Storage Systems

Main Points

- File systems
  - Useful abstractions on top of physical devices
- Storage hardware characteristics
  - Disks and flash memory
- File system usage patterns

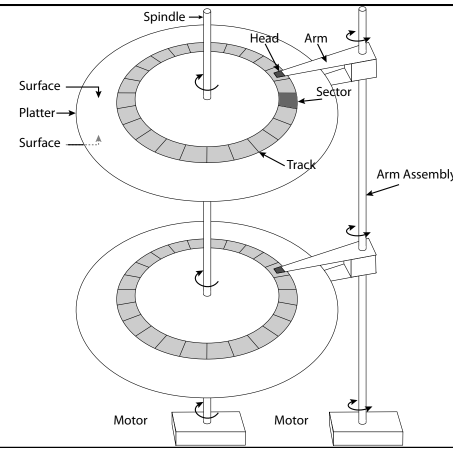
File System Abstraction

- File system
  - Persistent, named data
  - Hierarchical organization (directories, subdirectories)
  - Access control on data
- File: named collection of data
  - Linear sequence of bytes (or a set of sequences)
  - Read/write or memory mapped
- Crash and storage error tolerance
  - Operating system crashes (and disk errors) leave file system in a valid state
- Performance
  - Achieve close to the hardware limit in the average case

Storage Devices

- Magnetic disks
  - Storage that rarely becomes corrupted
  - Large capacity at low cost
  - Block level random access
  - Slow performance for random access
  - Better performance for streaming access
- Flash memory
  - Storage that rarely becomes corrupted
  - Capacity at intermediate cost (50x disk)
  - Block level random access
  - Good performance for reads; worse for random writes

Magnetic Disk



Disk Tracks

- ~ 1 micron wide
  - Wavelength of light is ~ 0.5 micron
  - Resolution of human eye: 50 microns
  - 100K on a typical 2.5" disk
- Separated by unused guard regions
  - Reduces likelihood neighboring tracks are corrupted during writes (still a small non-zero chance)
- Track length varies across disk
  - Outside: More sectors per track, higher bandwidth
  - Disk is organized into regions of tracks with same # of sectors/track
  - Only outer half of radius is used
    - Most of the disk area in the outer regions of the disk

Sectors

Sectors contain sophisticated error correcting codes
  - Disk head magnet has a field wider than track
  - Hide corruptions due to neighboring track writes
- Sector sparing
  - Remap bad sectors transparently to spare sectors on the same surface
- Slip sparing
  - Remap all sectors (when there is a bad sector) to preserve sequential behavior
- Track skewing
  - Sector numbers offset from one track to the next, to allow for disk head movement for sequential ops

Disk Performance

Disk Latency =

- Seek Time + Rotation Time + Transfer Time
- Seek Time: time to move disk arm over track (1-20ms)
  - Fine-grained position adjustment necessary for head to "settle"
  - Head switch time ~ track switch time (on modern disks)
- Rotation Time: time to wait for disk to rotate under disk head
  - Disk rotation: 4 – 15ms (depending on price of disk)
- Transfer Time: time to transfer data onto/off of disk
  - Disk head transfer rate: 50-100MB/s (5-10 usec/sector)
  - Host transfer rate dependent on I/O connector (USB, SATA, …)

Toshiba Disk (2008)

Size	
Platters/Heads	2/4
Capacity	320 GB
Performance	
Spindle speed	7200 RPM
Average seek time read/write	10.5 ms/ 12.0 ms
Maximum seek time	19 ms
Track-to-track seek time	1 ms
Transfer rate (surface to buffer)	54–128 MB/s
Transfer rate (buffer to host)	375 MB/s
Buffer memory	16 MB
Power	
Typical	16.35 W
Idle	11.68 W

Question

- How long to complete 500 random disk reads, in FIFO order?

