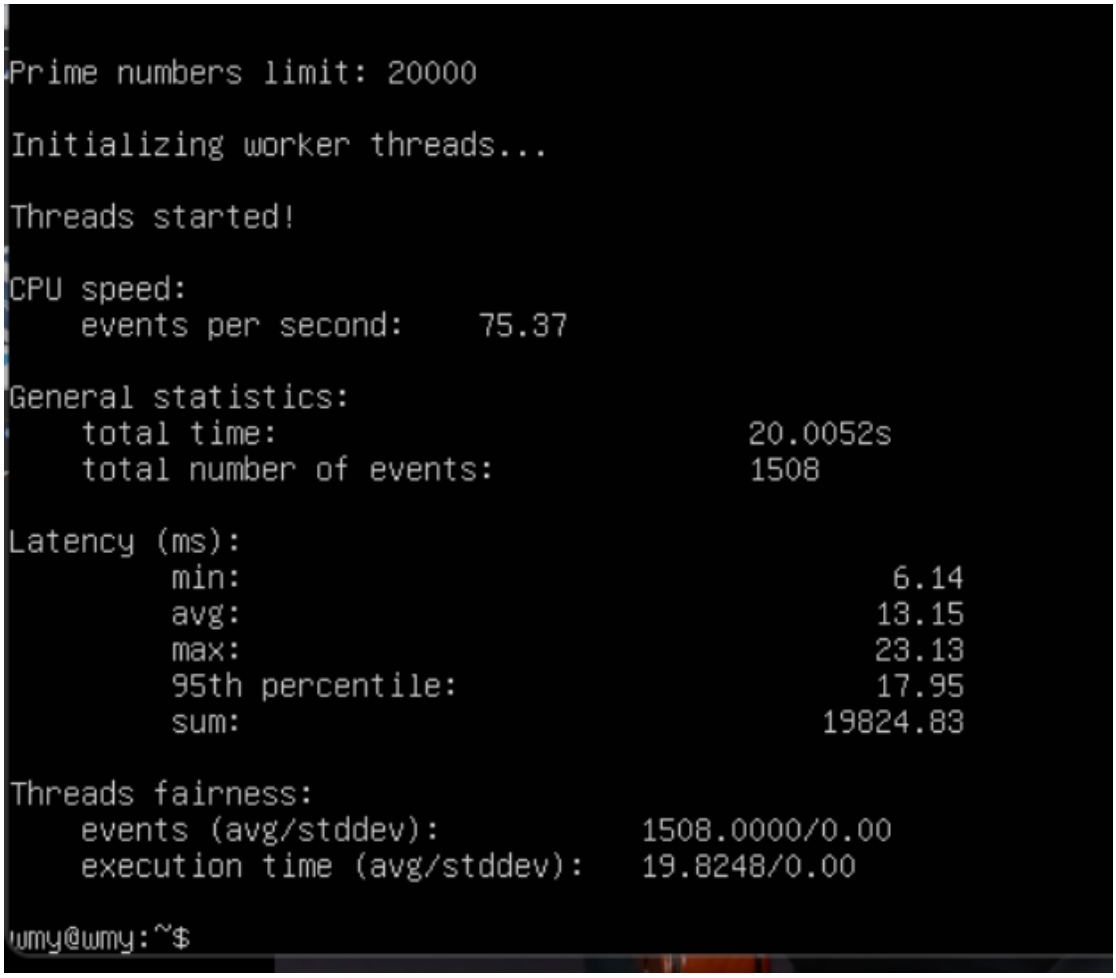
Test 1:



Test 2:


Prime numbers limit: 20000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 77.85
General statistics:
total time: 20.0102s
total number of events: 1558
Latency (ms):
min: 6.12
avg: 12.72
max: 37.57
95th percentile: 18.61
sum: 19822.00
Threads fairness:
events (avg/stddev): 1558.0000/0.00
execution time (avg/stddev): 19.8220/0.00
wmy@wmy:~$

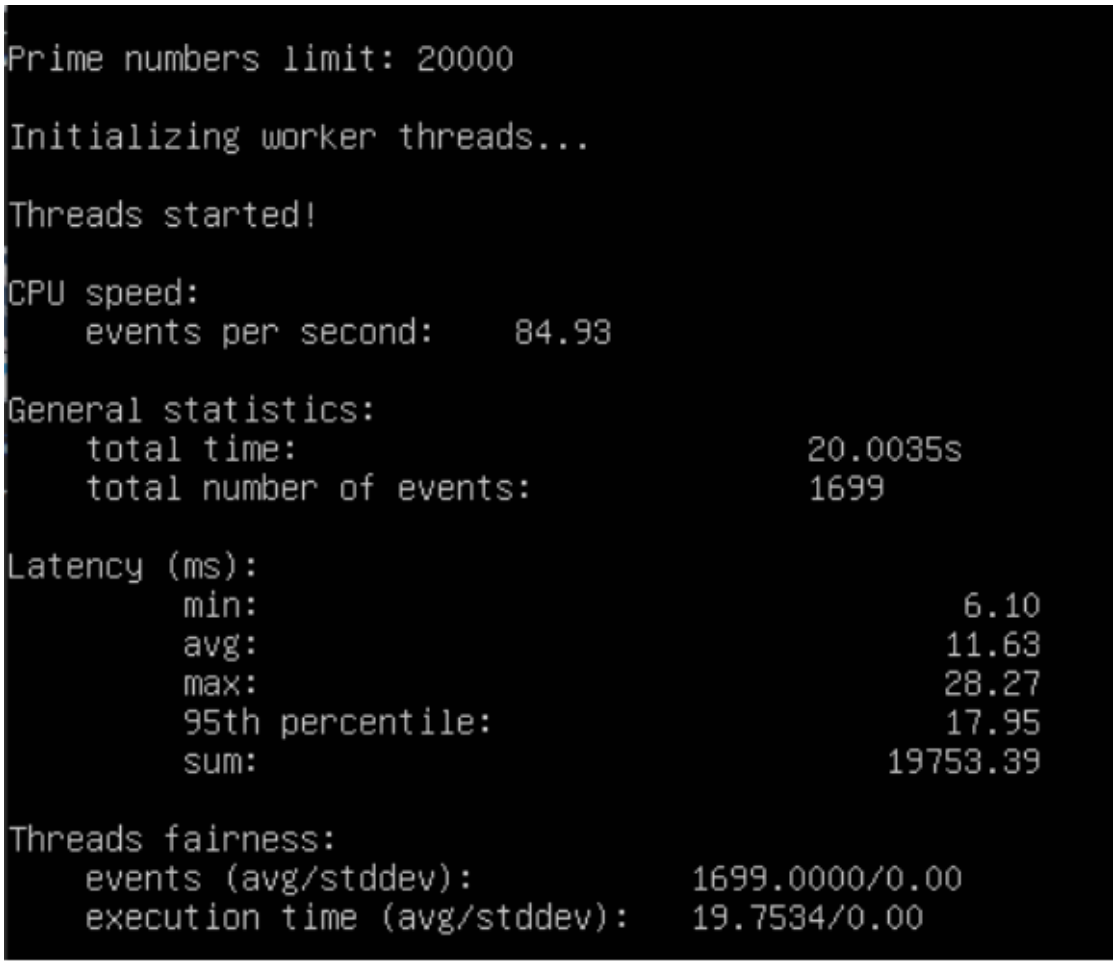
Test 3:


Prime numbers limit: 20000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 75.37
General statistics:
total time: 20.0052s
total number of events: 1508
Latency (ms):
min: 6.14
avg: 13.15
max: 23.13
95th percentile: 17.95
sum: 19824.83
Threads fairness:
events (avg/stddev): 1508.0000/0.00
execution time (avg/stddev): 19.8248/0.00
wmy@wmy:~$

Test 4:

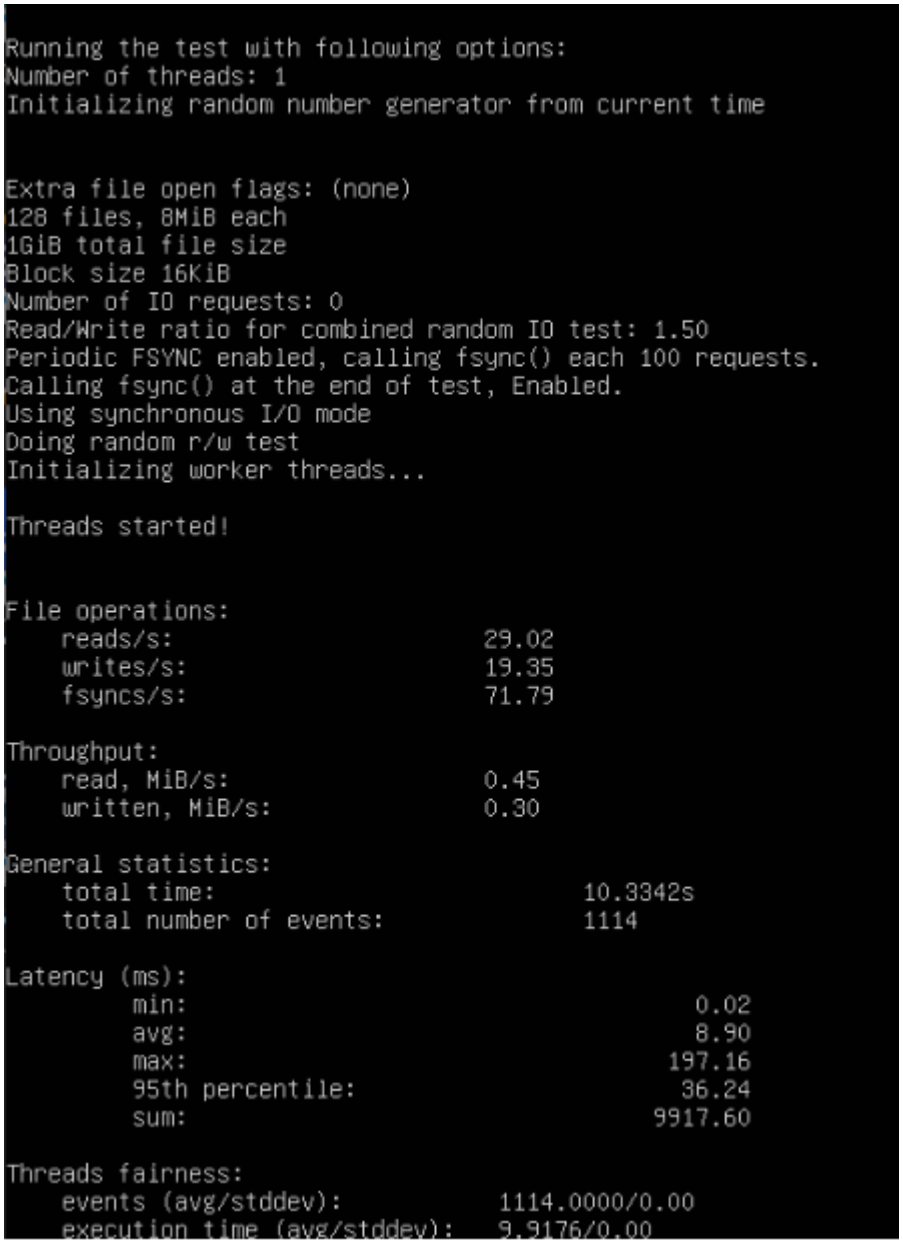

Prime numbers limit: 20000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 79.20
General statistics:
total time: 20.0121s
total number of events: 1585
Latency (ms):
min: 6.10
avg: 12.52
max: 48.69
95th percentile: 18.61
sum: 19846.83
Threads fairness:
events (avg/stddev): 1585.0000/0.00
execution time (avg/stddev): 19.8468/0.00
umy@wmy:~$

Test 5:


Prime numbers limit: 20000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 84.93
General statistics:
total time: 20.0035s
total number of events: 1699
Latency (ms):
min: 6.10
avg: 11.63
max: 28.27
95th percentile: 17.95
sum: 19753.39
Threads fairness:
events (avg/stddev): 1699.0000/0.00
execution time (avg/stddev): 19.7534/0.00

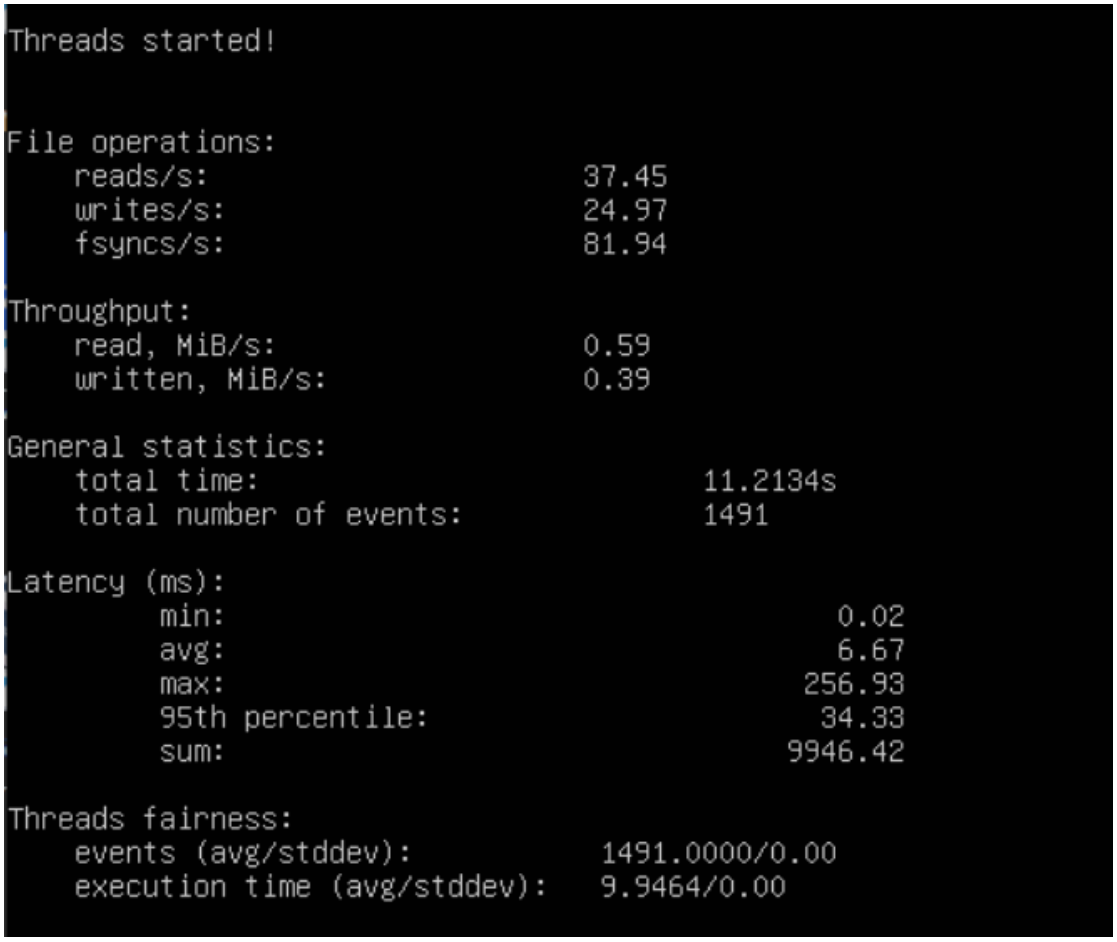
File I/O Experiments on QEMU:
Testing commands:
(1) $ sysbench fileio --file-total-size=1G --max-time=10 --max-requests=0 --file-test-mode=rndrw prepare
(2) $ sysbench fileio --file-total-size=1G --max-time=10 --max-requests=0 --file-test-mode=rndrw run
(3) $ sysbench fileio --file-total-size=1G --max-time=10 --max-requests=0 --file-test-mode=rndrw cleanup

