Operating System Concepts

Lecture 33: Disk Structure and Scheduling

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MWF 12:00-12:50 VVC 2 215

Today’s class

- Storage structure
  - Disk
  - NVM
- Disk scheduling

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  - the slowest major component of computers

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  - we use the term nonvolatile storage (NVS) to talk about all types of devices used for persistent data storage
- to a file system, disk looks like a linear array of blocks that can be read from or written to

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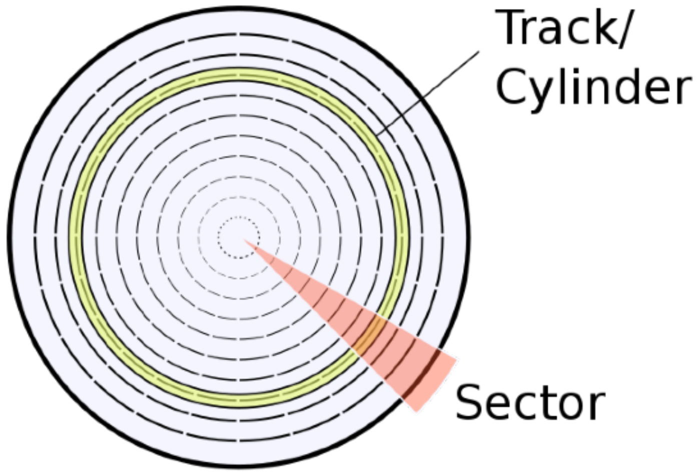
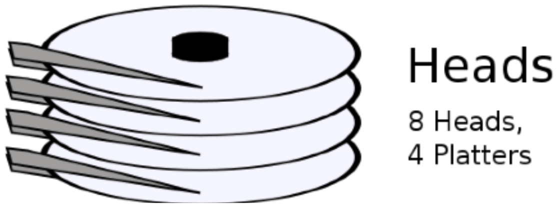
  - writing data: inducing magnetic changes on platters
  - reading data: detecting magnetic patterns on platters





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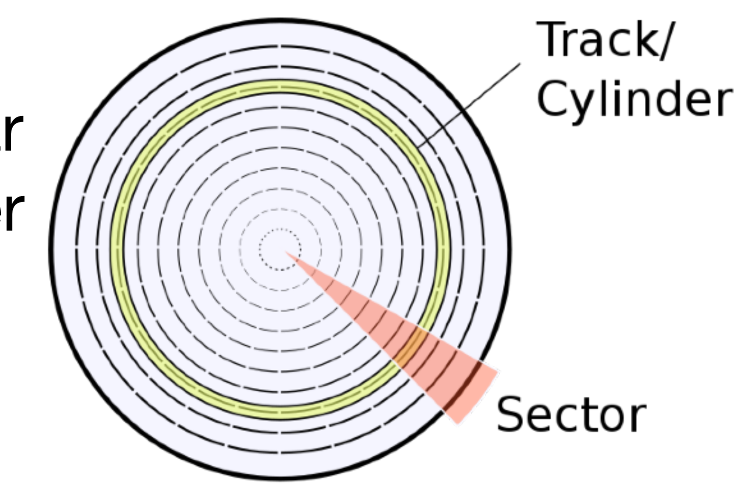

