

# Storage Systems

Jin-Soo Kim (jinsookim@skku.edu)  
Computer Systems Laboratory  
Sungkyunkwan University  
<http://csl.skku.edu>



# Today's Topics

- **HDDs (Hard Disk Drives)**
- **Disk scheduling policies**
- **Linux I/O schedulers**

# Secondary Storage

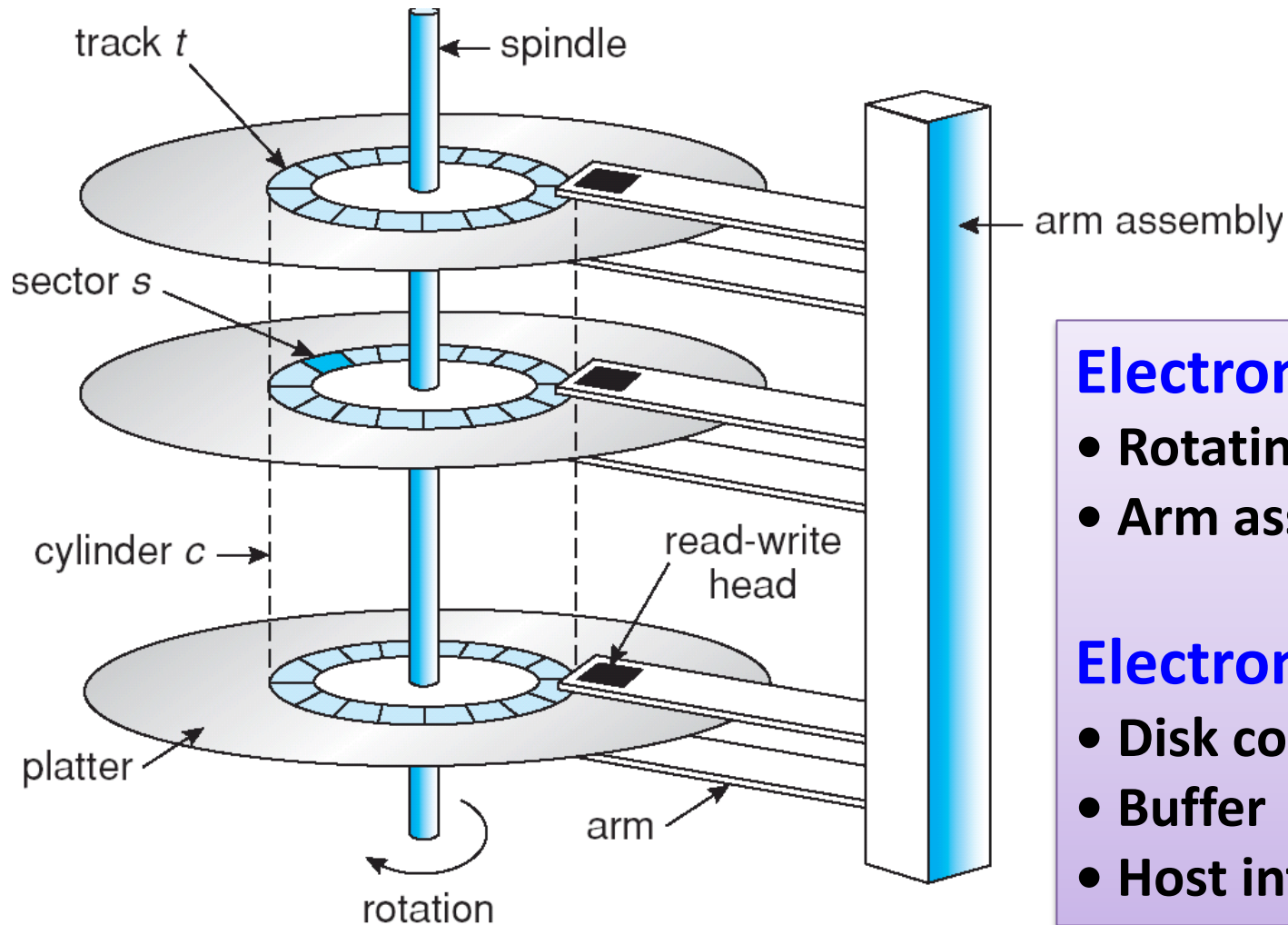
## ■ Secondary storage usually

- is anything that is outside of “primary memory”.
- does not permit direct execution of instructions or data retrieval via machine load/store instructions.

