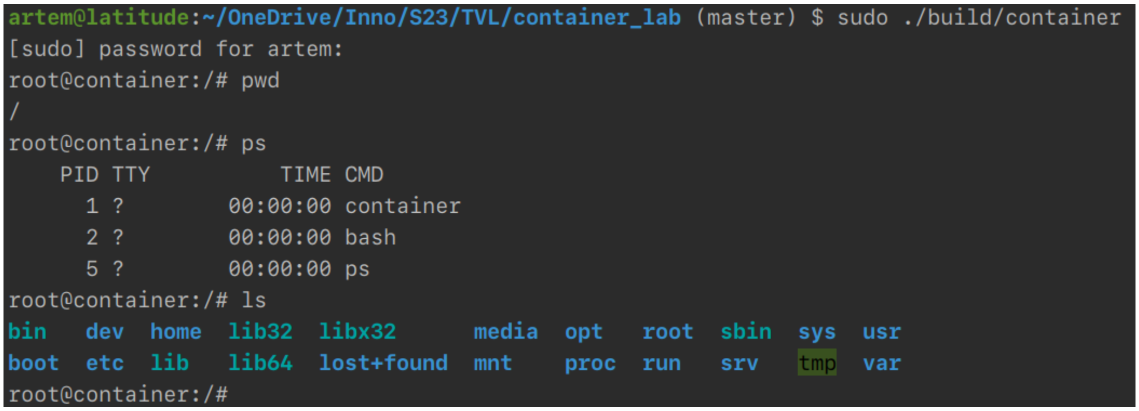
Lab 4 — create simple container

Intro

- The idea of the work is to `clone()` process with flags enabling the separate namespaces for it, etc., to prepare rootfs image for this process to `chroot` into, to configure `cgroups`.

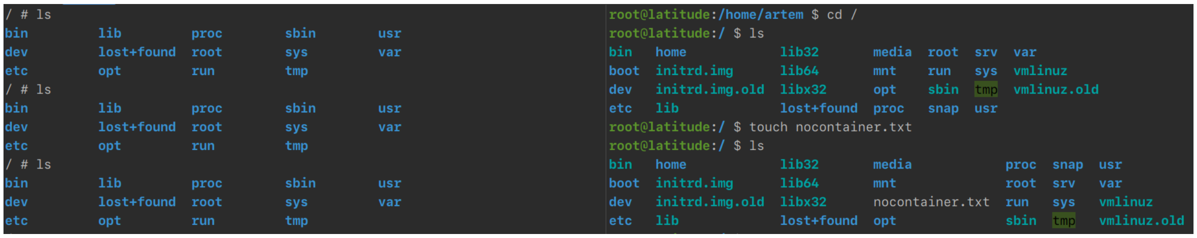
Features

  - Rootfs is based on Ubuntu 20.04 base image. Sysbench is added to the container filesystem image through `init_container.sh`. On startup, `bash` shell is invoked.
  - Container is created with its own namespaces:
    1. PID namespace (`CLONE_NEWPID`): The new process will have its own PID namespace. Processes in this namespace can only see the processes within the same namespace. The first process in this namespace is usually the init process, with a PID of 1.
    2. UTS namespace (`CLONE_NEWUTS`): The new process will have its own UTS namespace, which includes the hostname and domain name. This allows a process to have a different hostname inside and outside the namespace.
    3. Network namespace (`CLONE_NEWNET`): The new process will have its own network namespace. We create namespace within Bash script using `ip netns add` and further set it up. This means that it will have its own set of network interfaces, IP addresses, routing tables, and firewall rules, independent of the host and other processes. A pair of virtual interfaces is created: `veth_host` and `veth_container`, and assigned IP addresses 192.168.10.1 and 192.168.10.2, accordingly. The `container` binary simply joins existing namespace `container_network_ns`.
    4. Mount namespace (`CLONE_NEWNS`): The new process will have its own mount namespace. This means that it will have its own filesystem root directory and its own set of mount points, independent of the host and other processes.