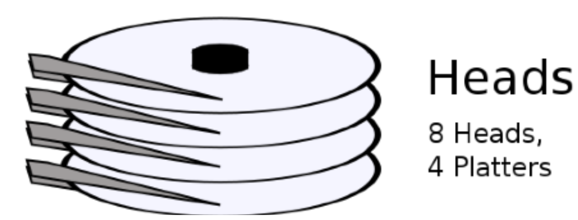

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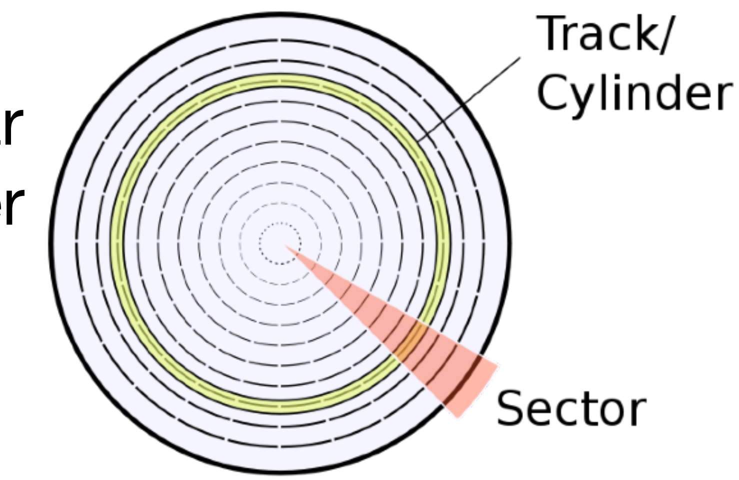
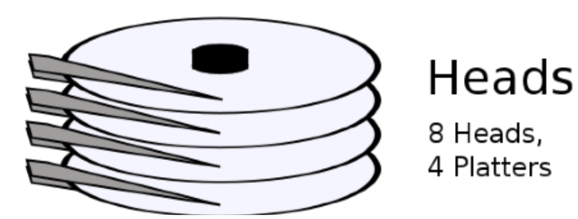
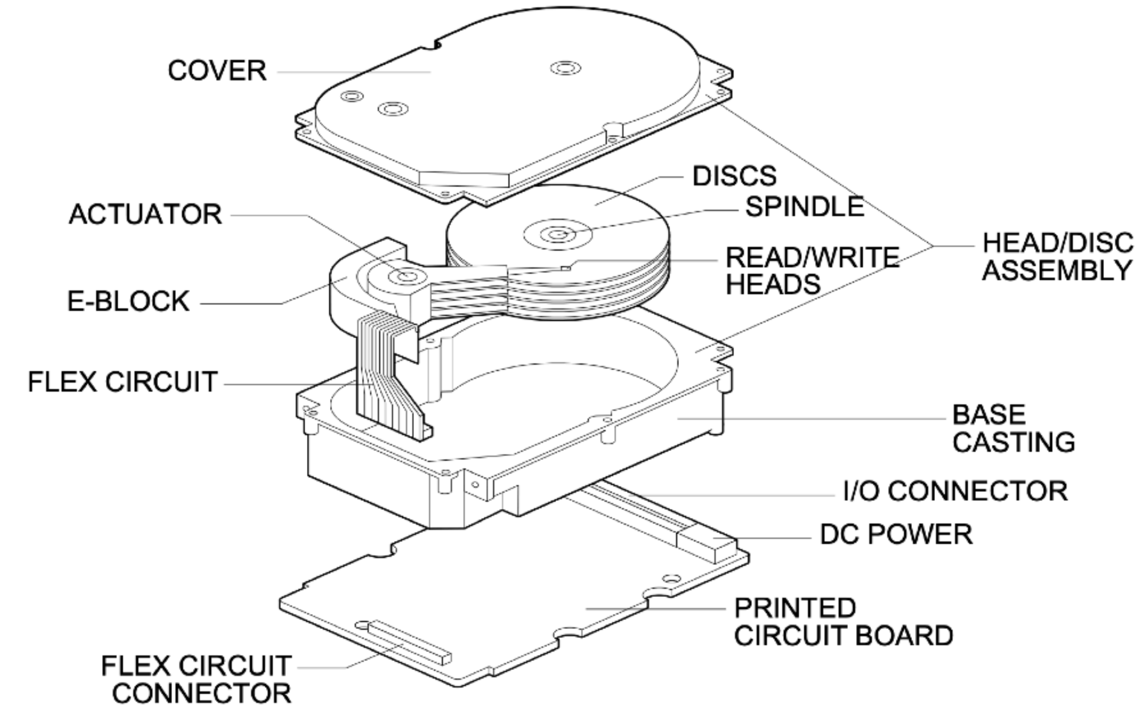
- tracks are divided into several hundreds of sectors (aka blocks) which are fixed-size array of bytes
  - sectors are the smallest unit of transfer and only a single sector read/ write is atomic
  - sector size was 512 bytes until ~2010 and then increased to 4KB
  - outer tracks tend to have more sectors than inner tracks





Seek and rotation

- read-write heads are attached to disk arms; a disk arm moves across the surface of a platter to position the head over the desired track
  - there is one head per surface
  - head will sometimes damage the magnetic surface (**head crash**); resulting in defective/bad sectors and loss of data



