Chapter 10: Mass-Storage Systems

- Overview of Mass Storage Structure
- Disk Structure
- Disk Attachment
- Disk Scheduling
- Disk Management
- Swap-Space Management
- RAID Structure
- Stable-Storage Implementation
Overview of Mass Storage Structure

- Magnetic disks provide bulk of secondary storage of modern computers
  - Drives rotate at 60 to 250 times per second
  - Transfer rate is the rate at which data flow between drive and computer
  - Positioning time (random-access time) is time to move disk arm to desired cylinder (seek time) and time for desired sector to rotate under the disk head (rotational latency)
    - Rotations per minute (RPM)
  - Head crash results from disk head making contact with the disk surface -- That’s bad
- Disks can be removable
- Drive attached to computer via I/O bus
  - Busses vary, including EIDE, ATA, SATA, USB, Fibre Channel, SCSI, SAS, Firewire
  - Host controller in computer uses bus to talk to disk controller built into drive or storage array
Hard Disks

- Platters range from .85” to 14” (historically)
  - Commonly 3.5”, 2.5”, and 1.8”
- Range from 30GB to 3TB per drive

Performance

- Transfer Rate – theoretical – 6 Gb/sec
- Effective Transfer Rate – real – 1Gb/sec
- Seek time from 3ms to 12ms – 9ms common for desktop drives
- Average seek time measured or calculated based on 1/3 of tracks
- Latency based on spindle speed
  - \( \frac{1}{\text{RPM} / 60} = \frac{60}{\text{RPM}} \)
- Average latency = \( \frac{1}{2} \) latency

(From Wikipedia)

Hard Disk Performance

- **Access Latency** = Average access time = average seek time + average latency
  - For fastest disk 3ms + 2ms = 5ms
  - For slow disk 9ms + 5.56ms = 14.56ms
- **Average I/O time** = average access time + (amount to transfer / transfer rate) + controller overhead
  - For example to transfer a 4KB block on a 7200 RPM disk with a 5ms average seek time, 1Gb/sec transfer rate with a .1ms controller overhead =
    - 5ms + 4.17ms + 0.1ms + transfer time =
    - Transfer time = \( \frac{4\text{KB}}{1\text{Gb/s}} \times \frac{8\text{Gb}}{\text{GB}} \times \frac{1\text{GB}}{1024^2\text{KB}} = \frac{32}{1024^2} = 0.031\text{ ms} \)
    - Average I/O time for 4KB block = 9.27ms + .031ms = 9.301ms
Disk Structure

- Disk drives are addressed as large 1-dimensional arrays of logical blocks, where the logical block is the smallest unit of transfer
  - Low-level formatting creates logical blocks on physical media
  - Disk address: cylinder #, track # within the cylinder, sector # within the track.
- The 1-dimensional array of logical blocks is mapped into the sectors of the disk sequentially
  - Sector 0 is the first sector of the first track on the outermost cylinder
  - Mapping proceeds in order through that track, then the rest of the tracks in that cylinder, and then through the rest of the cylinders from outermost to innermost
- Logical to physical address should be easy
  - Except for bad sectors
  - Non-constant # of sectors per track via constant angular velocity

Disk structure

- Constant linear velocity (CLV)
  - Uniform density
  - Less sectors inner zones, more sectors towards the edge
  - Drive increases rotation speed when the head moves from the outer to inner tracks to keep the same data rate. (CD-ROM and DVD-ROM)
- Constant angular velocity
  - Disk rotates constantly
  - Denser bits at inner tracks to keep the data rate constant.
Disk Scheduling

- The operating system is responsible for using hardware efficiently — for the disk drives, this means having a fast access time and disk bandwidth
- Minimize seek time
- Seek time = seek distance
- Disk bandwidth is the total number of bytes transferred, divided by the total time between the first request for service and the completion of the last transfer

What about rotational latency?
- Difficult for OS to calculate

Disk Scheduling (Cont.)

- There are many sources of disk I/O request
  - OS
  - System processes
  - Users processes
- I/O request includes input or output mode, disk address, memory address, number of sectors to transfer
- OS maintains queue of requests, per disk or device
- Idle disk can immediately work on I/O request, busy disk means work must queue
  - Optimization algorithms only make sense when a queue exists
Disk Scheduling (Cont.)

