Disks and I/O Scheduling

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Portions courtesy Emmett Witchel

Quick Recap

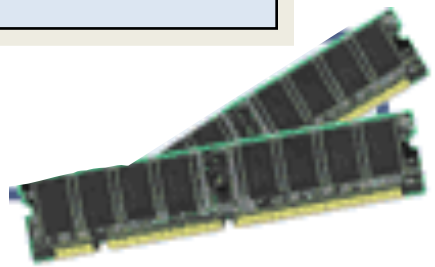
- CPU Scheduling
  - Balance competing concerns with heuristics
    - What were some goals?
  - No perfect solution
- Today: Block device scheduling
  - How different from the CPU?
  - Focus primarily on a traditional hard drive
  - Extend to new storage media

Disks: Just like memory, but different

- Why have disks?
  - Memory is small. Disks are large.
    - Short term storage for memory contents (e.g., swap space).
    - Reduce what must be kept in memory (e.g., code pages).
  - Memory is volatile. Disks are forever (?!)
    - File storage.

	GB/dollar	dollar/GB
RAM	0.013(0.015,0.01)	$77($68,$95)
Disks	3.3(1.4,1.1)	30¢ (71¢,90¢)

Capacity : 2GB vs. 1TB
2GB vs. 400GB
1GB vs 320GB



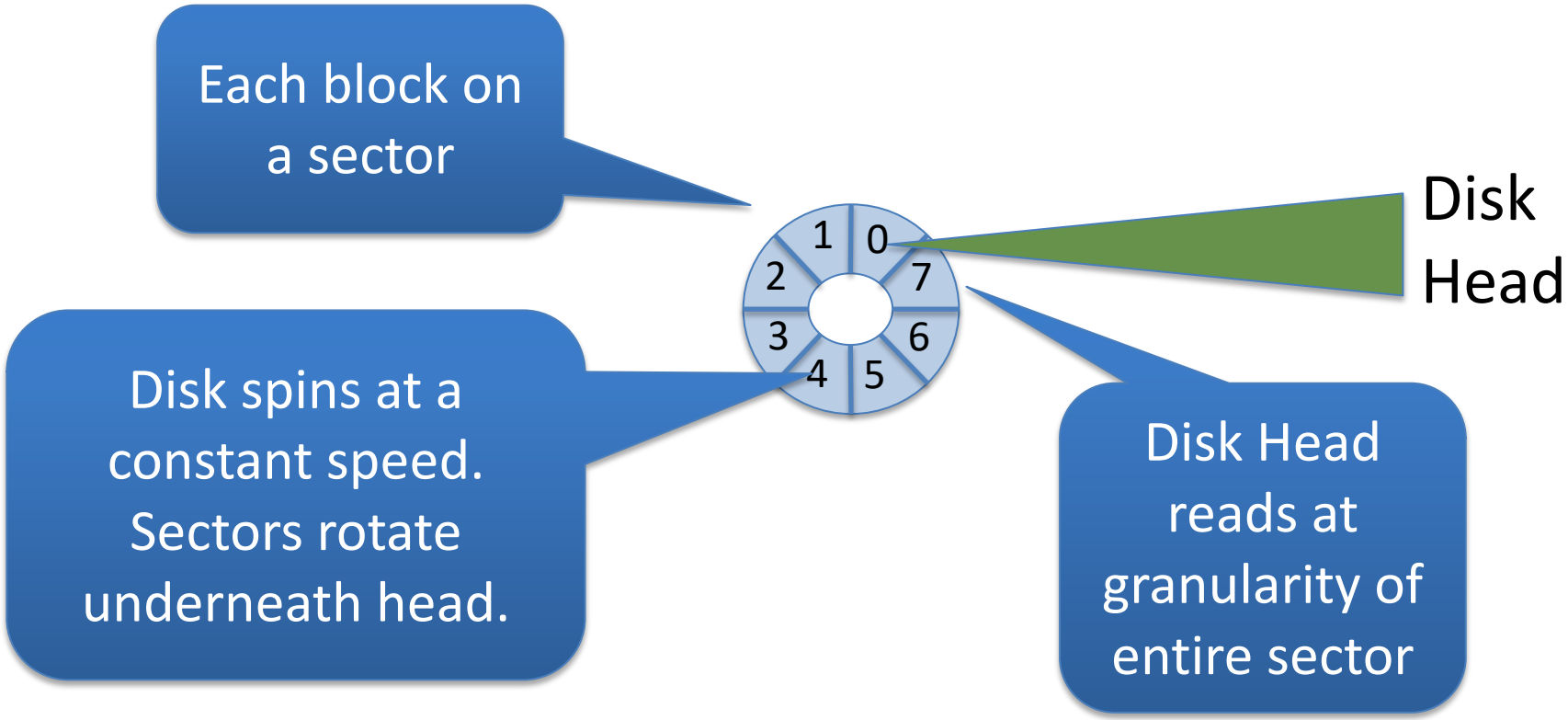
OS's view of a disk

- Simple array of blocks
  - Blocks are usually 512 or 4k bytes

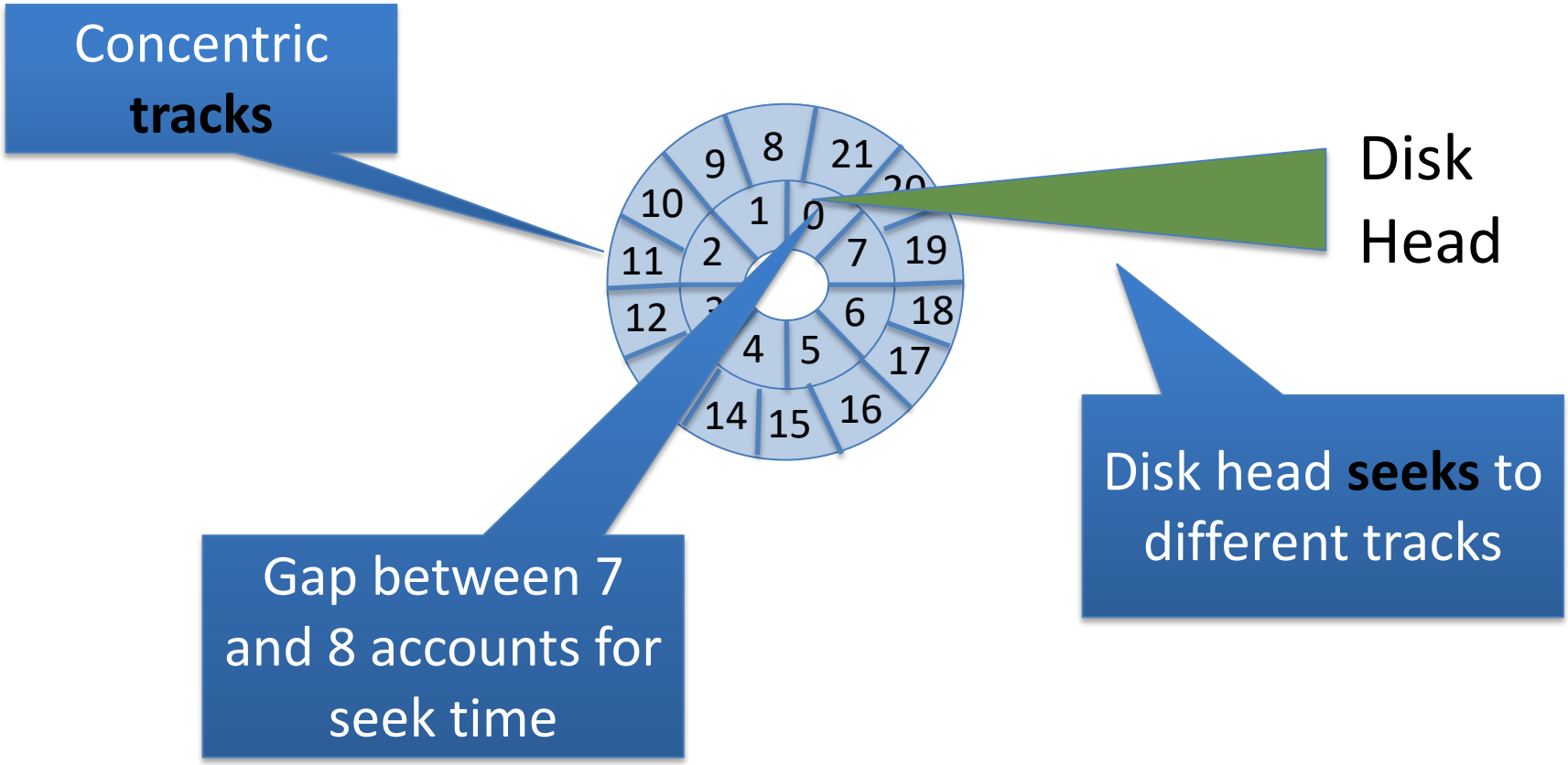
A simple disk model

- Disks are slow. Why?
  - Moving parts << circuits
- Programming interface: simple array of sectors (blocks)
- Physical layout:
  - Concentric circular "tracks" of blocks on a platter
  - E.g., sectors 0-9 on innermost track, 10-19 on next track, etc.
  - Disk arm moves between tracks
  - Platter rotates under disk head to align w/ requested sector

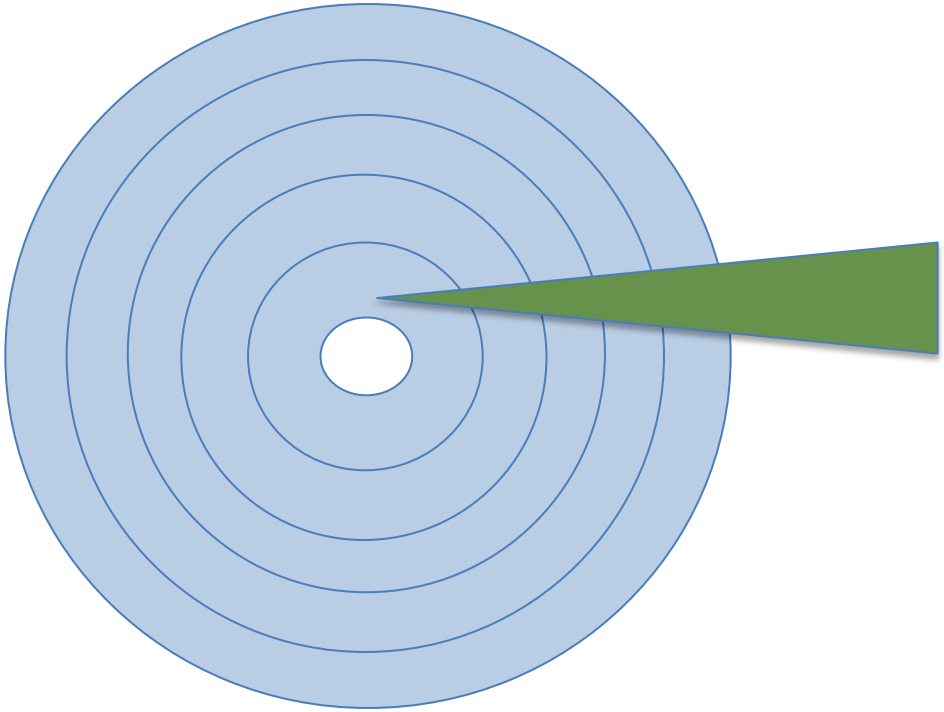
Disk Model


Each block on a sector
Disk spins at a constant speed. Sectors rotate underneath head.
Disk Head reads at granularity of entire sector
Disk Head
0
1
2
3
4
5
6
7

