Disks and RAID

CS 4410
Operating Systems

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Storage Devices

- Magnetic disks
  - Large capacity at low cost
  - Block level random access
  - Slow performance for random access
  - Good performance for streaming access
- Flash memory
  - Capacity at intermediate cost
  - Block level random access
  - Medium performance for random writes
  - Good performance otherwise

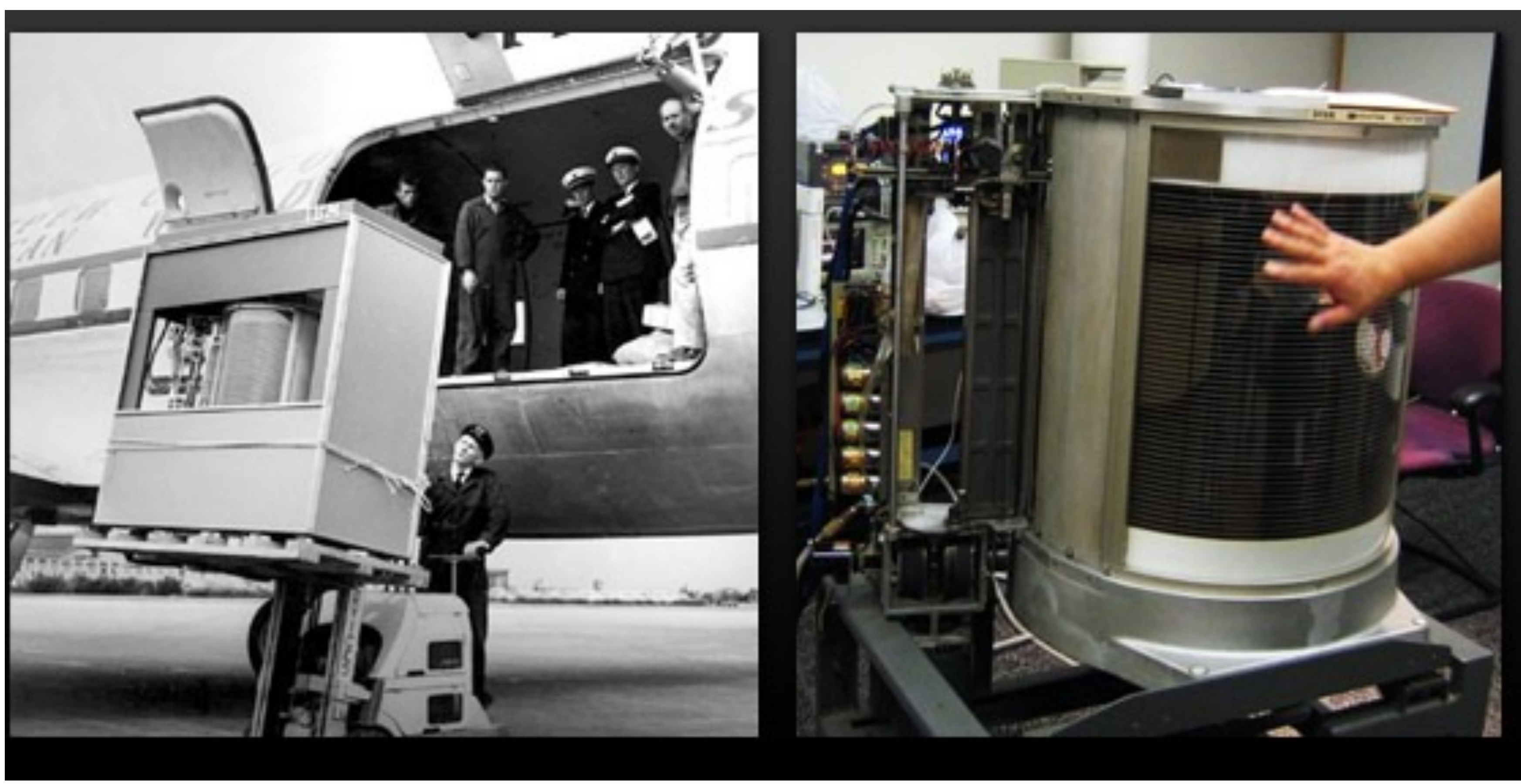
Magnetic Disks are 60 years old!

THAT WAS THEN

- 13th September 1956
- The IBM RAMAC 350
- Total Storage = 5 million characters (just under 5 MB)

THIS IS NOW

- 2.5-3.5” hard drive
- Example: 500GB Western Digital Scorpio Blue hard drive
- easily up to a few TB