Test 1:

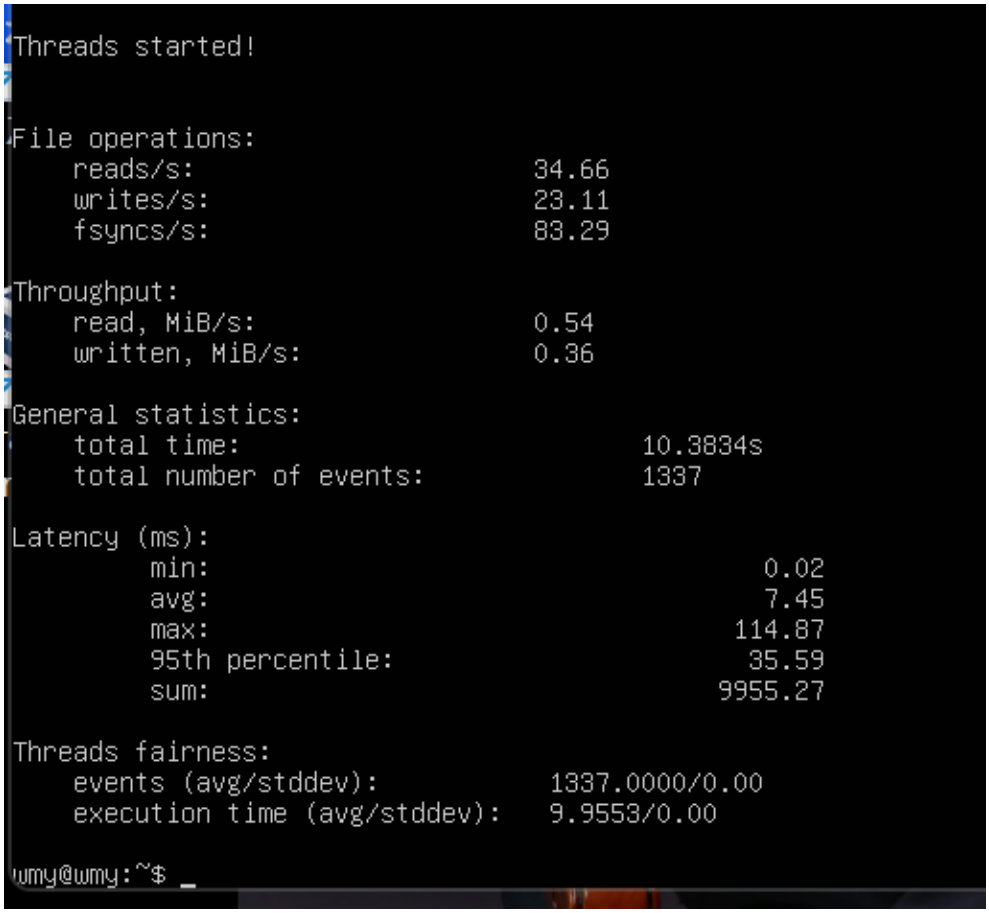


```
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time


Extra file open flags: (none)
128 files, 8MiB each
1GiB 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:                      29.02
    writes/s:                     19.35
    fsyncs/s:                     71.79

Throughput:
    read, MiB/s:                  0.45
    written, MiB/s:               0.30

General statistics:
    total time:                          10.3342s
    total number of events:              1114

Latency (ms):
         min:                                    0.02
         avg:                                    8.90
         max:                                  197.16
         95th percentile:                       36.24
         sum:                                 9917.60

Threads fairness:
    events (avg/stddev):           1114.0000/0.00
    execution time (avg/stddev):   9.9176/0.00
```

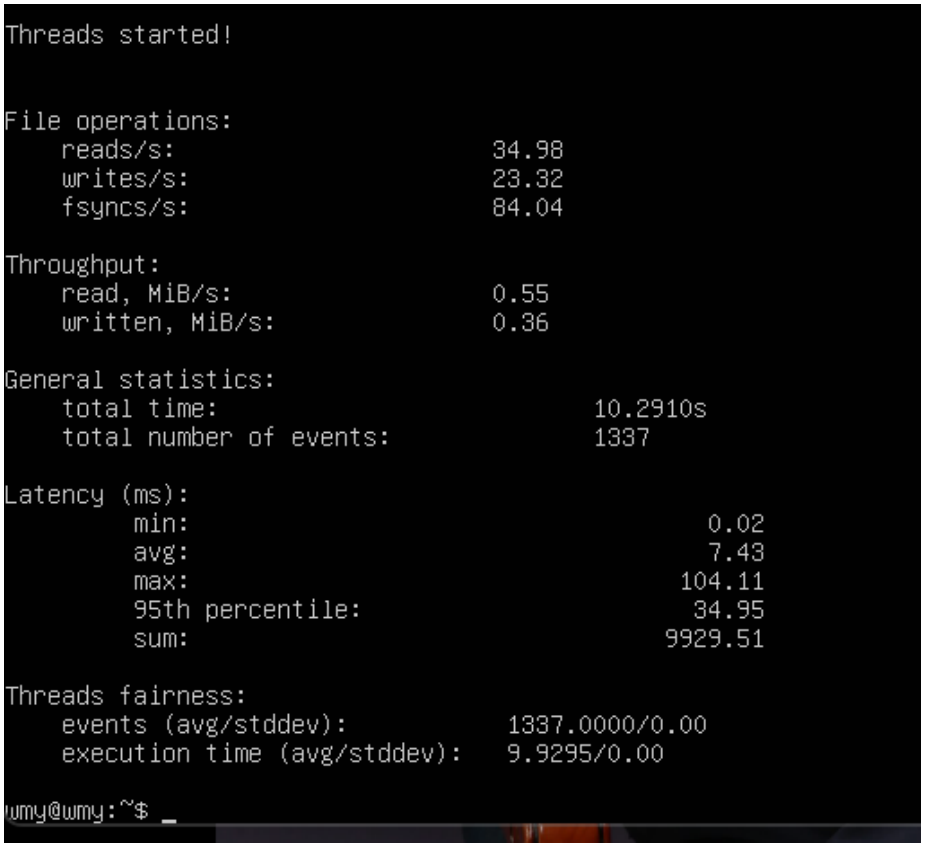
Test 2:


Threads started!
File operations:
reads/s: 37.45
writes/s: 24.97
fsyncs/s: 81.94
Throughput:
read, MiB/s: 0.59
written, MiB/s: 0.39
General statistics:
total time: 11.2134s
total number of events: 1491
Latency (ms):
min: 0.02
avg: 6.67
max: 256.93
95th percentile: 34.33
sum: 9946.42
Threads fairness:
events (avg/stddev): 1491.0000/0.00
execution time (avg/stddev): 9.9464/0.00

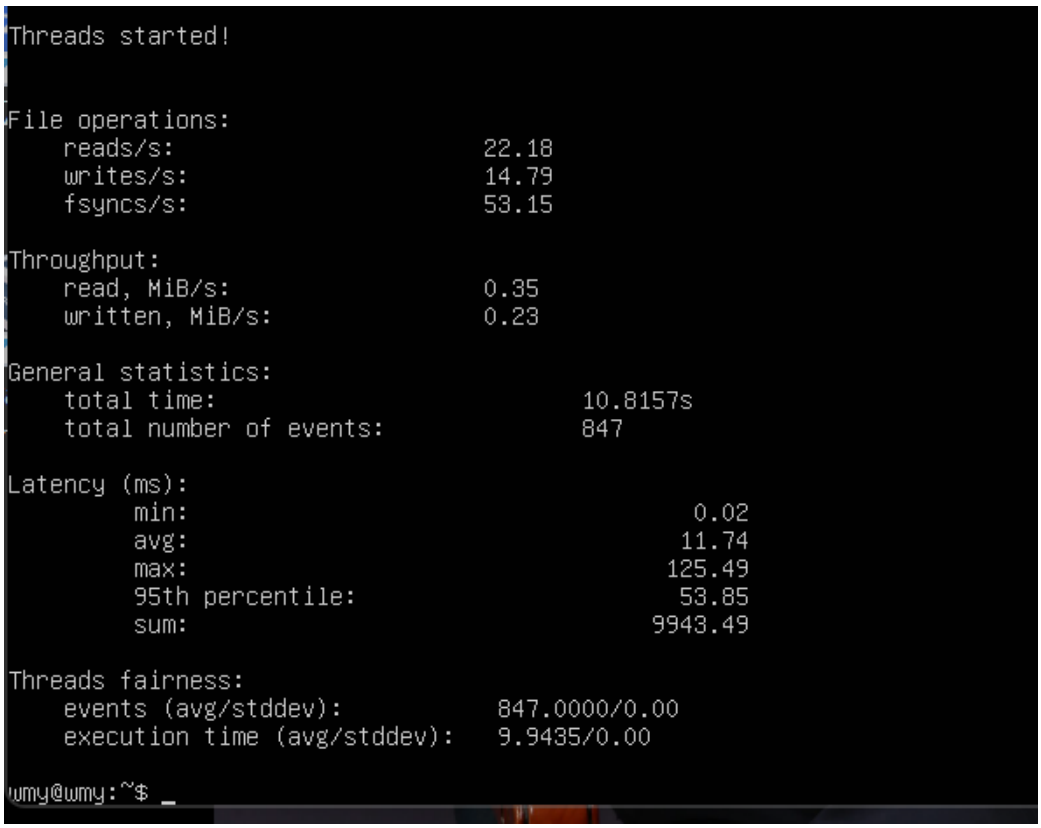
Test 3:


Threads started!
File operations:
reads/s: 34.66
writes/s: 23.11
fsyncs/s: 83.29
Throughput:
read, MiB/s: 0.54
written, MiB/s: 0.36
General statistics:
total time: 10.3834s
total number of events: 1337
Latency (ms):
min: 0.02
avg: 7.45
max: 114.87
95th percentile: 35.59
sum: 9955.27
Threads fairness:
events (avg/stddev): 1337.0000/0.00
execution time (avg/stddev): 9.9553/0.00
wmy@wmy:~$

Test 4:

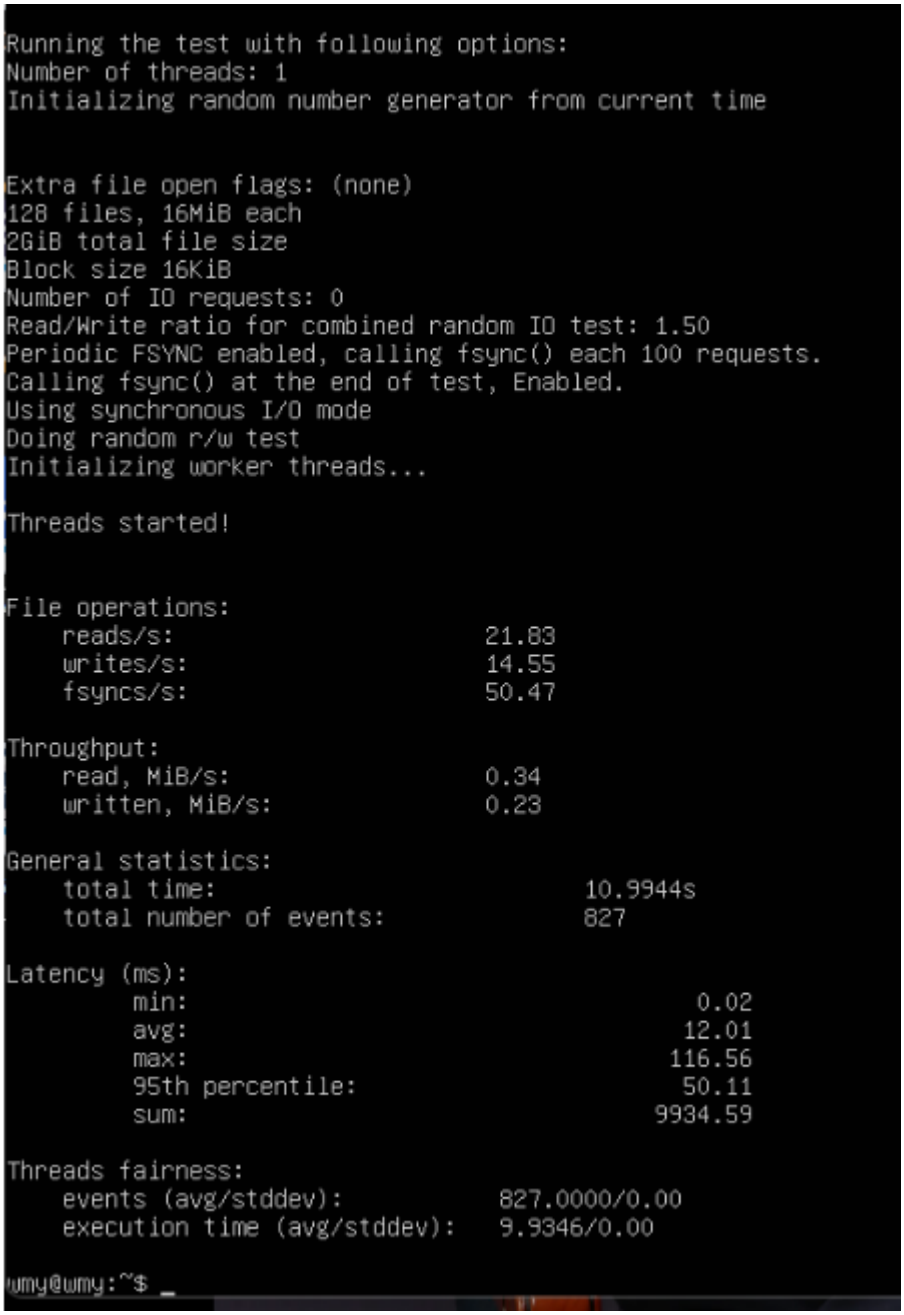

Threads started!
File operations:
reads/s: 34.98
writes/s: 23.32
fsyncs/s: 84.04
Throughput:
read, MiB/s: 0.55
written, MiB/s: 0.36
General statistics:
total time: 10.2910s
total number of events: 1337
Latency (ms):
min: 0.02
avg: 7.43
max: 104.11
95th percentile: 34.95
sum: 9929.51
Threads fairness:
events (avg/stddev): 1337.0000/0.00
execution time (avg/stddev): 9.9295/0.00
wmy@wmy:~$