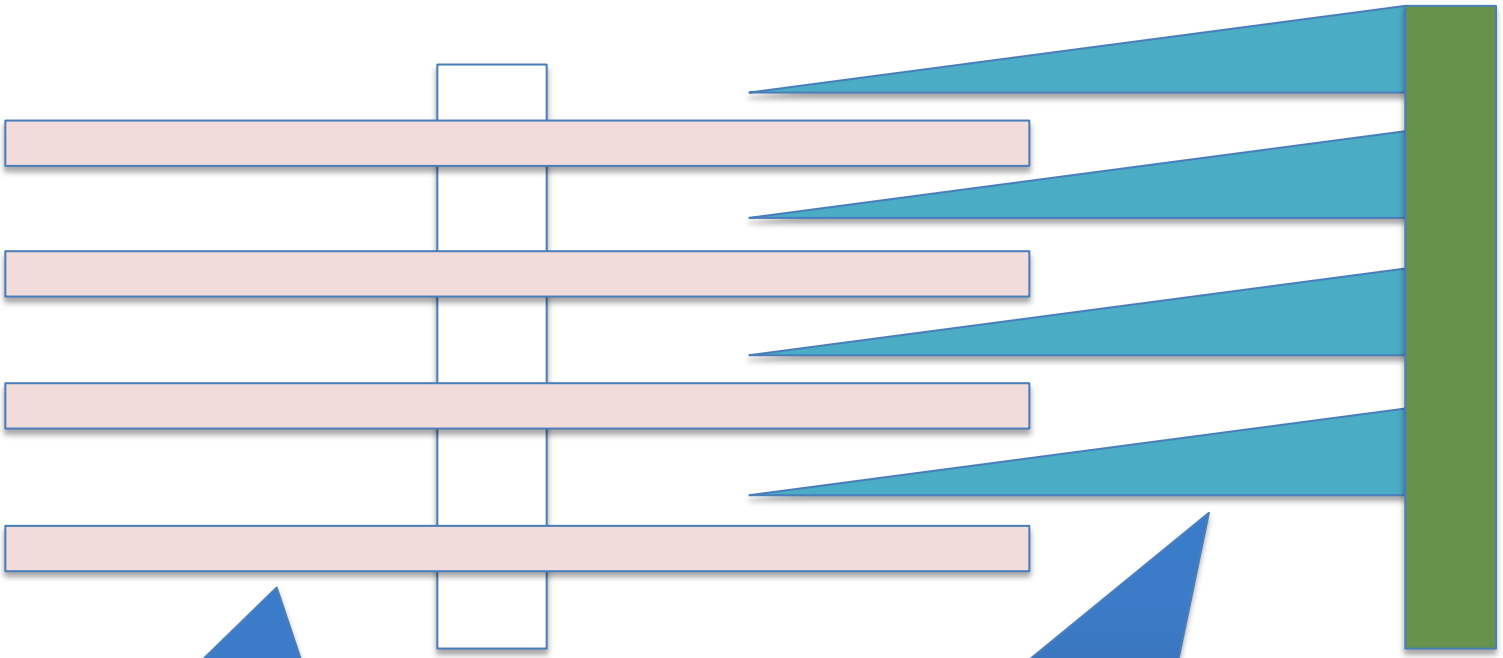
Disk Model


Concentric **tracks**
Disk Head
Disk head **seeks** to different tracks
Gap between 7 and 8 accounts for seek time
0
1
2
4
5
6
7
8
9
10
11
12
14
15
16
17
18
19
21

Many Tracks



Several (~4) Platters



Platters spin together at same speed

Each platter has a head; All heads seek together

Implications of multiple platters

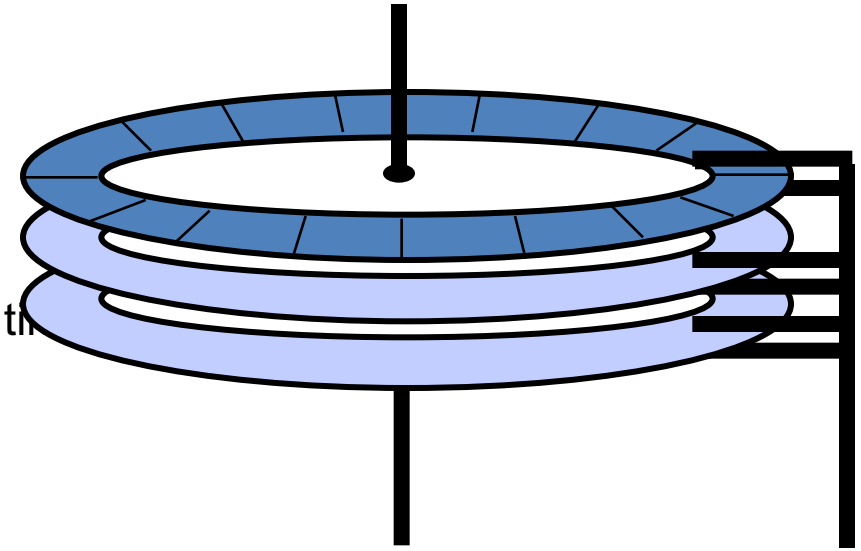
- Blocks actually striped across platters
- Also, both sides of a platter can store data
  - Called a **surface**
  - Need a head on top and bottom
- Example:
  - Sector 0 on platter 0 (top)
  - Sector 1 on platter 0 (bottom, same position)
  - Sector 2 on platter 1 at same position, top,
  - Sector 3 on platter 1, at same position, bottom
  - Etc.
  - 8 heads can read all 8 sectors simultaneously

Real Example

- Seagate 73.4 GB Fibre Channel Ultra 160 SCSI disk

- Specs:
  - 12 Platters
  - 24 Heads
  - Variable # of sectors/track
  - 10,000 RPM
    - Average latency: 2.99 *ms*
  - Seek times
    - Track-to-track: 0.6/0.9 *ms*
    - Average: 5.6/6.2 *ms*
    - Includes acceleration and settle ti
  - 160-200 MB/s peak transfer rate
    - 1-8K cache

- 12 Arms
- 14,100 Tracks
- 512 bytes/sector



3 Key Latencies

- I/O delay: time it takes to read/write a sector
- Rotational delay: time the disk head waits for the platter to rotate desired sector under it
  - Note: disk rotates continuously at constant speed
- Seek delay: time the disk arm takes to move to a different track

Observations

- Latency of a given operation is a function of current disk arm and platter position
- Each request changes these values
- Idea: build a model of the disk
  - Maybe use delay values from measurement or manuals
  - Use simple math to evaluate latency of each pending request
  - Greedy algorithm: always select lowest latency

Example formula

- s = seek latency, in time/track
- r = rotational latency, in time/sector
- i = I/O latency, in seconds

- Time = (Δtracks * s) + (Δsectors * r) + I
- Note: Δsectors must factor in position after seek is finished. Why?