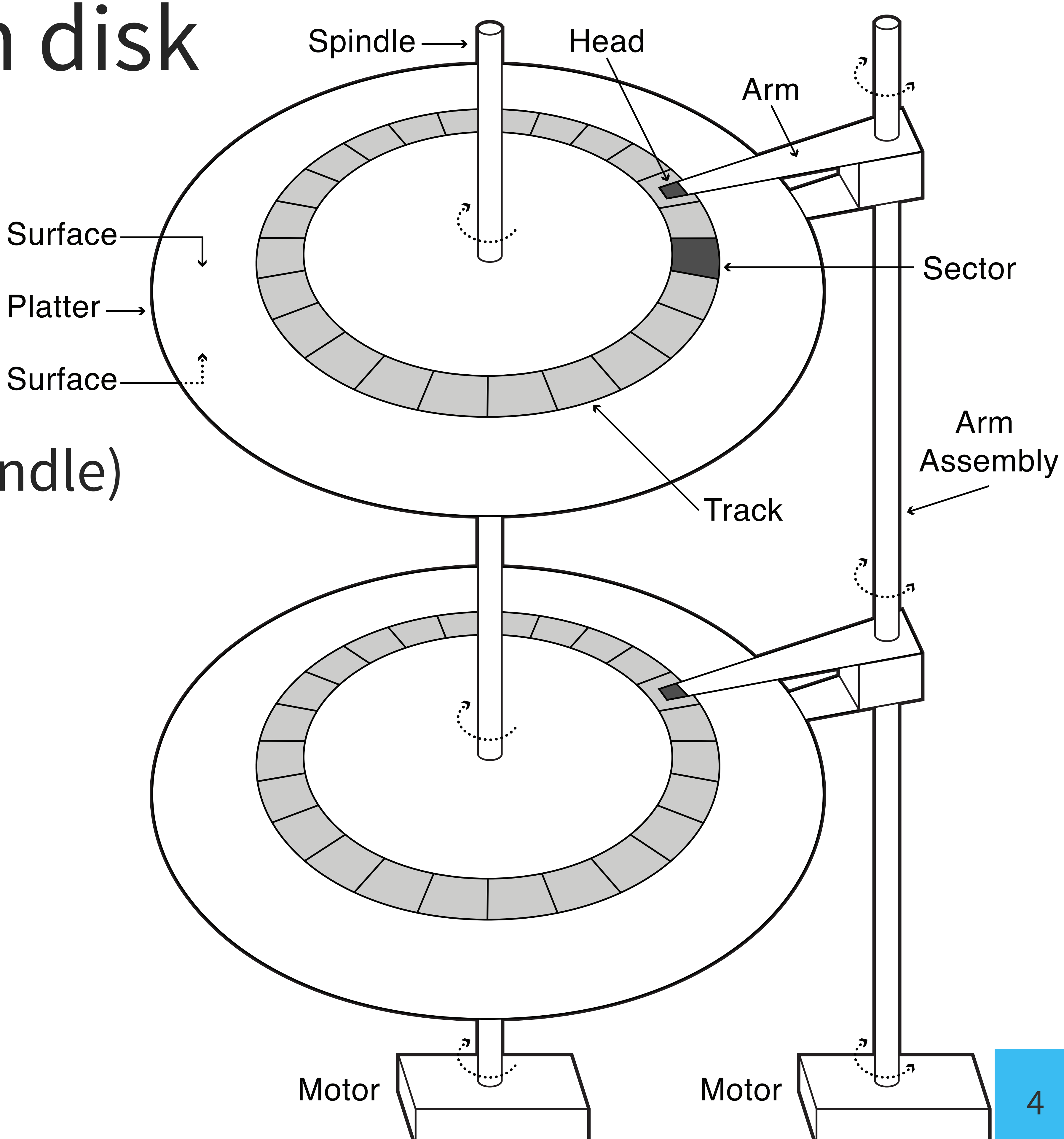


http://royal.pingdom.com/2008/04/08/the-history-of-computer-data-storage-in-pictures/

Reading from disk

Must specify:

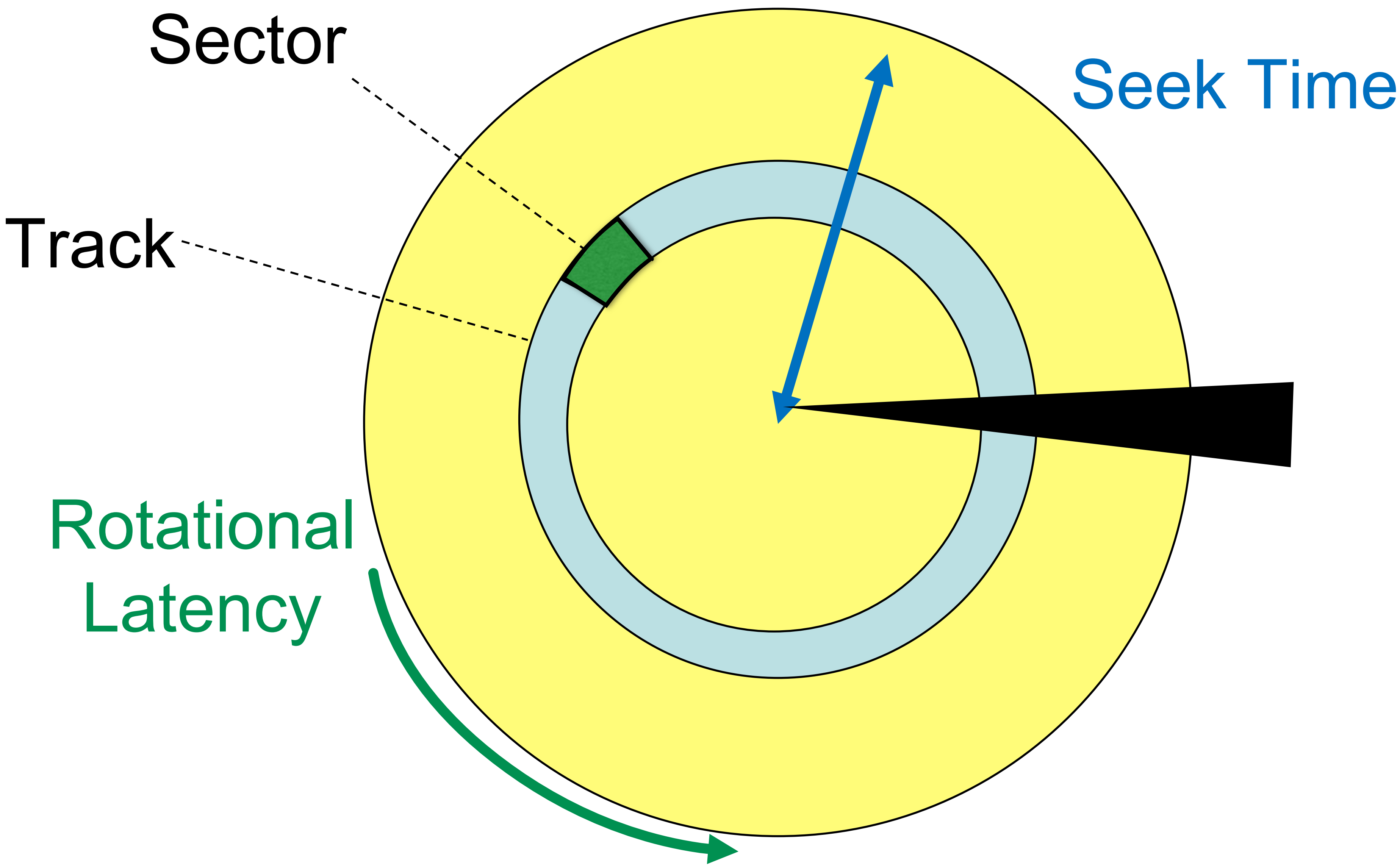
- cylinder # (distance from spindle)
- head #
- sector #
- transfer size
- memory address



Disk overheads

*Disk Latency = **Seek Time** + **Rotation Time** + Transfer Time*

- **Seek:** to get to the track (5-15 millisecs)
- **Rotational Latency:** to get to the sector (4-8 millisecs) (on average, only need to wait half a rotation)
- **Transfer:** get bits off the disk (25-50 microsecs)



Disk Scheduling

Objective: minimize seek time

Context: a queue of cylinder numbers (#0-199)

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

Metric: how many cylinders traversed?

