

Exploring Linux Memory Usage and Disk IO performance

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Topic: disk IO and disk IO performance

- The main topic of this presentation is disk IO performance on linux
- In order to understand disk IO performance, a detailed understanding of disk IO and related technologies is necessary.
- This presentation explains some the mechanics, in order to let the attendee understand buffered disk IO performance better.
- Memory usage is quite fundamentally closely related to cached IO performance.

Disk IO and memory

- Any regular disk IO is performed *buffered*.
- Buffered means: using the operating system memory for caching.
- You can do IO *without* using the operating system for caching.
 - Only if you explicitly request it: O_DIRECT.
 - Makes sense if you don't want to stage memory in two caches.
- If you are not sure which you are using *you are quite probably doing buffered IO*.

Where does buffered IO go?

- Linux does not have a dedicated memory area as 'page cache'.
 - Traditional Unix such as HPUX and AIX have that.
- Buffered IO *must* allocate memory to store the IO.
 - Even if that means it will get removed immediately b/c memory pressure(!)
 - Writes are special.
- Therefore it *competes* with regular memory usage.

Okay: but where does buffered IO go?

- Linux provides an insight into its memory usage via `/proc/meminfo`
 - Which is a messy gathering of memory related statistics.
- Named values in 'meminfo' do contain overlapping memory allocations, and can contain multiple, different allocations.
- Roughly put, it should be in 'Cached', 'Dirty' and 'Mapped', which can contain other types of allocated memory, such as shared memory.

You are not really making it understandable!

- I know.
- I think it's wrong to try to capture the exact page cache size.
- You must have memory that is usable for buffering purpose.
 - Which is also memory for application usage.
- The best way to assess usable memory is use `MemAvailable`

How about 'MemFree'?

- There also is the MemFree statistic in 'meminfo'?
- MemFree is not 'free' as in available.
 - It is a small amount of memory pre-cleaned for direct usage.
 - There will be lots after startup, because memory was never touched (yet).
- Linux tries to do the bare minimum, and thus keep used memory around.
 - And thus to reduce MemFree to a minimum (`vm.min_free_kbytes`).
 - The swapper force-frees memory. (Page daemon)
 - Processes explicitly freeing memory will add to MemFree.
 - <https://dev.to/yugabyte/what-is-free-memory-in-linux-18km>

MemAvailable

- Statistic in /proc/meminfo.
- Kernel estimation of available memory without requiring swapping.
- Many of the other statistics (in /proc/meminfo) contain information, are useful, but do not provide a full picture to assess available memory.

Why is this important actually?

- Buffering can do miracles for IO performance*.
- Equally it can do "miracles" for container/application performance.

Let's test!

- Tests done on Amazon EC2:
 - c5.large VM (20000/4000 IOPS, 594/82 MBPS)
 - EBS: GP3 250M (3000 IOPS, 125 MBPS)
- I am not running into my bursting limits so concrete:
 - IOPS: 3000
 - MBPS: 125
- EC2 VM limits page: <https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ebs-optimized.html>
 - Not easy to find.

Read: 2G

- Drop the page cache
- Validate available memory
- Run a fio **read** test reading 2G:

```
fio --name test --filename /tmp/fiotest  
--ioengine sync --rw randread --bs 8k  
--invalidate 0 --filesize 2G
```



centos@ip-172-158-19-16:~

8%

[centos@ip-172-158-19-16 ~]\$

█

```
[centos@ip-172-158-19-16 ~]$ sudo su - -c "echo 1 > /proc/sys/vm/drop_caches"
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory      :      3290 MB
total memory          :      3664 MB, free memory       :      3376 MB, used memory      :      161 MB
total swap            :      0 MB, free swap        :      0 MB, used swap        :      0 MB
[centos@ip-172-158-19-16 ~]$ 
```

```

[centos@ip-172-158-19-16 ~]$ sudo su - -c "echo 1 > /proc/sys/vm/drop_caches"
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory : 3290 MB
total memory : 3664 MB, free memory : 3376 MB, used memory : 161 MB
total swap : 0 MB, free swap : 0 MB, used swap : 0 MB
[centos@ip-172-158-19-16 ~]$ fio --name test --filename /tmp/fiotest --ioengine sync --rw randread --bs 8k --invalidate 0 --filesize 2G
test: (g=0): rw=randread, bs=(R) 8192B-8192B, (W) 8192B-8192B, (T) 8192B-8192B, ioengine=sync, iodepth=1
fio-3.7
Starting 1 process
Jobs: 1 (f=1): [r(1)][100.0%][r=21.1MiB/s,w=0KiB/s][r=2703,w=0 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=725: Wed Apr 13 19:01:52 2022
  read: IOPS=2609, BW=20.4MiB/s (21.4MB/s)(2048MiB/100465ms)
    clat (usec): min=195, max=27385, avg=382.22, stdev=263.41
    lat (usec): min=195, max=27385, avg=382.28, stdev=263.41
    clat percentiles (usec):
      | 1.00th=[ 253], 5.00th=[ 269], 10.00th=[ 277], 20.00th=[ 289],
      | 30.00th=[ 306], 40.00th=[ 318], 50.00th=[ 334], 60.00th=[ 351],
      | 70.00th=[ 379], 80.00th=[ 420], 90.00th=[ 510], 95.00th=[ 652],
      | 99.00th=[ 1106], 99.50th=[ 1237], 99.90th=[ 1647], 99.95th=[ 2999],
      | 99.99th=[11076]
    bw ( KiB/s): min=10640, max=23520, per=100.00%, avg=20874.93, stdev=1870.07, samples=200
    iops : min= 1330, max= 2940, avg=2609.35, stdev=233.77, samples=200
    lat (usec) : 250±0.5%, 500±8.75%, 750±7.09%, 1000±2.07%
    lat (msec) : 2±1.43%, 4±0.02%, 10±0.02%, 20±0.02%, 50±0.01%
    cpu : usr=0.45%, sys=1.95%, ctx=262144, majf=0, minf=36
  IO depths : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >=64=0.0%
              : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
    submit : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
    complete : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
  issued rwt: total=262144,0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1

Run status group 0 (all jobs):
  READ: bw=20.4MiB/s (21.4MB/s), 20.4MiB/s-20.4MiB/s (21.4MB/s-21.4MB/s), io=2048MiB (2147MB), run=100465-100465msec

Disk stats (read/write):
  nvme0n1: ios=62238/113, merge=0/11, ticks=97587/93, in_queue=97655, util=96.99%
[centos@ip-172-158-19-16 ~]$ █