Example read time:
seek time + *latency* + *transfer time*
(5.6 *ms* + 2.99 *ms* + 0.014 *ms*)

The Disk Scheduling Problem: Background

- Goals: Maximize disk throughput
  - Bound latency
- Between file system and disk, you have a queue of pending requests:
  - Read or write a given logical block address (LBA) range
- You can reorder these as you like to improve throughput
- What reordering heuristic to use? If any?
- Heuristic is called the **IO Scheduler**
  - Or "Disk Scheduler" or "Disk Head Scheduler"

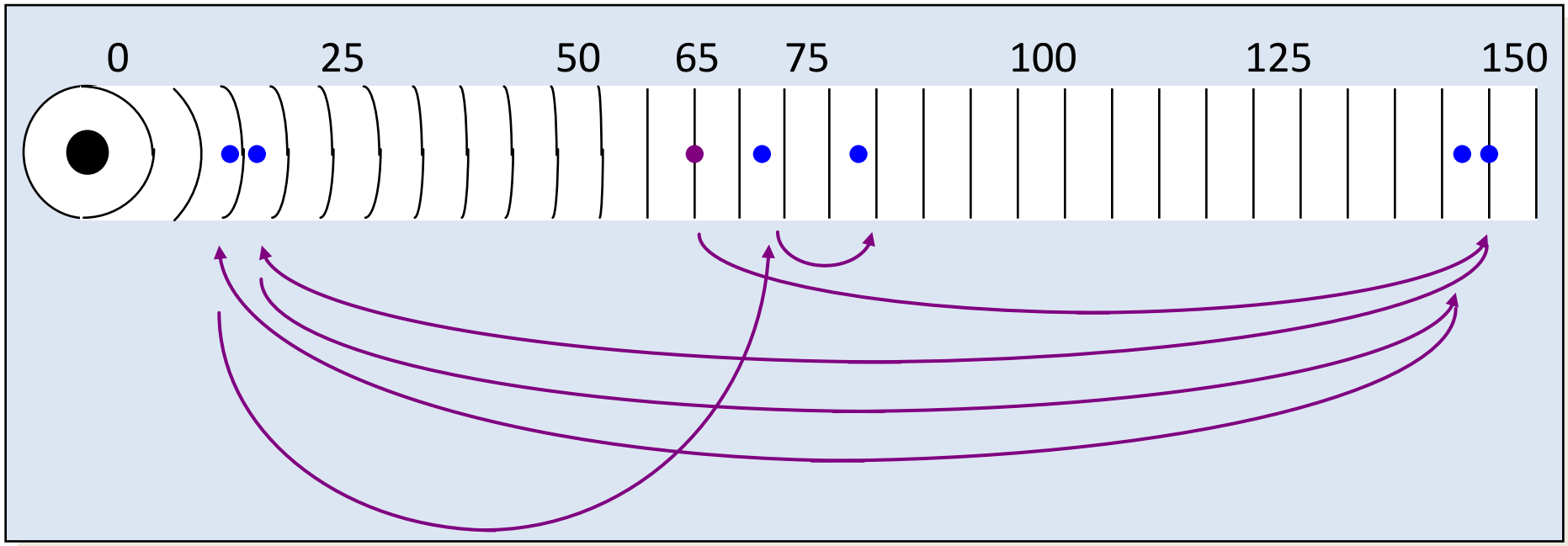
Evaluation: how many tracks head moves across

I/O Scheduling Algorithm 1: FCFS

- Assume a queue of requests exists to read/write tracks:

83	72	14	147	16	150

and the head is on track 65



FCFS: Moves head 550 tracks

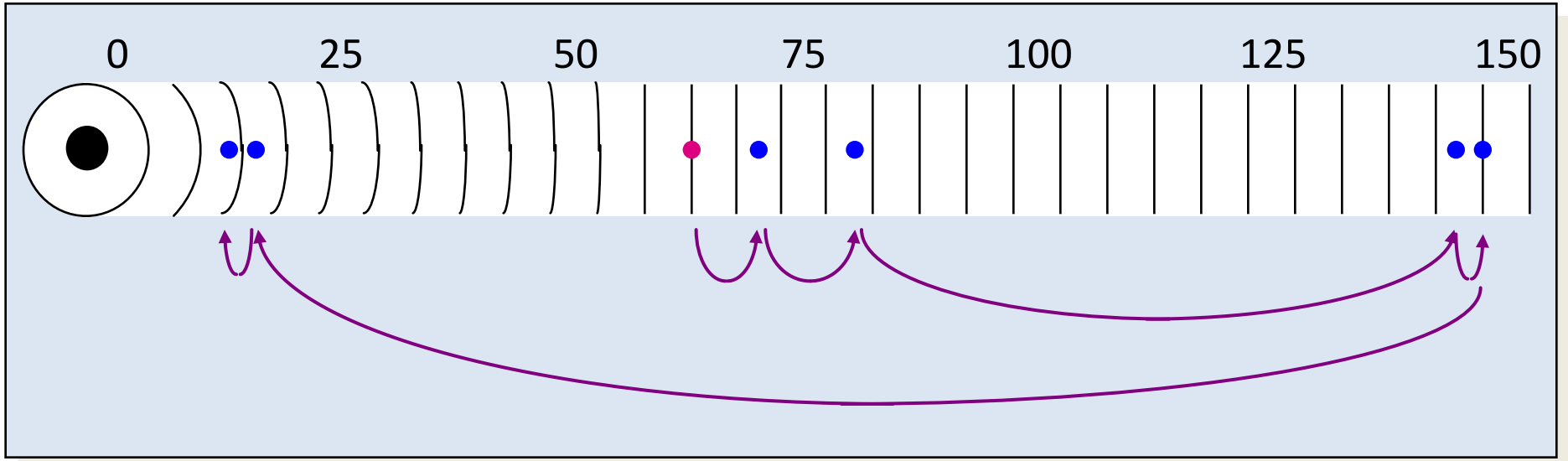
I/O Scheduling Algorithm 2: SSTF

- Greedy scheduling: *shortest seek time first*
  - Rearrange queue from:

83	72	14	147	16	150

To:

14	16	150	147	82	72



SSTF scheduling results in the head moving 221 tracks
Can we do better?

SSTF: 221 tracks (vs 550 for FCFS)

Other problems with greedy?

- "Far" requests will starve
  - Assuming you reorder every time a new request arrives
- Disk head may just hover around the "middle" tracks

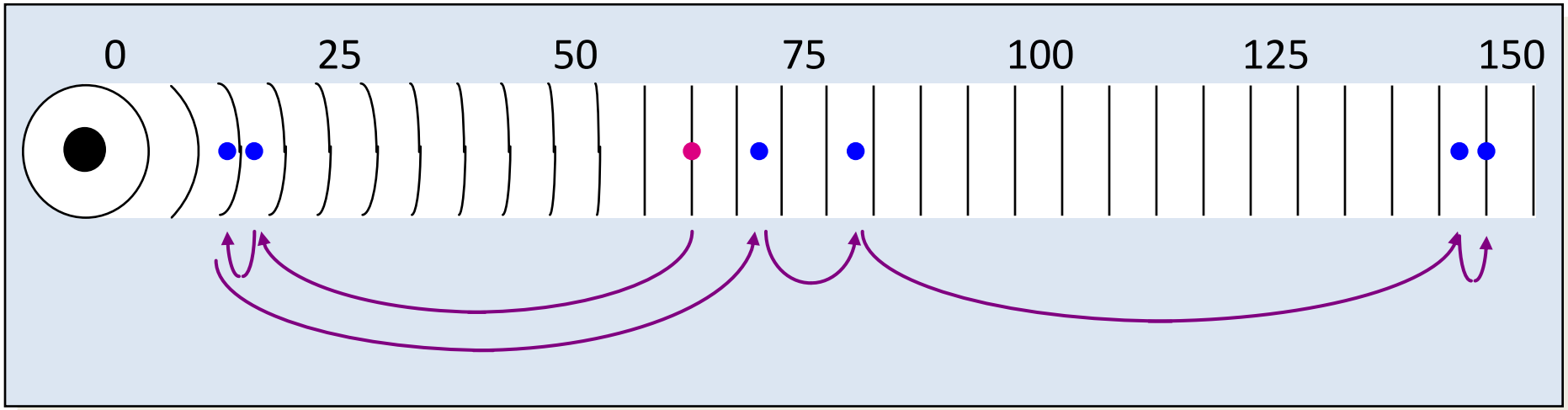
I/O Scheduling Algorithm 3: SCAN

- Move the head in one direction until all requests have been serviced, and then reverse.
- Also called Elevator Scheduling
- Rearrange queue from:

83	72	14	147	16	150

To:

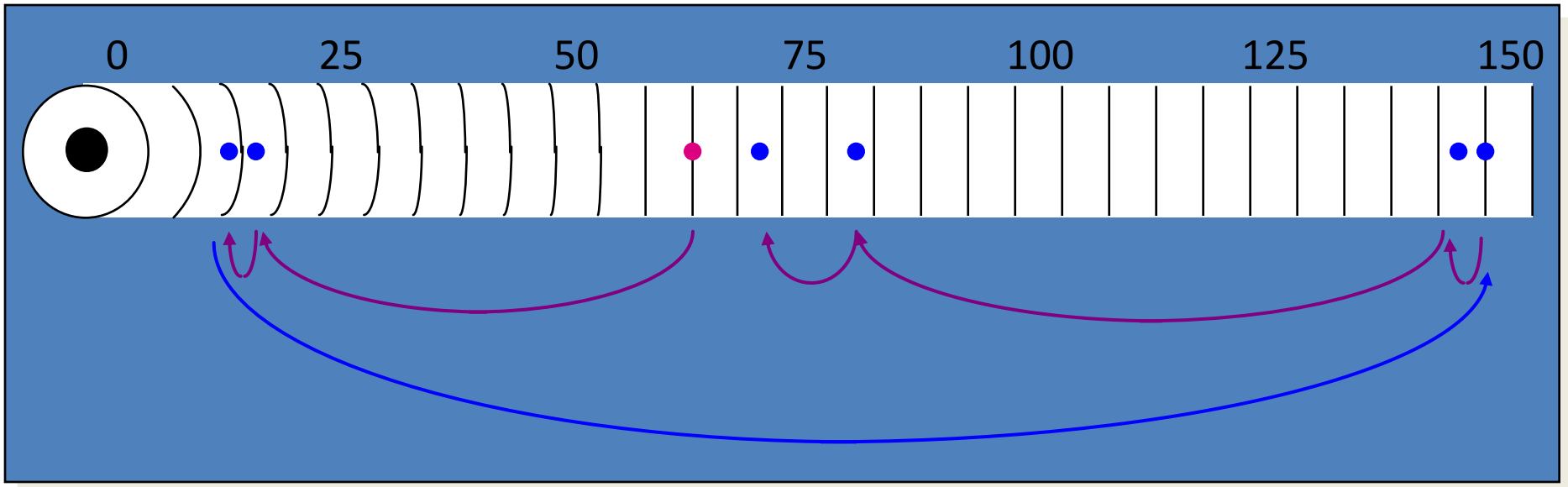
150	147	83	72	14	16



SCAN: 187 tracks (vs. 221 for SSTF)