Disk Scheduling: **FIFO**

- Schedule disk operations in order they arrive
- Downsides?

FIFO Schedule?
Total head movement?

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640 cylinders

Disk Scheduling: Shortest Seek Time First

- Select request with minimum seek time from current head position
- A form of Shortest Job First (SJF) scheduling
- Not optimal: suppose cluster of requests at far end of disk → starvation!

SSTF Schedule?

Total head movement?

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SSTF Schedule?

Total head movement?

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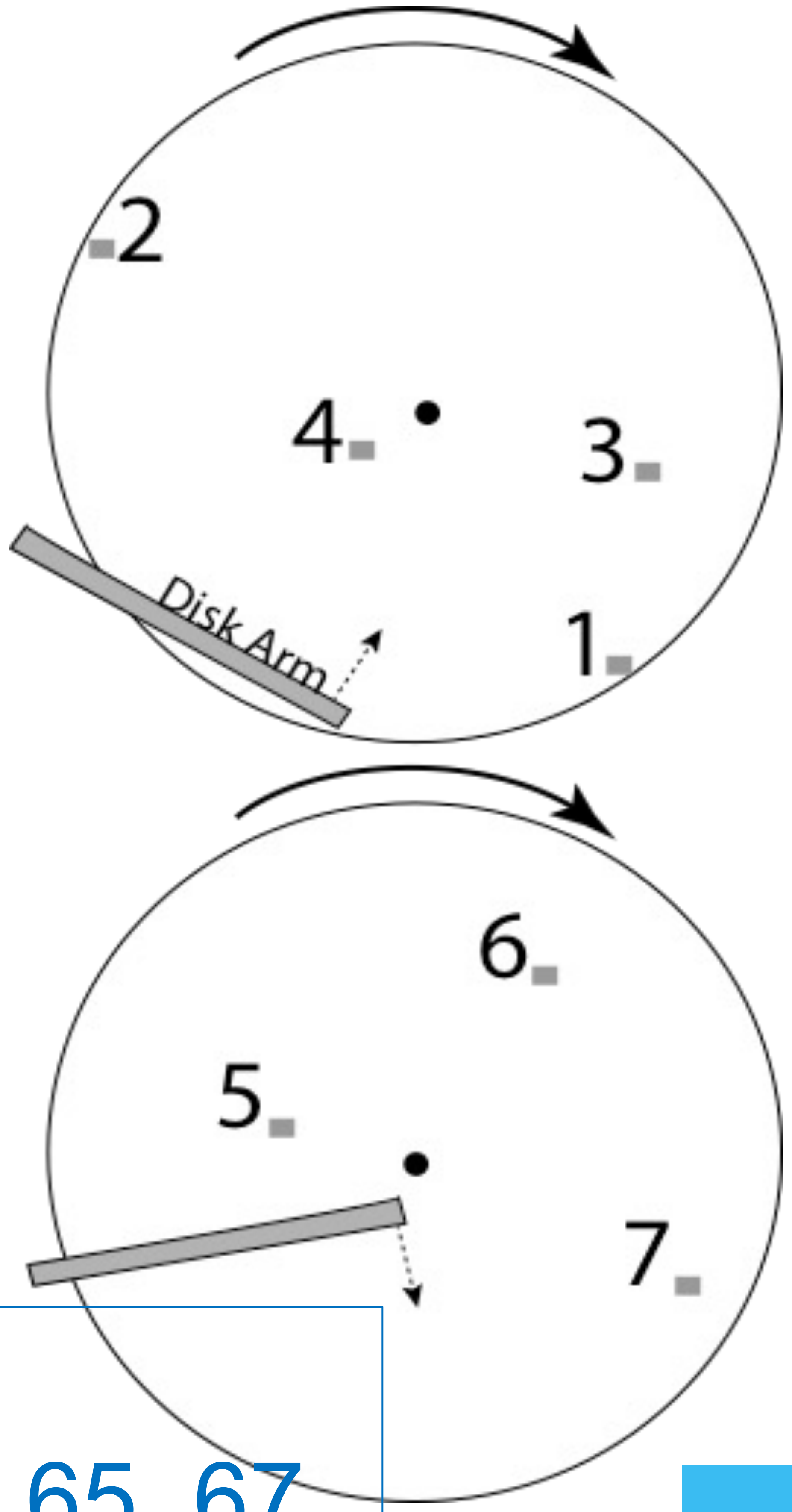
236 cylinders

Disk Scheduling: SCAN

Elevator Algorithm:

- arm starts at one end of disk
- moves to other end, servicing requests
- movement reversed @ end of disk
- repeat



SCAN Schedule?
Total head movement?