Test 5:

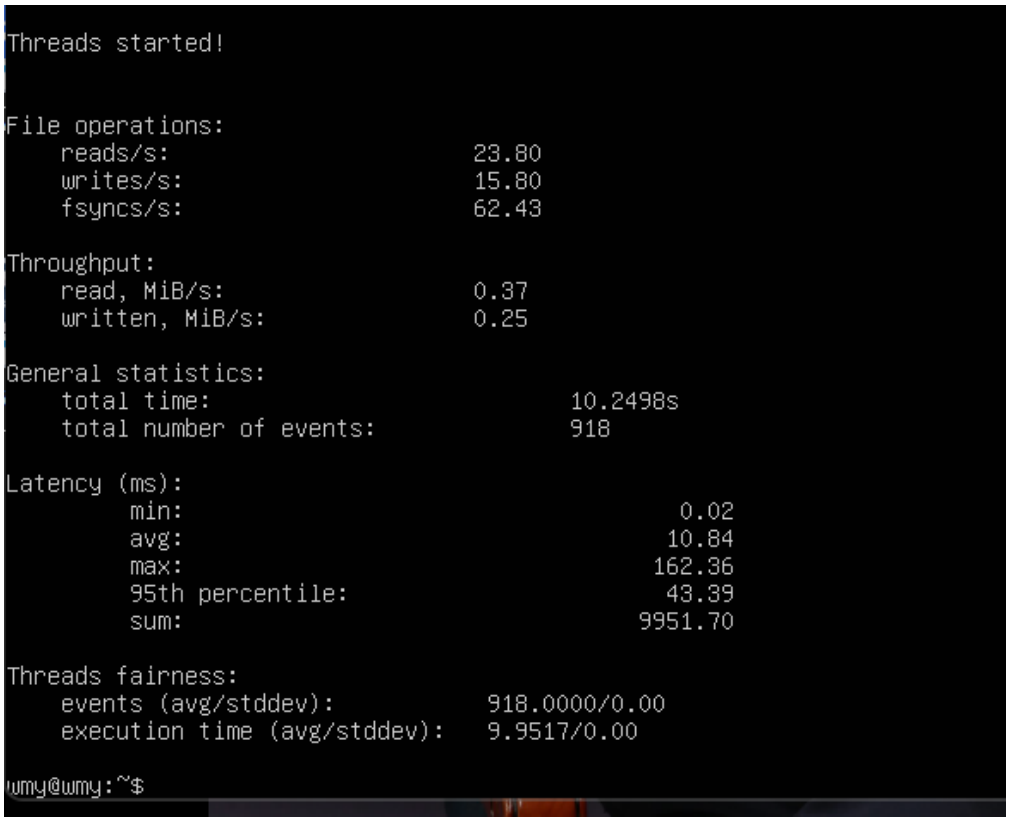

Threads started!
File operations:
reads/s: 22.18
writes/s: 14.79
fsyncs/s: 53.15
Throughput:
read, MiB/s: 0.35
written, MiB/s: 0.23
General statistics:
total time: 10.8157s
total number of events: 847
Latency (ms):
min: 0.02
avg: 11.74
max: 125.49
95th percentile: 53.85
sum: 9943.49
Threads fairness:
events (avg/stddev): 847.0000/0.00
execution time (avg/stddev): 9.9435/0.00
wmy@wmy:~$

Testing commands:
(1)$ sysbench fileio --file-total-size=2G --max-time=10 --max-requests=0 --file-test-mode=rndrw prepare
(2)$ sysbench fileio --file-total-size=2G --max-time=10 --max-requests=0 --file-test-mode=rndrw run
(3)$ sysbench fileio --file-total-size=2G --max-time=10 --max-requests=0 --file-test-mode=rndrw cleanup

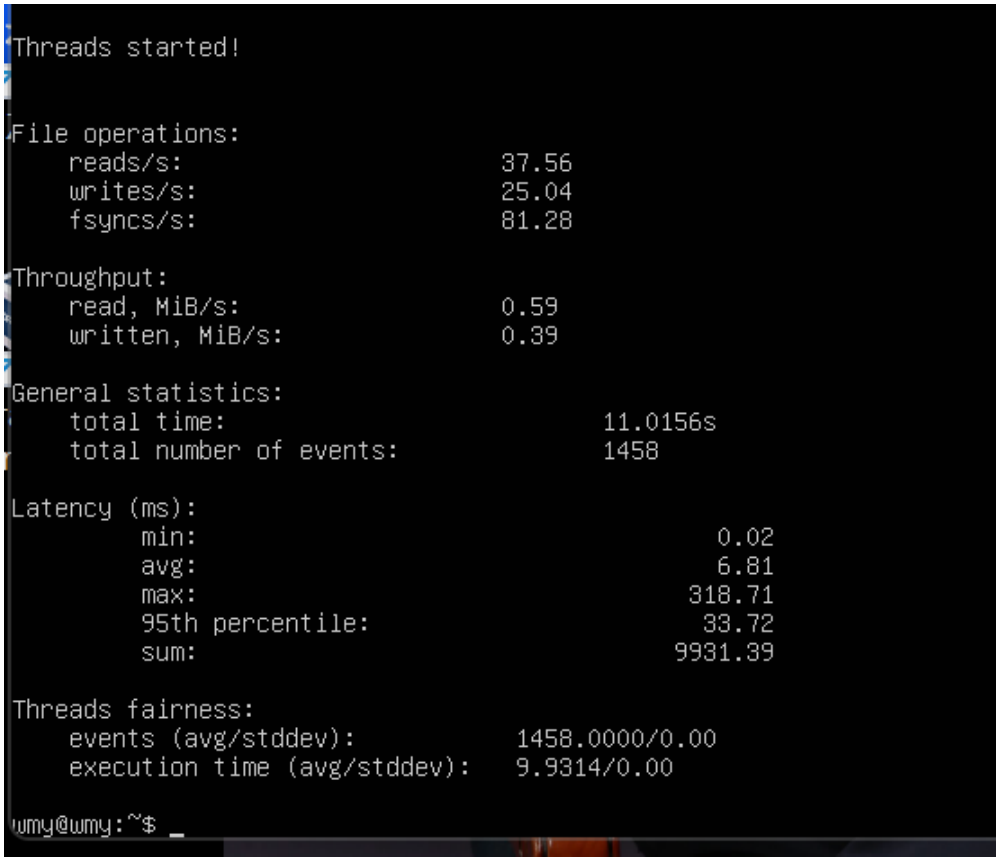
Test 1:



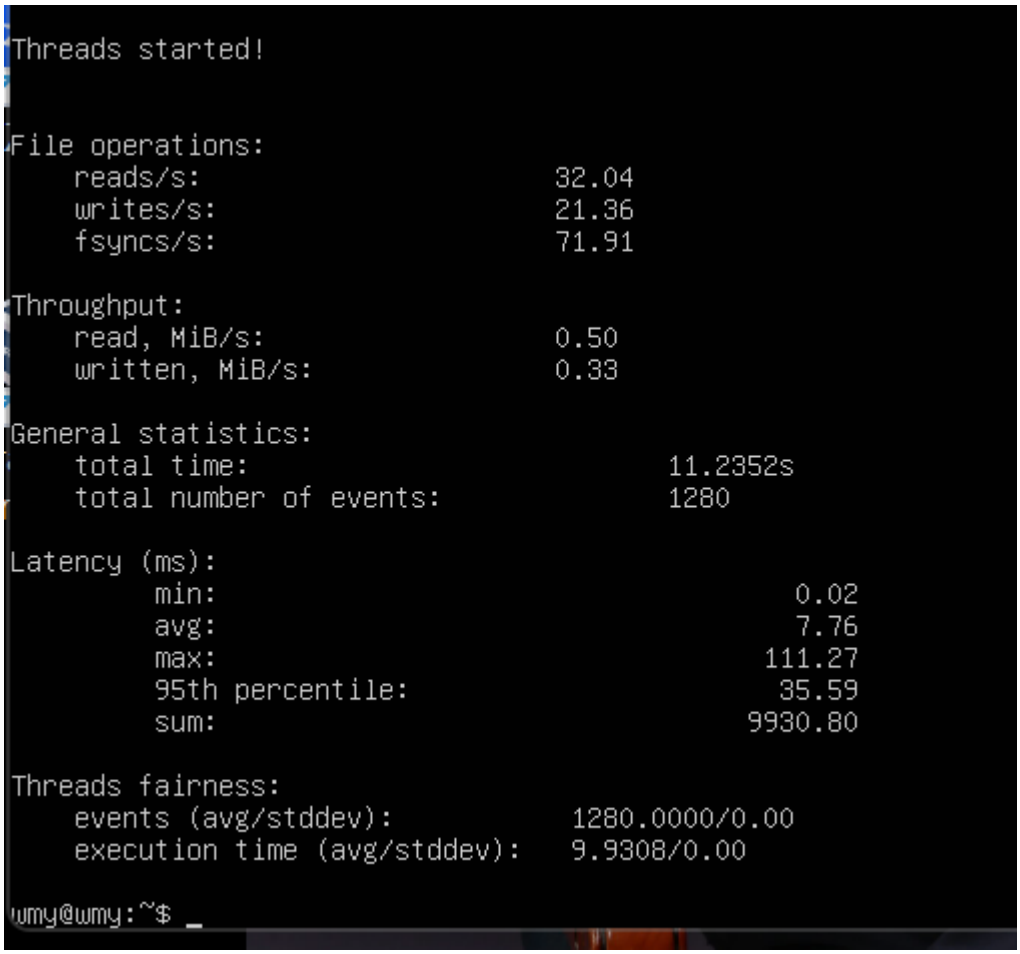
Test 2:


Threads started!
File operations:
reads/s: 23.80
writes/s: 15.80
fsyncs/s: 62.43
Throughput:
read, MiB/s: 0.37
written, MiB/s: 0.25
General statistics:
total time: 10.2498s
total number of events: 918
Latency (ms):
min: 0.02
avg: 10.84
max: 162.36
95th percentile: 43.39
sum: 9951.70
Threads fairness:
events (avg/stddev): 918.0000/0.00
execution time (avg/stddev): 9.9517/0.00
wmy@wmy:~$

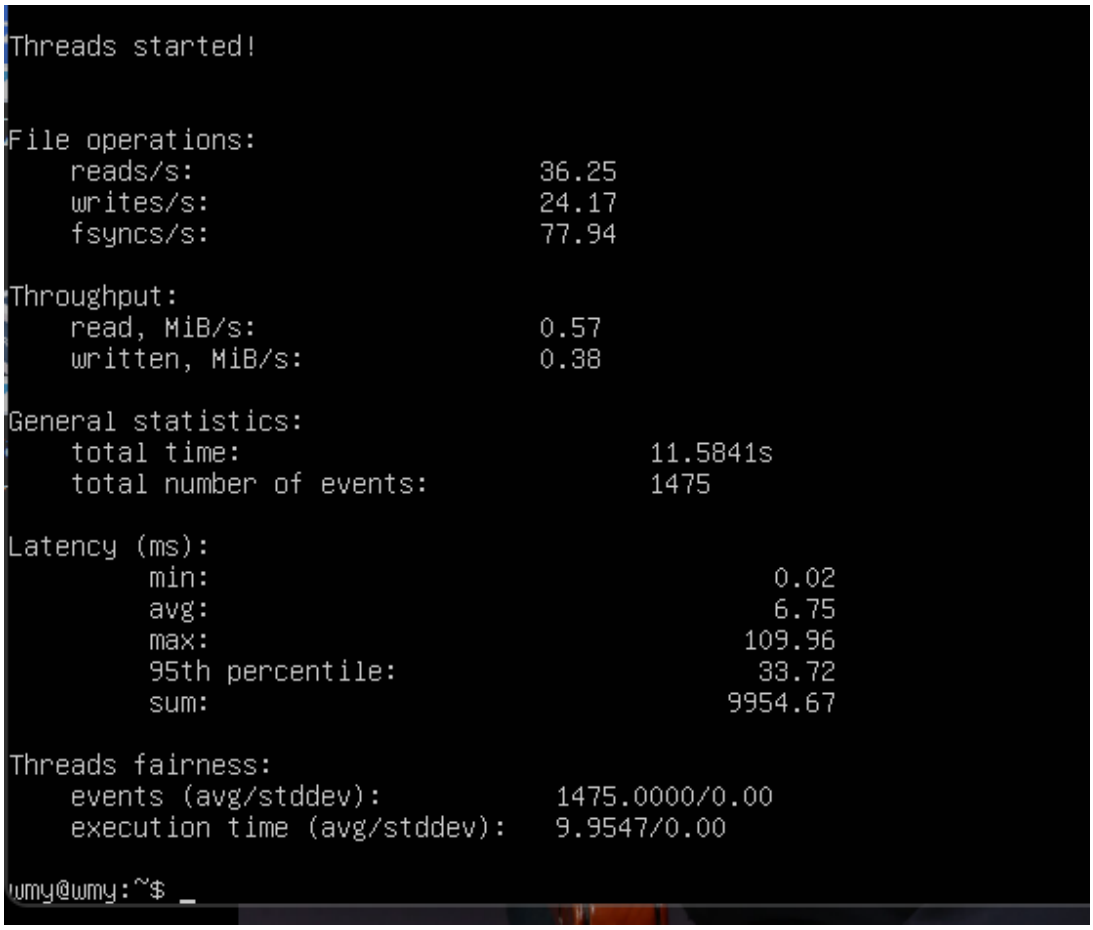
Test 3:


Threads started!
File operations:
reads/s: 37.56
writes/s: 25.04
fsyncs/s: 81.28
Throughput:
read, MiB/s: 0.59
written, MiB/s: 0.39
General statistics:
total time: 11.0156s
total number of events: 1458
Latency (ms):
min: 0.02
avg: 6.81
max: 318.71
95th percentile: 33.72
sum: 9931.39
Threads fairness:
events (avg/stddev): 1458.0000/0.00
execution time (avg/stddev): 9.9314/0.00
wmy@wmy:~$

Test 4:

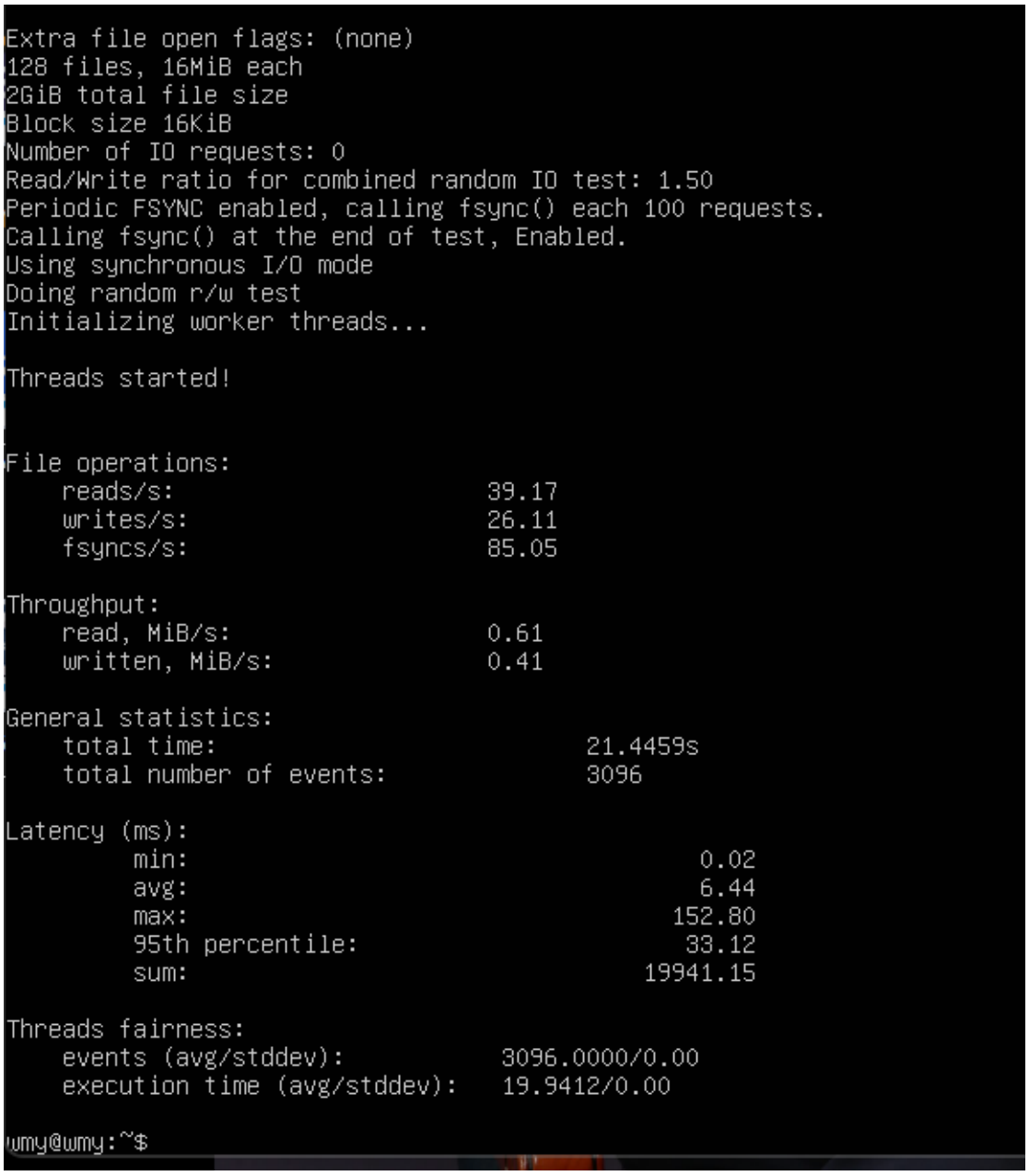

Threads started!
File operations:
reads/s: 32.04
writes/s: 21.36
fsyncs/s: 71.91
Throughput:
read, MiB/s: 0.50
written, MiB/s: 0.33
General statistics:
total time: 11.2352s
total number of events: 1280
Latency (ms):
min: 0.02
avg: 7.76
max: 111.27
95th percentile: 35.59
sum: 9930.80
Threads fairness:
events (avg/stddev): 1280.0000/0.00
execution time (avg/stddev): 9.9308/0.00
wmy@wmy:~$

Test 5:

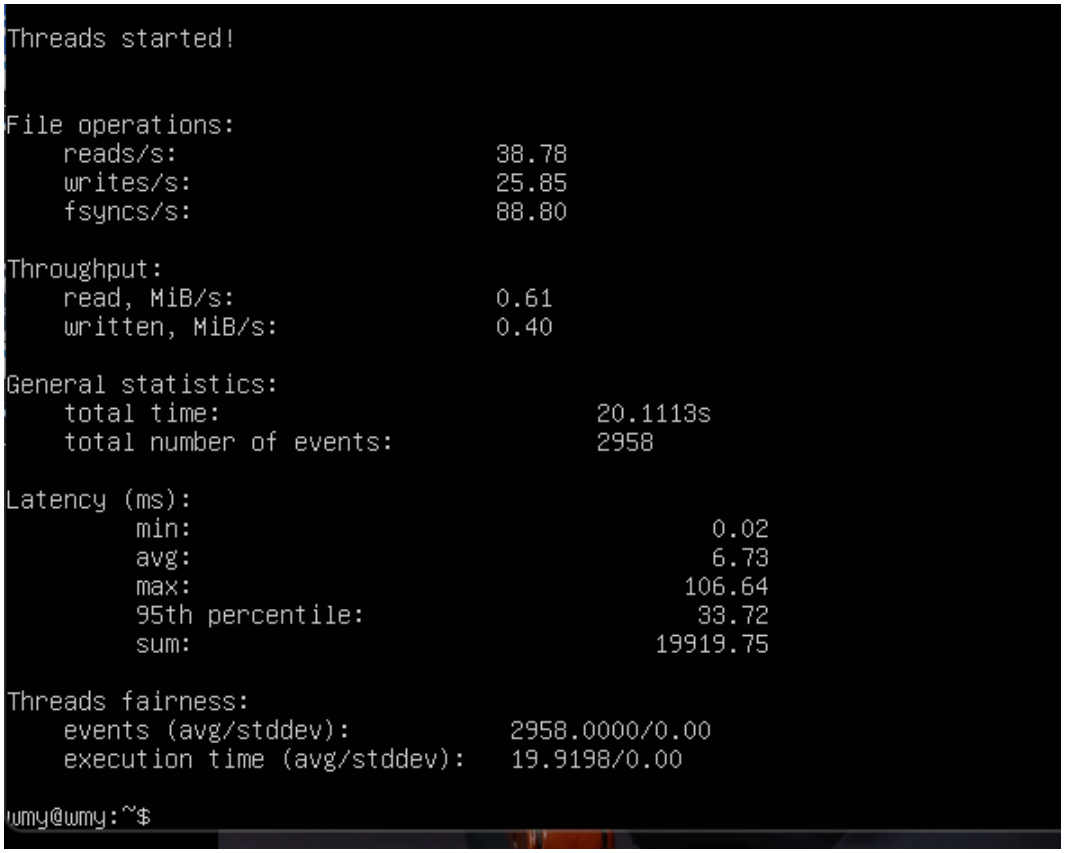

Threads started!
File operations:
reads/s: 36.25
writes/s: 24.17
fsyncs/s: 77.94
Throughput:
read, MiB/s: 0.57
written, MiB/s: 0.38
General statistics:
total time: 11.5841s
total number of events: 1475
Latency (ms):
min: 0.02
avg: 6.75
max: 109.96
95th percentile: 33.72
sum: 9954.67
Threads fairness:
events (avg/stddev): 1475.0000/0.00
execution time (avg/stddev): 9.9547/0.00
wmy@wmy:~$

Testing commands:
(1)$ sysbench fileio --file-total-size=2G --max-time=20 --max-requests=0 --file-test-mode=rndrw prepare
(2)$ sysbench fileio --file-total-size=2G --max-time=20 --max-requests=0 --file-test-mode=rndrw run
(3)$ sysbench fileio --file-total-size=2G --max-time=20 --max-requests=0 --file-test-mode=rndrw cleanup

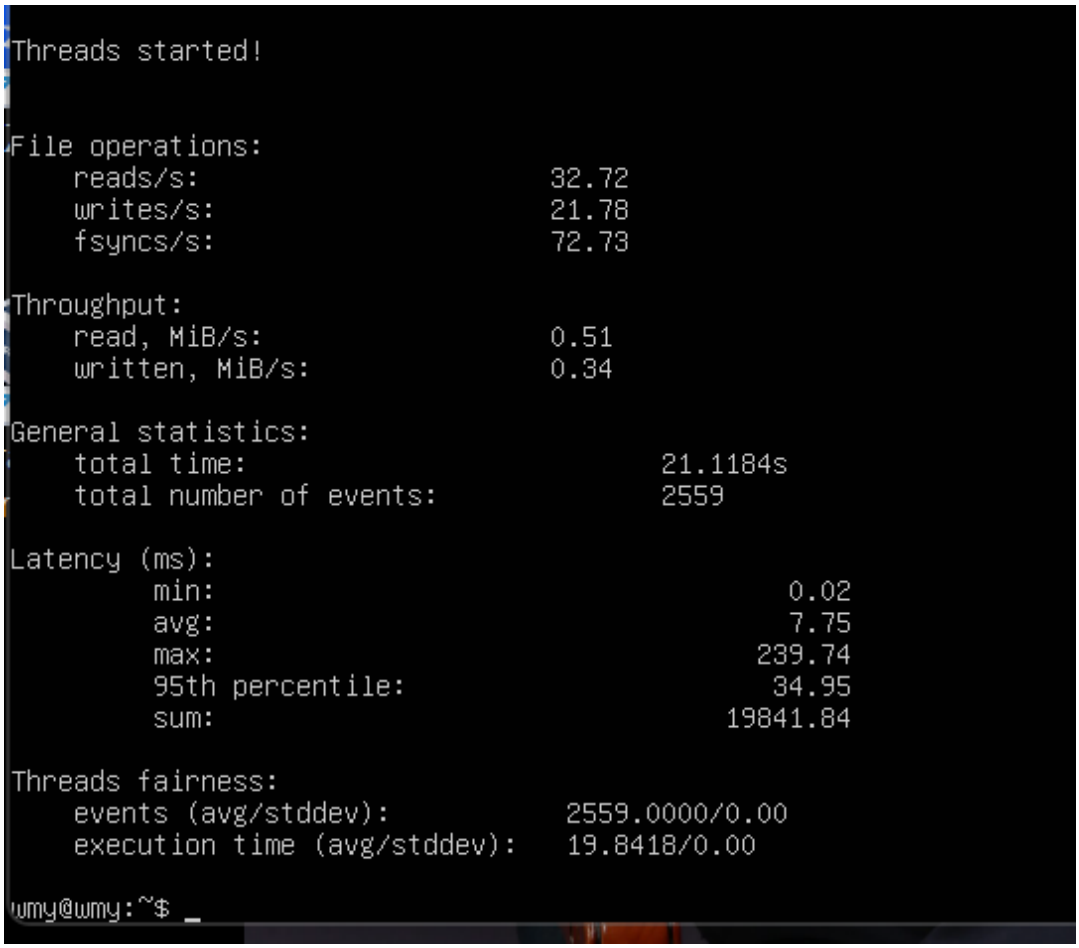
Test 1:



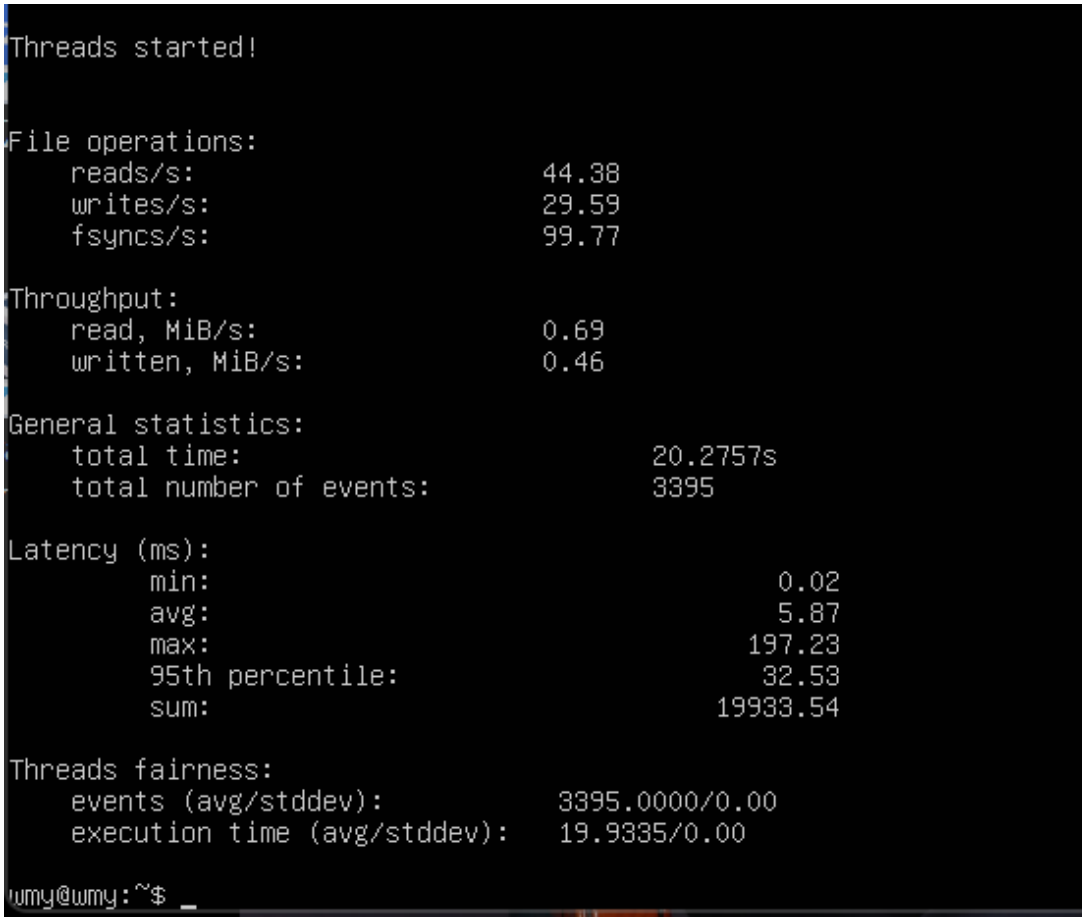
Test 2:


Threads started!
File operations:
reads/s: 38.78
writes/s: 25.85
fsyncs/s: 88.80
Throughput:
read, MiB/s: 0.61
written, MiB/s: 0.40
General statistics:
total time: 20.1113s
total number of events: 2958
Latency (ms):
min: 0.02
avg: 6.73
max: 106.64
95th percentile: 33.72
sum: 19919.75
Threads fairness:
events (avg/stddev): 2958.0000/0.00
execution time (avg/stddev): 19.9198/0.00
wmy@wmy:~$

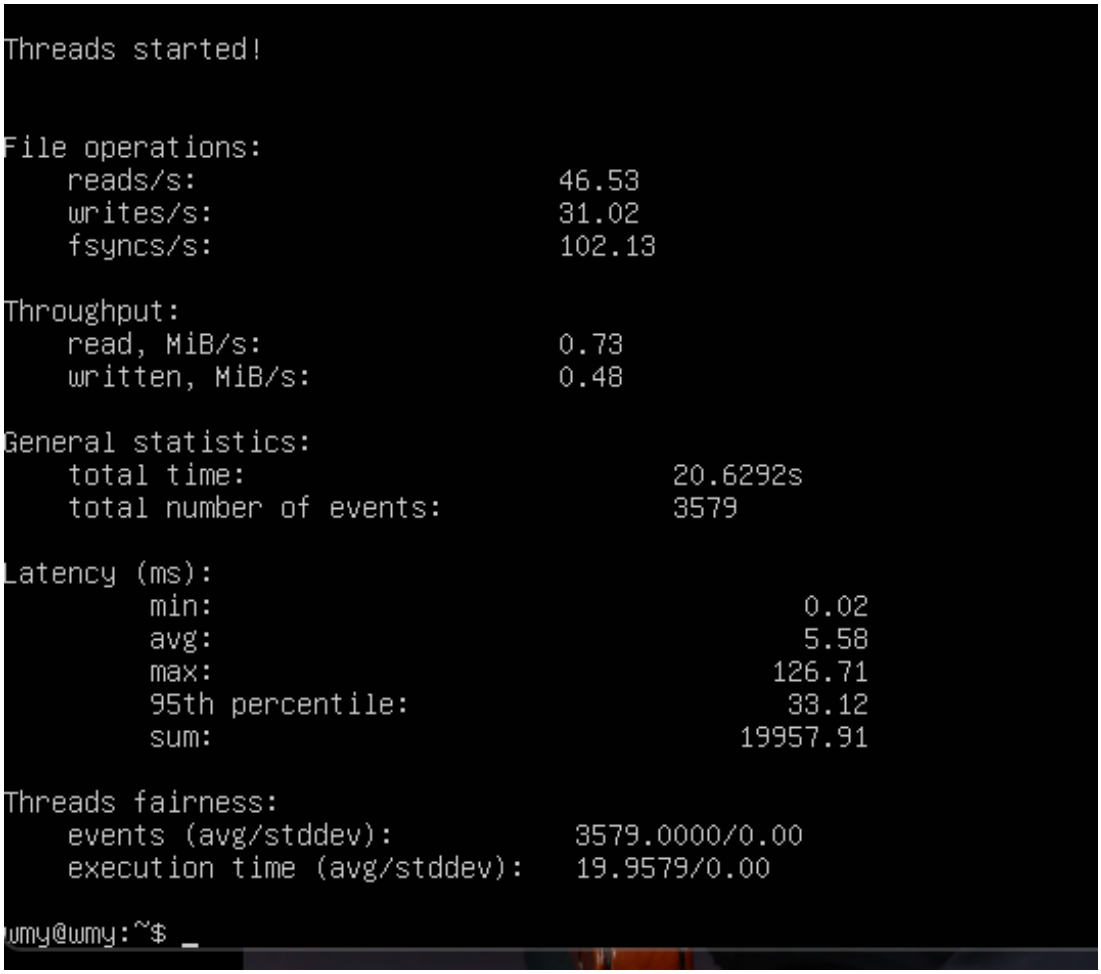
Test 3:


Threads started!
File operations:
reads/s: 32.72
writes/s: 21.78
fsyncs/s: 72.73
Throughput:
read, MiB/s: 0.51
written, MiB/s: 0.34
General statistics:
total time: 21.1184s
total number of events: 2559
Latency (ms):
min: 0.02
avg: 7.75
max: 239.74
95th percentile: 34.95
sum: 19841.84
Threads fairness:
events (avg/stddev): 2559.0000/0.00
execution time (avg/stddev): 19.8418/0.00
wmy@wmy:~$

Test 4:


Threads started!
File operations:
reads/s: 44.38
writes/s: 29.59
fsyncs/s: 99.77
Throughput:
read, MiB/s: 0.69
written, MiB/s: 0.46
General statistics:
total time: 20.2757s
total number of events: 3395
Latency (ms):
min: 0.02
avg: 5.87
max: 197.23
95th percentile: 32.53
sum: 19933.54
Threads fairness:
events (avg/stddev): 3395.0000/0.00
execution time (avg/stddev): 19.9335/0.00
wmy@wmy:~$

Test 5:


Threads started!
File operations:
reads/s: 46.53
writes/s: 31.02
fsyncs/s: 102.13
Throughput:
read, MiB/s: 0.73
written, MiB/s: 0.48
General statistics:
total time: 20.6292s
total number of events: 3579
Latency (ms):
min: 0.02
avg: 5.58
max: 126.71
95th percentile: 33.12
sum: 19957.91
Threads fairness:
events (avg/stddev): 3579.0000/0.00
execution time (avg/stddev): 19.9579/0.00
wmy@wmy:~$

CPU Experiments on Docker:

Check the list of shell scripts:

```
root@56f5eb51fd88:/# ls
bin   dev  home          hw1_cpu_2.sh  hw1_fileio_1.sh  hw1_fileio_3.sh  lib32  libx32  mnt  proc  run   srv  tmp  var
boot  etc  hw1_cpu_1.sh  hw1_cpu_3.sh  hw1_fileio_2.sh  lib              lib64  media   opt  root  sbin  sys  usr
root@56f5eb51fd88:/#
```

Test 1:

```
root@56f5eb51fd88: /
root@56f5eb51fd88:/# bash hw1_cpu_1.sh
CPU Performance Test
Test #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:  1094.45

General statistics:
    total time:                          10.0004s
    total number of events:              10947

Latency (ms):
         min:                                    0.89
         avg:                                    0.91
         max:                                    9.57
         95th percentile:                        0.97
         sum:                                 9979.87

Threads fairness:
    events (avg/stddev):           10947.0000/0.00
    execution time (avg/stddev):   9.9799/0.00
```

Test 2:

```
Test #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:  1096.46

General statistics:
    total time:                          10.0002s
    total number of events:              10968

Latency (ms):
         min:                                    0.89
         avg:                                    0.91
         max:                                   11.95
         95th percentile:                        0.95
         sum:                                 9979.58

Threads fairness:
    events (avg/stddev):           10968.0000/0.00
    execution time (avg/stddev):   9.9796/0.00
```

Test 3:

```
Test #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:  1101.14

General statistics:
    total time:                          10.0008s
    total number of events:              11014

Latency (ms):
         min:                                    0.89
         avg:                                    0.91
         max:                                    5.83
         95th percentile:                        0.95
         sum:                                 9981.52

Threads fairness:
    events (avg/stddev):           11014.0000/0.00
    execution time (avg/stddev):   9.9815/0.00
```

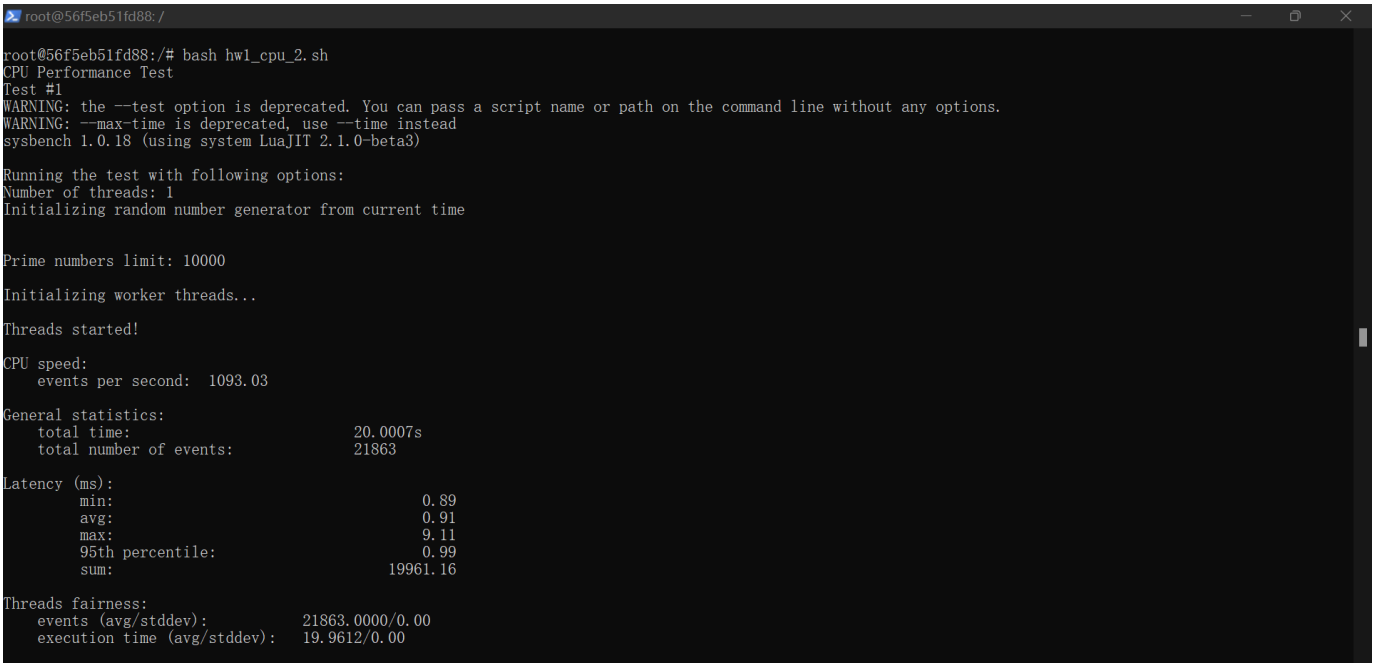
Test 4:

```
Test #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:  1101.33

General statistics:
    total time:                          10.0008s
    total number of events:              11016

Latency (ms):
         min:                                    0.89
         avg:                                    0.91
         max:                                    4.53
         95th percentile:                        0.95
         sum:                                 9982.04

Threads fairness:
    events (avg/stddev):           11016.0000/0.00
    execution time (avg/stddev):   9.9820/0.00
```

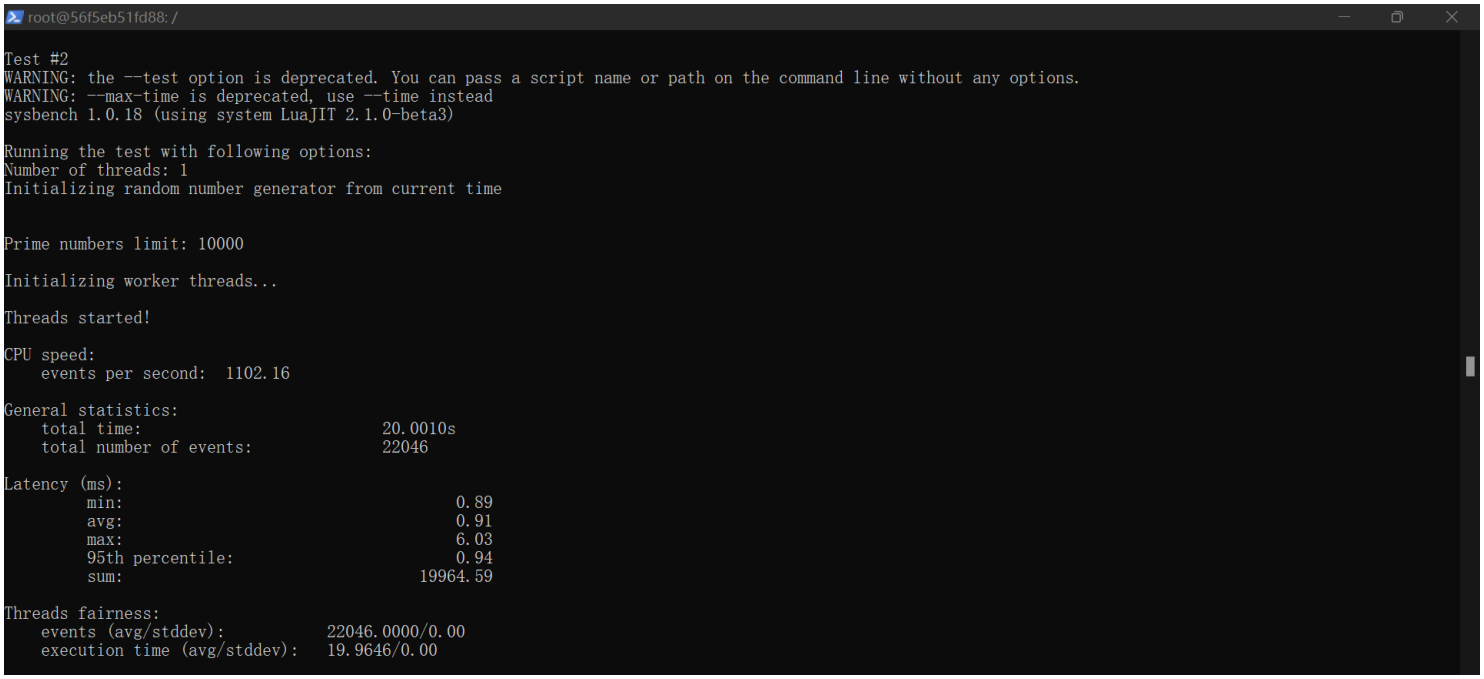
Test 5:

```
Test #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:  1097.20

General statistics:
    total time:                          10.0003s
    total number of events:              10974

Latency (ms):
         min:                                    0.89
         avg:                                    0.91
         max:                                    7.89
         95th percentile:                        0.95
         sum:                                 9978.58

Threads fairness:
    events (avg/stddev):           10974.0000/0.00
    execution time (avg/stddev):   9.9786/0.00

root@56f5eb51fd88:/#
```