I/O Scheduling Algorithm 4: C-SCAN

- Circular SCAN: Move the head in one direction until an edge of the disk is reached, and then reset to the opposite edge



- Marginally better fairness than SCAN

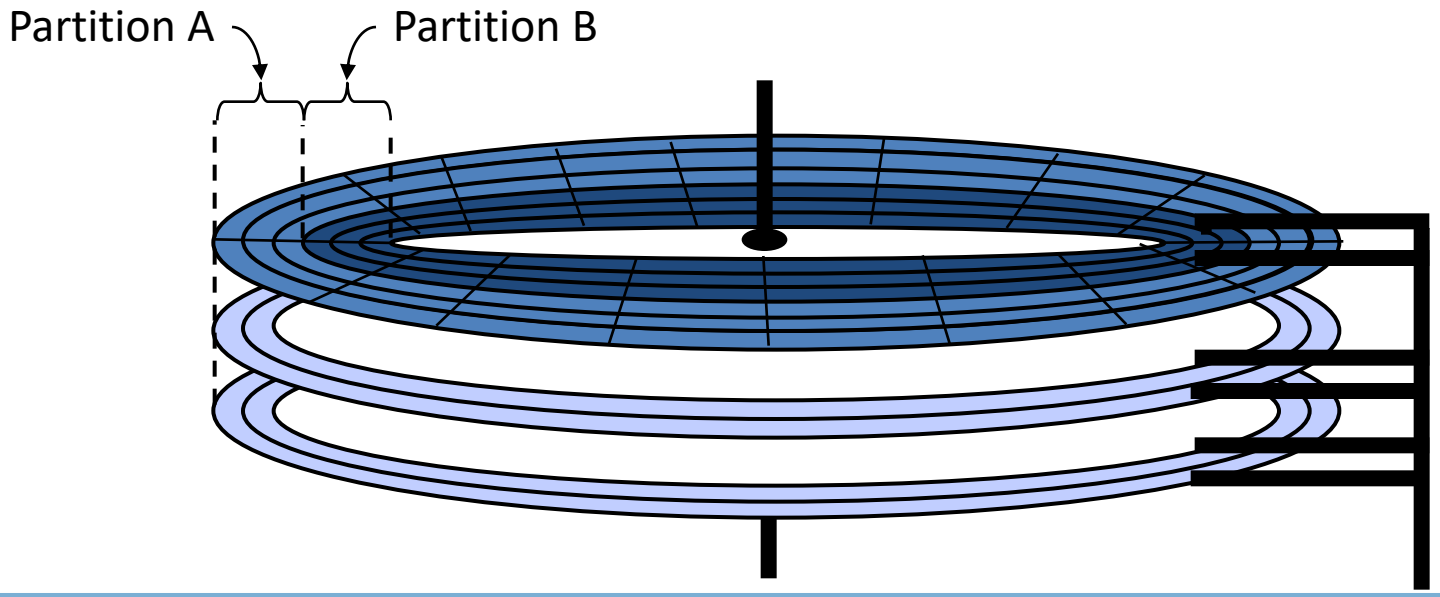
C-SCAN: 265 tracks (vs. 221 for SSTF, 187 for SCAN)

Scheduling Checkpoint

- SCAN seems most efficient for these examples
  - C-SCAN offers better fairness at marginal cost
  - Your mileage may vary (i.e., workload dependent)
- File systems would be wise to place related data ”near” each other
  - Files in the same directory
  - Blocks of the same file
- You will explore the practical implications of this model in Lab 4!

Disk Partitioning

- Multiple file systems can share a disk: **Partition** space
- Disks are typically partitioned to minimize the maximum seek time
  - A partition is a collection of cylinders
  - Each partition is a logically separate disk



Disks: Technology Trends

- Disks are getting smaller in size
  - Smaller → spin faster; smaller distance for head to travel; and lighter weight
- Disks are getting denser
  - More bits/square inch → small disks with large capacities
- Disks are getting cheaper
  - Well, in $/byte – a single disk has cost at least $50-100 for 20 years
  - 2x/year since 1991
- Disks are getting faster
  - Seek time, rotation latency: 5-10%/year (2-3x per decade)
  - Bandwidth: 20-30%/year (~10x per decade)
  - This trend is really flattening out on commodity devices; more apparent on high-end