```

Read: 2G

- This is a summary from the run:

IOPS=2609, BW=20.4MiB/s (21.4MB/s) (2048MiB/100465msec)

- My limits are 125 MBPS and 3000 IOPS.
- Why didn't we reach any of these? Is AWS lying?
- No: look at the latency:

clat (usec): min=195, max=27385, avg=382.22, stdev=263.41

- $382 \text{ (avg usec)} * 2609 \text{ (IOPS)} \approx 996638 \approx 1 \text{ second}$: latency bound!

Read: 2G

- Now lets perform the exact same run again

```

centos@ip-172-158-19-16 ~]$ sudo su - -c "echo 1 > /proc/sys/vm/drop_caches"
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory : 3290 MB
total memory : 3664 MB, free memory : 3376 MB, used memory : 161 MB
total swap : 0 MB, free swap : 0 MB, used swap : 0 MB
[centos@ip-172-158-19-16 ~]$ fio --name test --filename /tmp/fiotest --ioengine sync --rw randread --bs 8k --invalidate 0 --filesize 2G
test: (g=0): rw=randread, bs=(R) 8192B-8192B, (W) 8192B-8192B, (T) 8192B-8192B, ioengine=sync, iodepth=1
fio-3.7
Starting 1 process
Jobs: 1 (f=1): [r(1)][100.0%][r=21.1MiB/s,w=0KiB/s][r=2703,w=0 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=725: Wed Apr 13 19:01:52 2022
  read: IOPS=2609, BW=20.4MiB/s (21.4MB/s)(2048MiB/100465ms)
    clat (usec): min=195, max=27385, avg=382.22, stdev=263.41
      lat (usec): min=195, max=27385, avg=382.28, stdev=263.41
    clat percentiles (usec):
      | 1.00th=[ 253], 5.00th=[ 269], 10.00th=[ 277], 20.00th=[ 289],
      | 30.00th=[ 306], 40.00th=[ 318], 50.00th=[ 334], 60.00th=[ 351],
      | 70.00th=[ 379], 80.00th=[ 420], 90.00th=[ 510], 95.00th=[ 652],
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    bw ( KiB/s): min=10640, max=23520, per=100.00%, avg=20874.93, stdev=1870.07, samples=200
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    lat (usec) : 250±0.5%, 500±8.75%, 750±7.09%, 1000±2.07%
    lat (msec) : 2±1.43%, 4±0.02%, 10±0.02%, 20±0.02%, 50±0.01%
    cpu : usr=0.45%, sys=1.95%, ctx=262144, majf=0, minf=36
  IO depths : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >64=0.0%
              : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
    submit : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
    complete : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  issued rwt: total=262144,0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1

Run status group 0 (all jobs):
  READ: bw=20.4MiB/s (21.4MB/s), 20.4MiB/s-20.4MiB/s (21.4MB/s-21.4MB/s), io=2048MiB (2147MB), run=100465-100465msec

Disk stats (read/write):
  nvme0n1: ios=62238/113, merge=0/11, ticks=97587/93, in_queue=97655, util=96.99%
[centos@ip-172-158-19-16 ~]$ █

```

Read: 2G

- This is quite much different, isn't it?

```
read: IOPS=585k, BW=4571MiB/s (4793MB/s) (2048MiB/448msec)
```

- My limits are 125 MBPS and 3000 IOPS.
- Now I did 585000 IOPS and 4571 MBPS!

```
clat (nsec): min=893, max=19771, avg=1342.90, stdev=406.95
```