## ■ Characteristics

- It's large: 100GB and more
- It's cheap: 2TB SATA3 disk costs ₩100,000
- It's persistent: data survives power loss.
- It's slow: milliseconds to access.

# HDDs (1)



## Electromechanical

- Rotating disks
- Arm assembly

## Electronics

- Disk controller
- Buffer
- Host interface

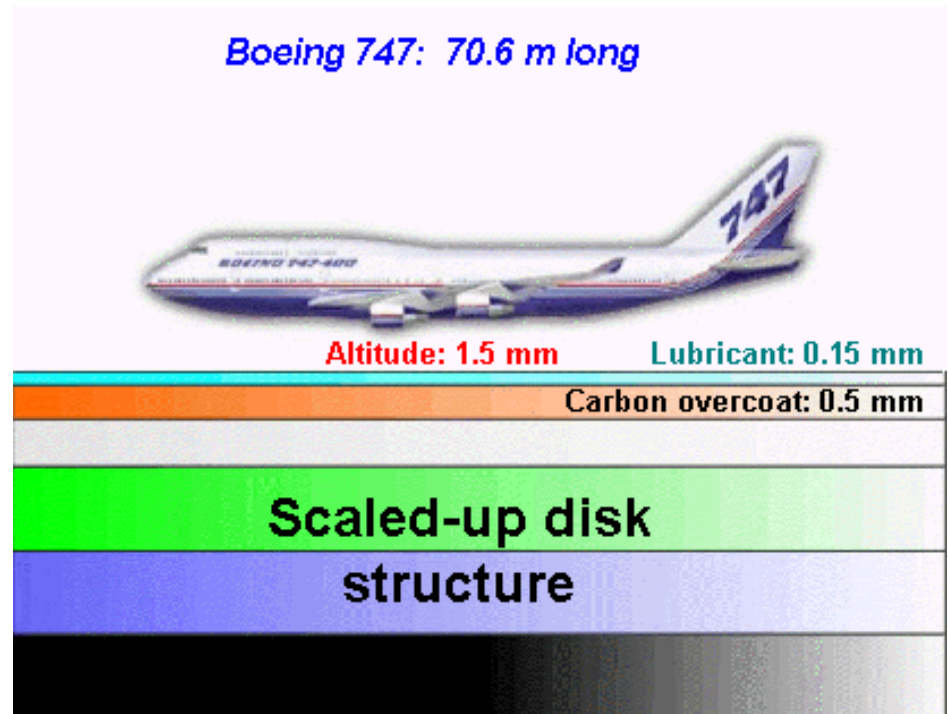
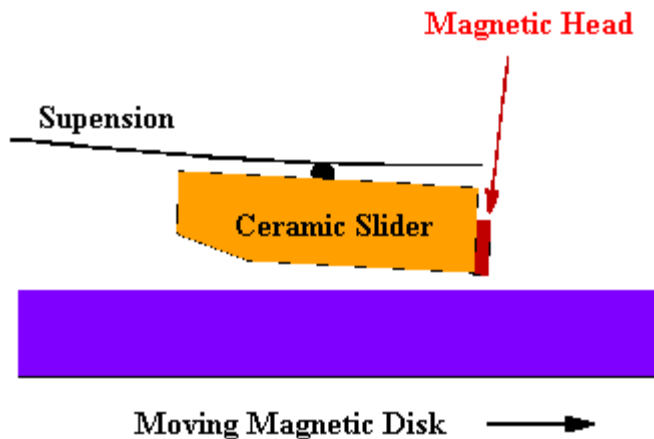
# HDDs (2)