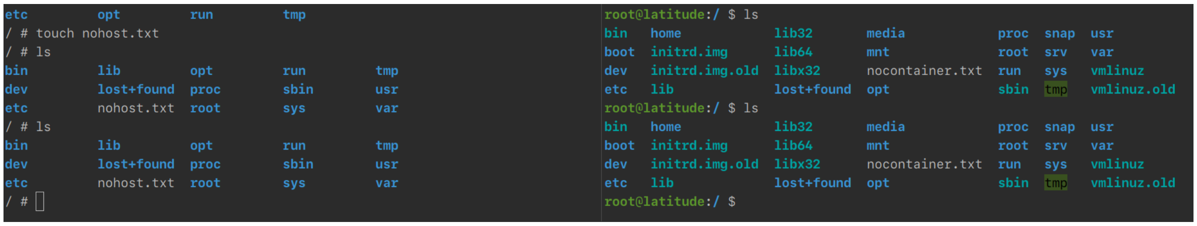
```
artem@latitude:~/OneDrive/Inno/S23/TVL/container_lab (master) $ sudo ./build/container
[sudo] password for artem:
root@container:/# pwd
/
root@container:/# ps
    PID TTY          TIME CMD
      1 ?        00:00:00 container
      2 ?        00:00:00 bash
      5 ?        00:00:00 ps
root@container:/# ls
bin   dev  home  lib32  libx32      media  opt   root  sbin  sys  usr
boot  etc  lib   lib64  lost+found  mnt    proc  run   srv   tmp  var
root@container:/#
```

Filesystem isolation



```
/ # ls
bin         lib         proc        sbin        usr
dev         lost+found  root        sys         var
etc         opt         run         tmp
/ # ls
bin         lib         proc        sbin        usr
dev         lost+found  root        sys         var
etc         opt         run         tmp
/ # ls
bin         lib         proc        sbin        usr
dev         lost+found  root        sys         var
etc         opt         run         tmp
```

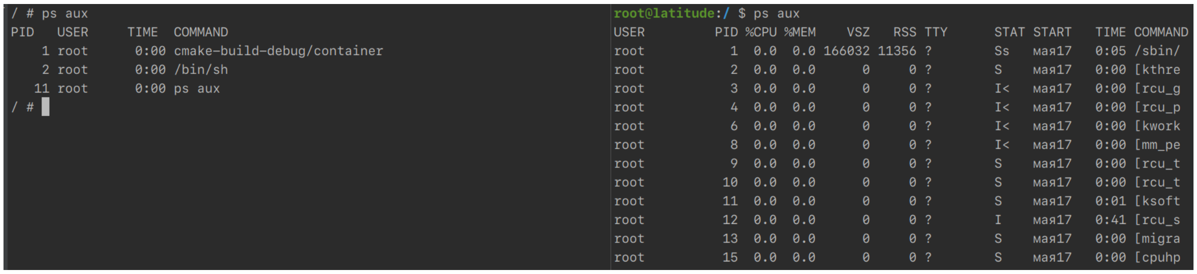
```
root@latitude:/home/artem $ cd /
root@latitude:/ $ ls
bin   home            lib32       media  root  srv  var
boot  initrd.img      lib64       mnt    run   sys  vmlinuz
dev   initrd.img.old  libx32      opt    sbin  tmp  vmlinuz.old
etc   lib             lost+found  proc   snap  usr
root@latitude:/ $ touch nocontainer.txt
root@latitude:/ $ ls
bin   home            lib32       media            proc  snap  usr
boot  initrd.img      lib64       mnt              root  srv   var
dev   initrd.img.old  libx32      nocontainer.txt  run   sys   vmlinuz
etc   lib             lost+found  opt              sbin  tmp   vmlinuz.old
```



```
etc         opt         run         tmp
/ # touch nohost.txt
/ # ls
bin         lib         opt         run         tmp
dev         lost+found  proc        sbin        usr
etc         nohost.txt  root        sys         var
/ # ls
bin         lib         opt         run         tmp
dev         lost+found  proc        sbin        usr
etc         nohost.txt  root        sys         var
/ # 
```

```
root@latitude:/ $ ls
bin   home            lib32       media            proc  snap  usr
boot  initrd.img      lib64       mnt              root  srv   var
dev   initrd.img.old  libx32      nocontainer.txt  run   sys   vmlinuz
etc   lib             lost+found  opt              sbin  tmp   vmlinuz.old
root@latitude:/ $ ls
bin   home            lib32       media            proc  snap  usr
boot  initrd.img      lib64       mnt              root  srv   var
dev   initrd.img.old  libx32      nocontainer.txt  run   sys   vmlinuz
etc   lib             lost+found  opt              sbin  tmp   vmlinuz.old
root@latitude:/ $
```