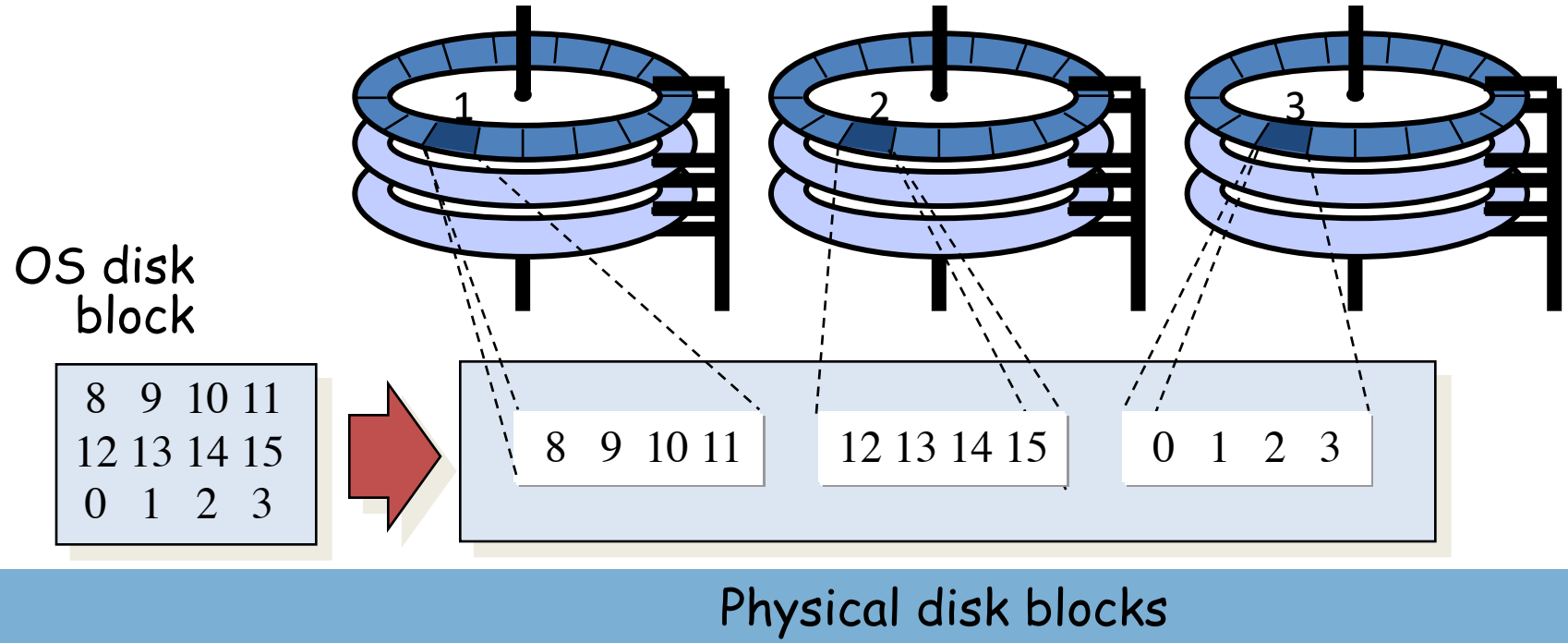
Overall: Capacity improving much faster than perf.

Parallel performance with disks

- Idea: Use more of them working together
  - Just like with multiple cores
- Redundant Array of Inexpensive Disks (RAID)
  - Intuition: Spread logical blocks across multiple devices
  - Ex: Read 4 LBAs from 4 different disks in parallel
- Does this help throughput or latency?
  - Definitely throughput, can construct scenarios where one request waits on fewer other requests (latency)
- It can also protect data from a disk failure
  - Transparently write one logical block to 1+ devices

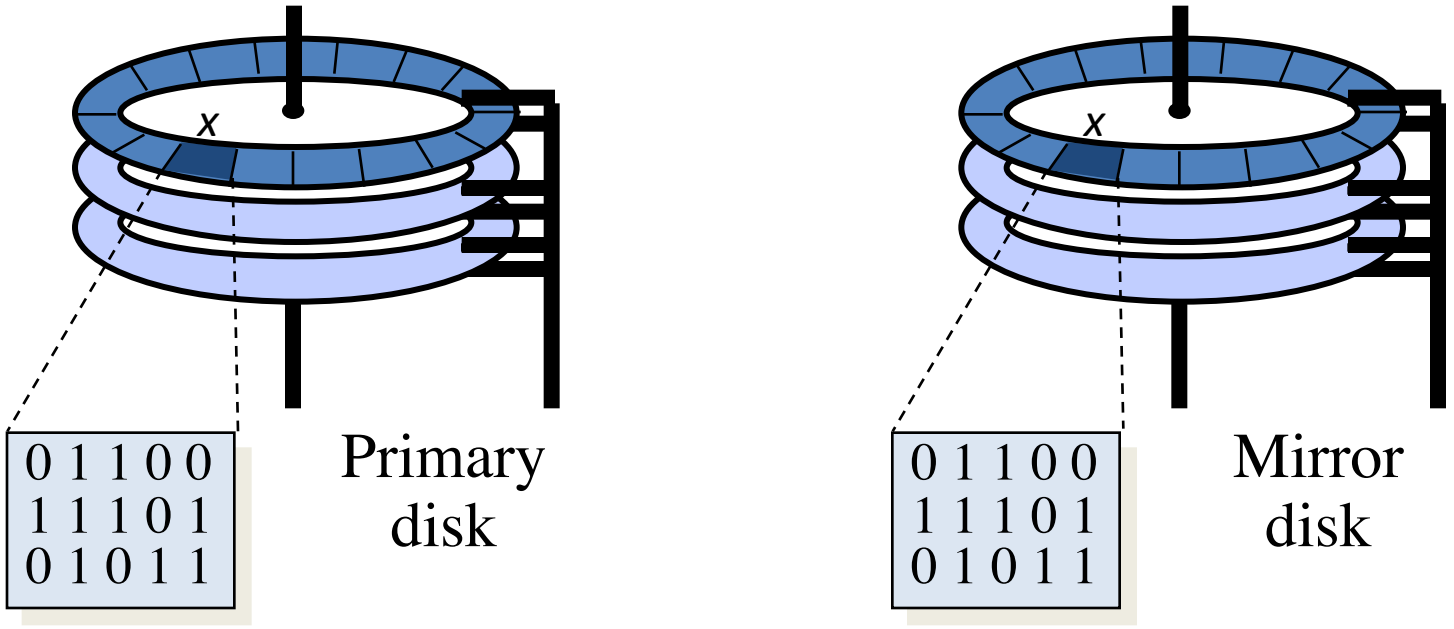
Disk Striping: RAID-0

- Blocks broken into sub-blocks that are stored on separate disks
  - similar to memory interleaving
- Provides for higher disk bandwidth through a larger effective block size



