STORAGE SYSTEMS

Operating Systems 2015 Spring
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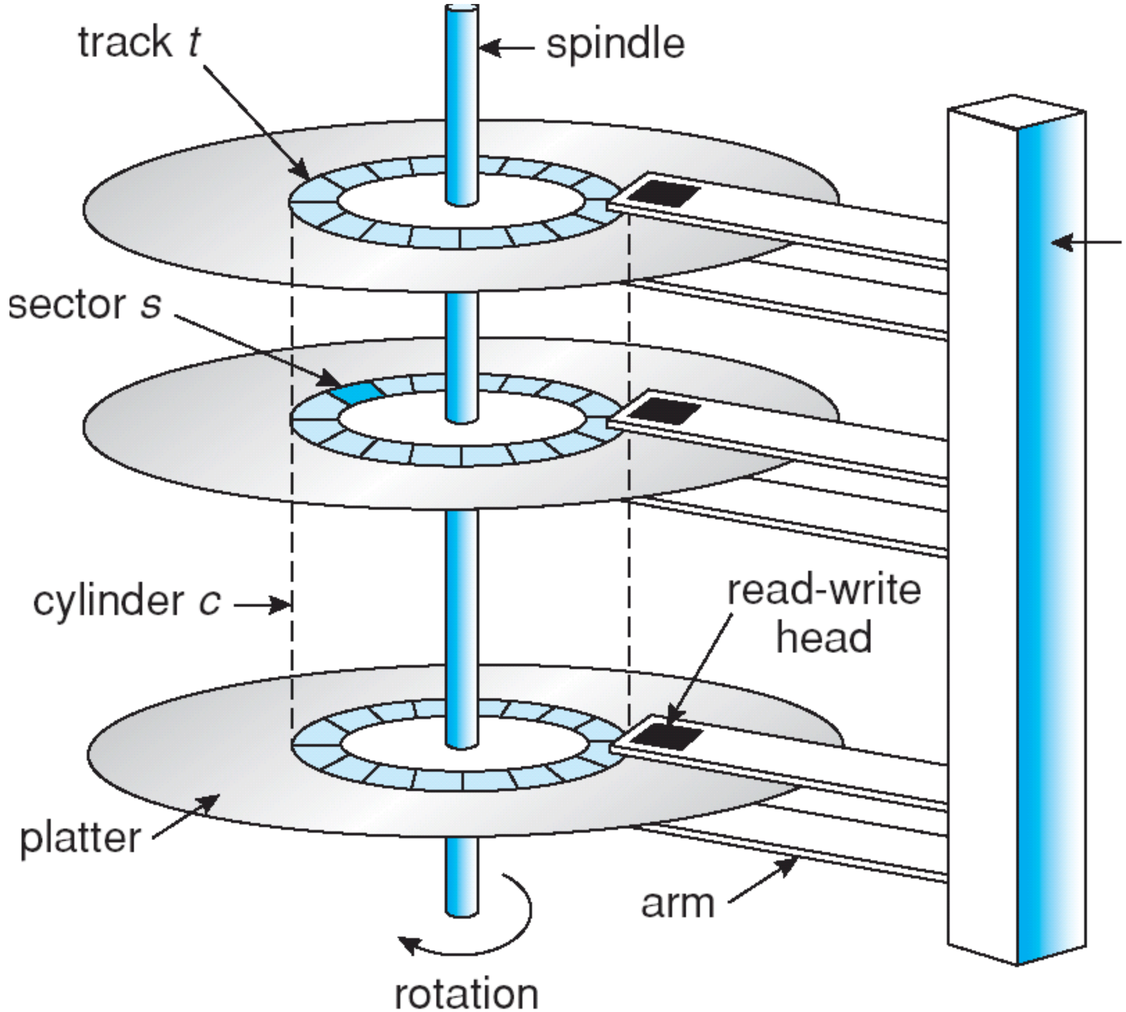
Today’s Topics

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

Secondary Storage

- Anything that is outside of “primary memory”
- Does not permit direct execution of instructions or data retrieval via load / store instructions
- Characteristics
  - It’s large: 100GB and more
  - It’s cheap: 2TB SATA2 disk costs ₩80,000
  - It’s persistent: data survives power loss
  - It’s slow: milliseconds to access

