Operating Systems

Secondary Storage

Lecture 14

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Overview

- Disk trends
- Memory Hierarchy
- Performance
- Scheduling
- SSDs
  - Read
  - Write
  - Performance
  - Cost

Secondary storage

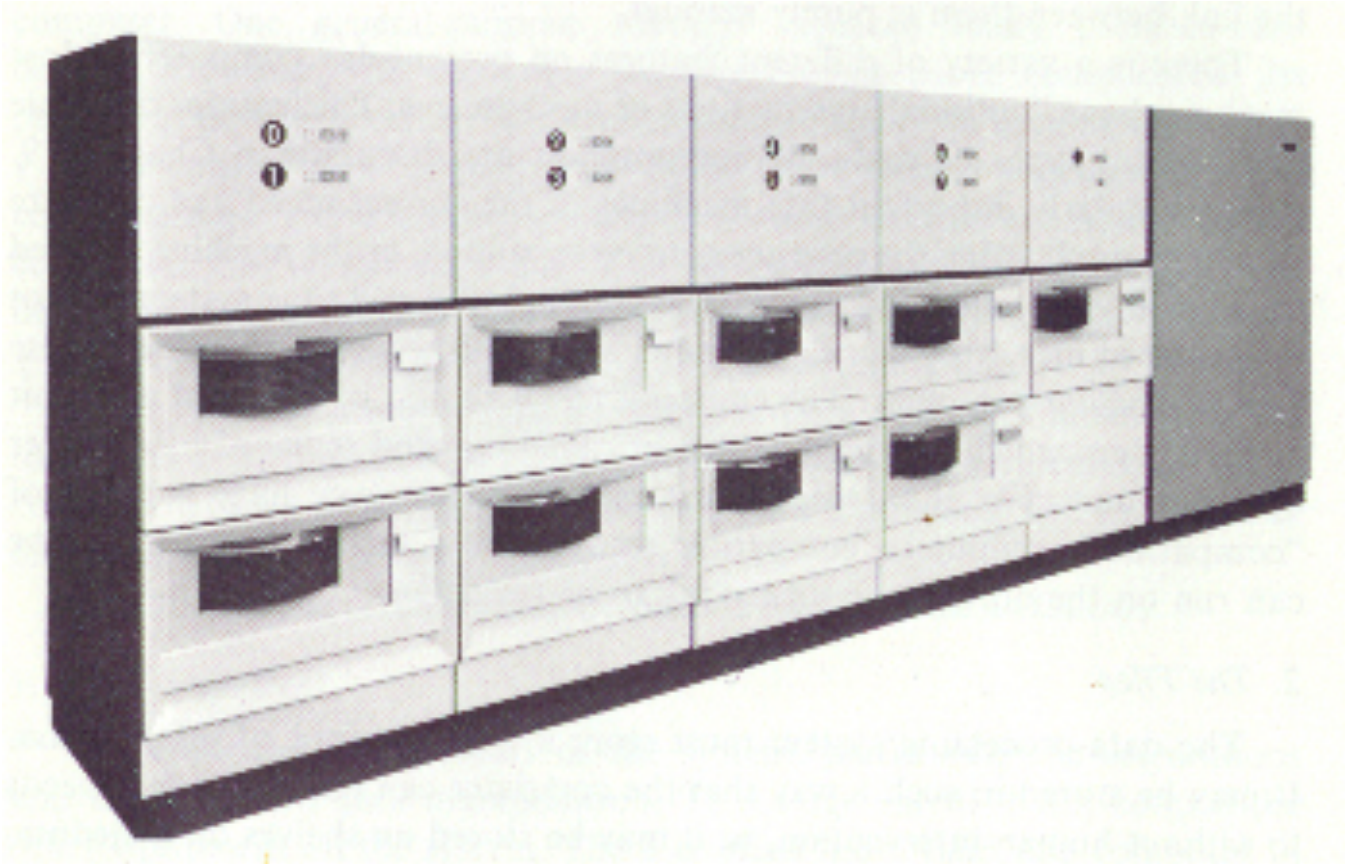
- Secondary storage:
  - anything outside “primary memory”
  - direct execution of instructions/ data retrieval via machine load/store
    - not permitted
- Characteristics:
  - it’s large: 250-2000GB and more
  - it’s cheap: $0.05/GB for hard drives
- Persistent: data survives power loss
  - it’s slow: milliseconds to access
- It *does* fail, if rarely
- Big failures
  - drive dies; Mean Time Between Failure ~3 years
  - 100K drives and MTBF is 3 years,
    - that’s 1 “big failure” every 15 minutes!
- Little failures (read/write errors, one byte in 10^{13})

The First Commercial Disk Drive

1956
IBM RAMDAC computer included the IBM Model 350 disk storage system

5M (7 bit) characters
50 x 24” platters
Access time = < 1 second

In the past



IBM 2314
About the size of
6 refrigerators
8 x 29MB
Required similar-sized air cond.