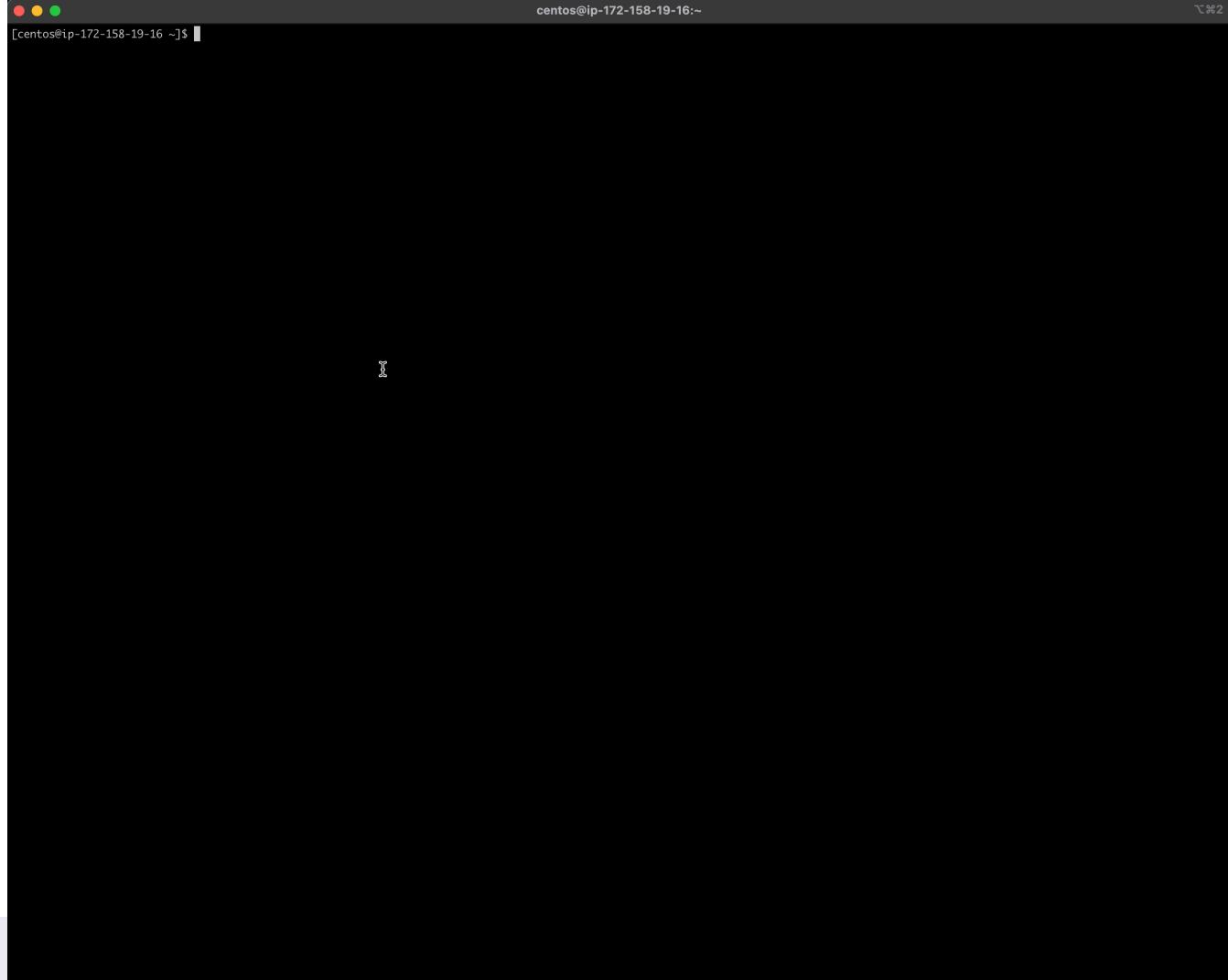
- It was all cache, no physical IOs were performed:

```
ios=0/0, merge=0/0, ticks=0/0, in_queue=0, util=0.00%
```

Read: 4G

- Drop the page cache
- Validate available memory
- Run a fio **read** test reading 4G:

```
fio --name test --filename /tmp/fiotest  
--ioengine sync --rw randread --bs 8k  
--invalidate 0 --filesize 4G
```



```
[centos@ip-172-158-19-16 ~]$ sudo su - -c "echo 1 > /proc/sys/vm/drop_caches"
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory      :      3179 MB
total memory          :      3664 MB, free memory       :      3267 MB, used memory      :      166 MB
total swap            :      0 MB, free swap        :      0 MB, used swap        :      0 MB
[centos@ip-172-158-19-16 ~]$ 
```

```

centos@ip-172-158-19-16 ~]$ sudo su - -c "echo 1 > /proc/sys/vm/drop_caches"
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory : 3179 MB
total memory : 3664 MB, free memory : 3267 MB, used memory : 166 MB
total swap : 0 MB, free swap : 0 MB, used swap : 0 MB
[centos@ip-172-158-19-16 ~]$ fio --name test --filename /tmp/fiotest --ioengine sync --rw randread --bs 8k --invalidate 0 --filesize 4G
test: (g=0): rw=randread, bs=(R) 8192B-8192B, (W) 8192B-8192B, (T) 8192B-8192B, ioengine=sync, iodepth=1
fio-3.7
Starting 1 process
Jobs: 1 (f=1): [r(1)][100.0%][r=18.3MiB/s,w=0KiB/s][r=2342,w=0 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=20803: Thu Apr 14 10:00:21 2022
  read: IOPS=2702, BW=21.1MB/s (22.1MB/s)(4096MiB/193996nsec)
    clat (usec): min=219, max=92699, avg=369.32, stdev=214.49
      lat (usec): min=219, max=92699, avg=369.36, stdev=214.49
    clat percentiles (usec):
      | 1.00th=[ 249], 5.00th=[ 262], 10.00th=[ 269], 20.00th=[ 281],
      | 30.00th=[ 293], 40.00th=[ 306], 50.00th=[ 322], 60.00th=[ 343],
      | 70.00th=[ 367], 80.00th=[ 412], 90.00th=[ 498], 95.00th=[ 635],
      | 99.00th=[ 1074], 99.50th=[ 1205], 99.90th=[ 1565], 99.95th=[ 1680],
      | 99.99th=[ 4621]
  bw ( KiB/s): min=10144, max=24368, per=100.00%, avg=21622.96, stdev=1704.10, samples=387
  iops : min= 1268, max= 3046, avg=2702.87, stdev=213.01, samples=387
  lat (usec) : 250±1.27%, 500±8.80%, 750±6.64%, 1000±1.96%
  lat (msec) : 2±1.30%, 4±0.01%, 10±0.01%, 20±0.01%, 100±0.01%
  cpu : usr=0.29%, sys=1.45%, ctx=524288, majf=0, minf=37
  IO depths : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >64=0.0%
            : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  submit : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  complete : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  issued rwt: total=524288, 0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1

Run status group 0 (all jobs):
  READ: bw=21.1MB/s (22.1MB/s), 21.1MiB/s-21.1MiB/s (22.1MB/s-22.1MB/s), io=4096MiB (4295MB), run=193996-193996msec

Disk stats (read/write):
  nvme0n1: ios=524247/140, merge=0/17, ticks=190788/67, in_queue=190821, util=98.31%
[centos@ip-172-158-19-16 ~]$ 

