# Chapter 15 I/O Scheduling - Notes

## 15.2 Introduction

System performance often depends very heavily on optimizing I/O scheduling strategy. Many (often competing) factors influence behavior, including minimizing hardw are access times, avoiding w ear/tear on storage media, ensuring data integrity, granting timely access to applications that need to do I/O, being able to prioritize important tasks. Linux offers variety of **I/O Schedulers** to choose from, each of w hich has tunable parameters + number of utilities for reporting on/analyzing I/O performance.

## 15.3 Learning Objectives:

- Explain the importance of I/O scheduling and describe the conflicting requirements that need to be satisfied.
- Delineate and contrast the options available under Linux.
- Understand how the **CFQ** (**C**ompletely **F**air **Q**ueue) and **Deadline** algorithms w ork.

## 15.4 I/O Scheduling

**I/O scheduler** provides interface betw een generic block layer and low -level physical device drivers. Both VM (Virtual Memory) and VFS (Virtual File System) layers submit I/O requests to block devices. Job of I/O scheduling layer to prioritize + order requests before they are given to block devices.

Any I/O scheduling algorithm has to satisfy certain (sometimes conflicting) requirements:

- Hardw are access times should be minimized; ie, requests should be order according to physical location on disk. Leads to **elevator** scheme w here requests inserted in pending queue in physical order
- Requests should be merged to extent possible to get as big a contiguous region as possible, w hich also minimizes disk access time
- Requests should be satisfied w ith as low a latency as feasible. In some cases, determinism (in sense of deadlines) important
- Write operations usually w ait to migrate from caches to disk w ithout stalling process. Read operations almost alw ays require process to w ait for completion before proceeding further. Favoring reads over w rites leads to better parallelism and system responsiveness
- Processes should share I/O bandw idth in fair, consciously prioritized fashion. Even if it means some overall performance slow dow n of I/O layer, process throughput should not suffer inordinately

## 15.5 I/O Scheduler Choices

Since demands can be conflicting, different I/O schedulers may be appropriate for different w orkloads, eg, large database server vs. desktop system. Different hardw are may mandate different strategy. To provide flexibility, Linux kernel has object oriented scheme, w here pointers to various needed functions supplied in a data structure, the particular one of w hich can be selected at boot on kernel command line:

```
linux ... elevator=[cfq|deadline|noop]
```

At least one of I/O scheduling algorithms must be compiled into kernel. Current choices:

- Completely Fair Queueing (CFQ)
- Deadline Scheduling

- noop (A simple scheme)

Default choice is compile configuration option. Modern distributions choose either CFQ or Deadline.

## 15.6 I/O Scheduling and SSD Devices

Gradual introduction of **SSD** (**S**olid **S**tate **D**rive) devices, w hich use flash memory to emulate hard disks, has important implications for I/O scheduling.

SSDs do not require elevator scheme + benefit from **wear leveling** to spread I/O over the devices w hich have limited w rite/erase cycles.

Can examine `/sys/block/<device>/queue/rotational` to see w hether or not device is **SSD** or not:

```
$ cat /sys/block/sda/queue/rotational
1
$ cat /sys/block/sdb/queue/rotational
0
```

## 15.7 Tunables and Switching the I/O Scheduler at Runtime

Each of I/O schedulers exposes parameters w hich can be used to tune behavior at run time. Parameters accessed through pseudo-filesystem mounted at `/sys`.

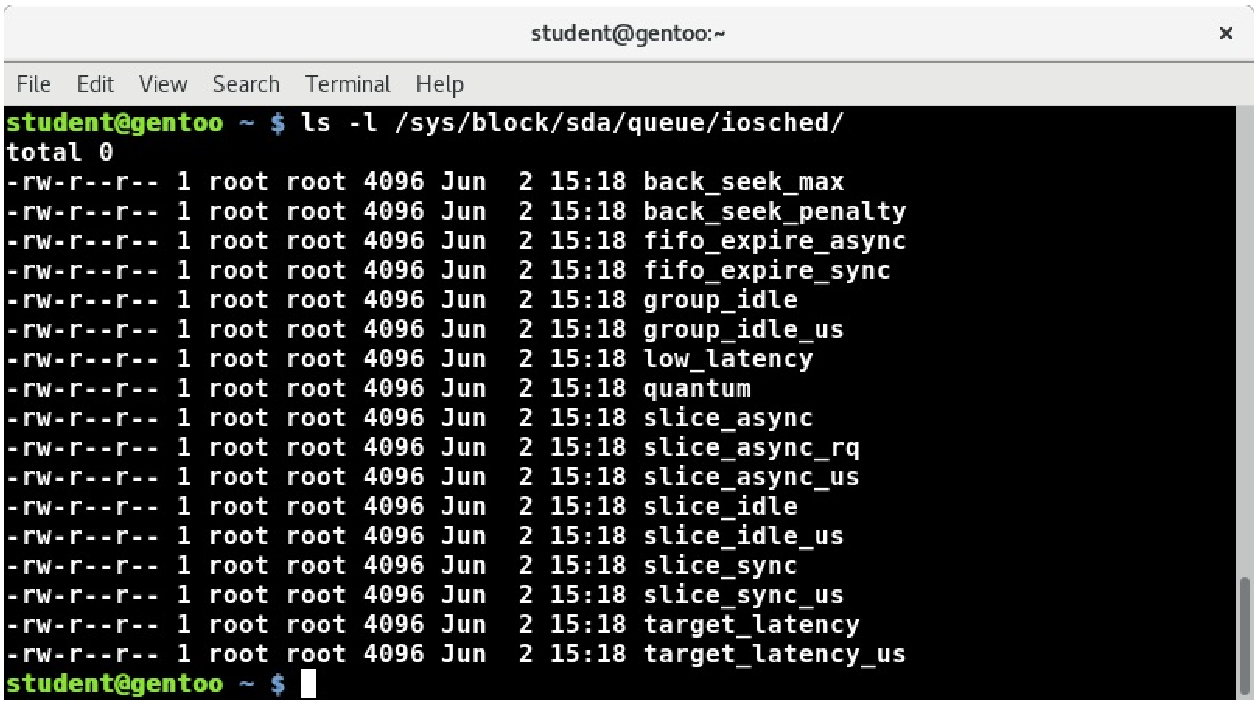
In addition, possible to use different I/O schedulers for different devices. Choice can be made easily through command line. For example:

```
$ cat /sys/block/sda/queue/scheduler
noop deadline [cfq]
$ echo noop > /sys/block/sda/queue/scheduler
$ cat /sys/block/sda/queue/scheduler
[noop] deadline cfq
```