HDD Physical Structure



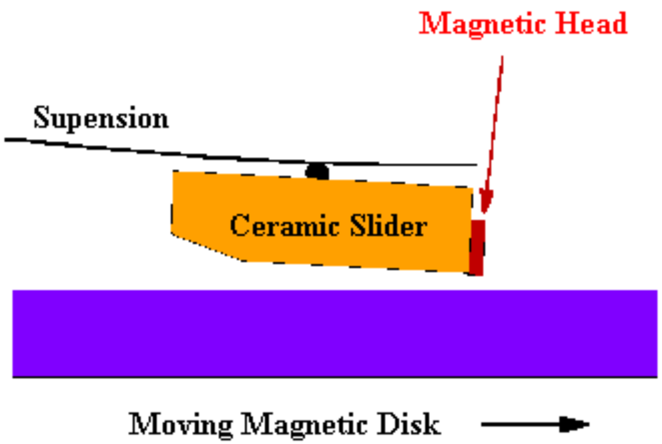
Electromechanical
- **Rotating disks**
- **Arm assembly**

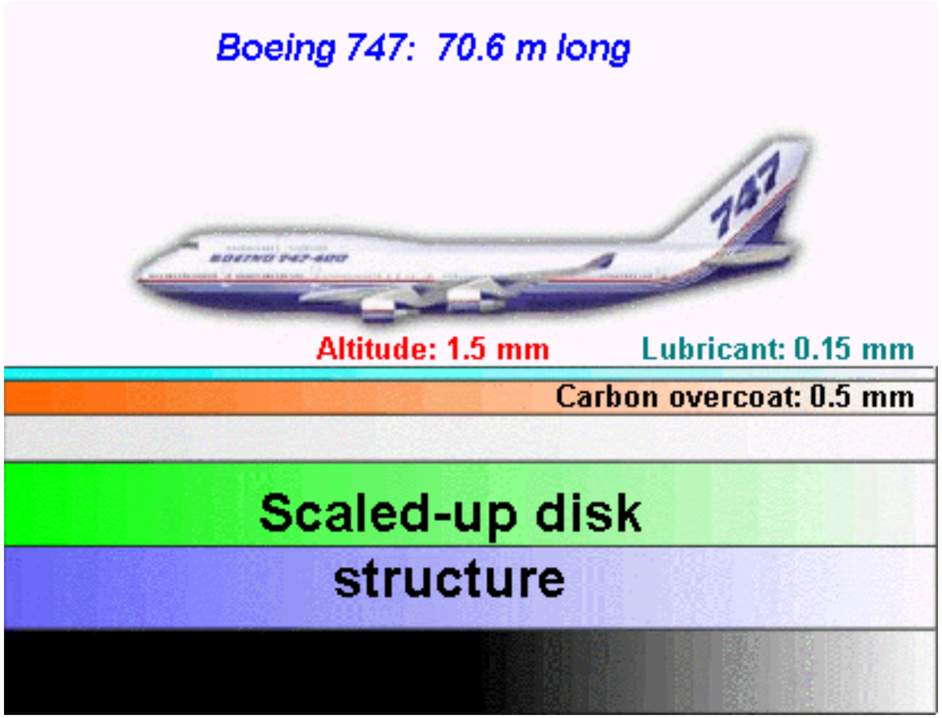
Electronics
- **Disk controller**
- **Buffer**
- **Host interface**

HDD Parameters Example

- 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

HDD Internal Dynamics





- Our Boeing 747 will fly at the altitude of only a few mm at the speed of approximately 65 mph 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