## ■ Seagate Barracuda ST31000528AS (1TB)

- 4 Heads, 2 Discs
- Max. recording density: 1413K BPI (bits/inch)
- Avg. track density: 236K TPI (tracks/inch)
- Avg. areal density: 329 Gbits/sq.inch
- Spindle speed: 7200rpm (8.3ms/rotation)
- Average seek time: < 8.5ms (read), < 9.5ms (write)
- Max. internal data transfer rate: 1695 Mbits/sec
- Max. I/O data transfer rate: 300MB/sec (SATA-2)
- Max. sustained data transfer rate: 125MB/sec
- Internal cache buffer: 32MB
- Max power-on to ready: < 10.0 sec

# HDDs (3)

## Hard disk internals



- Our Boeing 747 will fly at the altitude of only a few mm at the speed of approximately 65mph periodically landing and taking off.
- And still the surface of the runway, which consists of a few mm-thick layers, will stay intact for years.

# Managing Disks (1)

## ▪ Disks and the OS

- Disks are messy physical devices:
  - Errors, bad blocks, missed seeks, etc.
- The job of the OS is to hide this mess from higher-level software.
  - Low-level device drivers (initiate a disk read, etc)
  - Higher-level abstractions (files, databases, etc.)
- The OS may provide different levels of disk access to different clients.
  - Physical disk block (surface, cylinder, sector)
  - Disk logical block (disk block #)
  - Logical file (filename, block or record or byte #)

# Managing Disks (2)

## ■ Interacting with disks

- Specifying disk requests requires a lot of info:
  - Cylinder #, surface #, track #, sector #, transfer size, etc.
- Older disks required the OS to specify all of this
  - The OS needs to know all disk parameters.
- Modern disks are more complicated.
  - Not all sectors are the same size, sectors are remapped, etc.
- Current disks provide a higher-level interface (e.g., SCSI)
  - The disks exports its data as a logical array of blocks [0..N-1]
  - Disk maps logical blocks to cylinder/surface/track/sector.
  - Only need to specify the logical block # to read/write.
  - As a result, physical parameters are hidden from OS.