Actual tunables vary according to particular I/O scheduler, can be found under `/sys/block/<device>/queue/iosched`.

Can see actual tunables for disk using **CFQ** below.

Will discuss some parameters shortly.



```
student@gentoo ~ $ ls -l /sys/block/sda/queue/iosched/
total 0
-rw-r--r-- 1 root root 4096 Jun  2 15:18 back_seek_max
-rw-r--r-- 1 root root 4096 Jun  2 15:18 back_seek_penalty
-rw-r--r-- 1 root root 4096 Jun  2 15:18 fifo_expire_async
-rw-r--r-- 1 root root 4096 Jun  2 15:18 fifo_expire_sync
-rw-r--r-- 1 root root 4096 Jun  2 15:18 group_idle
-rw-r--r-- 1 root root 4096 Jun  2 15:18 group_idle_us
-rw-r--r-- 1 root root 4096 Jun  2 15:18 low_latency
-rw-r--r-- 1 root root 4096 Jun  2 15:18 quantum
-rw-r--r-- 1 root root 4096 Jun  2 15:18 slice_async
-rw-r--r-- 1 root root 4096 Jun  2 15:18 slice_async_rq
-rw-r--r-- 1 root root 4096 Jun  2 15:18 slice_async_us
-rw-r--r-- 1 root root 4096 Jun  2 15:18 slice_idle
-rw-r--r-- 1 root root 4096 Jun  2 15:18 slice_idle_us
-rw-r--r-- 1 root root 4096 Jun  2 15:18 slice_sync
-rw-r--r-- 1 root root 4096 Jun  2 15:18 slice_sync_us
-rw-r--r-- 1 root root 4096 Jun  2 15:18 target_latency
-rw-r--r-- 1 root root 4096 Jun  2 15:18 target_latency_us
student@gentoo ~ $
```

## 15.9 CFQ (Completely Fair Queue) Scheduler

**CFQ** (**C**ompletely **F**air **Q**ueue) method has goal of equal spreading of I/O bandw idth among all processes submitting requests.

Theoretically, each process has ow n I/O queue, w hich w orks together w ith dispatch queue w hich receives actual requests on w ay to device. In actual practice, number of queues fixed (at 64) and hash process based on process ID used to select queue w hen request submitted.

Dequeuing of requests done **round robin** style on all queues, each one of w hich w orks in **FIFO** (**F**irst **I**n **F**irst **O**ut) order. Thus, w ork spread out. To avoid excessive seeking operations, entire round selected, and then sorted into dispatch queue before actual I/O requests issued to device.

## 15.10 CFQ Tunables

In examples below, parameter `HZ` -> kernel-configured quantity, corresponds to number of **jiffies** per second, w hich kernel uses as coarse measure of time. Time unit `HZ/2` = 0.5 seconds, `5 * HZ` = 5 seconds, etc.

- `quantum` : Maximum queue length in one round of service (Default = 4)
- `queued` : Minimum request allocation per queue (Default = 8)
- `fifo_expire_sync` : `FIFO` timeout for sync requests (Default = `HZ/2` )
- `fifo_expire_async` : `FIFO` timeout for async requests (Default = `5 * HZ` )
- `fifo_batch_expire` : Rate at w hich the `FIFO` 's expire (Default = `HZ/8` )
- `back_seek_max` : Maximum backw ards seek, in KB (Default = 16K)
- `back_seek_penalty` : Penalty for a backw ards seek (Default = 2)

## 15.11 Deadline Scheduler

**Deadline** `I/O` scheduler aggressively reorders requests w ith simultaneous goals of improving overall performance + preventing large latencies for individual requests, ie, limiting starvation.

Kernel associates **deadline** w ith each and every request. Read requests = higher priority then w rite requests.

Five separate `I/O` queues maintained:

- Tw o sorted lists maintained, one for reading, one for w riting, arranged by starting block
- Tw o **FIFO** lists maintained, one for reading, one for w riting. Lists sorted by submission time
- Fifth queue contains requests to be shoveled to device driver itself. Called dispatch queue

Art of the algorithm: how requests are peeled off from first four queues and placed on fifth (dispatch queue).

## 15.12 Deadline Tunables

Available tunables for **Deadline** scheduler:

- `read_expire` : How long (in milliseconds) read request is guaranteed to occur w ithin (Default = `HZ/2 = 500` )
- `write_expire` : How long (in milliseconds) w rite request is guaranteed to occur w ithin (Default = `5 * HZ = 5000` )
- `writes_starved` : How many requests w e should give preference to reads over w rites (Default = `2` )
- `fifo_batch` : How many requests should be moved from sorted scheduler list to dispatch queue, w hen deadlines have expired (Default = `16` )
- `front_merges` : Back merges more common than front merges as contiguous request usually continues to next block. Setting this parameter to 0 disables front merges and can give boost if you know they are unlikely to be needed (Default = `1` )

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