- Note that drive controllers have small buffers and can manage a queue of I/O requests (of varying “depth”)
- Several algorithms exist to schedule the servicing of disk I/O requests
- The analysis is true for one or many platters
- We illustrate scheduling algorithms with a request queue (for a disk with cylinders 0-199)

98, 183, 37, 122, 14, 124, 65, 67
Head pointer 53

FCFS

Illustration shows total head movement of 640 cylinders

queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53
**SSTF**

- **Shortest Seek Time First**: selects the request with the minimum seek time from the current head position
- SSTF scheduling is a form of SJF scheduling; may cause starvation of some requests
- Illustration shows total head movement of 236 cylinders

```
queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53
```

**SCAN**

- The disk arm starts at one end of the disk, and moves toward the other end, servicing requests until it gets to the other end of the disk, where the head movement is reversed and servicing continues.
- **SCAN algorithm** Sometimes called the **elevator algorithm**
- Illustration shows total head movement of 208 cylinders
- But note that if requests are uniformly dense, largest density at other end of disk and those wait the longest
SCAN (Cont.)

C-SCAN

- Provides a more uniform wait time than SCAN
- The head moves from one end of the disk to the other, servicing requests as it goes
  - When it reaches the other end, however, it immediately returns to the beginning of the disk, without servicing any requests on the return trip
- Treats the cylinders as a circular list that wraps around from the last cylinder to the first one
- Total number of cylinders?
C-SCAN (Cont.)

Look and C-LOOK

- LOOK a version of SCAN, C-LOOK a version of C-SCAN
- Arm only goes as far as the last request in each direction, then reverses direction immediately, without first going all the way to the end of the disk
- Total number of cylinders?
C-LOOK (Cont.)

queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53

Selecting a Disk-Scheduling Algorithm

- SSTF is common and has a natural appeal
- SCAN and C-SCAN perform better for systems that place a heavy load on the disk
  - Less starvation
  - And Look and C-Look
- Performance depends on the number and types of requests
- Requests for disk service can be influenced by the file-allocation method
  - And metadata layout
- The disk-scheduling algorithm should be written as a separate module of the operating system, allowing it to be replaced with a different algorithm if necessary
- Either SSTF or LOOK is a reasonable choice for the default algorithm
- What about rotational latency?
  - Difficult for OS to calculate
- How does disk-based queueing effect OS queue ordering efforts?
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Disk Management

- Initialization
- Boot
- Bad-block recovery
Disk Management

- **Initialization:** Low-level formatting, or physical formatting — Dividing a disk into sectors that the disk controller can read and write

- **Data structure**
  - Each sector can hold header information, plus data, plus error correction code (ECC)
    - Error detection and correction, soft error
  - Usually 512 bytes of data but can be selectable

- To use a disk to hold files, the operating system still needs to record its own data structures on the disk
  - **Partition** the disk into one or more groups of cylinders, each treated as a logical disk
  - **Logical formatting** or “making a file system”
    - File system data structure (free and allocated spaces, empty directory)
  - To increase efficiency most file systems group blocks into clusters
    - Disk I/O done in blocks
    - File I/O done in clusters
  - **Raw disk** – an array of logical blocks
    - access for apps that want to do their own block management, keep OS out of the way (databases for example)
Disk Management (Cont.)

- Boot block initializes system
  - The bootstrap used to stored in ROM. Now **Bootstrap loader** program
  - Bootstrap stores in boot blocks of boot partition

- Windows example
  - Master boot record (MBR) at first sector

  ![Boot Sequence Diagram]

Booting from a Disk in Windows

Bad Blocks

- Methods such as **sector sparing** used to handle bad blocks

- Simple way, find bad blocks upon formatting or by a command, and flagged.

- Otherwise, not visible to OS:
  - controller maintain a list of bad blocks, and update it.
  - Controller replace bad blocks
    - Find bad block by ECC, report to OS, and OS abort the I/O
    - Next time, replace it. And always use the replaced one

- Replacement schemes:
  - Sector sparing
  - Sector slipping
Swap-Space Management

- Swap-space — Virtual memory uses disk space as an extension of main memory
  - Less common now due to memory capacity increases
- Swap-space can be carved out of the normal file system, or, more commonly, it can be in a separate disk partition (raw)
- Swap-space management
  - 4.3BSD allocates swap space when process starts; holds text segment (the program) and data segment
  - Kernel uses swap maps to track swap-space use
  - Solaris 2 allocates swap space only when a dirty page is forced out of physical memory, not when the virtual memory page is first created
    - File data written to swap space until write to file system requested
    - Other dirty pages go to swap space due to no other home
    - Text segment pages thrown out and reread from the file system as needed
- What if a system runs out of swap space?
- Some systems allow multiple swap spaces

End of Chapter 10