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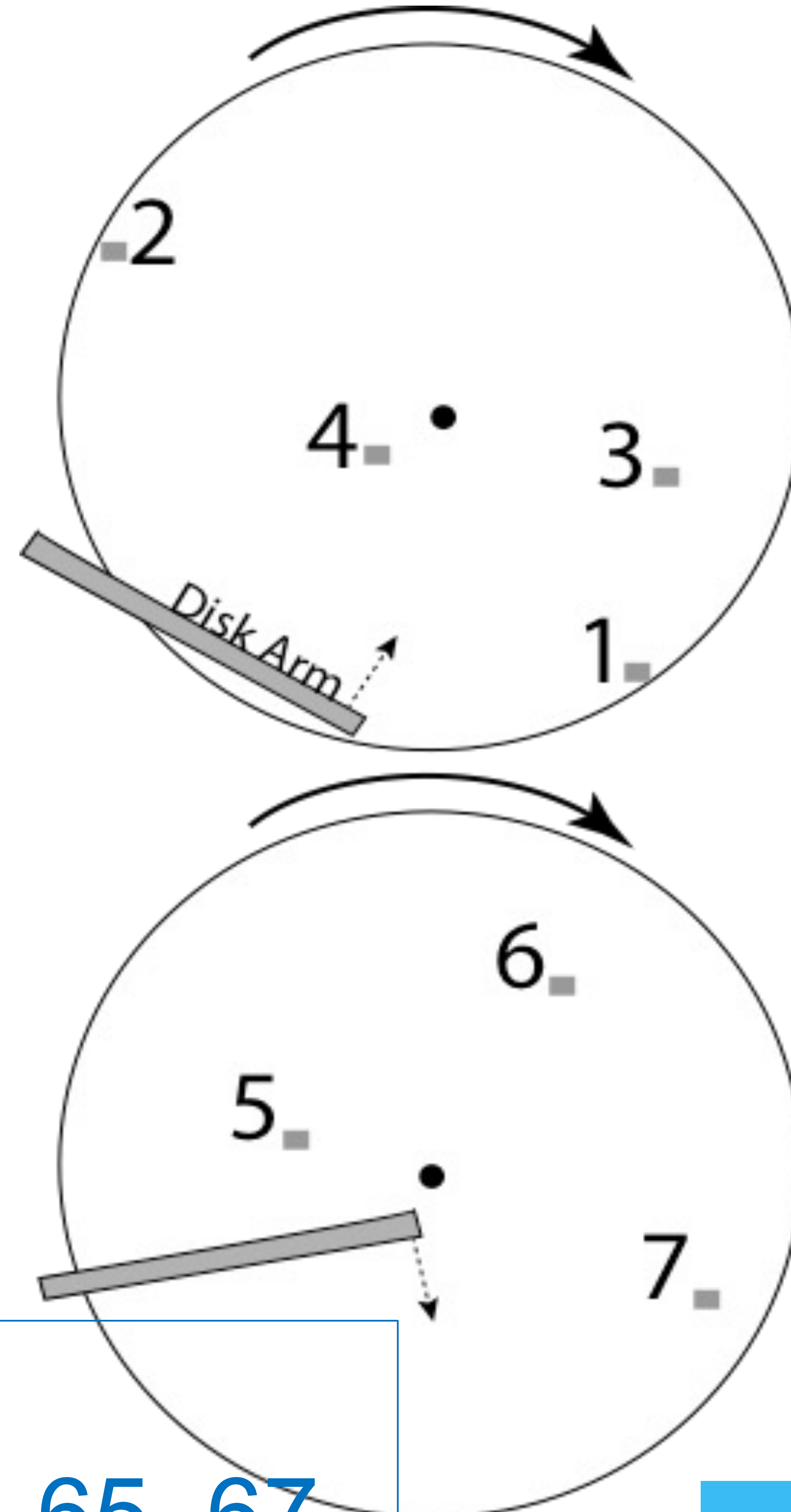


SCAN Schedule?
Total head movement?

208 cylinders

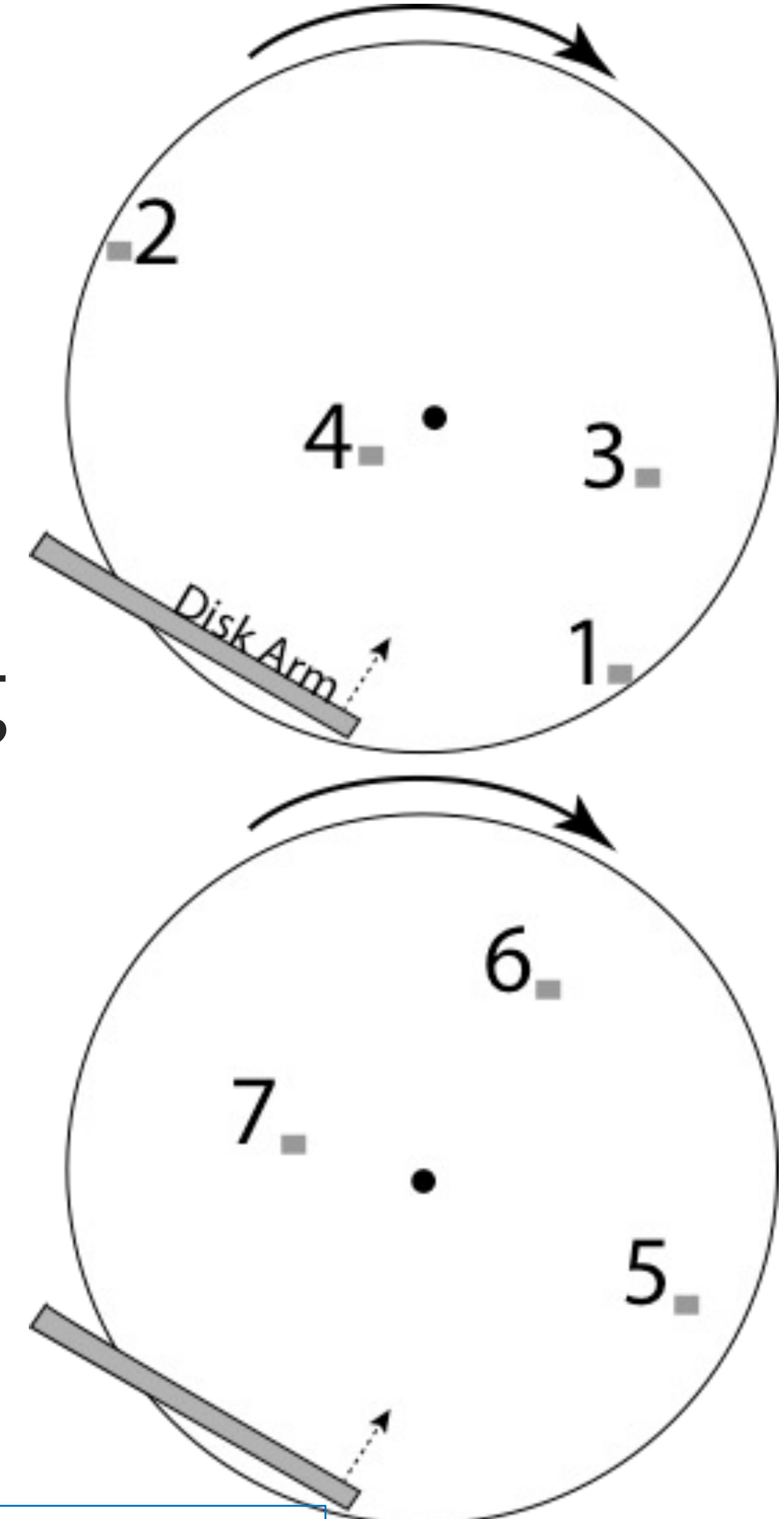
Head pointer @ 53
Queue: 98, 183, 37, 122, 14, 124, 65, 67