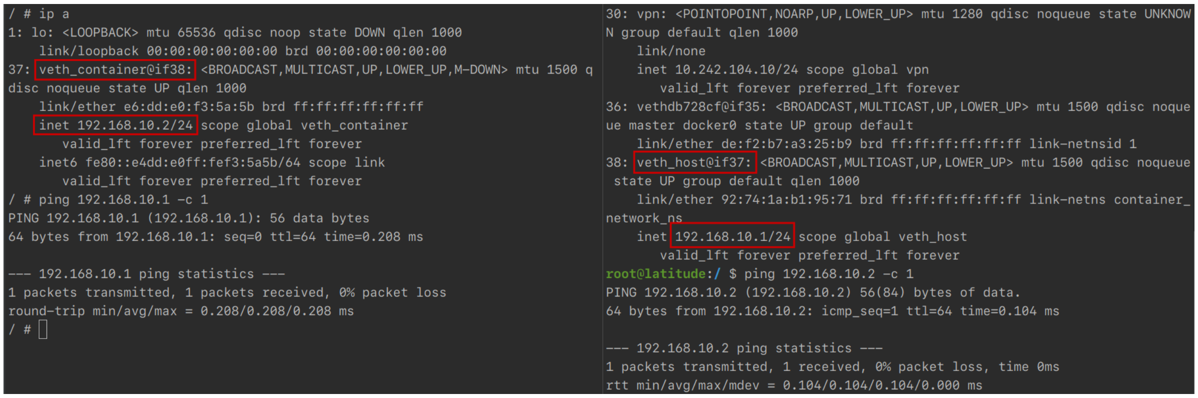
PID isolation



```
/ # ps aux
PID   USER     TIME  COMMAND
    1 root      0:00 cmake-build-debug/container
    2 root      0:00 /bin/sh
   11 root      0:00 ps aux
/ # 
```

```
root@latitude:/ $ ps aux
USER         PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
root           1  0.0  0.0 166032 11356 ?        Ss   мая17   0:05 /sbin/
root           2  0.0  0.0      0     0 ?        S    мая17   0:00 [kthre
root           3  0.0  0.0      0     0 ?        I<   мая17   0:00 [rcu_g
root           4  0.0  0.0      0     0 ?        I<   мая17   0:00 [rcu_p
root           6  0.0  0.0      0     0 ?        I<   мая17   0:00 [kwork
root           8  0.0  0.0      0     0 ?        I<   мая17   0:00 [mm_pe
root           9  0.0  0.0      0     0 ?        S    мая17   0:00 [rcu_t
root          10  0.0  0.0      0     0 ?        S    мая17   0:00 [rcu_t
root          11  0.0  0.0      0     0 ?        S    мая17   0:01 [ksoft
root          12  0.0  0.0      0     0 ?        I    мая17   0:41 [rcu_s
root          13  0.0  0.0      0     0 ?        S    мая17   0:00 [migra
root          15  0.0  0.0      0     0 ?        S    мая17   0:00 [cpuhp
```

Network isolation (and communication)