.01% the capacity of this $100 100x150x25mm item

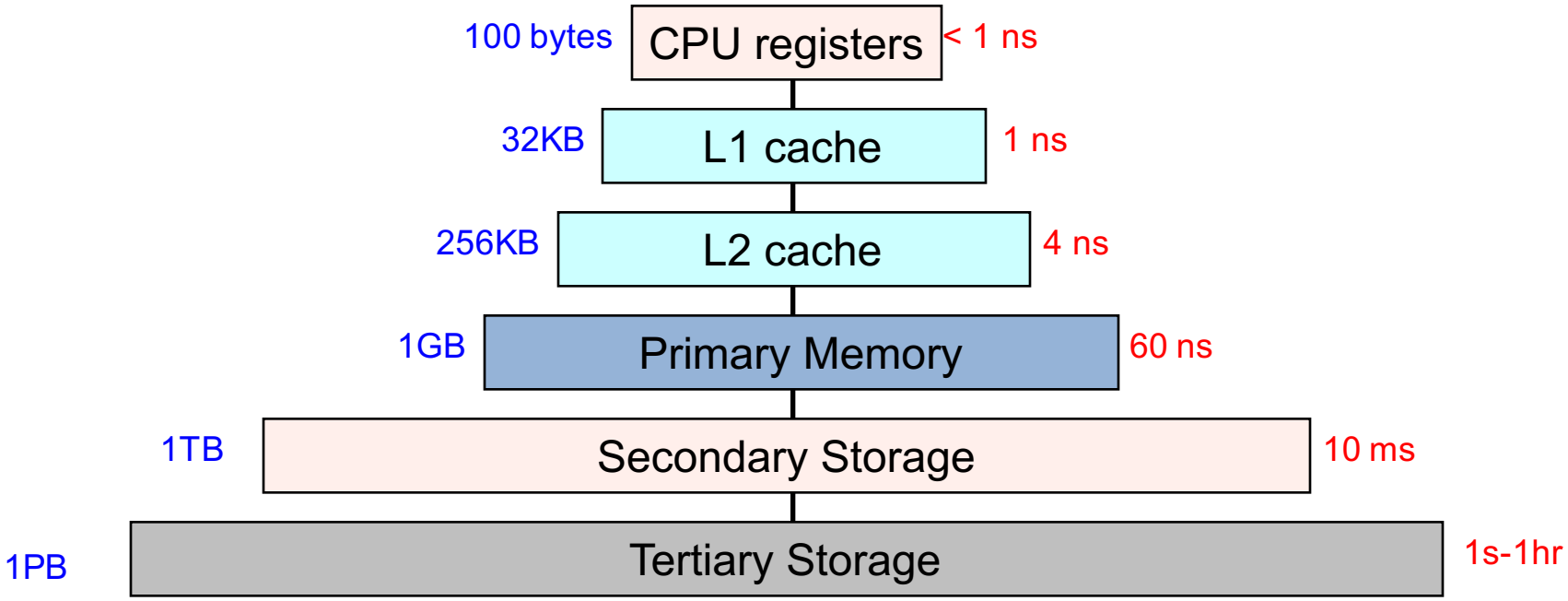
Disk trends

- Disk capacity, 1975-1989
  - doubled every 3+ years
  - 25% improvement each year
  - factor of 10 every decade
  - Still exponential, but far less rapid than processor performance
- Disk capacity, 1990-recently
  - doubling every 12 months
  - 100% improvement each year
  - factor of 1000 every decade
  - Capacity growth 10x as fast as processor performance!

Disk cost

- Only a few years ago, disks purchased by the megabyte
- Today, 1 GB (a billion bytes) costs $0.05 from Dell
  - (except you have to buy in increments of 1000 GB)
  - => 1 TB costs $50, 1 PB costs $50K
- Performance analogy
  - Flying an aircraft at 600 mph 6” above the ground
  - Reading/writing a strip of postage stamps