# Managing Disks (3)

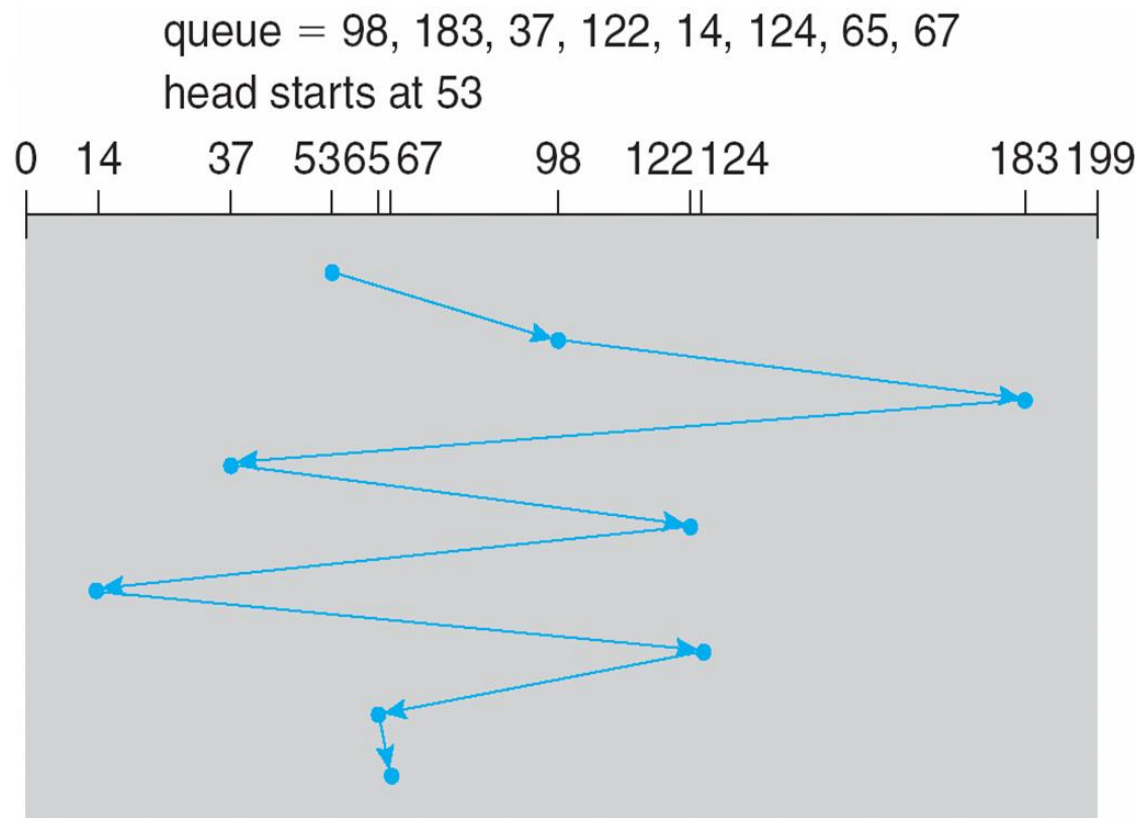
## ▪ Disk performance

- Performance depends on a number of steps
  - **Seek**: moving the disk arm to the correct cylinder
    - depends on how fast disk arm can move (increasing very slowly)
  - **Rotation**: waiting for the sector to rotate under head
    - depends on rotation rate of disk (increasing, but slowly)
  - **Transfer**: transferring data from surface into disk controller, sending it back to the host.
    - depends on density of bytes on disk (increasing, and very quickly)
- Disk scheduling:
  - Because seeks are so expensive, the OS tries to schedule disk requests that are queued waiting for the disk.

# FCFS

## ▪ FCFS (= do nothing)

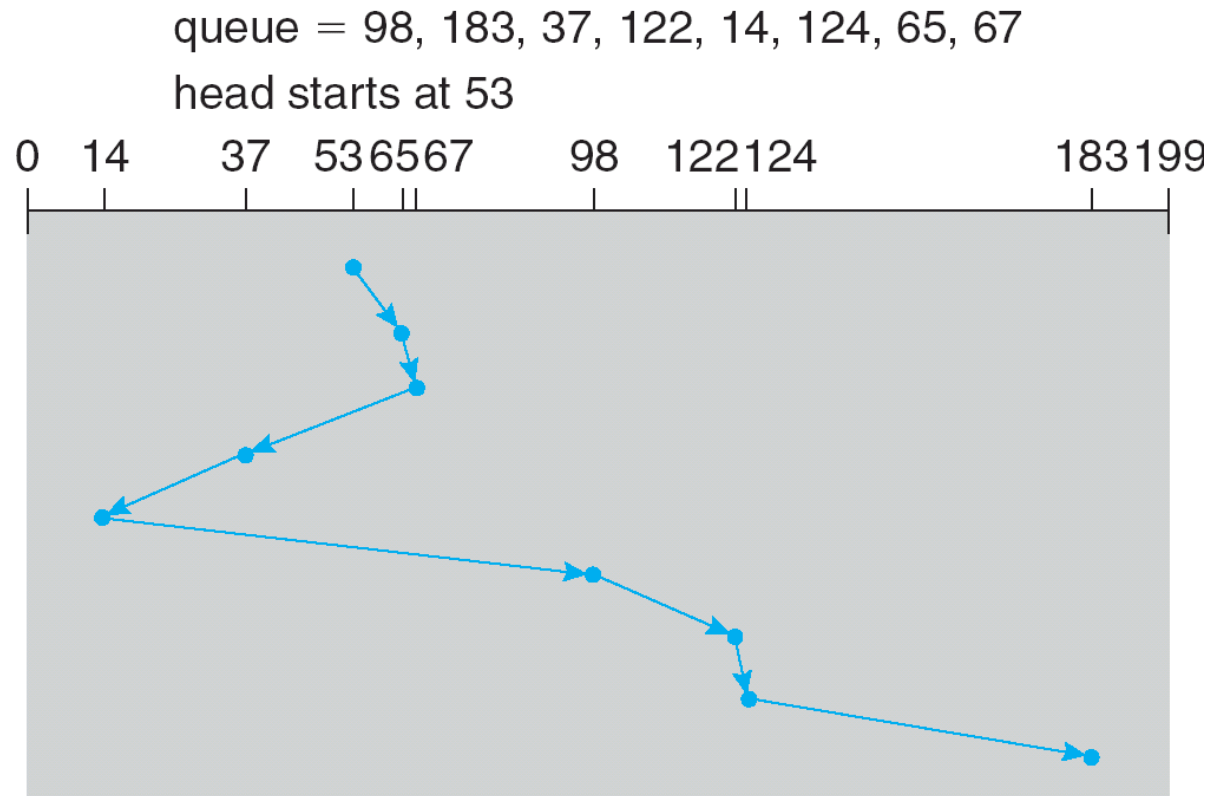
- Reasonable when load is low.
- Long waiting times for long request queues.