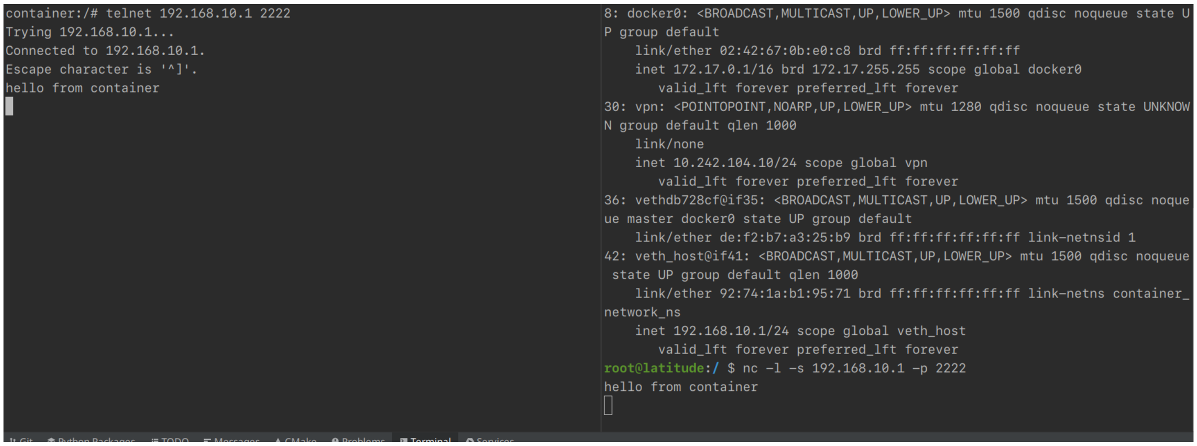


```
/ # ip a
1: lo: <LOOPBACK> mtu 65536 qdisc noop state DOWN qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
37: veth_container@if38: <BROADCAST,MULTICAST,UP,LOWER_UP,M-DOWN> mtu 1500 q
disc noqueue state UP qlen 1000
    link/ether e6:dd:e0:f3:5a:5b brd ff:ff:ff:ff:ff:ff
    inet 192.168.10.2/24 scope global veth_container
       valid_lft forever preferred_lft forever
    inet6 fe80::e4dd:e0ff:fef3:5a5b/64 scope link
       valid_lft forever preferred_lft forever
/ # ping 192.168.10.1 -c 1
PING 192.168.10.1 (192.168.10.1): 56 data bytes
64 bytes from 192.168.10.1: seq=0 ttl=64 time=0.208 ms

--- 192.168.10.1 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max = 0.208/0.208/0.208 ms
/ #
```

```
30: vpn: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1280 qdisc noqueue state UNKNOW
N group default qlen 1000
    link/none
    inet 10.242.104.10/24 scope global vpn
       valid_lft forever preferred_lft forever
36: vethdb728cf@if35: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noque
ue master docker0 state UP group default
    link/ether de:f2:b7:a3:25:b9 brd ff:ff:ff:ff:ff:ff link-netnsid 1
38: veth_host@if37: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
 state UP group default qlen 1000
    link/ether 92:74:1a:b1:95:71 brd ff:ff:ff:ff:ff:ff link-netns container_
network_ns
    inet 192.168.10.1/24 scope global veth_host
       valid_lft forever preferred_lft forever
root@latitude:/ $ ping 192.168.10.2 -c 1
PING 192.168.10.2 (192.168.10.2) 56(84) bytes of data.
64 bytes from 192.168.10.2: icmp_seq=1 ttl=64 time=0.104 ms

--- 192.168.10.2 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.104/0.104/0.104/0.000 ms
```