Memory hierarchy



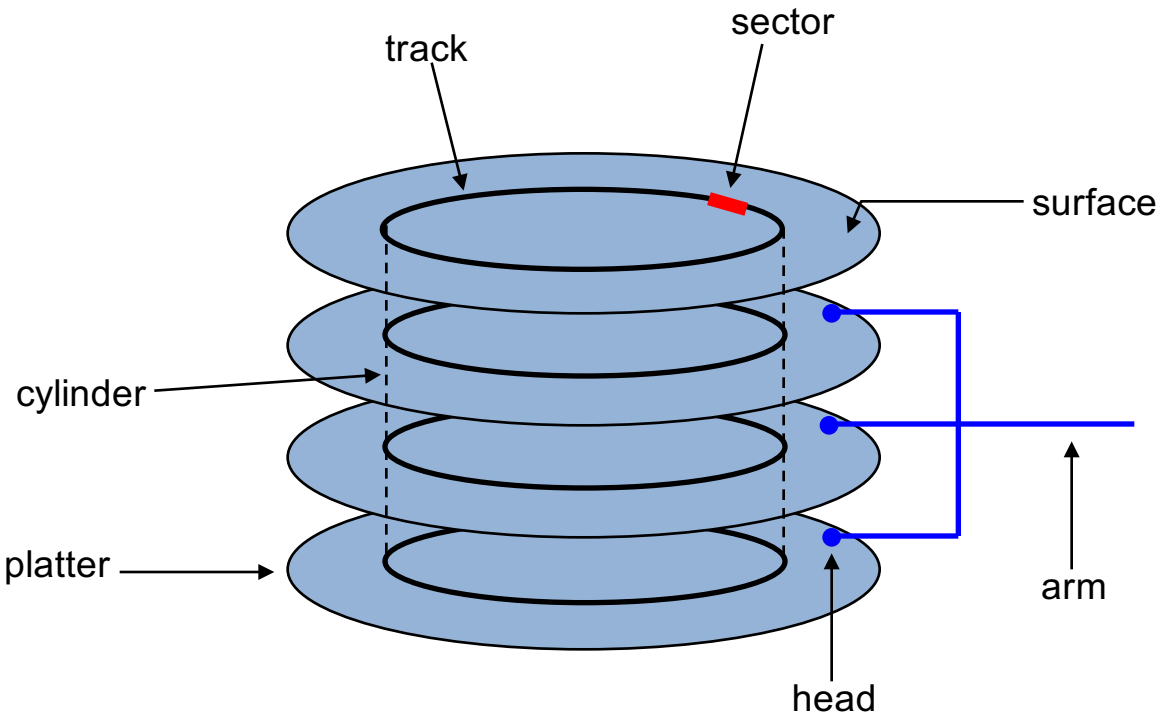
- Each level acts as a cache of lower levels

Disks and the OS

- Disks are difficult devices
  - errors, bad blocks, missed seeks, etc.
- OS abstracts this for higher-level software
  - low-level device drivers (initiate a disk read, etc.)
  - higher-level abstractions (files, databases, etc.)
  - disk hardware increasingly helps with this)
- OS provide different levels of disk access to different clients
  - physical disk block (surface, cylinder, sector)
  - disk logical block (disk block #)
  - file logical (filename, block or record or byte #)

Physical disk structure

- Disk components
  - platters
  - surfaces
  - tracks
  - sectors
  - cylinders
  - arm
  - heads



Disk Structure

- Disk drives are addressed as
  - large 1-dimensional arrays of **logical blocks**,
  - the logical block is the smallest unit of transfer
  - Low-level formatting creates **logical blocks** on physical media
- The 1-dimensional array of logical blocks
  - is mapped onto 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,
  - 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 performance

- Performance depends on a number of steps
- Seek: moving the disk arm to the correct cylinder
  - depends on how fast disk arm can move
    - not diminishing quickly due to physics
- Rotation (latency): waiting for the sector to rotate under head
  - depends on rotation rate of disk
    - rates are slowly increasing,
- Transfer: transferring data from surface to disk controller,
  - then sending it back to host
  - depends on density of bytes on disk
    - increasing, relatively quickly
- When the OS uses the disk, it tries to minimize the cost of all of these steps
  - particularly seeks and rotation