Test 1:


root@56f5eb51fd88: /
root@56f5eb51fd88:/# bash hw1_cpu_2.sh
CPU Performance Test
Test #1
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)
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: 1093.03
General statistics:
total time: 20.0007s
total number of events: 21863
Latency (ms):
min: 0.89
avg: 0.91
max: 9.11
95th percentile: 0.99
sum: 19961.16
Threads fairness:
events (avg/stddev): 21863.0000/0.00
execution time (avg/stddev): 19.9612/0.00

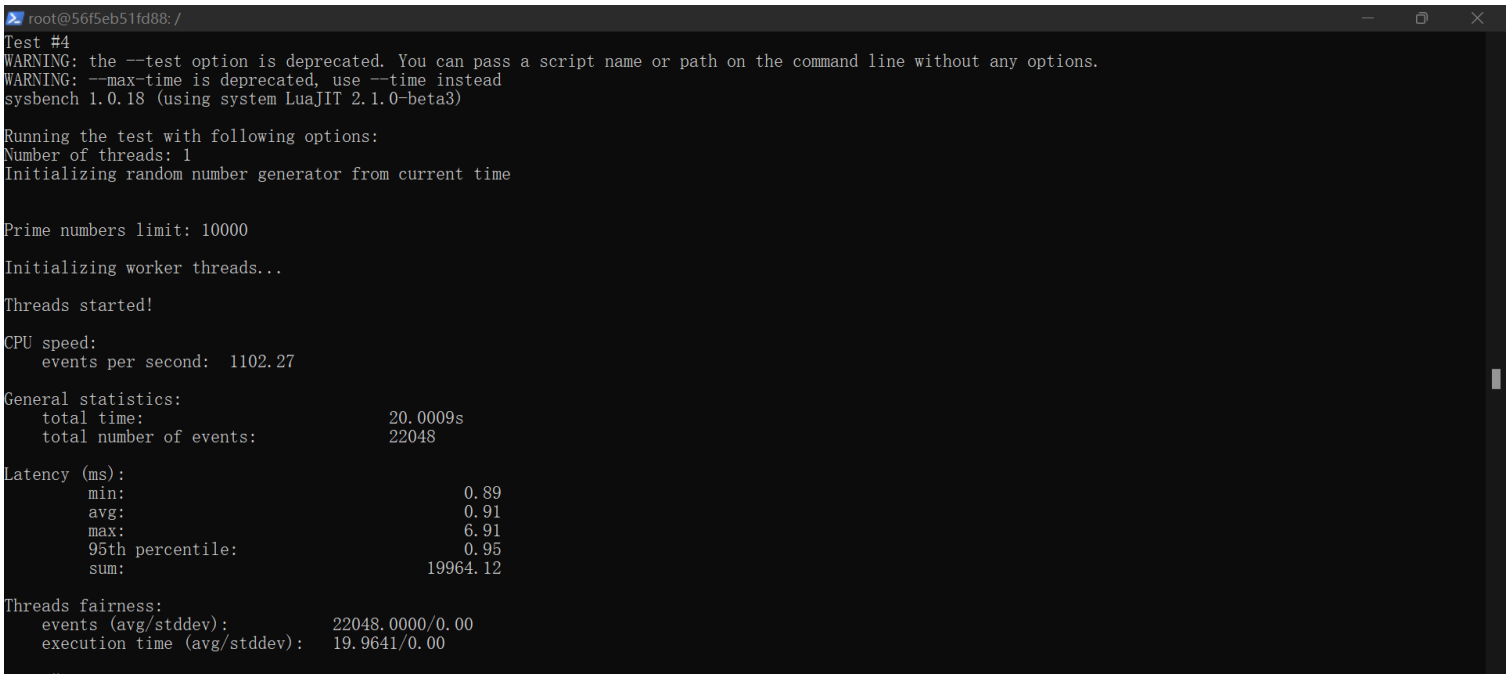
Test 2:


root@56f5eb51fd88: /
Test #2
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)
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: 1102.16
General statistics:
total time: 20.0010s
total number of events: 22046
Latency (ms):
min: 0.89
avg: 0.91
max: 6.03
95th percentile: 0.94
sum: 19964.59
Threads fairness:
events (avg/stddev): 22046.0000/0.00
execution time (avg/stddev): 19.9646/0.00

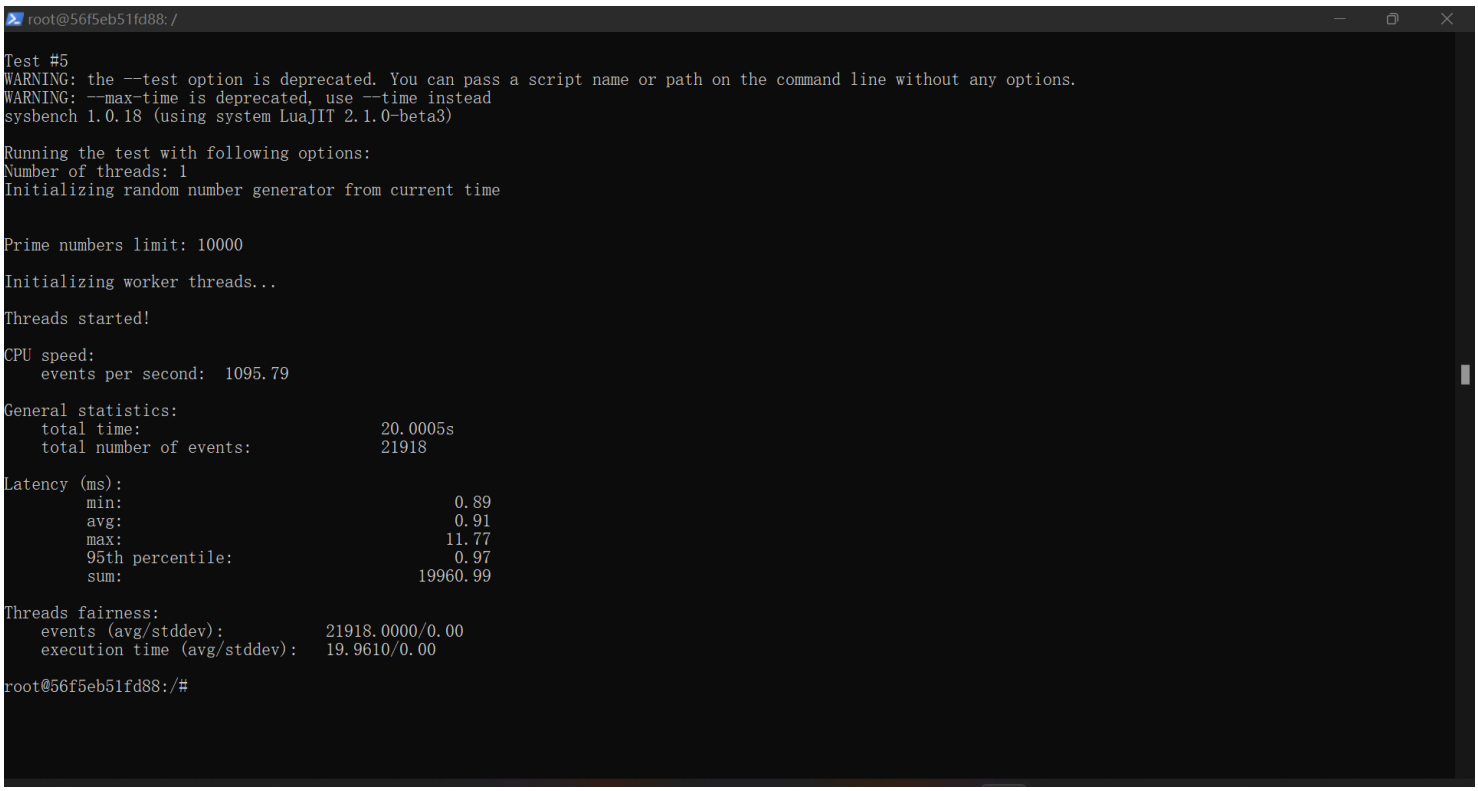
Test 3:

```
Test #3
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)

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:  1097.78

General statistics:
    total time:                          20.0006s
    total number of events:              21958

Latency (ms):
         min:                                    0.89
         avg:                                    0.91
         max:                                    7.38
         95th percentile:                        0.95
         sum:                                19962.11

Threads fairness:
    events (avg/stddev):           21958.0000/0.00
    execution time (avg/stddev):   19.9621/0.00
```

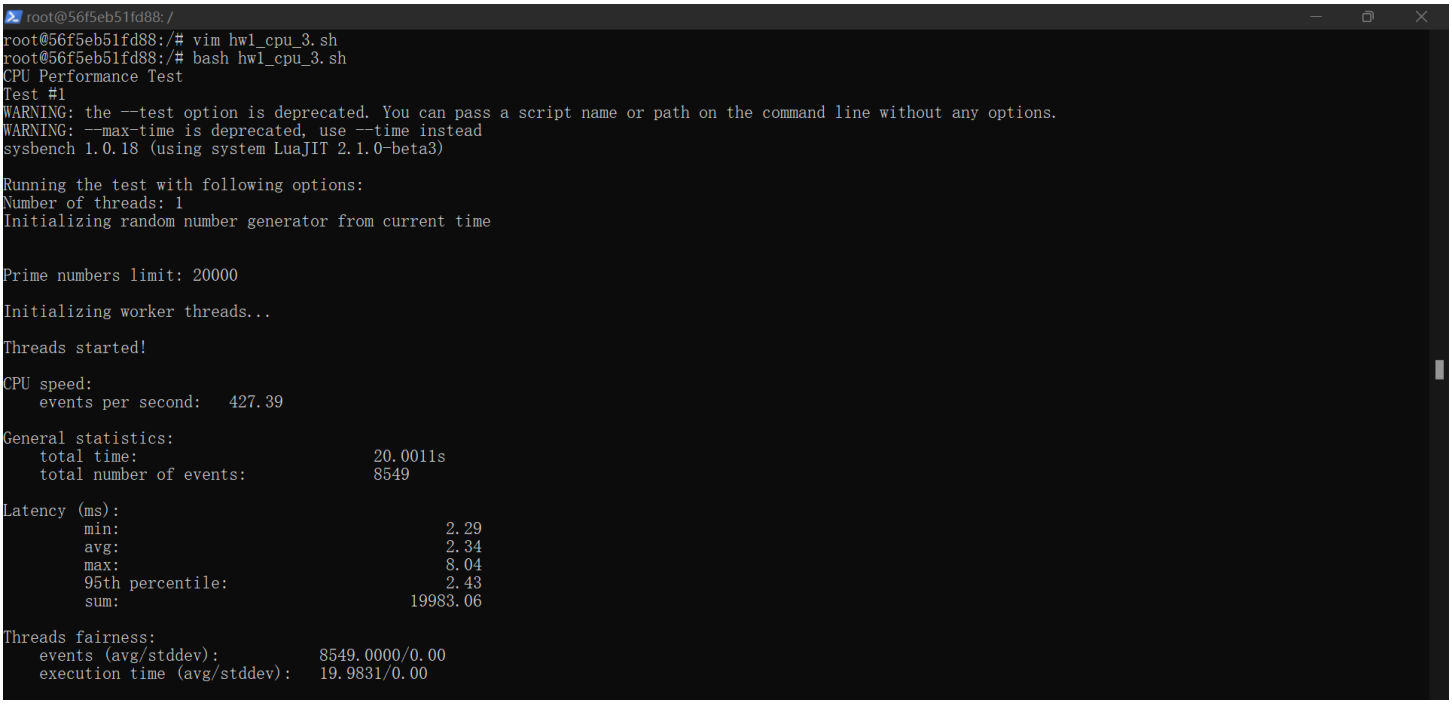
Test 4:


root@56f5eb51fd88: /
Test #4
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)
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: 1102.27
General statistics:
total time: 20.0009s
total number of events: 22048
Latency (ms):
min: 0.89
avg: 0.91
max: 6.91
95th percentile: 0.95
sum: 19964.12
Threads fairness:
events (avg/stddev): 22048.0000/0.00
execution time (avg/stddev): 19.9641/0.00

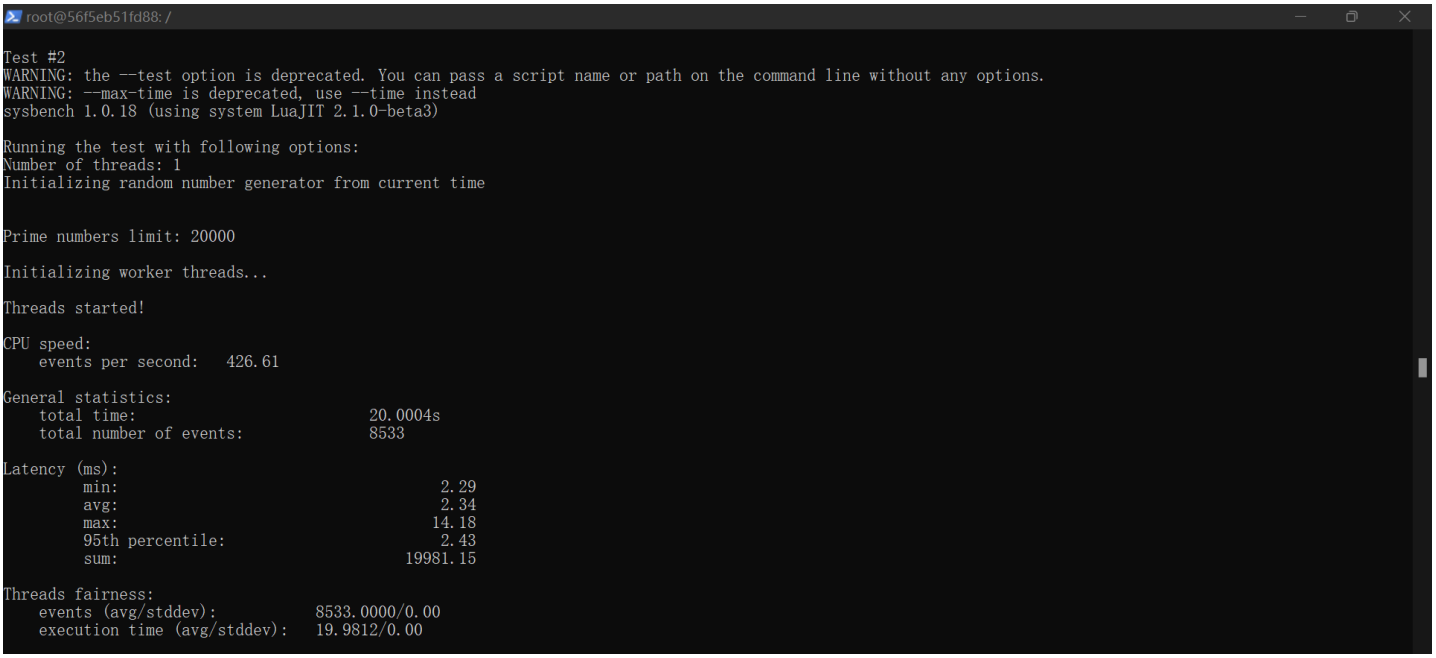
Test 5:


root@56f5eb51fd88: /
Test #5
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)
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: 1095.79
General statistics:
total time: 20.0005s
total number of events: 21918
Latency (ms):
min: 0.89
avg: 0.91
max: 11.77
95th percentile: 0.97
sum: 19960.99
Threads fairness:
events (avg/stddev): 21918.0000/0.00
execution time (avg/stddev): 19.9610/0.00
root@56f5eb51fd88:/#