RAID 1: Mirroring

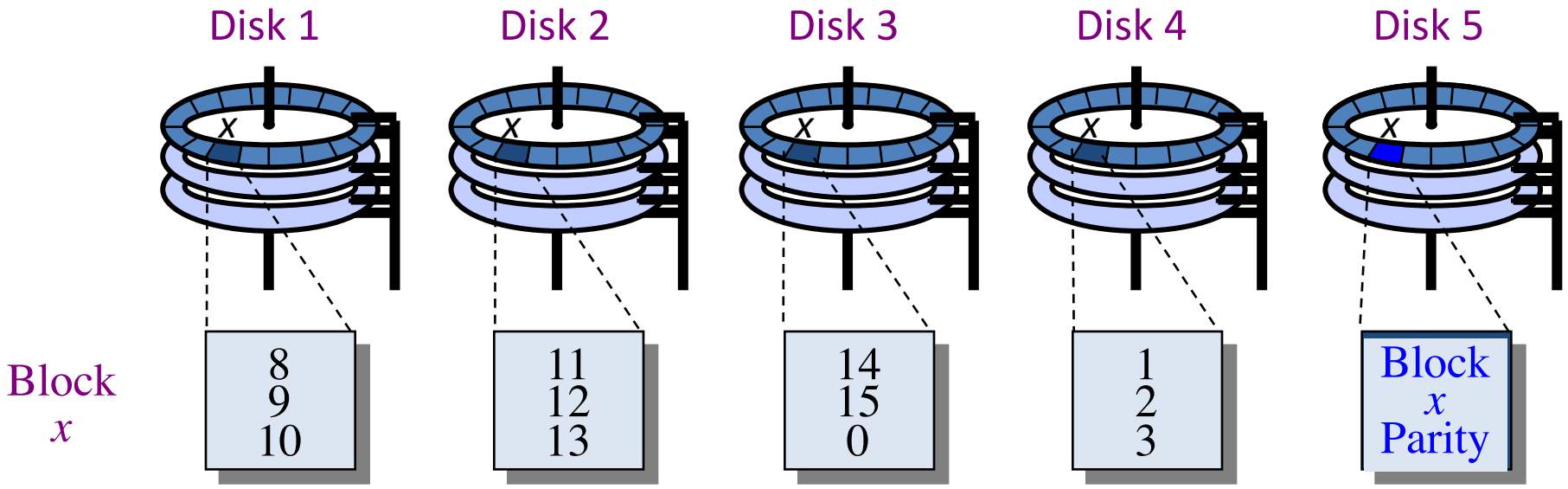
- To increase the reliability of the disk, redundancy must be introduced
  - Simple scheme: *disk mirroring (RAID-1)*
  - *Write to both disks, read from either.*



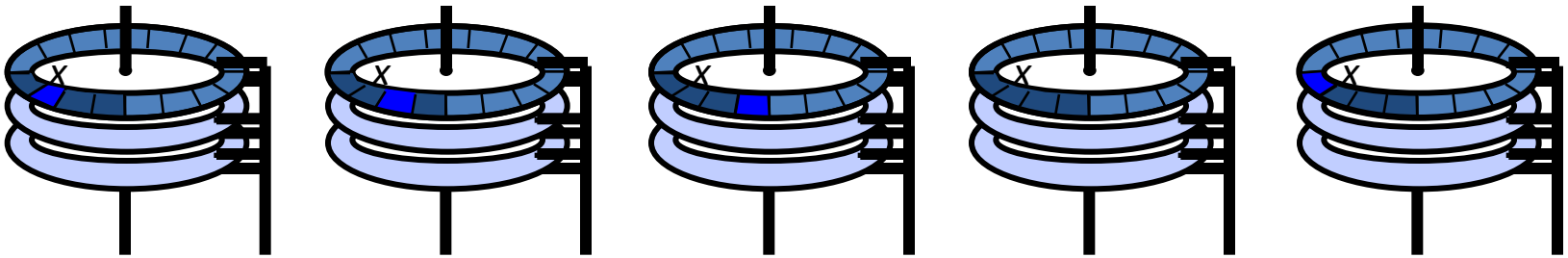
Can lose one disk without losing data

RAID 5: Performance and Redundancy

- Idea: Sacrifice one disk to store the parity bits of other disks (e.g., xor-ed together)
- Still get parallelism
- Can recover from failure of any one disk
- Cost: Extra writes to update parity



RAID 5: Interleaved Parity



	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5
Block *x*	8 9 10	11 12 13	14 15 0	1 2 3	Block *x* Parity
Block *x*+1	Block *x*+1 Parity	*a* *b* *c*	*d* *e* *f*	*g* *h* *i*	*j* *k* *l*
Block *x*+2	*m* *n* *o*	Block *x*+2 Parity	*p* *q* *r*	*s* *t* *u*	*v* *w* *x*
Block *x*+3	*y* *z* *aa*	*bb* *cc* *dd*	Block *x*+3 Parity	*ee* *ff* *gg*	*hh* *ii* *jj*

Other RAID variations

- Variations on encoding schemes, different trades for failures and performance
  - See wikipedia
  - But 0, 1, 5 are the most popular by far
- More general area of **erasure coding**:
  - Store k logical blocks (message) in n physical blocks (k < n)
  - In an optimal erasure code, recover from any k/n blocks
  - Xor parity is a (k, k+1) erasure code
  - Gaining popularity at data center granularity

Where is RAID implemented?

- Hardware (i.e., a chip that looks to OS like 1 disk)
  - +Tend to be reliable (hardware implementers test)
  - +Offload parity computation from CPU
    - Hardware is a bit faster for rewrite intensive workloads
  - -Dependent on card for recovery (replacements?)
  - -Must buy card (for the PCI bus)
  - -Serial reconstruction of lost disk
- Software (i.e., a "fake" disk driver)
  - -Software has bugs
  - -Ties up CPU to compute parity
  - +Other OS instances might be able to recover
  - +No additional cost
  - +Parallel reconstruction of lost disk

Most PCs have "fake" HW RAID: All work in driver

Word to the wise

- RAID is a good idea for protecting data
  - Can safely lose 1+ disks (depending on configuration)
- But there is another weak link: The power supply
  - I have personally had a power supply go bad and fry 2/4 disks in a RAID5 array, effectively losing all of the data

RAID is no substitute for backup to another machine

Summary

- Understand disk performance model
  - Will explore more in Lab 4
- Understand I/O scheduling algorithms
- Understand RAID