Performance

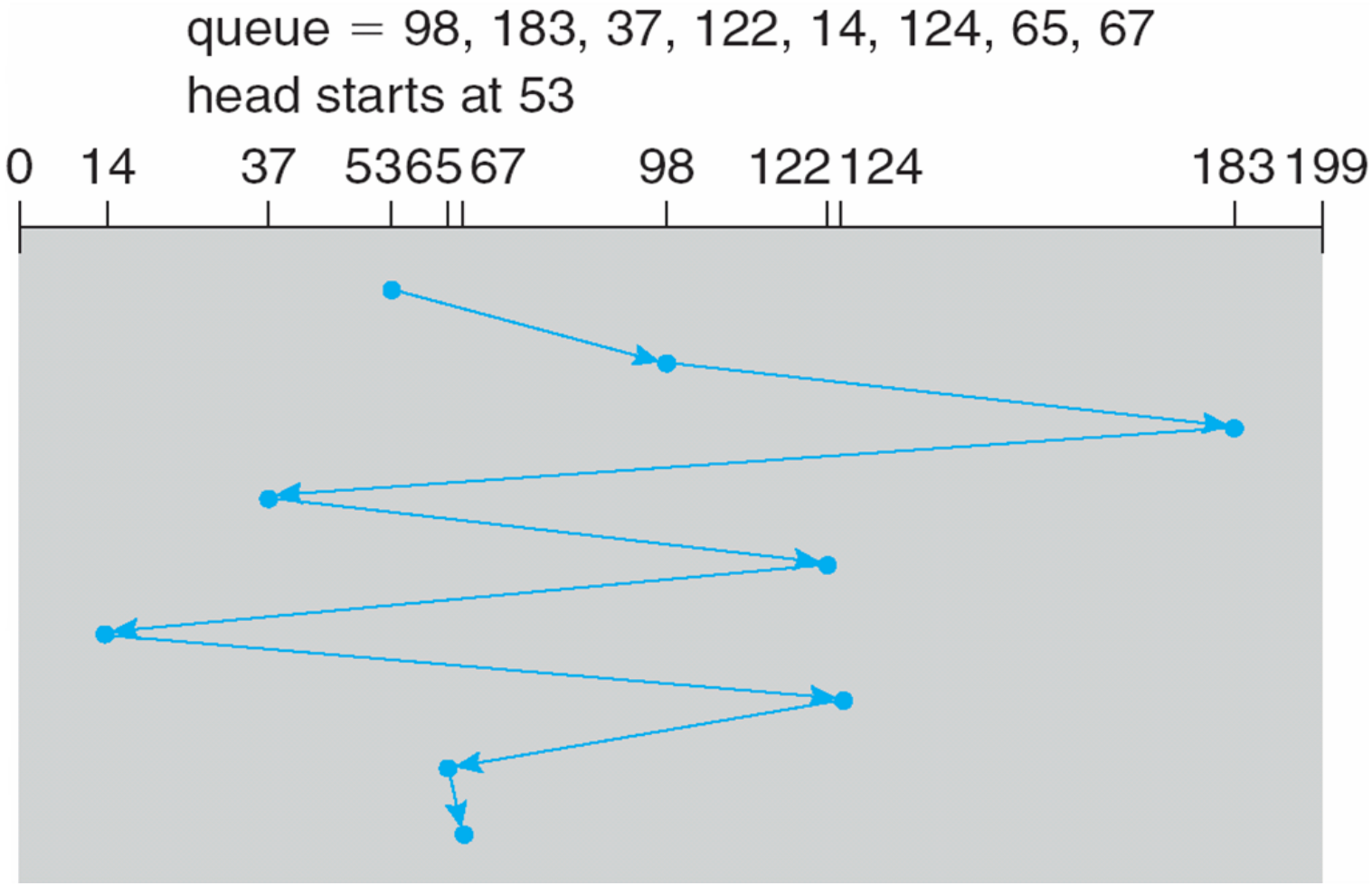
- OS may increase file block size
  - in order to reduce seeking
- OS may seek to co-locate “related” items
  - in order to reduce seeking
    - blocks of the same file
    - data and metadata for a file
- Keep data or metadata in memory to reduce physical disk access
  - Waste valuable physical memory?
- If file access is sequential,
  - fetch blocks into memory before requested

Performance via disk scheduling

- Seeks are very expensive, so the OS attempts to schedule disk requests that are queued waiting for the disk
  - FCFS (do nothing)
    - reasonable when load is low
    - long waiting time for long request queues
  - SSTF (shortest seek time first)
    - minimize arm movement (seek time), maximize request rate
    - unfairly favors middle blocks
  - SCAN (elevator algorithm)
    - service requests in one direction until done, then reverse
    - skews wait times non-uniformly
  - C-SCAN
    - like scan, but only go in one direction (typewriter)
    - uniform wait times
  - C-LOOK
    - Similar to C-SCAN
    - The arm goes only as far as the final request in each direction