```

Read: 4G

- This is a summary from the run:

```
read: IOPS=2702, BW=21.1MiB/s (22.1MB/s) (4096MiB/193996msec)
```

- My limits are 125 MBPS and 3000 IOPS.
- IOPS rate identical to 2G run, indicates being latency bound again.
- Time and disk physical IOs roughly doubled, as expected.

Read: 4G

- Now lets perform the exact same run again
- Caveat: I had to slightly alter the fio statement.
 - Add option `--norandommap`
 - This prevents every 8k IO offset from being touched exactly once.

```

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[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory : 3179 MB
total memory : 3664 MB, free memory : 3267 MB, used memory : 166 MB
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[centos@ip-172-158-19-16 ~]$ fio --name test --filename /tmp/fiotest --ioengine sync --rw randread --bs 8k --invalidate 0 --filesize 4G
test: (g=0): rw=randread, bs=(R) 8192B-8192B, (W) 8192B-8192B, (T) 8192B-8192B, ioengine=sync, iodepth=1
fio-3.7
Starting 1 process
Jobs: 1 (f=1): [r(1)][I00.0%][r=18.3MiB/s,w=0KiB/s][r=2342,w=0 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=20803: Thu Apr 14 10:00:21 2022
  read: IOPS=2702, BW=21.1MB/s (22.1MB/s)(4096MiB/193996msec)
    clat (usec): min=219, max=92699, avg=369.32, stdev=214.49
      lat (usec): min=219, max=92699, avg=369.36, stdev=214.49
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      | 99.00th=[ 1074], 99.50th=[ 1205], 99.90th=[ 1565], 99.95th=[ 1680],
      | 99.99th=[ 4621]
  bw ( KiB/s): min=10144, max=24368, per=100.00%, avg=21622.96, stdev=1704.10, samples=387
  iops : min= 1268, max= 3046, avg=2702.87, stdev=213.01, samples=387
  lat (usec) : 250±1.27%, 500±8.80%, 750±6.64%, 1000±1.96%
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  cpu : usr=0.29%, sys=1.45%, ctx=524288, majf=0, minf=37
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  complete : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  issued rwt: total=524288, 0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1

Run status group 0 (all jobs):
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[centos@ip-172-158-19-16 ~]$ 
```

Starting 1 process

```
Jobs: 1 (f=1): [r(1)][100.0%][r=18.3MiB/s,w=0KiB/s][r=2342,w=0 IOPS][eta 00m:05s]
test: (groupid=0, jobs=1): err= 0: pid=20803: Thu Apr 14 10:00:21 2022
  read: IOPS=2702, BW=21.1MiB/s (22.1MB/s)(4096MiB/193996msec)
    clat (usec): min=219, max=92699, avg=369.32, stdev=214.49
    lat (usec): min=219, max=92699, avg=369.36, stdev=214.49
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  issued r/wts: total=524288,0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1
```

Run status group 0 (all jobs):

```
READ: bw=21.1MiB/s (22.1MB/s), 21.1MiB/s-21.1MiB/s (22.1MB/s-22.1MB/s), io=4096MiB (4295MB), run=193996-193996msec
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Disk stats (read/write):

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nvme0n1: ios=524247/140, merge=0/17, ticks=190788/67, in_queue=190821, util=98.31%
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```
[centos@ip-172-158-19-16 ~]$ fio --name test --filename /tmp/fiotest --ioengine sync --rw randread --bs 8k --invalidate 0 --norandommap --filesize 4G
test: (g=0): rw=randread, bs=(R) 8192B-8192B, (W) 8192B-8192B, ioengine=sync, iodepth=1
fio-3.7
Starting 1 process
Jobs: 1 (f=1): [r(1)][99.2%][r=61.0MiB/s,w=0KiB/s][r=7935,w=0 IOPS][eta 00m:01s]
test: (groupid=0, jobs=1): err= 0: pid=22616: Thu Apr 14 10:09:11 2022
  read: IOPS=4206, BW=32.9MiB/s (34.5MB/s)(4096MiB/124633msec)
    clat (nsec): min=513, max=30504k, avg=237260.41, stdev=228596.70
    lat (nsec): min=534, max=30504k, avg=237293.03, stdev=228597.81
  clat percentiles (nsec):
    | 1.00th=[ 1176], 5.00th=[ 1256], 10.00th=[ 1336],
    | 20.00th=[ 1528], 30.00th=[ 1848], 40.00th=[ 264192],
    | 50.00th=[ 284672], 60.00th=[ 305152], 70.00th=[ 329728],
    | 80.00th=[ 366592], 90.00th=[ 448512], 95.00th=[ 552960],
    | 99.00th=[ 970752], 99.50th=[1123040], 99.90th=[1499136],
    | 99.95th=[1613824], 99.99th=[2768896]
  bw ( Kib/s): min=17760, max=64128, per=99.90%, avg=33619.46, stdev=9944.64, samples=249
  iops : min= 2220, max= 8016, avg=4202.43, stdev=1243.08, samples=249
  lat (nsec) : 750±0.01%, 1000±0.01%
  lat (usec) : 2±31.74%, 4±4.83%, 10±0.18%, 20±0.02%, 250±0.71%
  lat (msec) : 500±55.67%, 750±4.56%, 1000±1.38%
  cpu : usr=0.88%, sys=1.73%, ctx=331382, majf=0, minf=36
  IO depths : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >=64=0.0%
    submit : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
    complete : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
  issued r/wts: total=524288,0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1
```