Test 1:


root@56f5eb51fd88:/
root@56f5eb51fd88:/# vim hw1_cpu_3.sh
root@56f5eb51fd88:/# bash hw1_cpu_3.sh
CPU Performance Test
Test #1
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)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 20000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 427.39
General statistics:
total time: 20.0011s
total number of events: 8549
Latency (ms):
min: 2.29
avg: 2.34
max: 8.04
95th percentile: 2.43
sum: 19983.06
Threads fairness:
events (avg/stddev): 8549.0000/0.00
execution time (avg/stddev): 19.9831/0.00

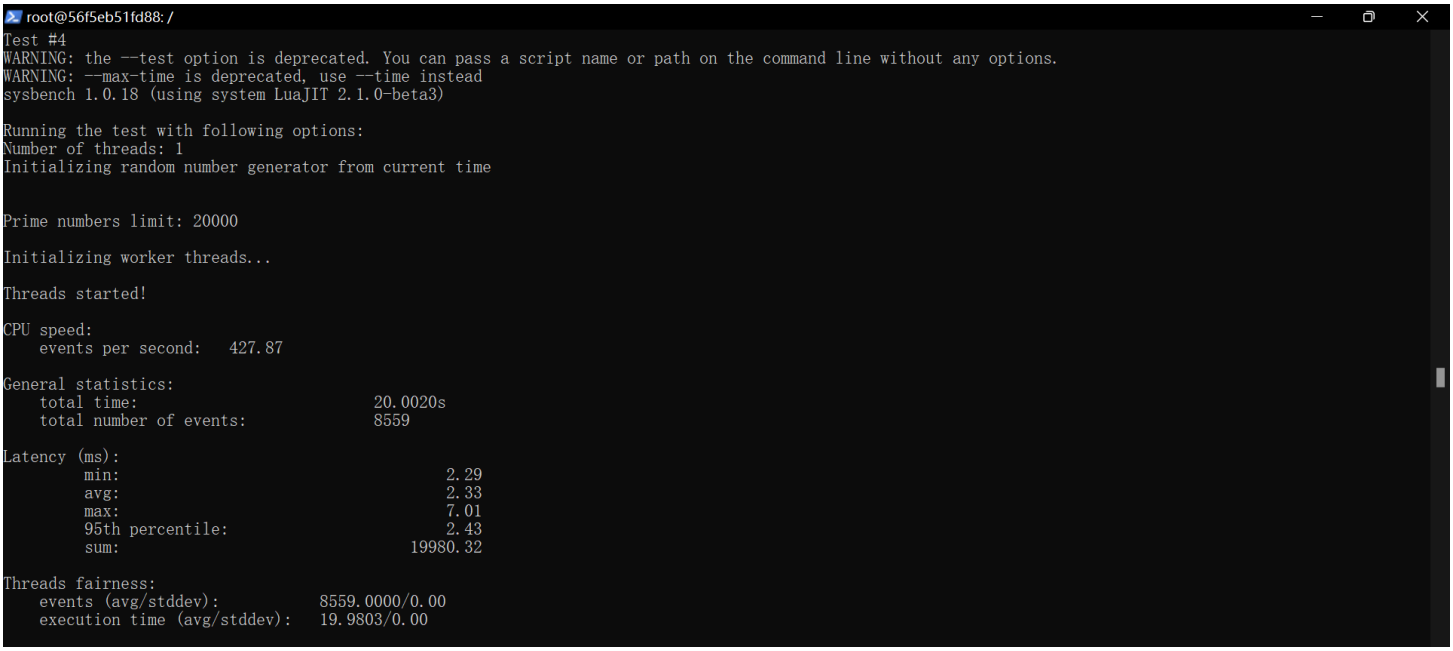
Test 2:


root@56f5eb51fd88: /
Test #2
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)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 20000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 426.61
General statistics:
total time: 20.0004s
total number of events: 8533
Latency (ms):
min: 2.29
avg: 2.34
max: 14.18
95th percentile: 2.43
sum: 19981.15
Threads fairness:
events (avg/stddev): 8533.0000/0.00
execution time (avg/stddev): 19.9812/0.00

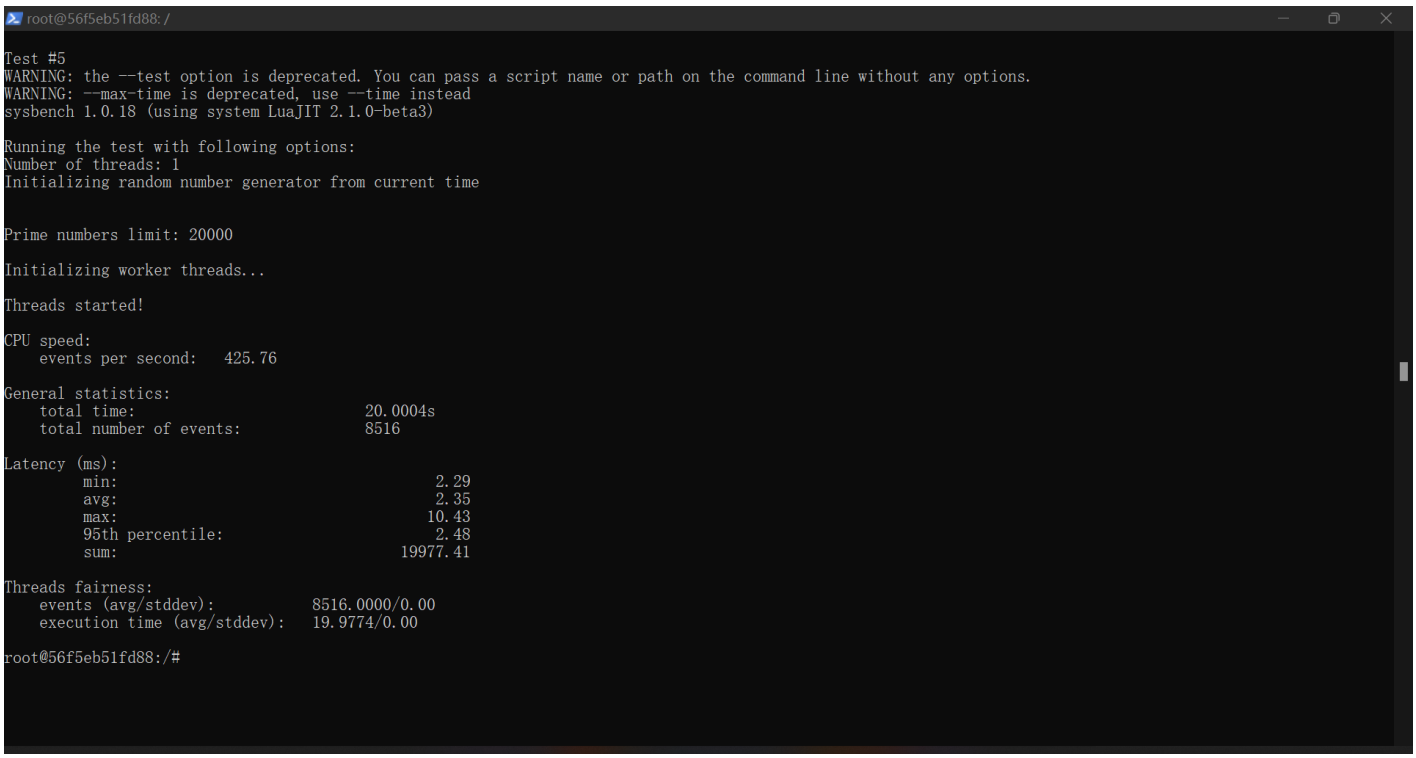
Test 3:

```
Test #3
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)

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


Prime numbers limit: 20000

Initializing worker threads...

Threads started!

CPU speed:
    events per second:   427.48

General statistics:
    total time:                          20.0017s
    total number of events:              8551

Latency (ms):
         min:                                    2.29
         avg:                                    2.34
         max:                                   11.24
         95th percentile:                        2.43
         sum:                                19983.20

Threads fairness:
    events (avg/stddev):           8551.0000/0.00
    execution time (avg/stddev):   19.9832/0.00
```

Test 4:


root@56f5eb51fd88: /
Test #4
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)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 20000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 427.87
General statistics:
total time: 20.0020s
total number of events: 8559
Latency (ms):
min: 2.29
avg: 2.33
max: 7.01
95th percentile: 2.43
sum: 19980.32
Threads fairness:
events (avg/stddev): 8559.0000/0.00
execution time (avg/stddev): 19.9803/0.00

Test 5:


root@56f5eb51fd88: /
Test #5
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)
Running the test with following options:
Number of threads: 1
Initializing random number generator from current time
Prime numbers limit: 20000
Initializing worker threads...
Threads started!
CPU speed:
events per second: 425.76
General statistics:
total time: 20.0004s
total number of events: 8516
Latency (ms):
min: 2.29
avg: 2.35
max: 10.43
95th percentile: 2.48
sum: 19977.41
Threads fairness:
events (avg/stddev): 8516.0000/0.00
execution time (avg/stddev): 19.9774/0.00
root@56f5eb51fd88:/#

File I/O Experiments on Docker:
Test 1:

```
Threads started!


File operations:
    reads/s:                      1069.11
    writes/s:                     712.74
    fsyncs/s:                     2281.16

Throughput:
    read, MiB/s:                  16.70
    written, MiB/s:               11.14

General statistics:
    total time:                          10.0442s
    total number of events:              40688

Latency (ms):
         min:                                    0.00
         avg:                                    0.24
         max:                                   65.39
         95th percentile:                        0.51
         sum:                                 9919.82

Threads fairness:
    events (avg/stddev):           40688.0000/0.00
    execution time (avg/stddev):   9.9198/0.00
```

Test 2:

```
Threads started!


File operations:
    reads/s:                      998.48
    writes/s:                     665.65
    fsyncs/s:                     2138.75

Throughput:
    read, MiB/s:                  15.60
    written, MiB/s:               10.40

General statistics:
    total time:                          10.0339s
    total number of events:              38035

Latency (ms):
         min:                                    0.00
         avg:                                    0.26
         max:                                   67.32
         95th percentile:                        0.50
         sum:                                 9922.73

Threads fairness:
    events (avg/stddev):           38035.0000/0.00
    execution time (avg/stddev):   9.9227/0.00
```

Test 3:

```
Threads started!


File operations:
    reads/s:                      454.53
    writes/s:                     303.02
    fsyncs/s:                     981.13

Throughput:
    read, MiB/s:                  7.10
    written, MiB/s:               4.73

General statistics:
    total time:                          10.0309s
    total number of events:              17315

Latency (ms):
         min:                                    0.00
         avg:                                    0.58
         max:                                  244.32
         95th percentile:                        0.53
         sum:                                 9962.22

Threads fairness:
    events (avg/stddev):           17315.0000/0.00
    execution time (avg/stddev):   9.9622/0.00
```

Test 4:

```
Threads started!


File operations:
    reads/s:                      1165.71
    writes/s:                     777.14
    fsyncs/s:                     2491.34

Throughput:
    read, MiB/s:                  18.21
    written, MiB/s:               12.14

General statistics:
    total time:                          10.0353s
    total number of events:              44377

Latency (ms):
         min:                                    0.00
         avg:                                    0.22
         max:                                   42.77
         95th percentile:                        0.49
         sum:                                 9913.21

Threads fairness:
    events (avg/stddev):           44377.0000/0.00
    execution time (avg/stddev):   9.9132/0.00
```

Test 5:

```
Threads started!


File operations:
    reads/s:                      1204.95
    writes/s:                     803.30
    fsyncs/s:                     2576.93

Throughput:
    read, MiB/s:                  18.83
    written, MiB/s:               12.55

General statistics:
    total time:                          10.0568s
    total number of events:              45992

Latency (ms):
         min:                                    0.00
         avg:                                    0.22
         max:                                   37.08
         95th percentile:                        0.49
         sum:                                 9909.13

Threads fairness:
    events (avg/stddev):           45992.0000/0.00
    execution time (avg/stddev):   9.9091/0.00

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...
root@56f5eb51fd88:/#
```

Test 1:

```
Initializing worker threads...

Threads started!


File operations:
    reads/s:                      1014.52
    writes/s:                     676.35
    fsyncs/s:                     2168.38

Throughput:
    read, MiB/s:                  15.85
    written, MiB/s:               10.57

General statistics:
    total time:                          10.0526s
    total number of events:              38673

Latency (ms):
         min:                                    0.00
         avg:                                    0.26
         max:                                   41.23
         95th percentile:                        0.52
         sum:                                 9920.37

Threads fairness:
    events (avg/stddev):           38673.0000/0.00
    execution time (avg/stddev):   9.9204/0.00
```

Test 2:

```
Threads started!


File operations:
    reads/s:                      1074.50
    writes/s:                     716.33
    fsyncs/s:                     2294.36

Throughput:
    read, MiB/s:                  16.79
    written, MiB/s:               11.19

General statistics:
    total time:                          10.0382s
    total number of events:              40933

Latency (ms):
         min:                                    0.00
         avg:                                    0.24
         max:                                   26.24
         95th percentile:                        0.52
         sum:                                 9915.08

Threads fairness:
    events (avg/stddev):           40933.0000/0.00
    execution time (avg/stddev):   9.9151/0.00
```