FCFS

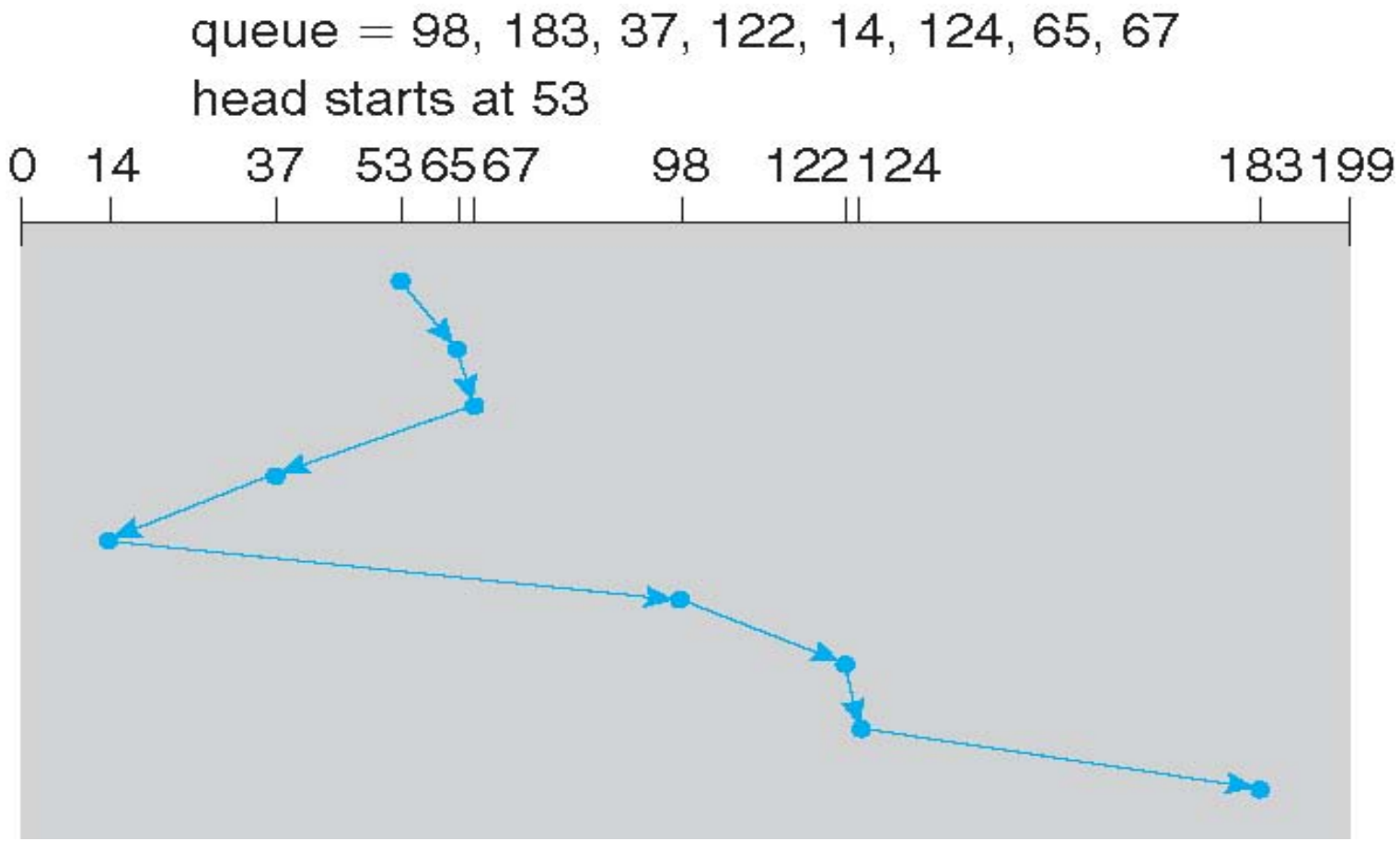
Illustration shows total head movement of *640 cylinders*