Run status group 0 (all jobs):

```
READ: bw=32.9MiB/s (34.5MB/s), 32.9MiB/s-32.9MiB/s (34.5MB/s-34.5MB/s), io=4096MiB (4295MB), run=124633-124633msec
```

Disk stats (read/write):

```
nvme0n1: ios=330920/105, merge=0/14, ticks=122124/59, in_queue=122162, util=98.04%
```

Read: 4G

- This is a summary from the run:

```
read: IOPS=4206, BW=32.9MiB/s (34.5MB/s) (4096MiB/124633msec)
```

- My limits are 125 MBPS and 3000 IOPS.
- IOPS rate increased, because of caching
- Still had to do a lot of IO:

```
ios=330920/105
```

```
issued rwts: total=524288, 0
```

Reality

- Let's take a look at the memory figures again:

```
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory      :      3179 MB
total memory          :      3664 MB, free memory      :      3267 MB, used memory      :      166 MB
total swap             :      0 MB, free swap      :      0 MB, used swap      :      0 MB
```

- Having 166MB used is not a realistic scenario.
- A server would typically have an application running!
- Which is what reads that data to serve it, right?
- What if we occupy 50% of memory?

eatmemory

- I build a tool that can do that: eatmemory

```
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -s 2000  
done. press enter to stop and deallocate
```

- Credits to original eatmemory.c tool (<https://github.com/julman99/eatmemory.git>)
- Let's try the same 2G run again!



centos@ip-172-158-19-16:~

2%

[centos@ip-172-158-19-16 ~]\$

II

```
centos@ip-172-158-19-16:~$ sudo su - -c "echo 1 > /proc/sys/vm/drop_caches"
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory      :       1135 MB
total memory          :     3664 MB, free memory      :       1228 MB, used memory      :       2215 MB
total swap            :        0 MB, free swap        :        0 MB, used swap        :        0 MB
[centos@ip-172-158-19-16 ~]$
```

```

centos@ip-172-158-19-16 ~]$ sudo su - -c "echo 1 > /proc/sys/vm/drop_caches"
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory : 1135 MB
total memory : 3664 MB, free memory : 1228 MB, used memory : 2215 MB
total swap : 0 MB, free swap : 0 MB, used swap : 0 MB
[centos@ip-172-158-19-16 ~]$ fio --name test --filename /tmp/fiotest --ioengine sync --rw randread --bs 8k --invalidate 0 --filesize 2G
test: (g=0): rw=randread, bs=(R) 8192B-8192B, (W) 8192B-8192B, (T) 8192B-8192B, ioengine=sync, iodepth=1
fio-3.7
Starting 1 process
Jobs: 1 (f=1): [r(1)][I00.0%][r=21.2MiB/s,w=0KiB/s][r=2719,w=0 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=26975: Thu Apr 14 10:36:21 2022
  read: IOPS=2671, BW=20.9MiB/s (21.9MB/s)2048MiB/98136msec
    clat (usec): min=173, max=24206, avg=373.64, stdev=218.70
      lat (usec): min=173, max=24207, avg=373.69, stdev=218.70
    clat percentiles (usec):
      | 1.00th=[ 251], 5.00th=[ 265], 10.00th=[ 273], 20.00th=[ 285],
      | 30.00th=[ 297], 40.00th=[ 310], 50.00th=[ 326], 60.00th=[ 347],
      | 70.00th=[ 371], 80.00th=[ 412], 90.00th=[ 498], 95.00th=[ 644],
      | 99.00th=[ 1074], 99.50th=[ 1221], 99.90th=[ 1614], 99.95th=[ 2409],
      | 99.99th=[10290]
  bw ( KiB/s): min=13392, max=23744, per=99.99%, avg=21365.87, stdev=1330.25, samples=196
    iops : min= 1674, max= 2968, avg=2670.73, stdev=166.30, samples=196
    lat (usec) : 250±0.87%, 500±0.28%, 750±0.43%, 1000±2.02%
    lat (msec) : 2±1.34%, 4±0.03%, 10±0.02%, 20±0.01%, 50±0.01%
    cpu : usr=0.31%, sys=1.49%, ctx=262145, majf=0, minf=36
  IO depths : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >64=0.0%
            : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  complete : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  issued rwt: total=262144,0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1

Run status group 0 (all jobs):
  READ: bw=20.9MiB/s (21.9MB/s), 20.9MiB/s-20.9MiB/s (21.9MB/s-21.9MB/s), io=2048MiB (2147MB), run=98136-98136msec

Disk stats (read/write):
  nvme0n1: ios=62560/146, merge=0/17, ticks=96004/105, in_queue=96092, util=97.37%
[centos@ip-172-158-19-16 ~]$ 
```

Read: 2G / 50% of 4G memory taken

- This is a summary from the run:

```
read: IOPS=2671, BW=20.9MiB/s (21.9MB/s) (2048MiB/98136msec)
```

- My limits are 125 MBPS and 3000 IOPS.
- Time is slightly less (98136 vs. 100465), but generally equal.
- Because despite the memory allocation, there was no change: bound by IO.