Test 3:

```
Threads started!


File operations:
    reads/s:                      1002.99
    writes/s:                     668.66
    fsyncs/s:                     2141.71

Throughput:
    read, MiB/s:                  15.67
    written, MiB/s:               10.45

General statistics:
    total time:                          10.0438s
    total number of events:              38196

Latency (ms):
         min:                                    0.00
         avg:                                    0.26
         max:                                   39.59
         95th percentile:                        0.51
         sum:                                 9919.98

Threads fairness:
    events (avg/stddev):           38196.0000/0.00
    execution time (avg/stddev):   9.9200/0.00
```

Test 4:

```
Threads started!


File operations:
    reads/s:                      1129.58
    writes/s:                     753.05
    fsyncs/s:                     2413.35

Throughput:
    read, MiB/s:                  17.65
    written, MiB/s:               11.77

General statistics:
    total time:                          10.0353s
    total number of events:              43000

Latency (ms):
         min:                                    0.00
         avg:                                    0.23
         max:                                   15.59
         95th percentile:                        0.52
         sum:                                 9913.52

Threads fairness:
    events (avg/stddev):           43000.0000/0.00
    execution time (avg/stddev):   9.9135/0.00
```

Test 5:

```
Threads started!


File operations:
    reads/s:                      1170.82
    writes/s:                     780.55
    fsyncs/s:                     2497.86

Throughput:
    read, MiB/s:                  18.29
    written, MiB/s:               12.20

General statistics:
    total time:                          10.0427s
    total number of events:              44561

Latency (ms):
         min:                                    0.00
         avg:                                    0.22
         max:                                   12.54
         95th percentile:                        0.49
         sum:                                 9910.06

Threads fairness:
    events (avg/stddev):           44561.0000/0.00
    execution time (avg/stddev):   9.9101/0.00
```

Test 1:

```
Threads started!


File operations:
    reads/s:                      1027.43
    writes/s:                     684.95
    fsyncs/s:                     2198.14

Throughput:
    read, MiB/s:                  16.05
    written, MiB/s:               10.70

General statistics:
    total time:                          20.0293s
    total number of events:              78202

Latency (ms):
         min:                                    0.00
         avg:                                    0.25
         max:                                   38.40
         95th percentile:                        0.53
         sum:                                19842.69

Threads fairness:
    events (avg/stddev):           78202.0000/0.00
    execution time (avg/stddev):   19.8427/0.00
```

Test 2:

```
Threads started!


File operations:
    reads/s:                      1126.51
    writes/s:                     751.04
    fsyncs/s:                     2407.16

Throughput:
    read, MiB/s:                  17.60
    written, MiB/s:               11.73

General statistics:
    total time:                          20.0455s
    total number of events:              85767

Latency (ms):
         min:                                    0.00
         avg:                                    0.23
         max:                                   42.16
         95th percentile:                        0.50
         sum:                                19826.04

Threads fairness:
    events (avg/stddev):           85767.0000/0.00
    execution time (avg/stddev):   19.8260/0.00
```

Test 3:

```
Threads started!


File operations:
    reads/s:                      1060.07
    writes/s:                     706.71
    fsyncs/s:                     2265.17

Throughput:
    read, MiB/s:                  16.56
    written, MiB/s:               11.04

General statistics:
    total time:                          20.0351s
    total number of events:              80658

Latency (ms):
         min:                                    0.00
         avg:                                    0.25
         max:                                   41.08
         95th percentile:                        0.50
         sum:                                19839.41

Threads fairness:
    events (avg/stddev):           80658.0000/0.00
    execution time (avg/stddev):   19.8394/0.00
```

Test 4:

```
Threads started!


File operations:
    reads/s:                      1077.96
    writes/s:                     718.64
    fsyncs/s:                     2301.34

Throughput:
    read, MiB/s:                  16.84
    written, MiB/s:               11.23

General statistics:
    total time:                          20.0365s
    total number of events:              81986

Latency (ms):
         min:                                    0.00
         avg:                                    0.24
         max:                                   72.91
         95th percentile:                        0.51
         sum:                                19835.57

Threads fairness:
    events (avg/stddev):           81986.0000/0.00
    execution time (avg/stddev):   19.8356/0.00
```

Test 5:

```
Threads started!


File operations:
    reads/s:                      1047.91
    writes/s:                     698.60
    fsyncs/s:                     2238.33

Throughput:
    read, MiB/s:                  16.37
    written, MiB/s:               10.92

General statistics:
    total time:                          20.0386s
    total number of events:              79728

Latency (ms):
         min:                                    0.00
         avg:                                    0.25
         max:                                   83.51
         95th percentile:                        0.51
         sum:                                19837.38

Threads fairness:
    events (avg/stddev):           79728.0000/0.00
    execution time (avg/stddev):   19.8374/0.00

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...
root@56f5eb51fd88:/#
```

System Virtualization (QEMU) & OS Virtualization (Docker):

CPU Experiments:
(1)Test command: $ sysbench --test=cpu --cpu-max-prime=10000 run
QEMU:

Attributes	Total time	CPU Speed	Avg Latency
Min	10.0012	178.24	4.84
Max	10.0224	202.21	5.24
Average	10.00538	189.0	5.078
Std	0.0088	7.6482	0.1372

Docker:

Attributes	Total time	CPU Speed	Avg Latency
Min	10.0002	1094	0.91
Max	10.0008	1101	0.91
Average	10.0005	1097.8	0.91
Std	0.00025	2.7857	0

(2)Test command: $ sysbench –-test=cpu --cpu-max-prime=10000 --max-time=20 run
QEMU:

Attributes	Total time	CPU Speed	Avg Latency
Min	20.0043	178.22	5.08
Max	20.0078	195.16	5.54
Average	20.00668	188.26	5.268
Std	0.0013	6.3256	0.1713

Docker:

Attributes	Total time	CPU Speed	Avg Latency
Min	20.0005	1093	0.91
Max	20.0010	1102	0.91
Average	20.0074	1097.8	0.91
Std	0.0002	3.6551	0

(3)Test command: $ sysbench --test=cpu --cpu-max-prime=20000 --max-time=20 run
QEMU:

Attributes	Total time	CPU Speed	Avg Latency
Min	20.0035	74.15	11.63
Max	20.0121	84.93	13.27
Average	20.00846	78.3	12.658
Std	0.0035	3.7624	0.5825

Docker:

Attributes	Total time	CPU Speed	Avg Latency
Min	20.0004	425.76	2.33
Max	20.0020	427.87	2.35
Average	20.00112	426.4	2.34
Std	0.0007	0.8	0.0063

File I/O Experiments:
(1)Test commands:
$ sysbench fileio --file-total-size=1G --max-time=10 --max-requests=0
--file-test-mode=rndrw prepare
$ sysbench fileio --file-total-size=1G --max-time=10 --max-requests=0
--file-test-mode=rndrw run
$ sysbench fileio --file-total-size=1G --max-time=10 --max-requests=0
--file-test-mode=rndrw cleanup
QEMU:

Attributes	Total time	Read	Write	Avg Latency
Min	10.2910	0.35	0.23	6.67
Max	11.2134	0.59	0.39	11.74
Average	10.60754	0.496	0.328	8.438
Std	0.3565	0.0862	0.0571	1.8019

Docker:

Attributes	Total time	Read	Write	Avg Latency
Min	10.0309	7.10	4.73	0.22
Max	10.0568	18.83	12.55	0.58
Average	10.04022	15.288	10.192	0.312
Std	0.0094	4.2478	2.8330	0.1348

(2)Test commands:
$ sysbench fileio --file-total-size=2G --max-time=10 --max-requests=0
--file-test-mode=rndrw prepare
$ sysbench fileio --file-total-size=2G --max-time=10 --max-requests=0
--file-test-mode=rndrw run
$ sysbench fileio --file-total-size=2G --max-time=10 --max-requests=0
--file-test-mode=rndrw cleanup
QEMU:

Attributes	Total time	Read	Write	Avg Latency
Min	10.2498	0.34	0.23	6.75
Max	11.5848	0.59	0.39	12.01
Average	11.01582	0.474	0.316	8.834
Std	0.4378	0.1021	0.0656	2.1773

Docker:

Attributes	Total time	Read	Write	Avg Latency
Min	10.0353	15.67	10.45	0.22
Max	10.0526	18.29	12.20	0.26
Average	10.04252	16.85	11.236	0.242
Std	0.0059	1.0109	0.6750	0.0160

(3)Test commands:

$ sysbench fileio --file-total-size=2G --max-time=20 --max-requests=0 --file-test-mode=rndrw prepare

$ sysbench fileio --file-total-size=2G --max-time=20 --max-requests=0 --file-test-mode=rndrw run

$ sysbench fileio --file-total-size=2G --max-time=20 --max-requests=0 --file-test-mode=rndrw cleanup

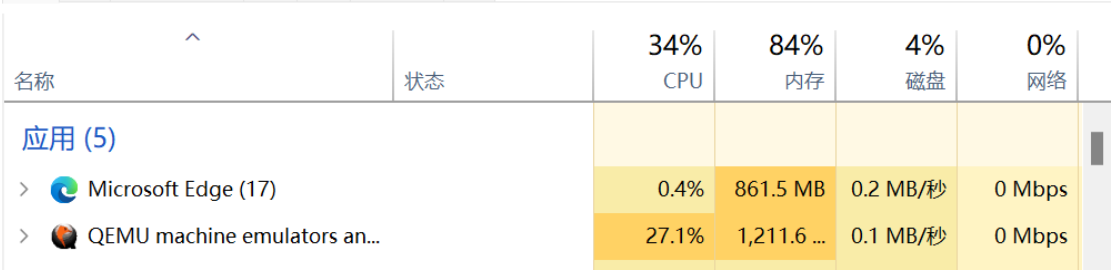
QEMU:

Attributes	Total time	Read	Write	Avg Latency
Min	20.1113	0.51	0.34	5.58
Max	21.4459	0.73	0.48	7.75
Average	20.7161	0.63	0.418	6.474
Std	0.5023	0.0759	0.0492	0.7562

Docker:

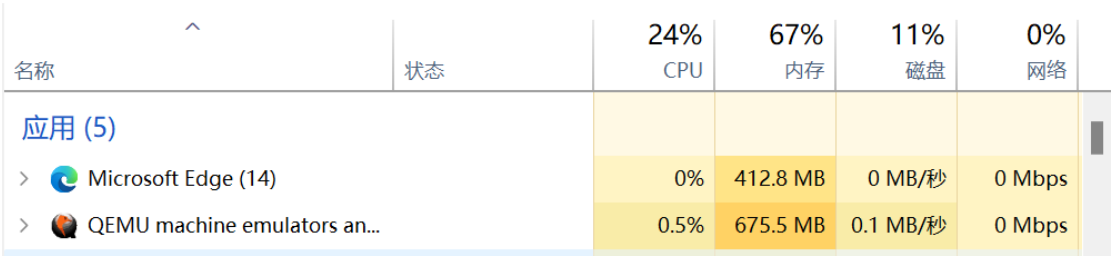
Attributes	Total time	Read	Write	Avg Latency
Min	20.0293	16.05	10.70	0.23
Max	20.0455	17.60	11.73	0.25
Average	20.0370	16.684	11.124	0.244
Std	0.0053	0.5252	0.3484	0.0080

Performance:
In a Windows 11 system, we can check the performance by typing CTRL+SHIFT+ESC to open the Windows Task Manager.
Performance data of QEMU:
(1) During CPU Test:



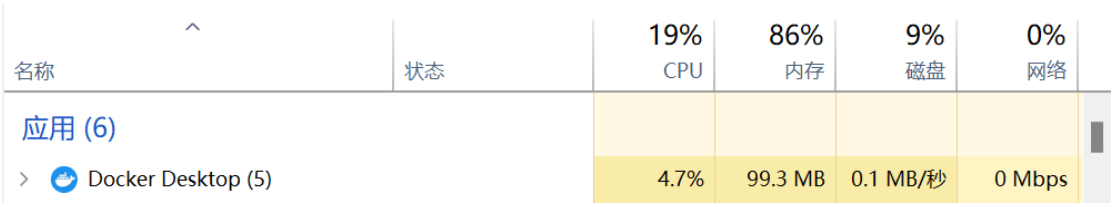
名称	状态	34% CPU	84% 内存	4% 磁盘	0% 网络
应用 (5)					
Microsoft Edge (17)		0.4%	861.5 MB	0.2 MB/秒	0 Mbps
QEMU machine emulators an...		27.1%	1,211.6 ...	0.1 MB/秒	0 Mbps

(2) During File I/O Test:



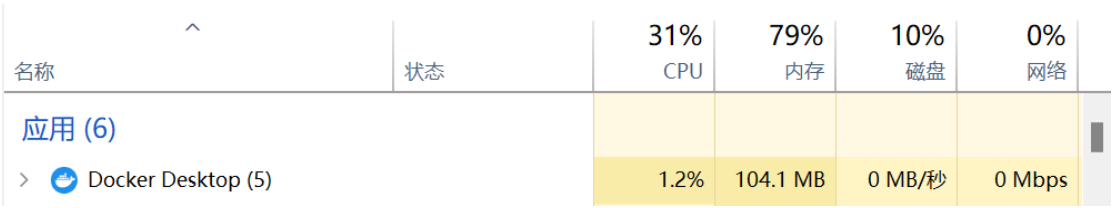
名称	状态	24% CPU	67% 内存	11% 磁盘	0% 网络
应用 (5)					
Microsoft Edge (14)		0%	412.8 MB	0 MB/秒	0 Mbps
QEMU machine emulators an...		0.5%	675.5 MB	0.1 MB/秒	0 Mbps

Performance data of Docker:
(1) During CPU Test:



名称	状态	19% CPU	86% 内存	9% 磁盘	0% 网络
应用 (6)					
Docker Desktop (5)		4.7%	99.3 MB	0.1 MB/秒	0 Mbps

(2) During File I/O Test:



名称	状态	31% CPU	79% 内存	10% 磁盘	0% 网络
应用 (6)					
Docker Desktop (5)		1.2%	104.1 MB	0 MB/秒	0 Mbps

For CPU Test:
CPU utilization in case of QEMU was around 27% whereas in case of Docker it was 5%

For File I/O Test:
The memory utilization of Docker (80%) was higher than QEMU (41.5%)

Conclusion:
From the CPU and File I/O performance data above, we can easily see that the Docker's performance is far more higher than QEMU's performance. In this case we can conclude that containers are always the best choice for virtualization compared with VMs.

Git Repository Information:
https://github.com/mingyang1998/COEN241-HWs.git

References:

[1] https://qemu.weilnetz.de/doc/6.0/
[2] https://imysql.com/wp-content/uploads/2014/10/sysbench-manual.pdf
[3] https://docs.docker.com/engine/reference/commandline/exec/