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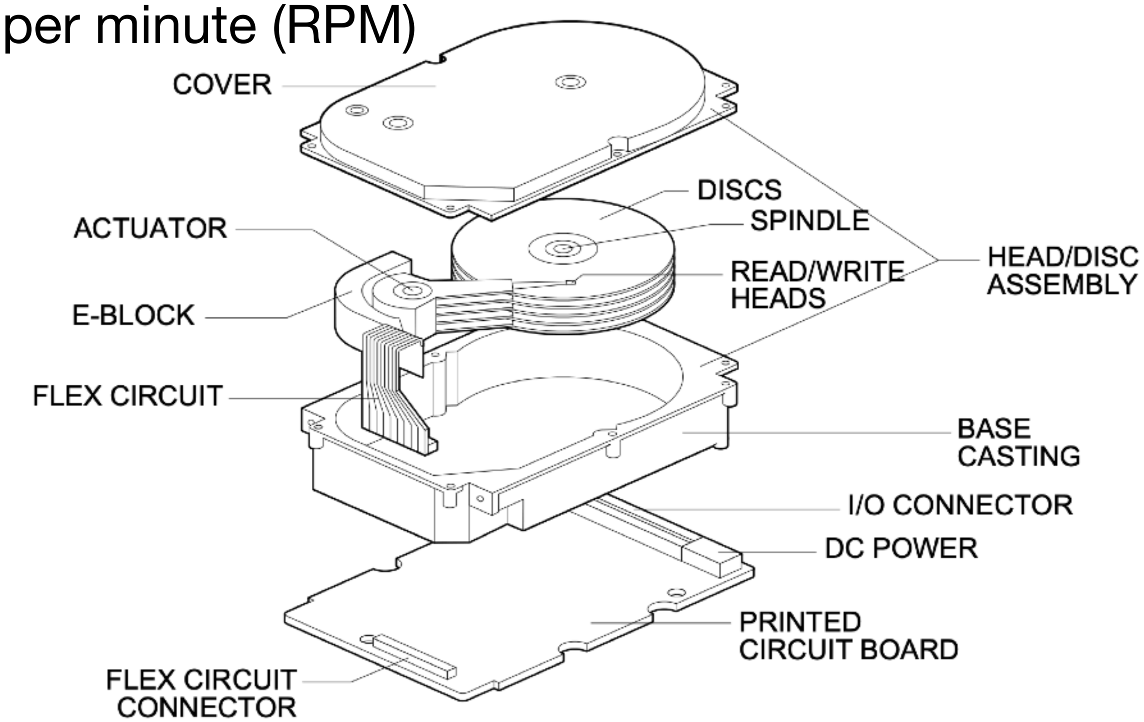
- a spindle connected to a motor spins platters around at a constant rate
  - disk rotates at high speed: 5,400 to 15,000 times per minute (RPM) so a single rotation takes a few milliseconds
  - rotation speed determines the transfer rate



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Unwritten contract

- accessing two nearby disk blocks is usually faster than accessing two blocks that are far apart
  - may need fewer head movements
- accessing disk blocks sequentially is typically much faster than any random access pattern
  - may need fewer head movements

Understanding disk performance: rotation

- rotational delay: time necessary for the spindle to rotate the desired sector to the disk head
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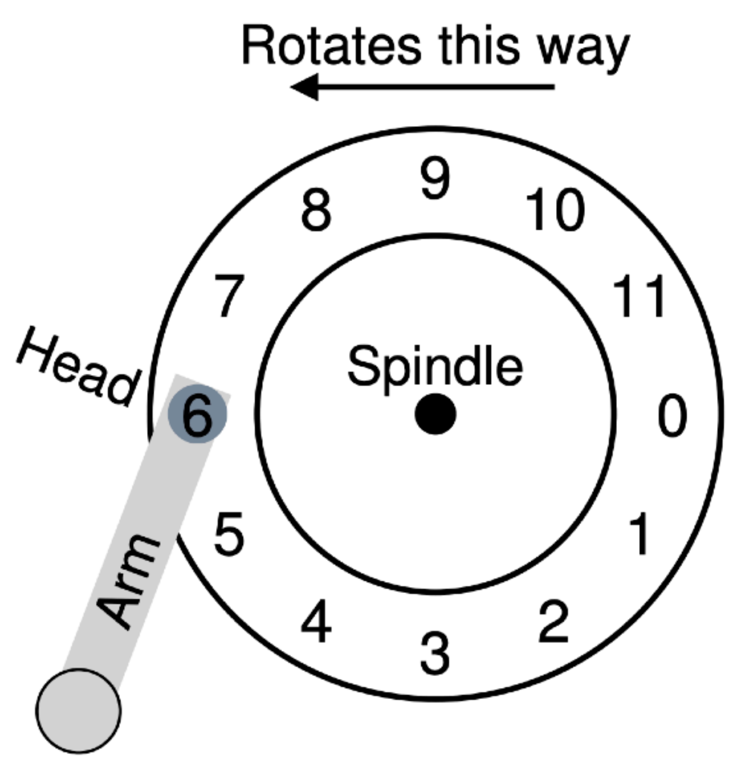