Disk Scheduling: C-SCAN

Circular list treatment:

- head moves from one end to other
- servicing requests as it goes
- reaches the end, returns to beginning
- no requests serviced on return trip

\+ More uniform wait time than SCAN



C-SCAN Schedule?

Total Head movement?

Head pointer @ 53

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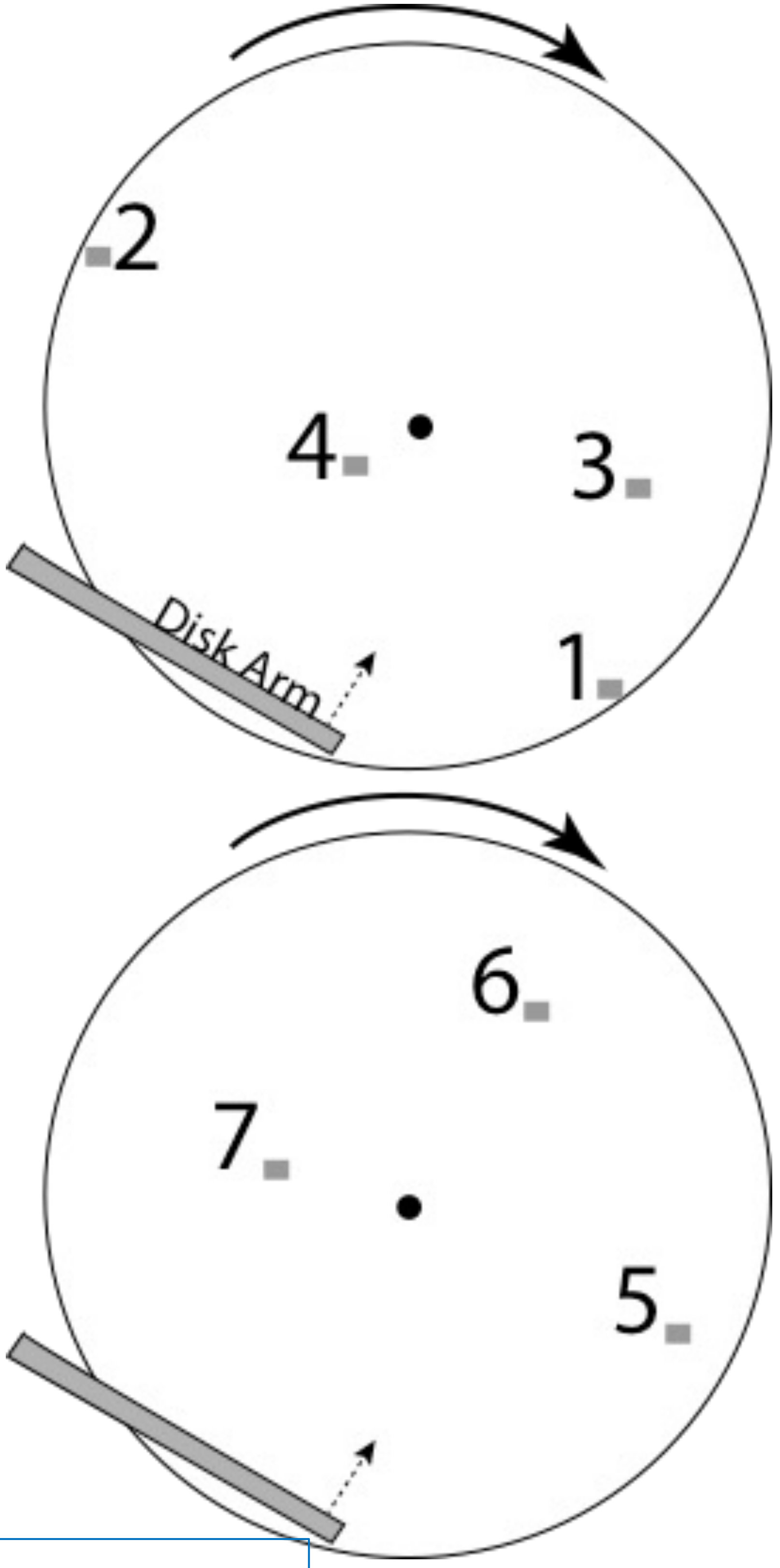


C-SCAN Schedule?