- 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

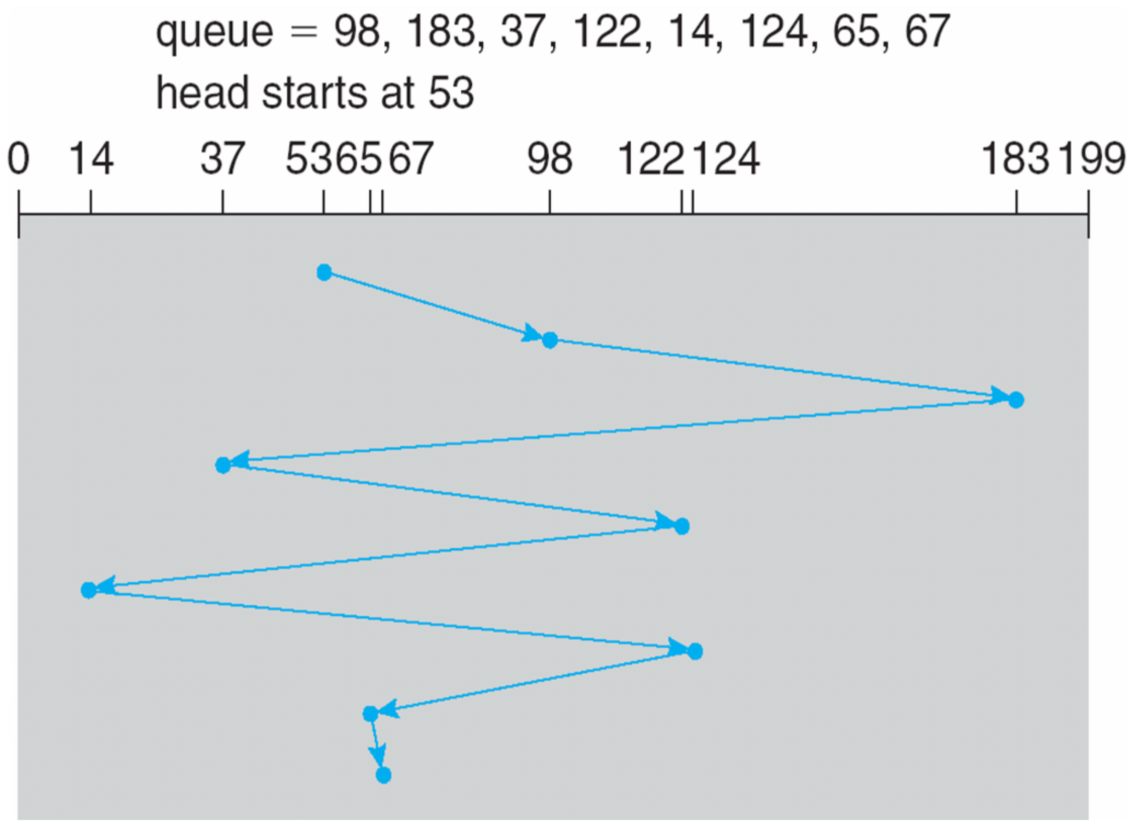
- Interacting with disks
  - Specifying disk requests requires a lot of info
    - Cylinder #, surface #, track #, sector #, transfer size, etc
  - Older disks required the OS to specify all of this
    - The OS needs to know all disk parameters
  - Modern disks are more complicated
    - Not all sectors 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