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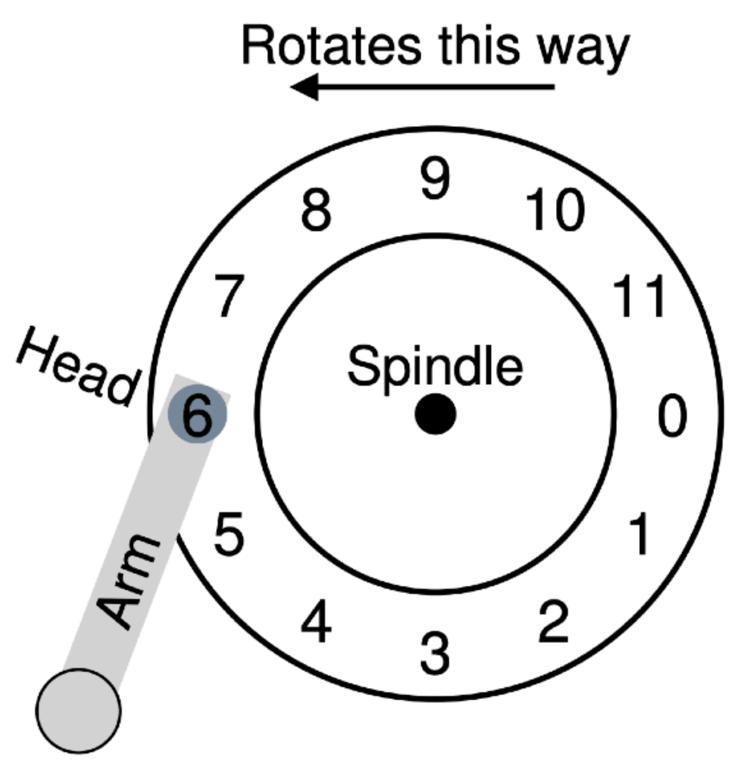
- example: disk head is currently positioned over sector 6
  - average case: if rotational delay is R, the disk has to incur a rotational delay of about R/2 to wait for sector 0 to come under the read/write head
  - worst case: wait for sector 5 to come under the read/write head (almost one full rotation)



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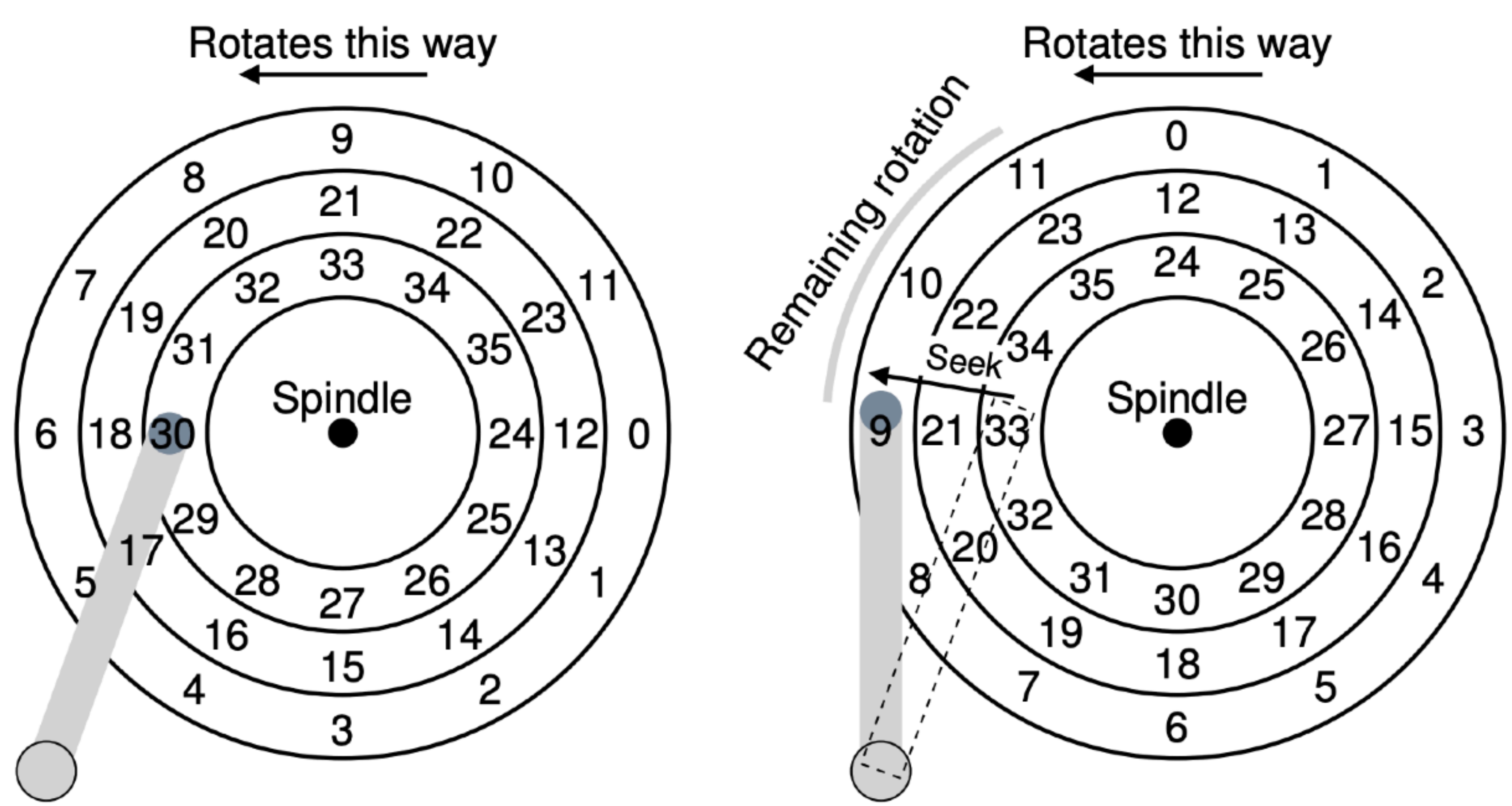