Total Head movement? 322 cylinders

Head pointer @ 53

Queue: 98, 183, 37, 122, 14, 124, 65, 67

Disk Failure Cases

(1) Isolated Disk Sectors (1+ sectors down, rest OK)

Permanent: physical malfunction (magnetic coating, scratches, contaminants)
Transient: data corrupted but new data can be successfully written to / read from sector

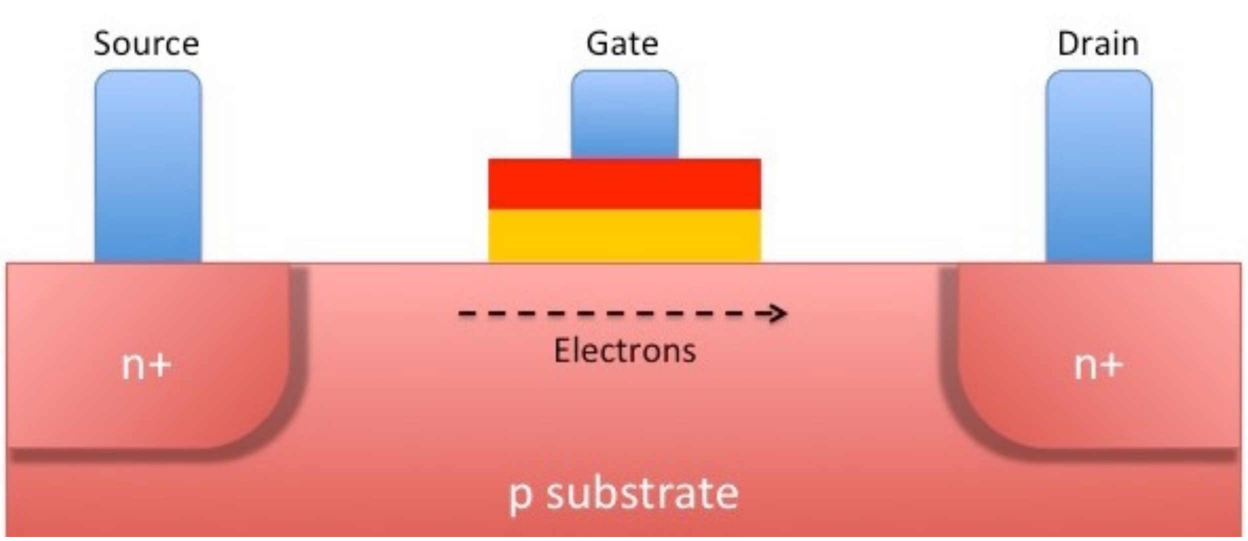
(2) Entire Device Failure

- Damage to disk head, electronic failure, wear out
- Detected by device driver, accesses return error codes
- Annual failure rates or Mean Time To Failure (MTTF)

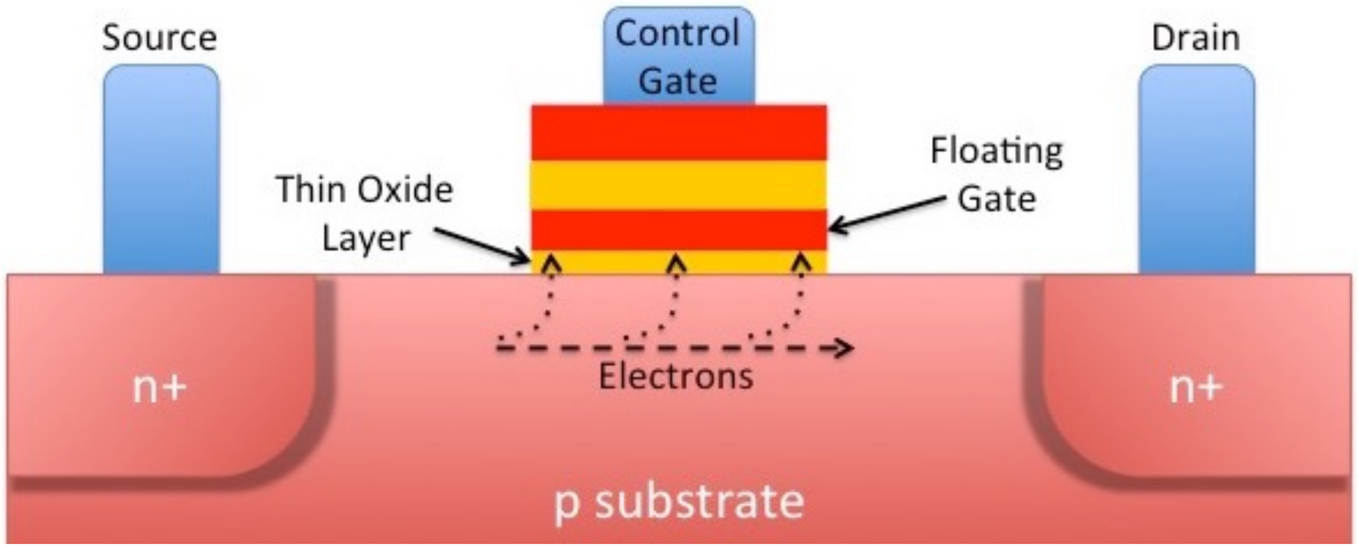
Solid State Drives (Flash)

Most SSDs based on NAND-flash

- retains its state for years without power



Metal Oxide Semiconductor Field Effect **Transistor** (MOSFET)



Floating Gate MOSFET (FGMOS)

https://flashdba.com/2015/01/09/understanding-flash-floating-gates-and-wear/

Flash Operations

- **Erase block:** sets each cell to “1”
  - erase granularity = “erasure block” = 128-512 KB
  - time: several ms
- **Write page:** can only write erased pages
  - write granularity = 1 page = 2-4KBytes
- **Read page:**
  - read granularity = 1 page = 2-4KBytes

Flash Limitations

- can't overwrite individual pages (must write blocks)
- limited # of erase cycles per block (memory wear)
  - 10^3-10^6 erases and the cell wears out
  - reads can "disturb" nearby words and overwrite them with garbage

- **Lots of techniques to compensate:**
  - error correcting codes
  - bad page/erasure block management
  - wear leveling: trying to distribute erasures across the entire driver

Flash Translation Layer

Flash device firmware maps logical page # to a physical location

- Garbage collect erasure block by copying live pages to new location, then erase
  - More efficient if blocks stored at same time are kept together
- Wear-leveling: only write each physical page a limited number of times
- Remap pages that no longer work (sector sparing)

Transparent to the device user

RAM (Memory) vs. HDD (Disk) vs. SSD, 2020

	RAM	HDD	SSD
Typical Size	100 GB	1 TB	1TB
Cost	$5-10 per GB	$0.05 per GB	$0.10 per GB
Latency	15 ns	15 ms	1ms
Throughput (Sequential)	8000 MB/s	175 MB/s	500 MB/s
Power Reliance	volatile	non-volatile	non-volatile

What do we want from storage?