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

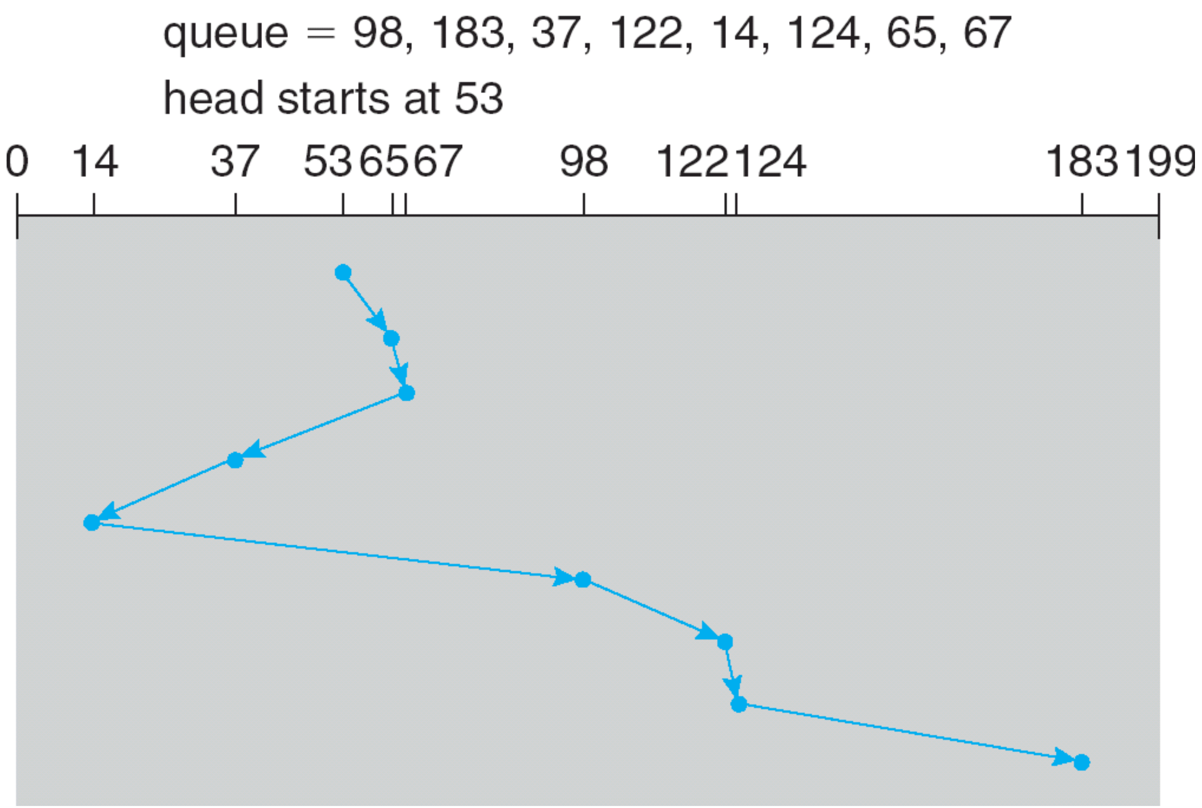
FCFS

- FCFS (= do nothing)
  - Reasonable when load is low.
  - Long waiting times for long request queues.