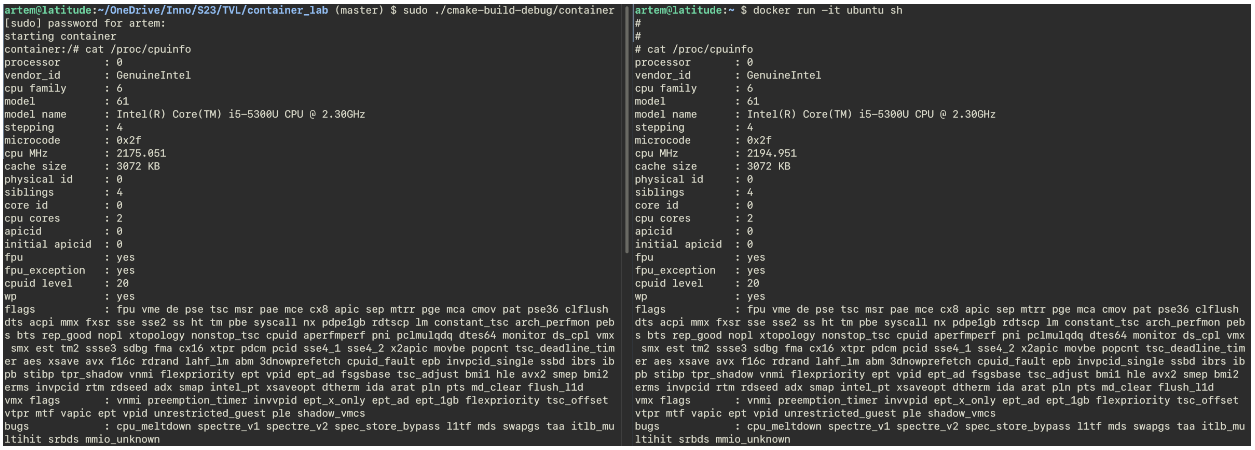


```
container:/# telnet 192.168.10.1 2222
Trying 192.168.10.1...
Connected to 192.168.10.1.
Escape character is '^]'.
hello from container
```

```
8: docker0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state U
P group default
    link/ether 02:42:67:0b:e0:c8 brd ff:ff:ff:ff:ff:ff
    inet 172.17.0.1/16 brd 172.17.255.255 scope global docker0
       valid_lft forever preferred_lft forever
30: vpn: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1280 qdisc noqueue state UNKNOW
N group default qlen 1000
    link/none
    inet 10.242.104.10/24 scope global vpn
       valid_lft forever preferred_lft forever
36: vethdb728cf@if35: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noque
ue master docker0 state UP group default
    link/ether de:f2:b7:a3:25:b9 brd ff:ff:ff:ff:ff:ff link-netnsid 1
42: veth_host@if41: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
 state UP group default qlen 1000
    link/ether 92:74:1a:b1:95:71 brd ff:ff:ff:ff:ff:ff link-netns container_
network_ns
    inet 192.168.10.1/24 scope global veth_host
       valid_lft forever preferred_lft forever
root@latitude:/ $ nc -l -s 192.168.10.1 -p 2222
hello from container
```

Comparison with Docker

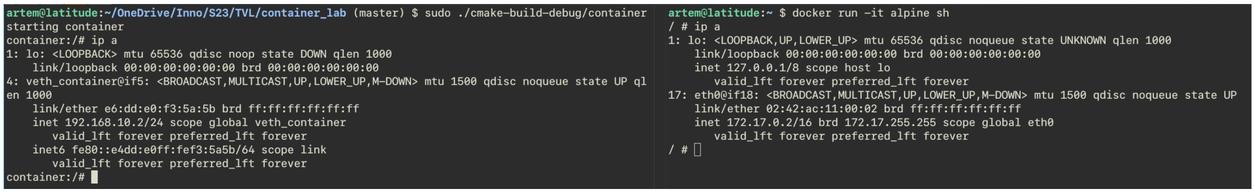
- CPU info:



```
artem@latitude:~/OneDrive/Inno/S23/TVL/container_lab (master) $ sudo ./cmake-build-debug/container
[sudo] password for artem:
starting container
container:/# cat /proc/cpuinfo
processor       : 0
vendor_id       : GenuineIntel
cpu family      : 6
model           : 61
model name      : Intel(R) Core(TM) i5-5300U CPU @ 2.30GHz
stepping        : 4
microcode       : 0x2f
cpu MHz         : 2175.051
cache size      : 3072 KB
physical id     : 0
siblings        : 4
core id         : 0
cpu cores       : 2
apicid          : 0
initial apicid  : 0
fpu             : yes
fpu_exception   : yes
cpuid level     : 20
wp              : yes
flags           : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat pse36 clflush
dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp lm constant_tsc arch_perfmon peb
s bts rep_good nopl xtopology nonstop_tsc cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx
 smx est tm2 ssse3 sdbg fma cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_tim
er aes xsave avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single ssbd ibrs ib
pb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust bmi1 hle avx2 smep bmi2
erms invpcid rtm rdseed adx smap intel_pt xsaveopt dtherm ida arat pln pts md_clear flush_l1d
vmx flags       : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority tsc_offset
vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs
bugs            : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs taa itlb_mu
ltihit srbds mmio_unknown
```

```
artem@latitude:~ $ docker run -it ubuntu sh
#
#
# cat /proc/cpuinfo
processor       : 0
vendor_id       : GenuineIntel
cpu family      : 6
model           : 61
model name      : Intel(R) Core(TM) i5-5300U CPU @ 2.30GHz
stepping        : 4
microcode       : 0x2f
cpu MHz         : 2194.951
cache size      : 3072 KB
physical id     : 0
siblings        : 4
core id         : 0
cpu cores       : 2
apicid          : 0
initial apicid  : 0
fpu             : yes
fpu_exception   : yes
cpuid level     : 20
wp              : yes
flags           : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat pse36 clflush
dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp lm constant_tsc arch_perfmon peb
s bts rep_good nopl xtopology nonstop_tsc cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx
 smx est tm2 ssse3 sdbg fma cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_tim
er aes xsave avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single ssbd ibrs ib
pb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust bmi1 hle avx2 smep bmi2
erms invpcid rtm rdseed adx smap intel_pt xsaveopt dtherm ida arat pln pts md_clear flush_l1d
vmx flags       : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority tsc_offset
vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs
bugs            : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs taa itlb_mu
ltihit srbds mmio_unknown
```

