Section 10: Disks, Performance, and Queuing Theory

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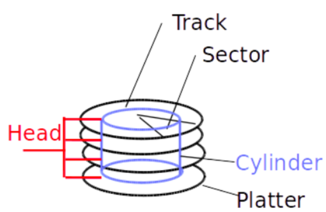
1 Vocabulary

- **I/O** In the context of operating systems, input/output (I/O) consists of the processes by which the operating system receives and transmits data to connected devices.
- **Controller** The operating system performs the actual I/O operations by communicating with a device controller, which contains addressable memory and registers for communicating the the CPU, and an interface for communicating with the underlying hardware.
- **Response Time** Response time measures the time between a requested I/O operating and its completion, and is an important metric for determining the performance of an I/O device.
- **Throughput** Another important metric is throughput, which measures the rate at which operations are performed over time.
- **Hard Disk Drive (HDD)** - A storage device that stores data on magnetic disks. Each disk consists of multiple **platters** of data. Each platter includes multiple concentric **tracks** that are further divided into **sectors**. Data is accessed (for reading or writing) one sector at a time. The **head** of the disk can transfer data from a sector when positioned over it.



- **Seek Time** - The time it takes for an HDD to reposition its disk head over the desired track.
- **Rotational Latency** - The time it takes for the desired sector to rotate under the disk head.
- **Transfer Rate** - The rate at which data is transferred under the disk head.
- **Checksum** - A mathematical function which maps a (typically large) input to a fixed size output. Checksums are meant to detect changes to the underlying data and should change if changes occur to the underlying data. Common checksum algorithms include CRC32, MD5, SHA-1, and SHA-256.
- **Replication** - Replication or duplication is a common technique for preserving data in the face of disk failure or corruption. If a disk fails, data can be read from the replica. If a sector is corrupted, it will be detected in the checksum. The data can then be read from another replica.
- **Queuing Theory** Here are some useful symbols: (both the symbols used in lecture and in the book are listed)
  - μ is the average service rate (jobs per second)
  - T_{ser} or S is the average service time, so $T_{ser} = \frac{1}{\mu}$
  - λ is the average arrival rate (jobs per second)
  - U or u or ρ is the utilization (fraction from 0 to 1), so $U = \frac{\lambda}{\mu} = \lambda S$
  - T_q or W is the average queuing time (aka waiting time) which is how much time a task needs to wait before getting serviced (it does not include the time needed to actually perform the task)
  - T_{sys} or R is the response time, and it's equal to $T_q + T_{ser}$ or $W + S$
  - L_q or Q is the average length of the queue, and it's equal to λT_q (this is Little's law)

2 Disks

What are the major components of disk latency? Explain each one.

In class we said that the operating system deals with bad or corrupted sectors. Some disk controllers magically hide failing sectors and re-map to "back-up" locations on disk when a sector fails.

If you had to choose where to lay out these "back-up" sectors on disk - where would you put them? Why?

How do you think that the disk controller can check whether a sector has gone bad?

Can you think of any drawbacks of hiding errors like this from the operating system?

3 I/O Performance

This question will explore the performance consequences of using traditional disks for storage. Assume we have a hard drive with the following specifications:

- An average seek time of 8 ms
- A rotational speed of 7200 revolutions per minute (RPM)
- A controller that can transfer data at a maximum rate of 50 MiB/s

We will ignore the effects of queueing delay for this problem.

1. What is the expected throughput of the hard drive when reading 4 KiB sectors from a random location on disk?

2. What is the expected throughput of the hard drive when reading 4 KiB sectors from the same track on disk (i.e., the read/write head is already positioned over the correct track when the operation starts)?

3. What is the expected throughput of the hard drive when reading the very next 4 KiB sector (i.e. the read/write head is immediately over the proper track and sector at the start of the operation)?

4. What are some ways the Unix Fast File System (FFS) was designed to deal with the discrepancy in performance we just saw?

4 Queuing Theory

Explain intuitively why response time is nonlinear with utilization. Draw a plot of utilization (x axis) vs response time (y axis) and label the endpoints on the x axis.

If 50 jobs arrive at a system every second and the average response time for any particular job is 100ms, how many jobs are in the system (either queued or being serviced) on average at a particular moment? Which law describes this relationship?

Is it better to have N queues, each of which is serviced at the rate of 1 job per second, or 1 queue that is serviced at the rate of N jobs per second? Give reasons to justify your answer.

What is the average queueing time for a work queue with 1 server, average arrival rate of λ, average service time S, and squared coefficient of variation of service time $\mathbf{C}$?

What does it mean if $\mathbf{C} = 0$? What does it mean if $\mathbf{C} = 1$?

5 Tying it all together

Assume that you have a disk with the following parameters:

- 1TB in size
- 6000RPM
- Data transfer rate of 4MB/s (4×10^6 bytes/sec)
- Average seek time of 3ms
- I/O controller with 1ms of controller delay
- Block size of 4000 bytes

What is the average rotational delay?

What is the average time it takes to read 1 random block? Assume no queuing delay.

Will the actual measured average time to read a block from disk (excluding queuing delay) tend to be lower, equal, or higher than this? Why?

Assume that the average I/O operations per second demanded is 50 IOPS. Assume a squared coefficient of variation of $\mathbf{C} = 1.5$. What is the average queuing time and the average queue length?