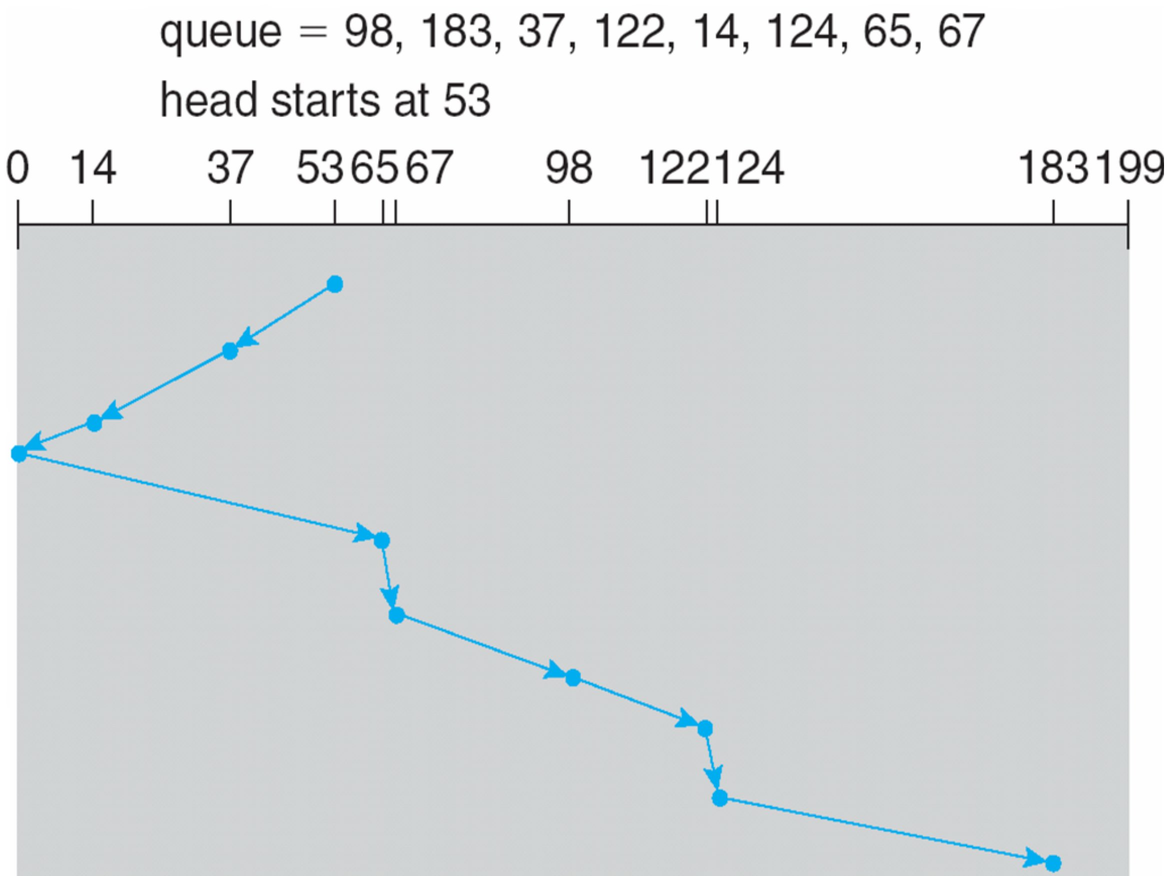
SSTF

- 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

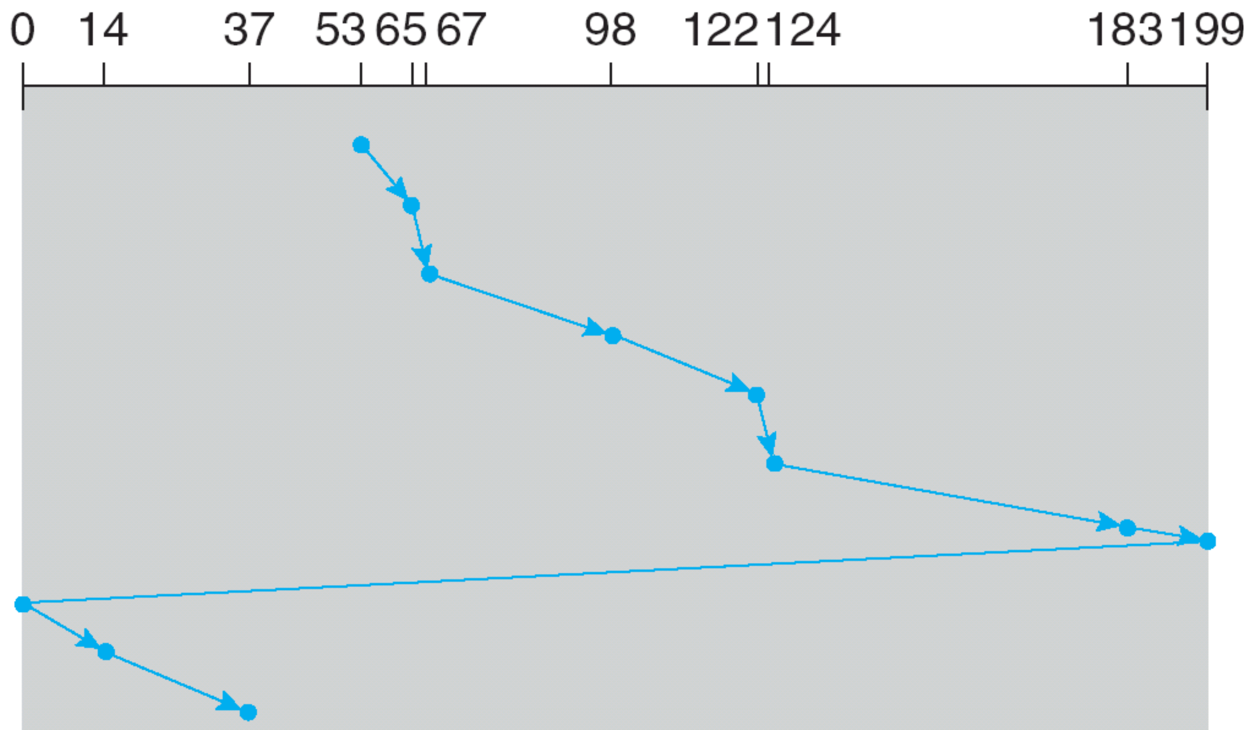


C-SCAN

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

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

head starts at 53

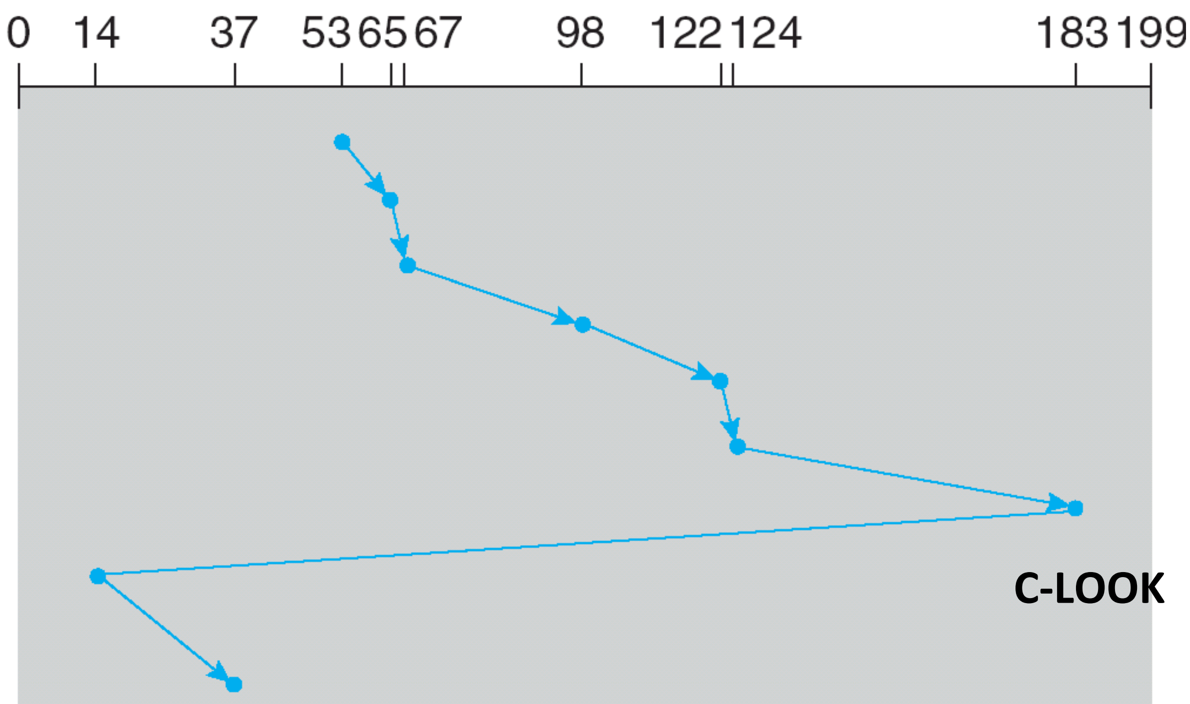


LOOK / C-LOOK

- 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 Algorithm Selection

- 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

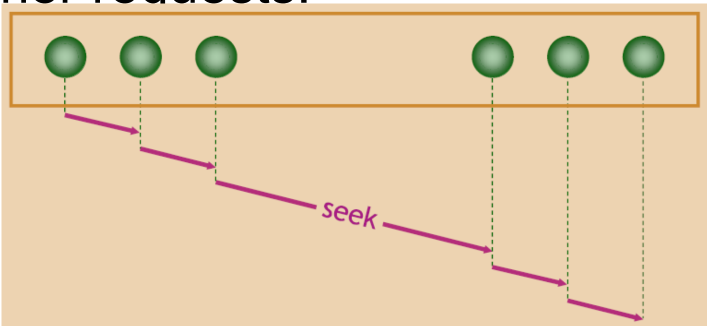
- Linus elevator scheduler
  - Merges adjacent I/O requests
  - Sorts I/O requests in ascending block order
  - Writes-starving-reads
    - Stop insertion-sorting if there is a sufficiently old request in the queue
  - Trades fairness for improved global throughput
  - Not really an elevator: puts requests 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

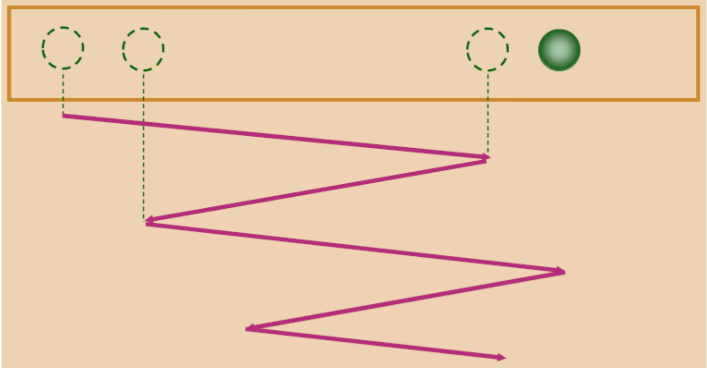
Linux I/O Schedulers

- 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

- 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

- 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)