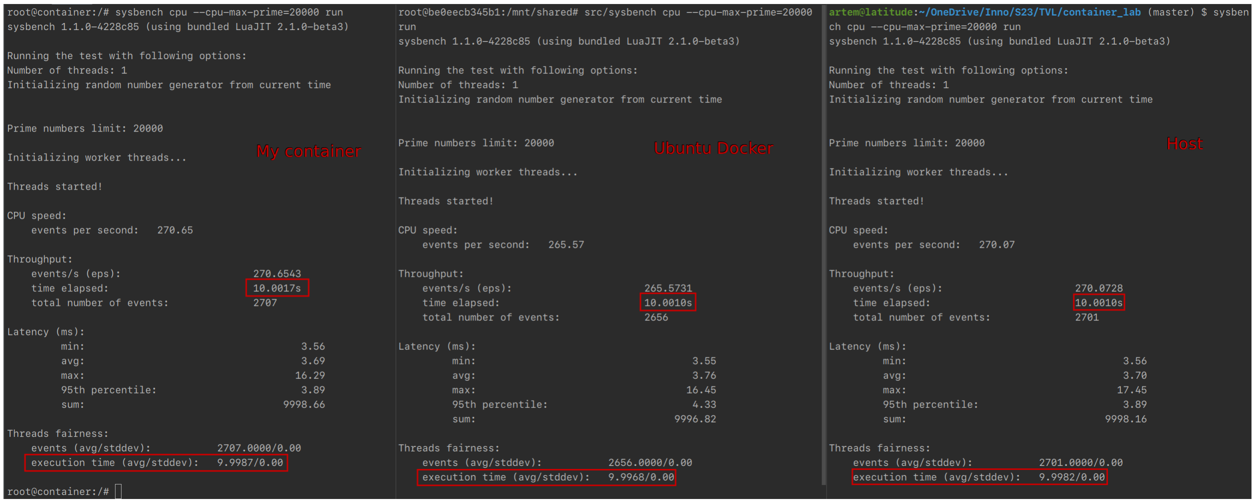
- Networking info:



```
artem@latitude:~/OneDrive/Inno/S23/TVL/container_lab (master) $ sudo ./cmake-build-debug/container
starting container
container:/# ip a
1: lo: <LOOPBACK> mtu 65536 qdisc noop state DOWN qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
4: veth_container@if5: <BROADCAST,MULTICAST,UP,LOWER_UP,M-DOWN> mtu 1500 qdisc noqueue state UP ql
en 1000
    link/ether e6:dd:e0:f3:5a:5b brd ff:ff:ff:ff:ff:ff
    inet 192.168.10.2/24 scope global veth_container
       valid_lft forever preferred_lft forever
    inet6 fe80::e4dd:e0ff:fef3:5a5b/64 scope link
       valid_lft forever preferred_lft forever
container:/# 
```

```
artem@latitude:~ $ docker run -it alpine sh
/ # ip a
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
17: eth0@if18: <BROADCAST,MULTICAST,UP,LOWER_UP,M-DOWN> mtu 1500 qdisc noqueue state UP
    link/ether 02:42:ac:11:00:02 brd ff:ff:ff:ff:ff:ff
    inet 172.17.0.2/16 brd 172.17.255.255 scope global eth0
       valid_lft forever preferred_lft forever
/ # 
```