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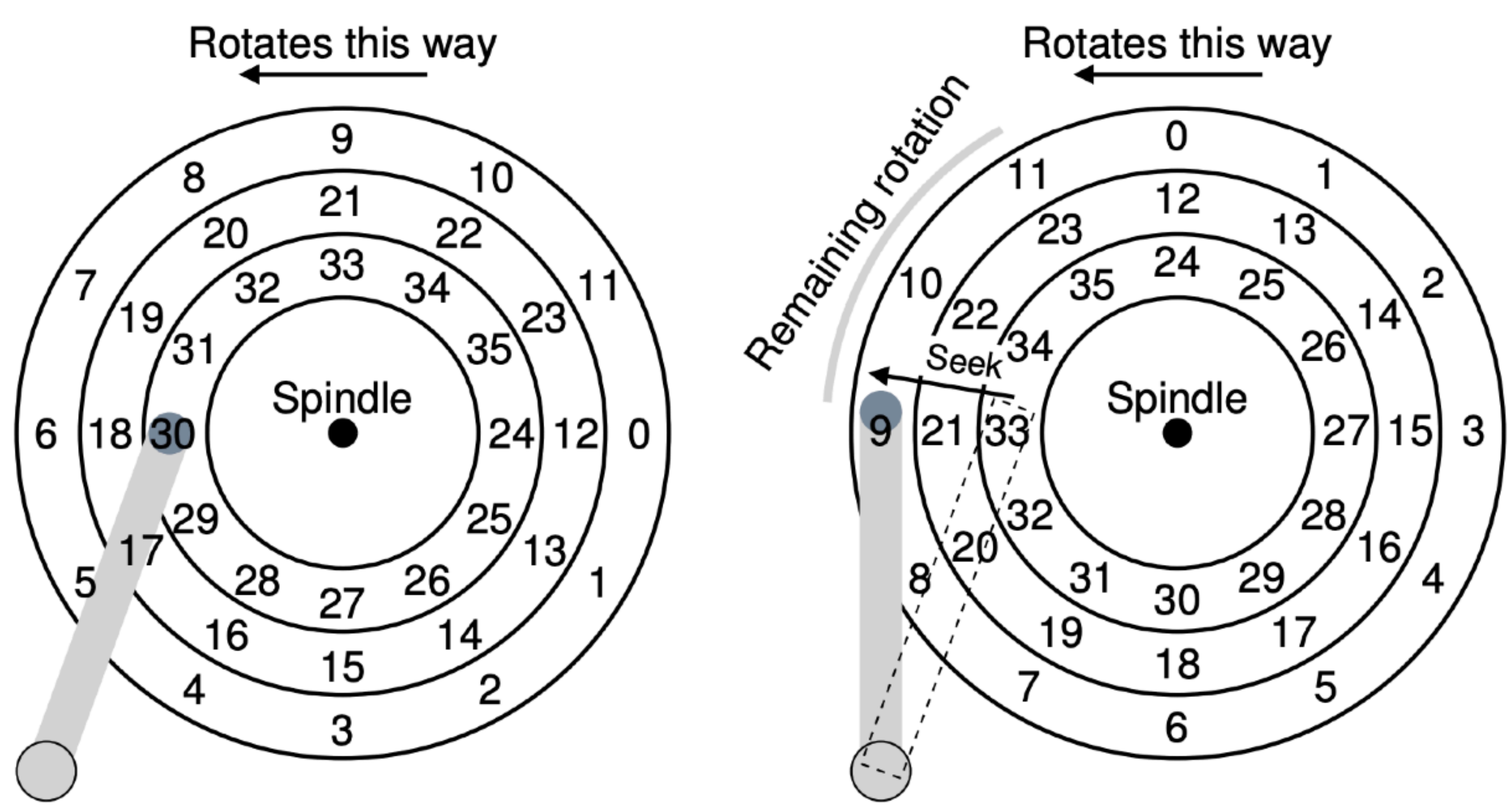
- example: servicing a request for logical block 11
  - disk arm has to move to the outermost cylinder/track
  - during the seek, the arm has been moved to the desired track, and the platter of course has rotated (about 3 sectors in this example)
  - still need to wait until the disk spins and the desired sector comes under the disk head