Read: 2G / 50% of 4G memory taken

- Now lets perform the same run again
 - Add option --norandommap

```

centos@ip-172-158-19-16 ~]$ sudo su - -c "echo 1 > /proc/sys/vm/drop_caches"
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory : 1135 MB
total memory : 3664 MB, free memory : 1228 MB, used memory : 2215 MB
total swap : 0 MB, free swap : 0 MB, used swap : 0 MB
[centos@ip-172-158-19-16 ~]$ fio --name test --filename /tmp/fiotest --ioengine sync --rw randread --bs 8k --invalidate 0 --filesize 2G
test: (g=0): rw=randread, bs=(R) 8192B-8192B, (W) 8192B-8192B, (T) 8192B-8192B, ioengine=sync, iodepth=1
fio-3.7
Starting 1 process
Jobs: 1 (f=1): [r(1)][100.0%][r=21.2MiB/s,w=0KiB/s][r=2719,w=0 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=26975: Thu Apr 14 10:36:21 2022
  read: IOPS=2671, BW=20.9MiB/s (21.9MB/s)2048MiB/98136msec
    clat (usec): min=173, max=24206, avg=373.64, stdev=218.70
      lat (usec): min=173, max=24207, avg=373.69, stdev=218.70
    clat percentiles (usec):
      | 1.00th=[ 251], 5.00th=[ 265], 10.00th=[ 273], 20.00th=[ 285],
      | 30.00th=[ 297], 40.00th=[ 310], 50.00th=[ 326], 60.00th=[ 347],
      | 70.00th=[ 371], 80.00th=[ 412], 90.00th=[ 498], 95.00th=[ 644],
      | 99.00th=[ 1074], 99.50th=[ 1221], 99.90th=[ 1614], 99.95th=[ 2409],
      | 99.99th=[10290]
  bw ( KiB/s): min=13392, max=23744, per=99.99%, avg=21365.87, stdev=1330.25, samples=196
  iops : min= 1674, max= 2968, avg=2670.73, stdev=166.30, samples=196
  lat (usec) : 250±0.87%, 500±0.28%, 750±0.43%, 1000±2.02%
  lat (msec) : 2±1.34%, 4±0.03%, 10±0.02%, 20±0.01%, 50±0.01%
  cpu : usr=0.31%, sys=1.49%, ctx=262145, majf=0, minf=36
  IO depths : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >64=0.0%
            : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  submit : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  complete : issued rwt: total=262144,0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1

Run status group 0 (all jobs):
  READ: bw=20.9MiB/s (21.9MB/s), 20.9MiB/s-20.9MiB/s (21.9MB/s-21.9MB/s), io=2048MiB (2147MB), run=98136-98136msec

Disk stats (read/write):
  nvme0n1: ios=62560/146, merge=0/17, ticks=96004/105, in_queue=96092, util=97.37%
[centos@ip-172-158-19-16 ~]$ 
```

Starting 1 process

```
Jobs: 1 (f=1): [r(1)][100.0%][r=21.2MiB/s,w=0KiB/s][r=2719,w=0 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=26975: Thu Apr 14 10:36:21 2022
  read: IOPS=2671, BW=20.9MiB/s (21.9MB/s)(2048MiB/98136msec)
    clat (usec): min=173, max=24206, avg=373.64, stdev=218.70
    lat (usec): min=173, max=24207, avg=373.69, stdev=218.70
  clat percentiles (usec):
    | 1.00th=[ 251], 5.00th=[ 265], 10.00th=[ 273], 20.00th=[ 285],
    | 30.00th=[ 297], 40.00th=[ 310], 50.00th=[ 326], 60.00th=[ 347],
    | 70.00th=[ 371], 80.00th=[ 412], 90.00th=[ 498], 95.00th=[ 644],
    | 99.00th=[ 1074], 99.50th=[ 1221], 99.90th=[ 1614], 99.95th=[ 2409],
    | 99.99th=[10290]
  bw ( Kib/s): min=13392, max=23744, per=99.99%, avg=21365.87, stdev=1330.25, samples=196
  iops : min= 1674, max= 2968, avg=2670.73, stdev=166.30, samples=196
  lat (usec) : 250±0.87%, 500±89.28%, 750±6.43%, 1000±2.02%
  lat (msec) : 2±1.34%, 4±0.03%, 10±0.02%, 20±0.01%, 50±0.01%
  cpu : usr=0.31%, sys=1.49%, ctx=262145, majf=0, minf=36
  IO depths : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >=64=0.0%
    submit : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
    complete : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
  issued rwt: total=262144,0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1
```

Run status group 0 (all jobs):

```
READ: bw=20.9MiB/s (21.9MB/s), 20.9MiB/s-20.9MiB/s (21.9MB/s-21.9MB/s), io=2048MiB (2147MB), run=98136-98136msec
```

Disk stats (read/write):

```
nvme0n1: ios=262560/146, merge=0/17, ticks=96004/105, in_queue=96092, util=97.37%
[cenots@ip-172-158-19-16 ~]$ fio --name test --filename /tmp/fiotest --ioengine sync --rw randread --bs 8k --invalidate 0 --norandommap --filesize 2G
test: (g=0): rw=randread, bs=(R) 8192B-8192B, (W) 8192B-8192B, ioengine=sync, iodepth=1
fio-3.7
```