SSTF

Illustration shows total head movement of *236 cylinders*

-may cause starvation

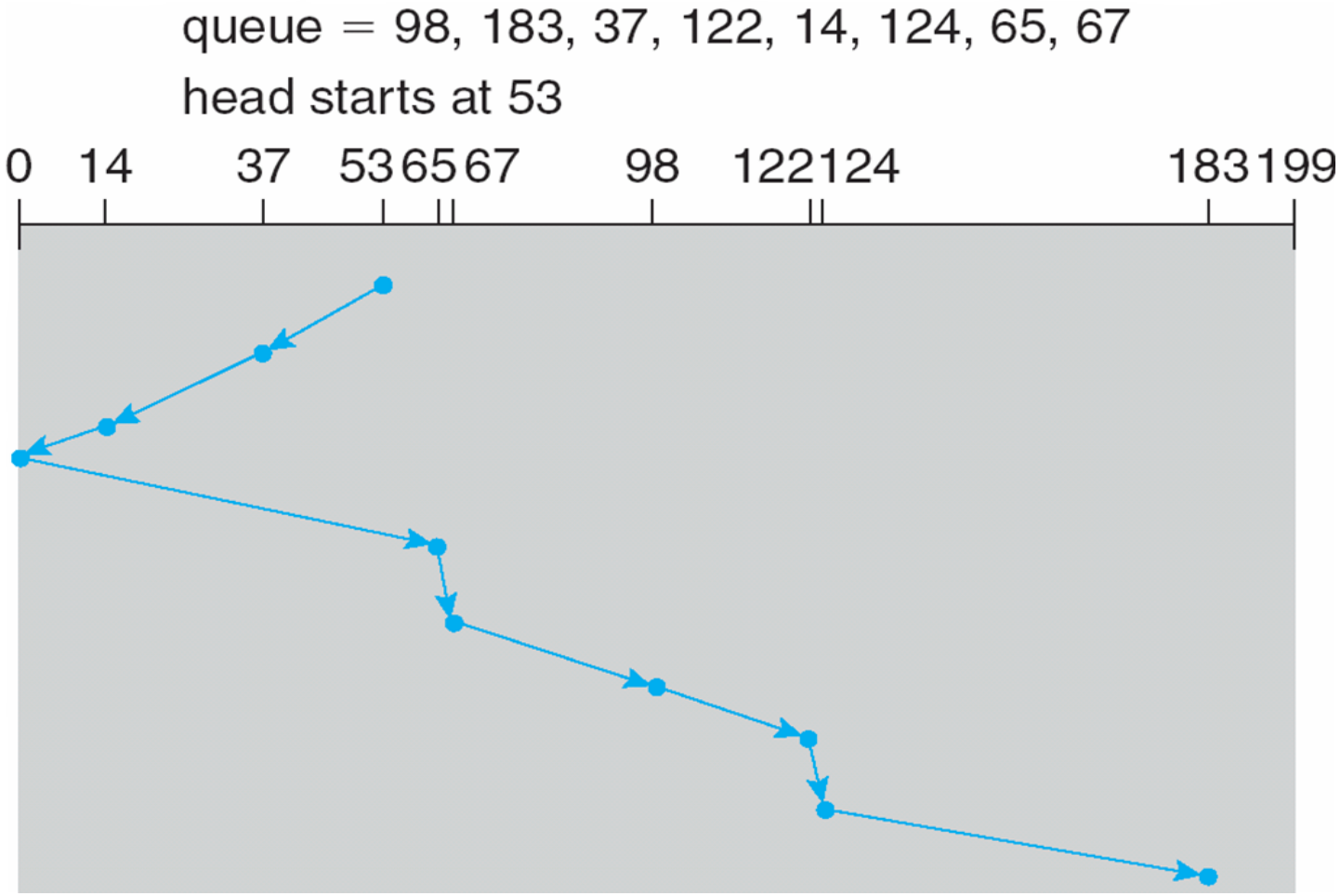


SCAN

- 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**
- But note
  - that if requests are uniformly dense,
  - largest density at other end of disk
  - and those wait the longest