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- disk I/O rate is the amount of data to be transferred divided by the disk I/O time

Example

what is the average I/O time to transfer a 4KB block on a 7200 RPM disk with a 5ms average seek time, a 0.1ms controller overhead, and 1Gb/s transfer rate?

$$avg.\ rotational\ delay = \frac{1}{2 \times \frac{7200\ rotation}{1\ min} \times \frac{1\ min}{60{,}000\ ms}} = 4.17\ ms$$

$$avg.\ seek\ delay = 5\ ms$$

$$controller\ overhead = 0.1\ ms$$

$$transfer\ time = \frac{4KB}{\frac{1\ Gb}{s} \times \frac{1\ GB}{8\ Gb} \times \frac{1{,}024 \times 1{,}024\ KB}{1\ GB} \times \frac{1\ s}{1{,}000\ ms}} = 0.03\ ms$$

$$avg.\ I/O\ time = 4.17\ ms + 5\ ms + 0.1\ ms + 0.03\ ms = 9.30\ ms$$

Other considerations

- HDDs usually have some small amount of memory (8 to 16 MB) referred to as cache or track buffer which holds data read from or written to the disk
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- **write through**: the request to write data is acknowledged only after the data is actually written to disk

How to reduce disk access time?

- sequential I/O is optimal on HDD
  - disk seek is necessary only when reaching the end of a track and have to move head to the beginning of the next track
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- how to minimize disk I/O time?
  1. make disks smaller and spin faster
  2. deciding the order in which I/O requests are issued to disk (minimize head movement)
     - disk scheduler can make a good guess at how long servicing a specific I/O request will take
  3. lay out data on disk so that related data are on nearby tracks
     - e.g., put file contents near its metadata
  4. choose sector size more carefully
     - smaller sectors means more disk seeks for the same amount of data

Nonvolatile memory

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  - so there is no disk head
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- two main types of NVM are SSD and NAND semiconductors
- solid-state disks (SSD) are built out of transistors
  - USB drives (aka thumb/flash drive) are similar
  - more reliable than HDDs because they have no moving parts
  - faster than HDDs because they have no seek time to rotational latency
  - more energy efficient than HDDs

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- data cannot be overwritten so to write to a page within a block, you first have to erase the entire block first
  - invalid pages: NAND pages (like disk blocks) containing old data that must be erased before they can be rewritten
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- lifetime is approx. 100,000 program erase cycles (due to deterioration)
  - lifespan is measured in Drive Writes Per Day (DWPD)
  - a 1TB NAND drive rated at 5 DWPD is expected to have 5TB per day data written for it for the warranty period without failure
  - frequently erased block wear faster, hence controller does wear levelling by erasing and overwriting less erased pages