Starting 1 process

```
Jobs: 1 (f=1): [r(1)][100.0%][r=31.2MiB/s,w=0KiB/s][r=3988,w=0 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=32758: Thu Apr 14 11:10:09 2022
  read: IOPS=3525, BW=27.5MiB/s (28.9MB/s)(2048MiB/74366msec)
    clat (nsec): min=516, max=28349k, avg=283194.64, stdev=256978.87
    lat (nsec): min=538, max=28349k, avg=283232.46, stdev=256979.92
  clat percentiles (nsec):
    | 1.00th=[ 1208], 5.00th=[ 1320], 10.00th=[ 1448],
    | 20.00th=[ 1768], 30.00th=[ 261120], 40.00th=[ 284672],
    | 50.00th=[ 301056], 60.00th=[ 321536], 70.00th=[ 350208],
    | 80.00th=[ 395264], 90.00th=[ 485376], 95.00th=[ 618496],
    | 99.00th=[1056768], 99.50th=[1204224], 99.90th=[1581056],
    | 99.95th=[1728512], 99.99th=[5079040]
  bw ( Kib/s): min=17144, max=34736, per=99.96%, avg=28190.05, stdev=4400.47, samples=148
  iops : min= 1468, max= 4342, avg=3523.75, stdev=550.06, samples=148
  lat (nsec) : 750±0.01%, 1000±0.01%
  lat (usec) : 2±22.80%, 4±3.41%, 10±0.31%, 20±0.02%, 250±0.99%
  lat (msec) : 500±63.35%, 750±6.05%, 1000±1.79%
  cpu : usr=0.27%, sys=1.63%, ctx=192535, majf=0, minf=36
  IO depths : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >=64=0.0%
    submit : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
    complete : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
  issued rwt: total=262144,0,0,0 short=0,0,0 dropped=0,0,0
  latency : target=0, window=0, percentile=100.00%, depth=1
```

Run status group 0 (all jobs):

```
READ: bw=27.5MiB/s (28.9MB/s), 27.5MiB/s-27.5MiB/s (28.9MB/s-28.9MB/s), io=2048MiB (2147MB), run=74366-74366msec
```

Disk stats (read/write):

```
nvme0n1: ios=192264/64, merge=0/6, ticks=72937/55, in_queue=72978, util=98.01%
[cenots@ip-172-158-19-16 ~]$
```

Read: 2G / 50% of 4G memory taken

```
read: IOPS=3525, BW=27.5MiB/s (28.9MB/s) (2048MiB/74366msec)
```

- My limits are 125 MBPS and 3000 IOPS.
- This gone beyond the limits (IOPS 3525).
- Time difference with previous 2nd 2G run: 74.3 ⇠ 0.4 second (!)
- Reason: physical IO had to be performed:
`ios=192264/64, merge=0/6, ticks=72937/55, in_queue=72978, util=98.01%`

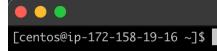
Write

- Now let's look at writes, and investigate that!
- Here too I start off with an idle machine.

Write: 2G

- Validate available memory
- Run a fio **write** test writing 2G:

```
fio --name test --filename /tmp/fiotest  
--ioengine sync --rw randwrite --bs 8k  
--filesize 2G
```



centos@ip-172-158-19-16:~

2%

[centos@ip-172-158-19-16 ~]\$

Write: 2G

- This is a summary from the run:

```
IOPS=22.1k, BW=173MiB/s (181MB/s) (2048MiB/11840msec)
clat (usec): min=2, max=18861, avg=44.34, stdev=597.77
```

- My limits are 125 MBPS and 3000 IOPS.
- IOPS = 22100, which is significantly more than 3000 IOPS.
- Reason: only 24% was written;

```
ios=0/61815
```

```
issued rwts: total=0,262144
```

Write: 2G -- write details

- Why aren't all writes cached, like all reads were?
 - Writes are special!
 - Writes cannot be discarded like reads can, they **must** be written first.
 - Writes can/should not exhaust available memory.
 - Therefore: `vm.dirty_background_ratio`, `vm.dirty_ratio`, others.
 - Ratio is taken from **available memory**, unlike popular believe of total mem.
 - <https://dev.to/fritshooglandyugabyte/linux-buffered-write-latency-10mc>
- In linux, processes performing buffered writes do not actually write to disk.
 - Produce dirty pages, and get throttled (wait in `write()`) to balance.

Write: 500M

- Validate available memory
- Run a fio **write** test writing 500M:

```
fio --name test --filename /tmp/fiotest  
--ioengine sync --rw randwrite --bs 8k  
--filesize 500M
```



centos@ip-172-158-19-16:~

2%

[centos@ip-172-158-19-16 ~]\$

Write: 500M

- This is a summary from the run:

IOPS=193k, BW=1506MiB/s (1579MB/s) (500MiB/332msec)

- My limits are 125 MBPS and 3000 IOPS.
- IOPS = 193000, MBPS = 1506.
- Reason; no write (throttling):

ios=0/0, merge=0/0, ticks=0/0, in_queue=0, util=0.00%

- Why? Available: 3072 MB, vm.dirty_ratio: 30% = 922MB

Reality

- The writes so far were also conducted with no memory used.
- Let's occupy 50% and perform the same tests again.