SCAN

Illustration shows total head movement

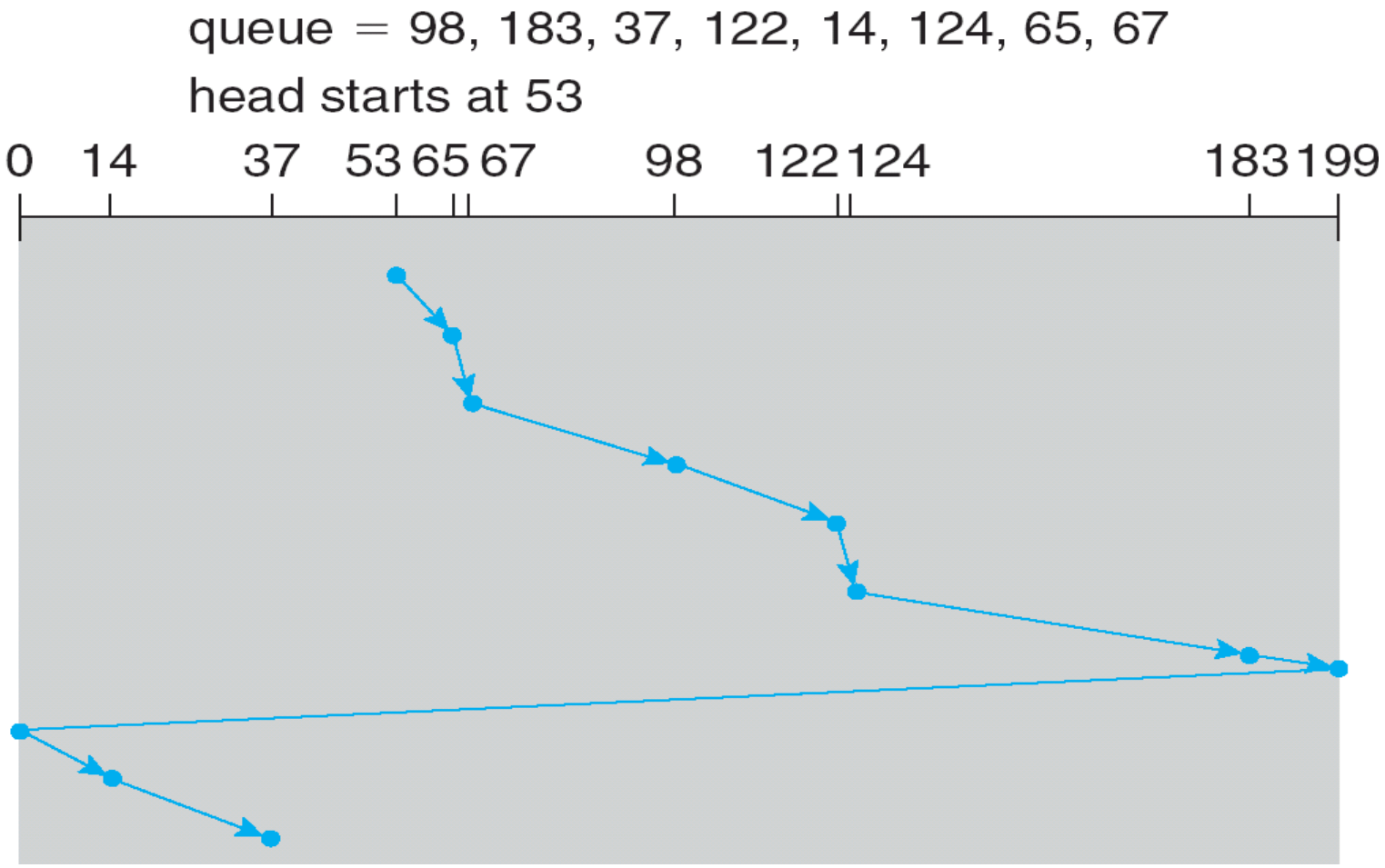


C-SCAN

- 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

C-SCAN

Illustration shows total head movement of *382 cylinders*

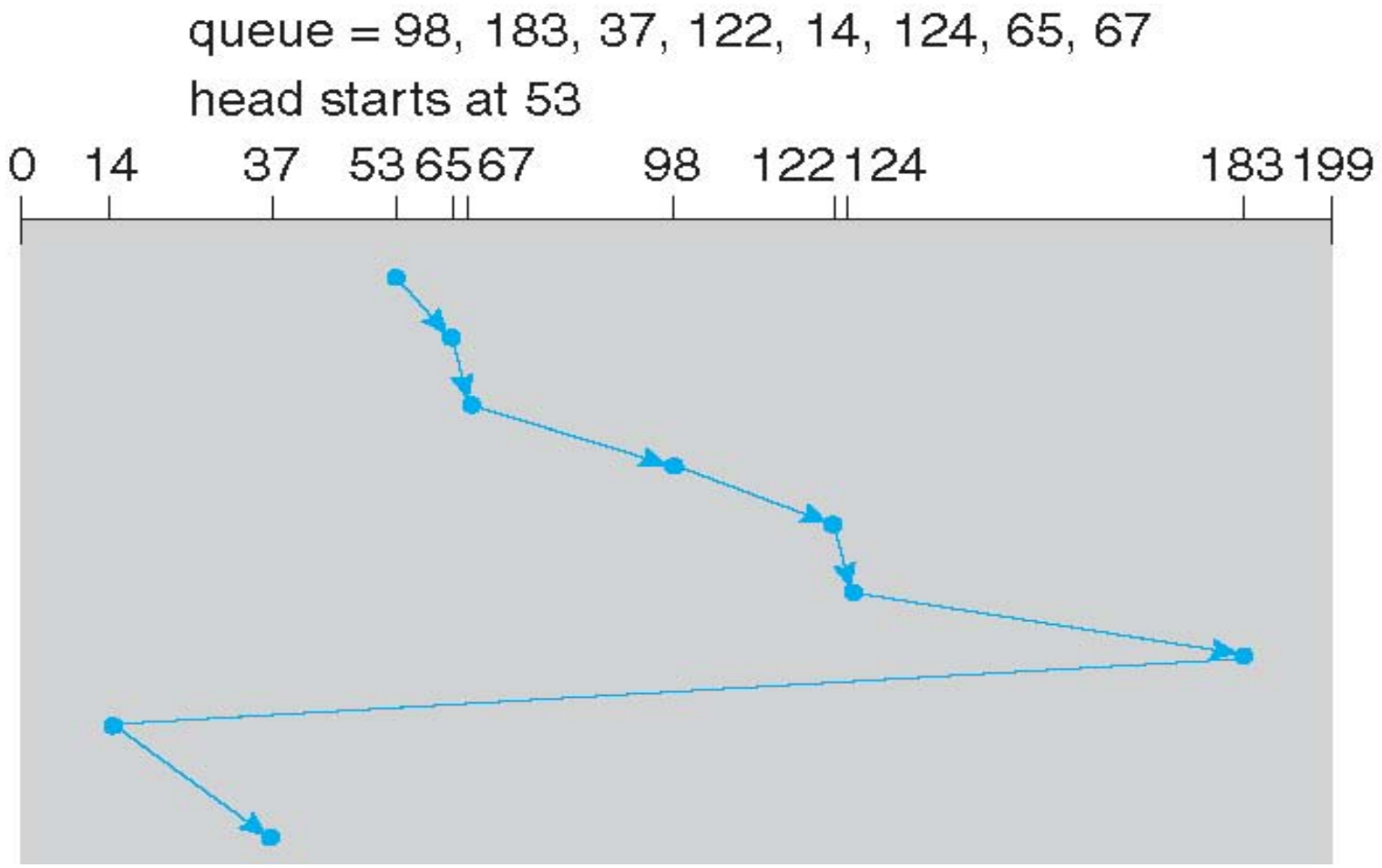


C-LOOK

- 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

C-LOOK

Illustration shows total head movement of *322 cylinders*



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
- 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

Interacting with disks

- Previously
  - OS would specify cylinder #, sector #, surface #, transfer size
    - i.e., OS needs to know all of the disk parameters
- Modern disks more complex
  - not all sectors are the same size, sectors are remapped, …
- Disk provides a higher-level interface, e.g., SCSI
    - exports data as a logical array of blocks [0 … N]
    - maps logical blocks to cylinder/surface/sector
- OS only names logical block #,
  - disk maps this to cylinder/surface/sector
  - on-board cache
  - as a result, physical parameters are hidden from OS

Seagate Barracuda 9cm disk drive

- 1Terabyte of storage (1000 GB)
- $100
- 4 platters, 8 disk heads
- 63 sectors (512 bytes) per track
- 16,383 cylinders (tracks)
- 164 Gbits / inch-squared (!)
- 7200 RPM
- 300 MB/second transfer
- 9 ms avg. seek, 4.5 ms avg. rotational latency
- 1 ms track-to-track seek
- 32 MB cache

Solid state drives: ongoing disruption

- Hard drives are based on spinning magnetic platters
  - *mechanics* of drives determine performance characteristics
    - sector addressable, not byte addressable
    - capacity improving exponentially
    - sequential bandwidth improving reasonably
    - random access latency improving very slowly
- Cost dictated by
  - massive economies of scale,
  - and many decades of commercial development and optimization

SSD

- Solid state drives are based on NAND flash memory
  - no moving parts; performance characteristics driven by electronics and physics – more like RAM than spinning disk