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- How long to complete 500 random disk reads, in FIFO order?
  - Seek: average 10.5 msec
  - Rotation: average 4.15 msec
  - Transfer: 5-10 usec
- 500 * (10.5 + 4.15 + 0.01)/1000 = 7.3 seconds

Question

- How long to complete 500 sequential disk reads?

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- How long to complete 500 sequential disk reads?
  - Seek Time: 10.5 ms (to reach first sector)
  - Rotation Time: 4.15 ms (to reach first sector)
  - Transfer Time: (outer track)
    - 500 sectors * 512 bytes / 128MB/sec = 2ms

Total: 10.5 + 4.15 + 2 = 16.7 ms

Might need an extra head or track switch (+1ms)

Track buffer may allow some sectors to be read off disk out of order (-2ms)

Question

- How large a transfer is needed to achieve 80% of the max disk transfer rate?

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Assume x rotations are needed, then solve for x:

0.8 (10.5 ms + (1ms + 8.4ms) x) = 8.4ms x

Total: x = 9.1 rotations, 9.8MB

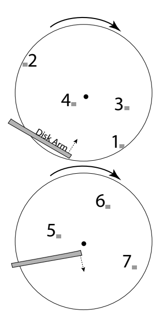
Disk Scheduling

- FIFO
  - Schedule disk operations in order they arrive
  - Downsides?

Disk Scheduling

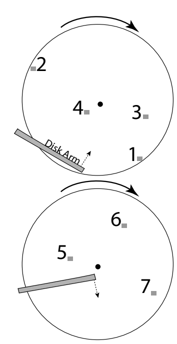
- Shortest seek time first
  - Not optimal!
    - Suppose cluster of requests at far end of disk
  - Downsides?

Disk Scheduling



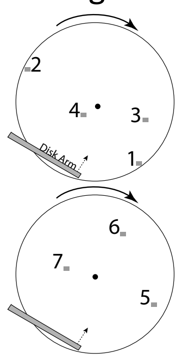
Disk Scheduling

- SCAN: move disk arm in one direction, until all requests satisfied, then reverse direction



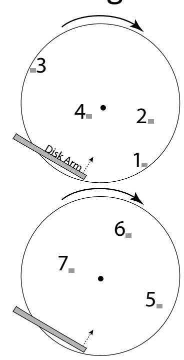
Disk Scheduling

- CSCAN: move disk arm in one direction, until all requests satisfied, then start again from farthest request



Disk Scheduling

- R-CSCAN: CSCAN but take into account that short track switch is < rotational delay



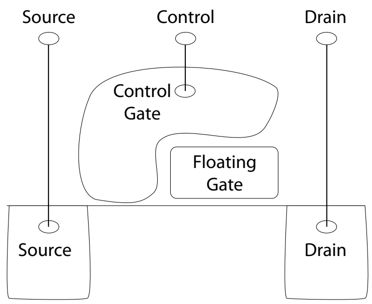
Question

- How long to complete 500 random disk reads, in any order?

Question

- How long to complete 500 random disk reads, in any order?
  - Disk seek: 1ms (most will be short)
  - Rotation: 4.15ms
  - Transfer: 5-10usec
- Total: 500 * (1 + 4.15 + 0.01) = 2.2 seconds
  - May be a bit shorter with R-CSCAN

Flash Memory



Flash Memory

- Writes require large erasure block first
  - No update in place
  - 128 – 512 KB
  - Several milliseconds
- Write/read page (2-4KB)
  - 10s of microseconds

Flash Translation Layer

- Flash device firmware maps logical page # to a physical location
  - Allows firmware to move pages as needed
  - Wear-levelling (can only write a physical page a limited number of times)
  - Avoid pages that no longer work
  - Coalesce live pages during erasure
- TRIM command
  - File system tells device when pages are no longer in use

File System Workload

- File sizes
  - Are most files small or large?
  - Which accounts for more total storage: small or large files?
- File access
  - Are most accesses to small or large files?
  - Which accounts for more total I/O bytes: small or large files?