# SSTF

## ▪ Shortest seek time first

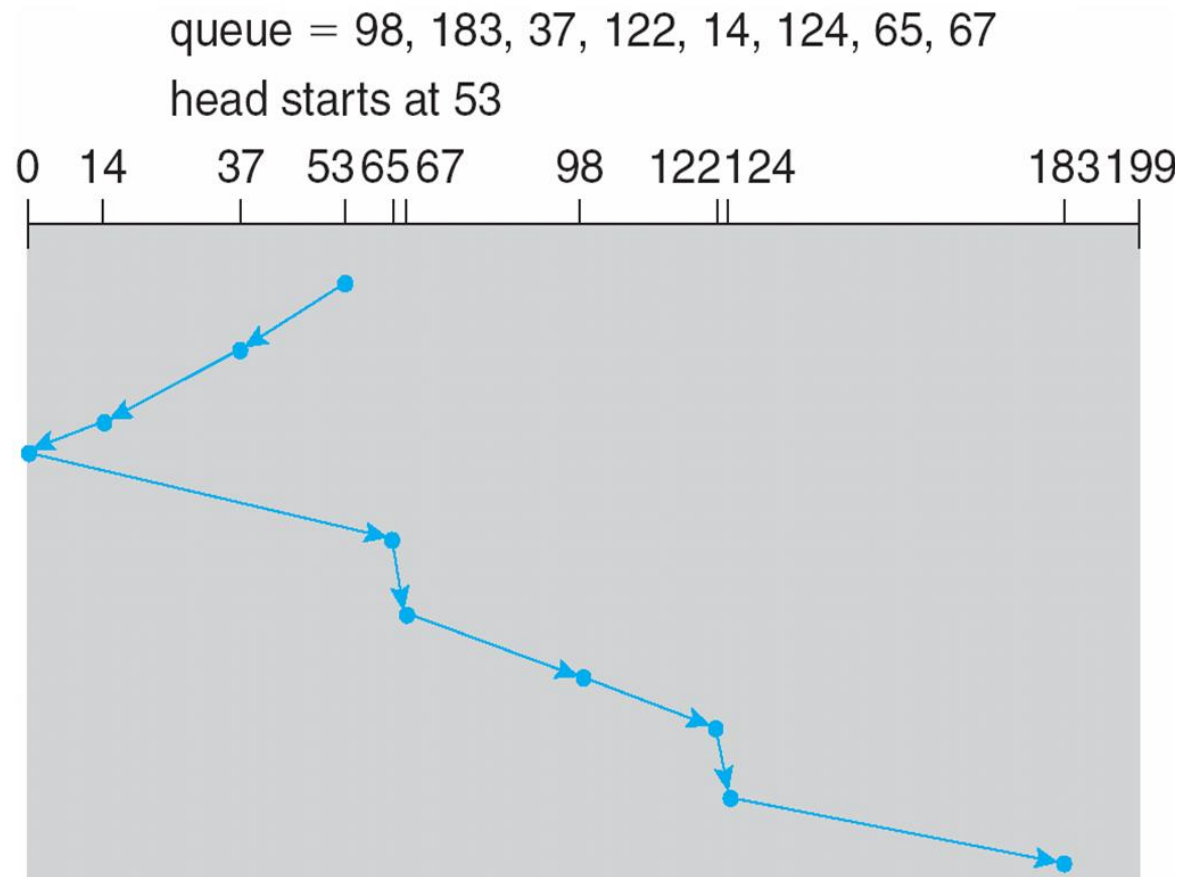
- Minimizes arm movement (seek time)
- Maximizes request rate
- Unfairly favors middle blocks
- May cause starvation of some requests