- Fast: data is there when you want it
- Reliable: data fetched is what you stored
- Affordable: won’t break the bank

Enter: Redundant Array of Inexpensive Disks (RAID)

- In industry, “I” is for “Independent”
- The alternative is SLED, single large expensive disk
- RAID + RAID controller looks just like SLED to computer (*yay, abstraction!*)

RAID-0

Files striped across disks

+ Fast

latency?

throughput?

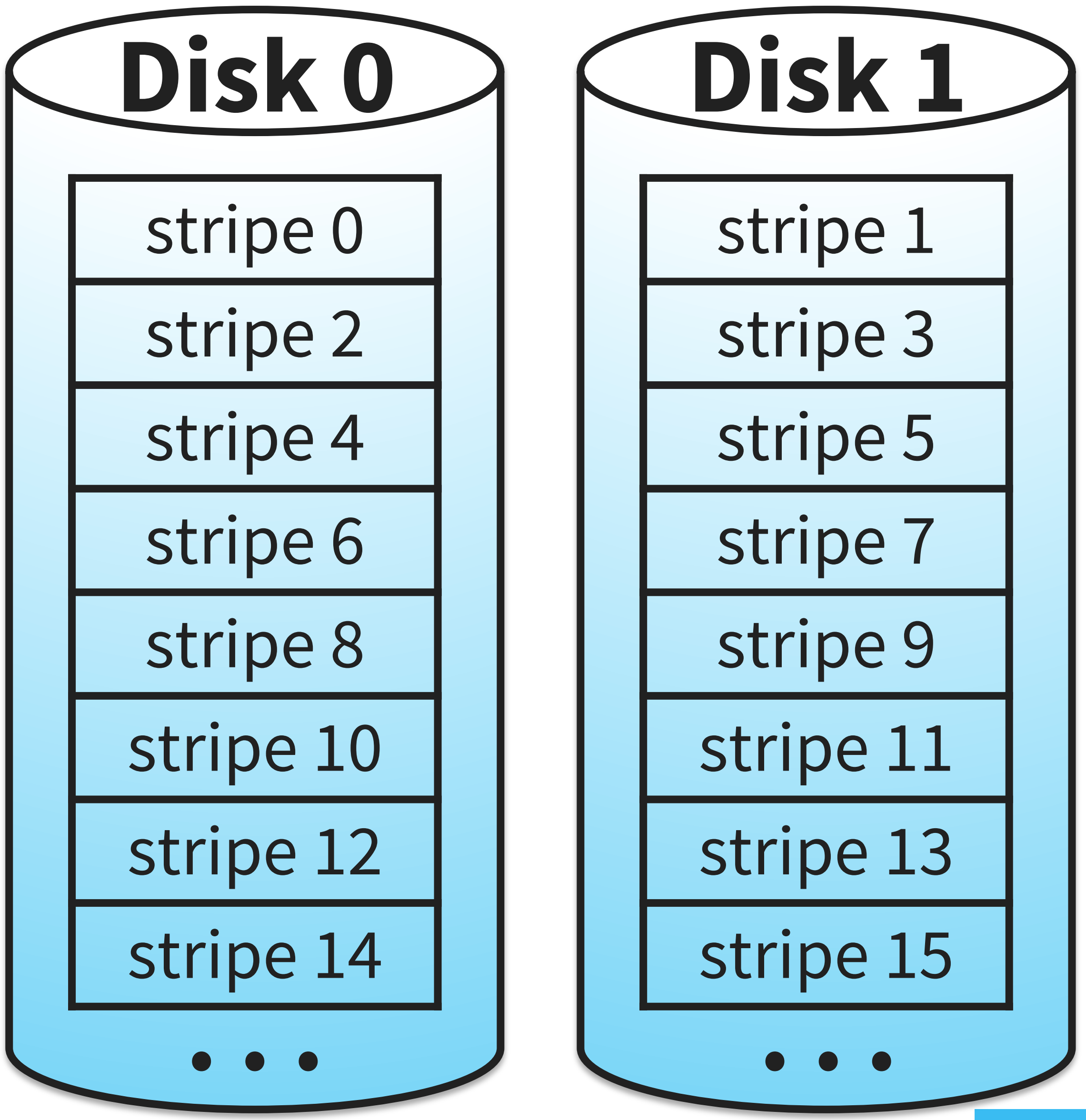
+ Cheap

capacity?

– Unreliable

max #failures?

MTTF?



Striping and Reliability

Striping *reduces* reliability

- More disks ➜ higher probability of some disk failing
- *N* disks: 1/N^{th} mean time between failures of 1 disk

😞

What can we do to improve Disk Reliability?

RAID-1

Disks Mirrored:

data written in 2 places

+ Reliable

deals well with disk loss

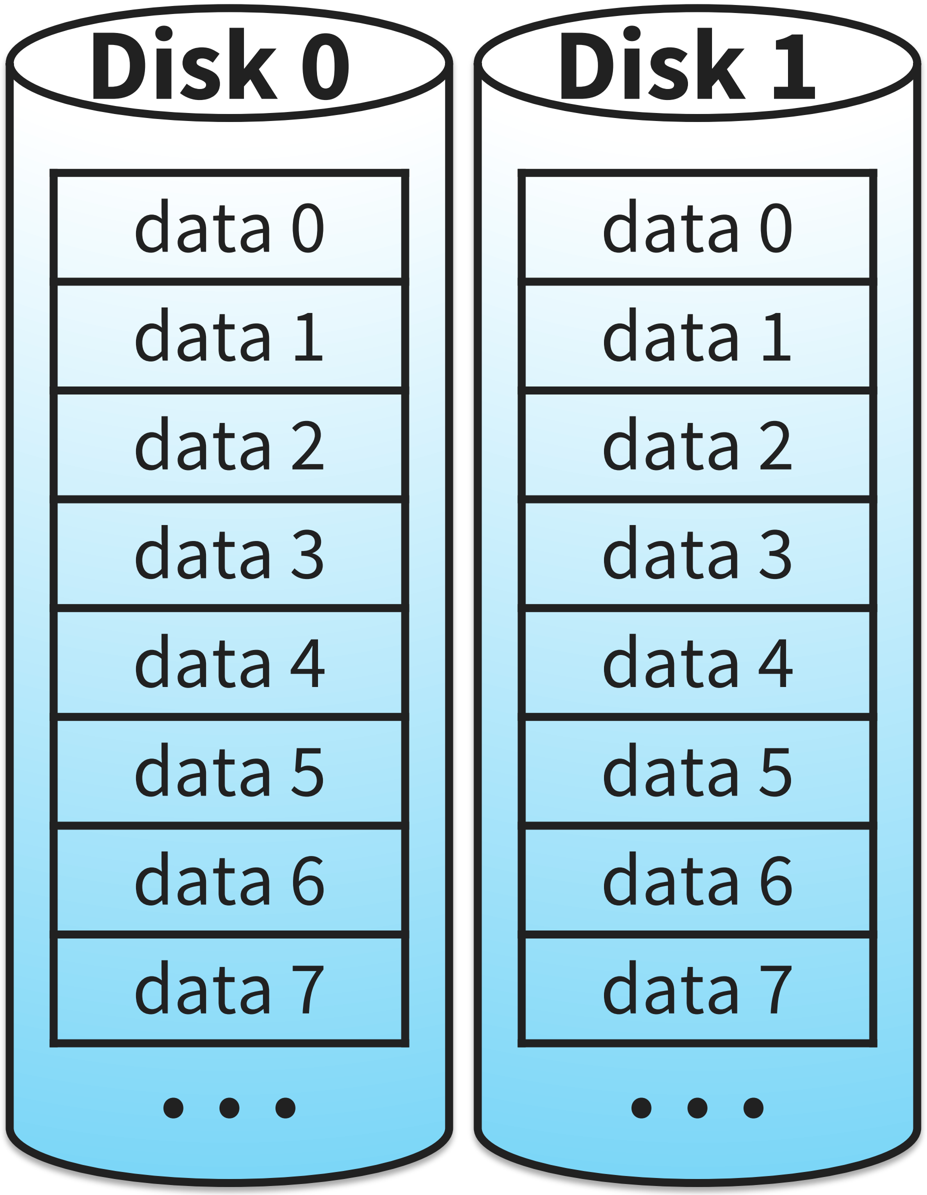
but not corruption

+ Fast

latency?

throughput?

– Expensive



RAID-4 (rarely used)

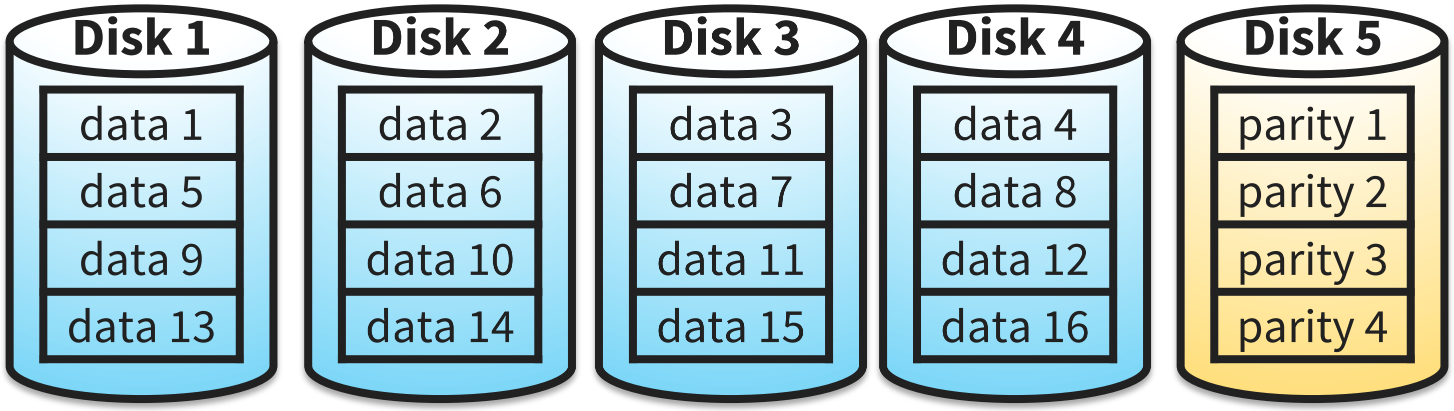
block-level striping + parity disk

+ Cheap

– Slow Writes

– Unreliable

parity disk is write bottleneck and wears out faster



Using a parity disk

- $D_N = D_1 \oplus D_2 \oplus \ldots \oplus D_{N-1}$
  - $\oplus$ = XOR operation
- If one of $D_1 \ldots D_{N-1}$ fails, we can reconstruct its data by XOR-ing all the remaining drives

Updating a block in RAID-4

- Suppose block lives on disk D_1
- Method 1:
  - read corresponding blocks on $D_2 \ldots D_{N-1}$
  - XOR all with new content of block
  - write disk D_1 and D_N in parallel
- Method 2:
  - read D_1 (old content) and D_N
  - XOR both with new content of block
  - write disk D_1 and D_N in parallel
- Note that in both write cases D_N must always be updated
  ➔ D_N is a write performance bottleneck
- Either way:
  - throughput: ½ of single disk
  - latency: double of single disk

Streaming update in RAID-4

- Save up updates to stripe across $D_1 \ldots D_{N-1}$
- Compute $D_N = D_1 \oplus D_2 \oplus \ldots \oplus D_{N-1}$
- Write $D_1 \ldots D_N$ in parallel
- (N-1)x seq. throughput of single disk

RAID 5: Rotating Parity w/Striping

+ Reliable

you can lose one disk

+ Fast

(*N*-1)x seq. throughput of single disk

***N*/4x random write throughput**

+ Affordable