Disk Scheduling

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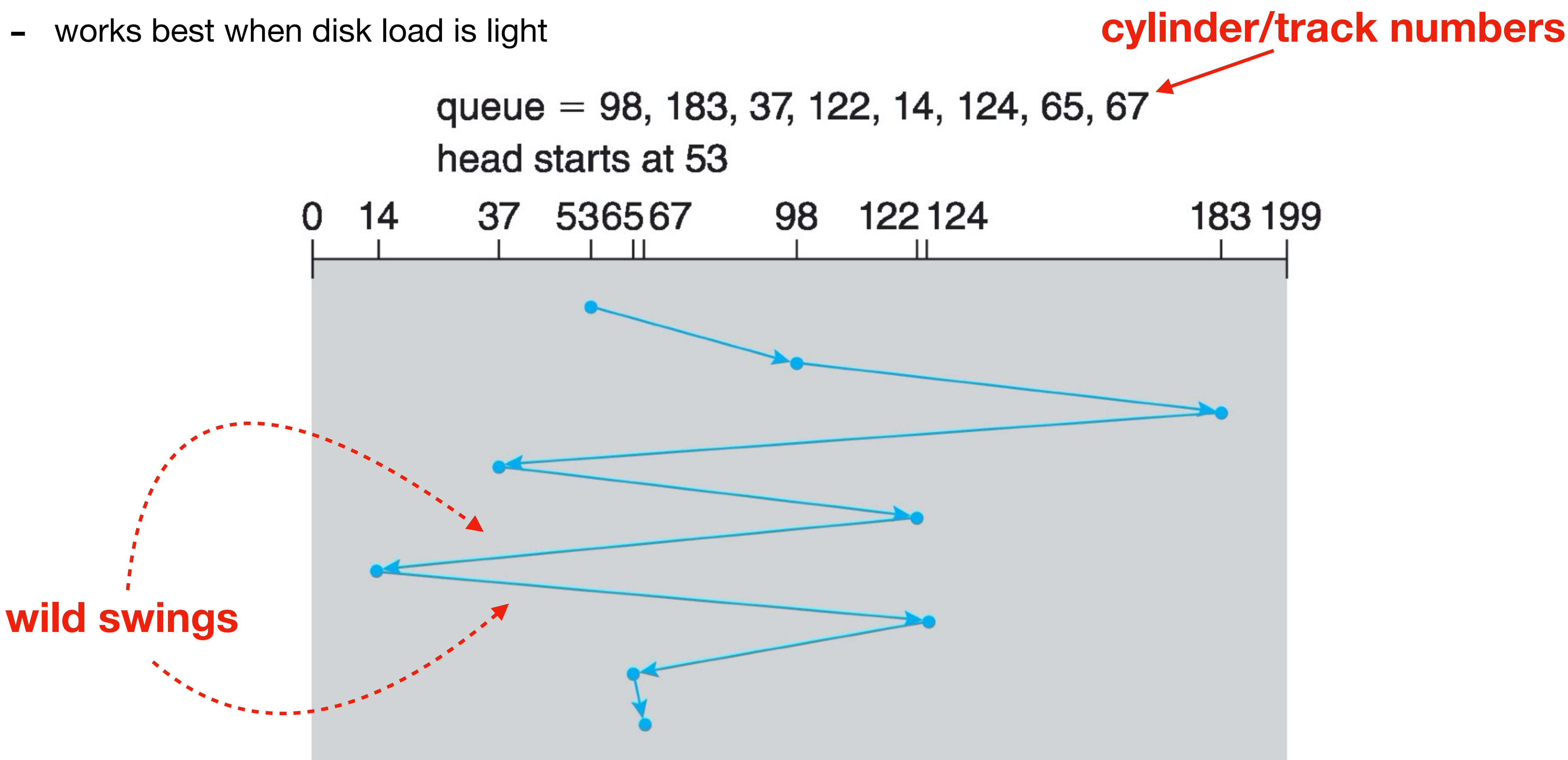
  - **Goal:** optimize/balance fairness, timeliness, and performance
- **Definition of disk scheduling:** permute the order of servicing disk I/O requests from the order they arrive to an order that reduces the length and number of seeks