# SCAN

## ▪ Elevator algorithm

- Service requests in one direction until done, then reverse
- Skews wait times non-uniformly

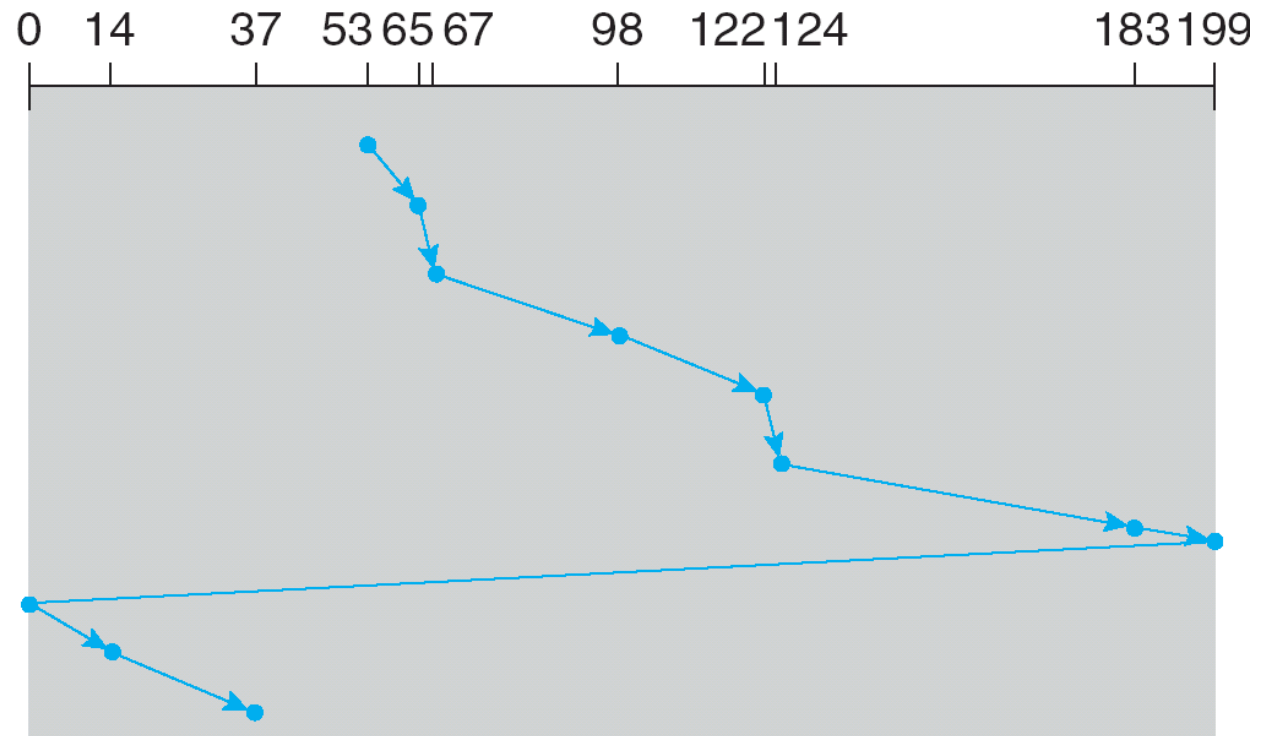


# C-SCAN

## ■ Circular SCAN

- Like SCAN, but only go in one direction (e.g. typewriters)
- Uniform wait times