Benchmark



My container

```
root@container:/# sysbench cpu --cpu-max-prime=20000 run
sysbench 1.1.0-4228c85 (using bundled 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:   270.65

Throughput:
    events/s (eps):                      270.6543
    time elapsed:                        10.0017s
    total number of events:              2707

Latency (ms):
         min:                                    3.56
         avg:                                    3.69
         max:                                   16.29
         95th percentile:                        3.89
         sum:                                 9998.66

Threads fairness:
    events (avg/stddev):           2707.0000/0.00
    execution time (avg/stddev):   9.9987/0.00

root@container:/# 
```

Ubuntu Docker

```
root@be0eecb345b1:/mnt/shared# src/sysbench cpu --cpu-max-prime=20000
run
sysbench 1.1.0-4228c85 (using bundled 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:   265.57

Throughput:
    events/s (eps):                      265.5731
    time elapsed:                        10.0010s
    total number of events:              2656

Latency (ms):
         min:                                    3.55
         avg:                                    3.76
         max:                                   16.45
         95th percentile:                        4.33
         sum:                                 9996.82

Threads fairness:
    events (avg/stddev):           2656.0000/0.00
    execution time (avg/stddev):   9.9968/0.00
```

Host

```
artem@latitude:~/OneDrive/Inno/S23/TVL/container_lab (master) $ sysben
ch cpu --cpu-max-prime=20000 run
sysbench 1.1.0-4228c85 (using bundled 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:   270.07

Throughput:
    events/s (eps):                      270.0728
    time elapsed:                        10.0010s
    total number of events:              2701

Latency (ms):
         min:                                    3.56
         avg:                                    3.70
         max:                                   17.45
         95th percentile:                        3.89
         sum:                                 9998.16

Threads fairness:
    events (avg/stddev):           2701.0000/0.00
    execution time (avg/stddev):   9.9982/0.00
```

Table with metrics

	command executed	my container	Docker (ubuntu 22.04)	host machine
CPU total time	`sysbench cpu --cpu-max-prime=20000 run`	9.9899 s	9.9968 s	9.9982 s
File IO write	`sysbench fileio --file-total-size=1G --file-num=128 --file-test-mode=seqwr run`	1073741824 bytes written in 6.60 seconds (155.11 MiB/sec).	1073741824 bytes written in 5.06 seconds (202.51 MiB/sec).	1073741824 bytes written in 7.89 seconds (129.82 MiB/sec).
File IO read	`sysbench fileio --file-total-size=1G --file-num=128 --file-test-mode=seqrd run`	IOPS=308201.48 4815.65 MiB/s (5049.57 MB/s)	IOPS=323803.01 5059.42 MiB/s (5305.19 MB/s)	IOPS=324396.52 5068.70 MiB/s (5314.91 MB/s)
Memory access	`sysbench memory --memory-block-size=1K --memory-total-size=4G run`	0.4148 s	0.4163 s	0.4164

- After conducting several tests, it was found that the performance of the container created in this lab and Docker's Ubuntu 22.04 image differed insignificantly. The CPU time, file IO write and read, and memory access of both containers were similar. The reason for this is that mechanism I used in my container are nearly identical to those used in Docker. Overall, the container in this lab and Docker's Ubuntu 22.04 image performed similarly, with the slight edge going to Docker due to its more optimized storage driver.
- One of the difficulties that worth highlighting in this lab was figuring out how to set up the network within the container. It was also found that the capabilities required to run containers are quite high, and the simplest way to run a container is to run as root. Creating an appropriate rootfs with all necessary utilities was also a challenge, but a script provided by Alpine Linux was used to create a rootfs with sysbench, telnet, and ping: https://github.com/alpinelinux/alpine-make-rootfs. This rootfs is stored as a dependency in `deps/` directory of the GitHub repo.

Links

- This project on Github: https://github.com/ar7ch/lab4tv

Sources

1. https://man7.org/linux/man-pages/man7/namespaces.7.html
2. https://cesarvr.io/post/2018-05-22-create-containers/
3. https://github.com/akopytov/sysbench#general-syntax
4. https://docs.docker.com/storage/storagedriver/
5. https://man7.org/linux/man-pages/man8/ip-netns.8.html