  - relative technological newcomer, so costs are still quite high in comparison to hard drives, but dropping fast

SSD performance: reads

- Reads
  - unit of read is a *page*, typically 4KB large
- Today's SSD can typically handle
  - 10,000 – 100,000 reads/s
- 0.01 – 0.1 ms read latency
  - 50-1000x better than disk seeks
- 40-400 MB/s read throughput
  - 1-3x better than disk seq. throughput

SSD performance: writes

- Writes
  - flash media must be *erased* before it can be written to
  - unit of erase is a block, typically 64-256 pages long
    - usually takes 1-2ms to erase a block
    - blocks can only be erased a certain number of times before they become unusable – typically 10,000 – 1,000,000 times
  - unit of write is a page
    - writing a page can be 2-10x slower than reading a page
- Writing to an SSD is complicated
  - random write to existing block: read block, erase block, write back modified block
    - leads to hard-drive like performance (300 random writes / s)
  - sequential writes to erased blocks: fast!
    - SSD-read like performance (100-200 MB/s)

SSDs: dealing with erases, writes

- Lots of higher-level strategies can help hide the warts of an SSD
- Many of these work by
  - exposing logical pages, not physical pages
- Wear-levelling:
  - when writing,
  - try to spread erases out evenly across physical blocks of of the SSD
    - Intel promises 100GB/day x 5 years for its SSD drives
- Log-structured filesystems:
  - convert random writes within a filesystem
  - to log appends on the SSD

SSD cost

- Capacity
  - today, flash SSD costs ~$2.50/GB
    - 1TB drive costs around $2500
      - 1TB hard drive costs around $50
  - Data on cost trends is volatile/preliminary

- Energy
  - SSD is typically more energy efficient than a hard drive
    - 1-2 watts to power an SSD
    - ~10 watts to power a high performance hard drive
      - (can also buy a 1 watt lower-performance drive)

Summary

- Disk trends
- Memory Hierarchy
- Performance
- Scheduling
- SSDs
  - Read
  - Write
  - Performance
  - Cost
- Next lecture: Revision tutorial