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



# LOOK / C-LOOK

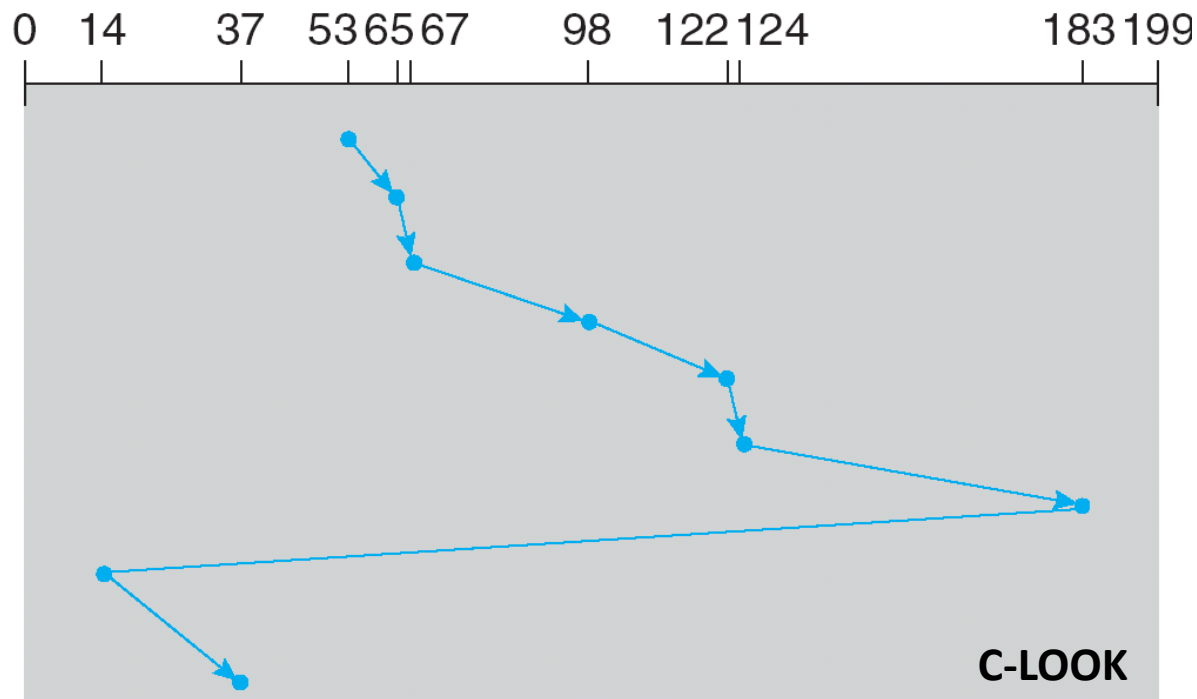


## LOOK / C-LOOK

- Similar to SCAN/C-SCAN, but the arm goes only as far as the final request in each direction.

queue 98, 183, 37, 122, 14, 124, 65, 67

head starts at 53



# Disk Scheduling (1)

## ▪ 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.
- Either SSTF or LOOK is a reasonable choice for the default algorithm.
- Performance depends on the number and types of requests.
- Requests for disk service can be influenced by the file allocation method.
- In general, unless there are request queues, disk scheduling does not have much impact.
  - Important for servers, less so for PCs
- Modern disks often do the disk scheduling themselves.
  - Disks know their layout better than OS, can optimize better.
  - Ignores, undoes any scheduling done by OS.

# Modern Disks

## ■ Intelligent controllers

- A small CPU + many kilobytes of memory.
- They run a program written by the controller manufacturer to process I/O requests from the CPU and satisfy them.
- Intelligent features:
  - Read-ahead: the current track
  - Caching: frequently-used blocks
  - Command queueing
  - Request reordering: for seek and/or rotational optimality
  - Request retry on hardware failure
  - Bad block/track identification
  - Bad block/track remapping: onto spare blocks and/or tracks



# I/O Schedulers

## ▪ I/O scheduler's job

- Improve overall disk throughput
  - Merging requests to reduce the number of requests
  - Reordering and sorting requests to reduce disk seek time
- Prevent starvation
  - Submit requests before deadline
  - Avoid read starvation by write
- Provide fairness among different processes
- Guarantee quality-of-service (QoS) requirement