Write: 2G / 50% of 4G memory taken

- Validate available memory
- Run a fio **write** test writing 2G:

```
fio --name test --filename /tmp/fiotest  
--ioengine sync --rw randwrite --bs 8k  
--filesize 2G
```



centos@ip-172-158-19-16:~

2%

[centos@ip-172-158-19-16 ~]\$

```
[centos@ip-172-158-19-16 ~]$ ./eatmemory-rust/target/release/eatmemory -q
available memory      :      1018 MB
total memory          : 3664 MB, free memory       :      134 MB, used memory       : 2217 MB
total swap            :      0 MB, free swap        :      0 MB, used swap        :      0 MB
[centos@ip-172-158-19-16 ~]$
```

[centos@ip-172-158-19-16 ~]\$./eatmemory-rust/target/release/eatmemory -q

```

available memory      :       1018 MB
total memory         :     3664 MB, free memory      :       134 MB, used memory       :     2217 MB
total swap           :        0 MB, free swap          :        0 MB, used swap          :        0 MB
[centos@ip-172-158-19-16 ~]$ fio --name test --filename /tmp/fiotest --ioengine sync --rw randwrite --bs 8K --filesize 2G
test: (g=0): rw=randwrite, bs=(R) 8192B-8192B, (W) 8192B-8192B, (T) 8192B-8192B, ioengine=sync, iodepth=1
fio-3.7
Starting 1 process
Jobs: 1 (f=1): [w(1)][100.0%][r=0KiB/s,w=43.1MiB/s][r=0,w=5516 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=14088: Thu Apr 14 12:22:20 2022
  write: IOPS=6581, BW=51.4MiB/s (53.9MB/s)(2048MiB/39832msec)
    clat (usec): min=2, max=15892, avg=151.04, stdev=920.26
    lat (usec): min=2, max=15892, avg=151.09, stdev=920.26
    clat percentiles (usec):
      |  1.00th=[   4],  5.00th=[   4], 10.00th=[   4], 20.00th=[   4],
      | 30.00th=[   4], 40.00th=[   4], 50.00th=[   4], 60.00th=[   5],
      | 70.00th=[   5], 80.00th=[   5], 90.00th=[   6], 95.00th=[   8],
      | 99.00th=[ 5866], 99.50th=[ 5866], 99.90th=[ 5866], 99.95th=[ 5866],
      | 99.99th=[ 9765]
  bw ( KIB/s): min=31872, max=451584, per=100.00%, avg=52686.61, stdev=52446.86, samples=79
  iops          : min= 3984, max=56448, avg=6585.82, stdev=6555.86, samples=79
  lat (usec)    : 4=52.09%, 10=45.08%, 20=0.33%, 50=0.01%, 250=0.01%
  lat (usec)    : 1000=0.01%
  lat (msec)    : 10=2.49%, 20=0.01%
  cpu           : usr=0.28%, sys=3.17%, ctx=6580, majf=0, minf=33
  IO depths    : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >64=0.0%
                  0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  submit        : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  complete      : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >64=0.0%
  issued rwt: total=0,262144,0,0 short=0,0,0 dropped=0,0,0
  latency      : target=0, window=0, percentile=100.00%, depth=1

Run status group 0 (all jobs):
  WRITE: bw=51.4MiB/s (53.9MB/s), 51.4MiB/s-51.4MiB/s (53.9MB/s-53.9MB/s), io=2048MiB (2147MB), run=39832-39832msec

Disk stats (read/write):
  nvme0n1: ios=26/151456, merge=0/37180, ticks=2139/1488942, in_queue=1491142, util=99.45%
```

[centos@ip-172-158-19-16 ~]\$ █

Write: 2G / 50% of 4G memory taken

- This is a summary from the run:

IOPS=6581, BW=51.4MiB/s (53.9MB/s) (2048MiB/39832msec)

- My limits are 125 MBPS and 3000 IOPS.
- IOPS = 6581, MBPS = 51 (vs . 22100 IOPS, 173 MBPS no mem pressure)
- Reason; write throttling:

ios=216/151456

- Why? Available: 1018 MB, vm.dirty_ratio: 30% = 305MB

Write: 500M / 50% of 4G memory taken

- How about writing 500M? That was really fast previously?
- Run a fio **write** test writing 500M:

```
fio --name test --filename /tmp/fiotest  
--ioengine sync --rw randwrite --bs 8k  
--filesize 500M
```



centos@ip-172-158-19-16:~



[centos@ip-172-158-19-16 ~]\$ []

Write: 500M / 50% of 4G memory taken

- This is a summary from the run:

IOPS=25.1k, BW=196MiB/s (206MB/s) (500MiB/2549msec) (332ms)

- My limits are 125 MBPS and 3000 IOPS.
- IOPS = 25100, MBPS = 196 (vs . 193000 IOPS, 1506 MBPS no mem pressure)
- *Despite feeling fast, performance was severely impacted!!*
- Reason; write throttling:

ios=17/20846

- Why? Available: 1023 MB, vm.dirty_ratio: 30% = 307MB

Conclusion

- If you are using buffered IO, do you rely on caching for performance?
- Are you keeping track of Available Memory?
- Available memory \approx memory *acting as/available for* cache + regular alloc.
- Understand the differences between read and write cache properties:
 - Data must be read before it can be cached and reused.
 - A variable proportional limit is imposed on # dirty buffers.
 - Kernel applies write throttling when # dirty pages increases.

Conclusion

- You have to understand your *active dataset*
 - Which consists of reads and writes.
 - The cache effectivity is relative to available memory.
- This means you might seem to suffer random IO performance issues.
 - Which can be caused by either:
 - Change in the active dataset.
 - Change in available memory

PS

- The tests were performed on linux without swap.
 - Buffered IO needs buffers which is a memory allocation.
 - It competes with regular IO allocations.
- Therefore, linux will evaluate available memory using a LRU mechanism.
 - Therefore, bursts of IO buffers usage
 - Could push seldom used mapped allocations to swap.