# Linux I/O Schedulers (1)

## ▪ Linus elevator scheduler

- Merges adjacent I/O requests
- Sorts I/O requests in ascending block order
- Writes-starving-reads:
  - Stop insertion-sorting if there is a sufficiently old request in the queue
- Trades fairness for improved global throughput
- Not really an elevator: puts requests with a low sector number at the top of the queue regardless of the current head position
- Real-time?
- Was the default I/O scheduler in Linux 2.4

# Linux I/O Schedulers (2)

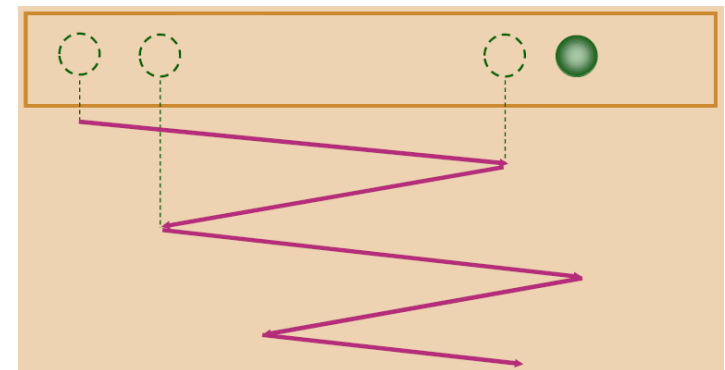
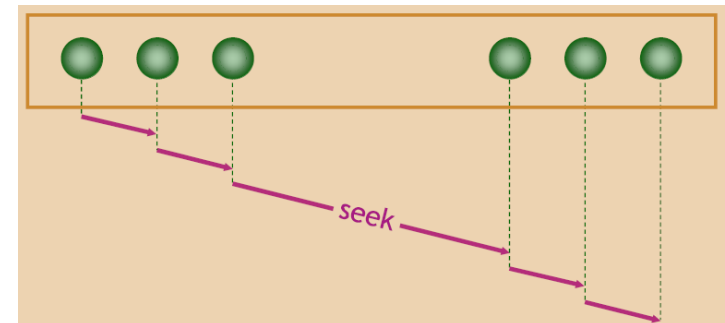
## ■ Deadline scheduler

- Two standard Read/Write sorted queues (by LBA) + Two Read/Write FIFO queues (by submission time)
- Each FIFO queue is assigned an expiration value.
  - Read: 500 msec
  - Write: 5 sec
- Normally, send I/O requests from the head of the standard sorted queue.
- If the request at the head of one of the FIFO queues expires, services the FIFO queue
- Emphasizes average read request response time
- No strict guarantees over request latency

# Linux I/O Schedulers (3)

## Anticipatory scheduler

- Considers “deceptive idleness”
  - Process A is about to issue next request, but scheduler hastily assumes that process A has no further requests!
- Adds an anticipation heuristic:
  - Sometimes wait for process whose request was last serviced.
- Was the default I/O scheduler in the 2.6 kernel
- Dropped in the Linux Kernel 2.6.33 in favor of the CFQ scheduler



# Linux I/O Schedulers (4)

## ▪ Noop scheduler

- Minimal overhead I/O scheduler
- Only performs merging
- For random-access devices such as RAM disks and solid state drives (SSDs)
- For storage with intelligent HBA or externally attached controller (RAID, TCQ drives)

# Linux I/O Schedulers (5)

- **CFQ (Complete Fair Queuing) scheduler**
  - Assigns incoming I/O requests to specific queues based on the process originating the I/O request
    - Within each queue, requests are coalesced with adjacent requests and insertion sorted
    - Service the queues round robin, plucking a configurable number of requests (by default, four) from each queue before continuing on to the next
  - Fairness at a per-process level
  - Initially for multimedia applications, but works well across many workloads
  - Subsumes anticipatory scheduling
  - New default scheduler for Linux 2.6+ (from 2.6.18)