FCFS scheduling

- First-come first-served (FCFS): order the queue of I/O requests by arrival time
  - intrinsically fair, but does not guarantee fastest service
  - works best when disk load is light



total head movement (seek distance) of 640 cylinders

SSTF scheduling

- shortest seek time first (SSTF): order the queue of I/O requests by track, picking requests on the nearest track to service first
  - always go to the next closest request (greedy algorithm)
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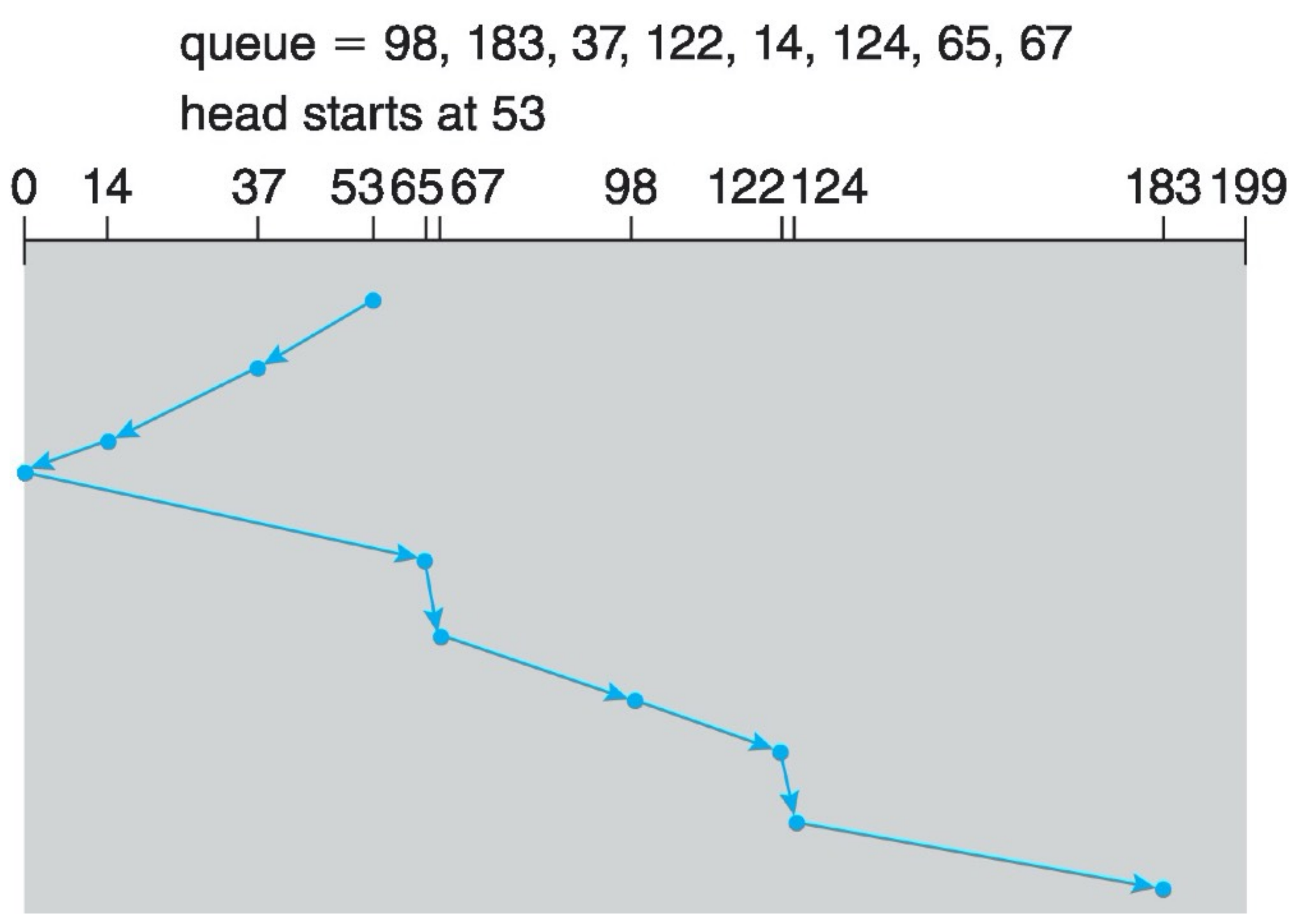
  - starvation is possible: what if there is a steady stream of requests to the inner track, where the head currently is positioned

SCAN scheduling (elevator algorithm)

- disk head continuously scans back and forth across the disk (preventing starvation)
  - each pass across the disk is called a **sweep**
  - disk arm starts at one end of the disk and moves toward the other end, servicing requests as it reaches each cylinder
  - the direction of head movement is then reversed and servicing requests continues

a request arriving in the queue just in front of the head is serviced immediately

a request arriving in the queue just behind the head will have to wait



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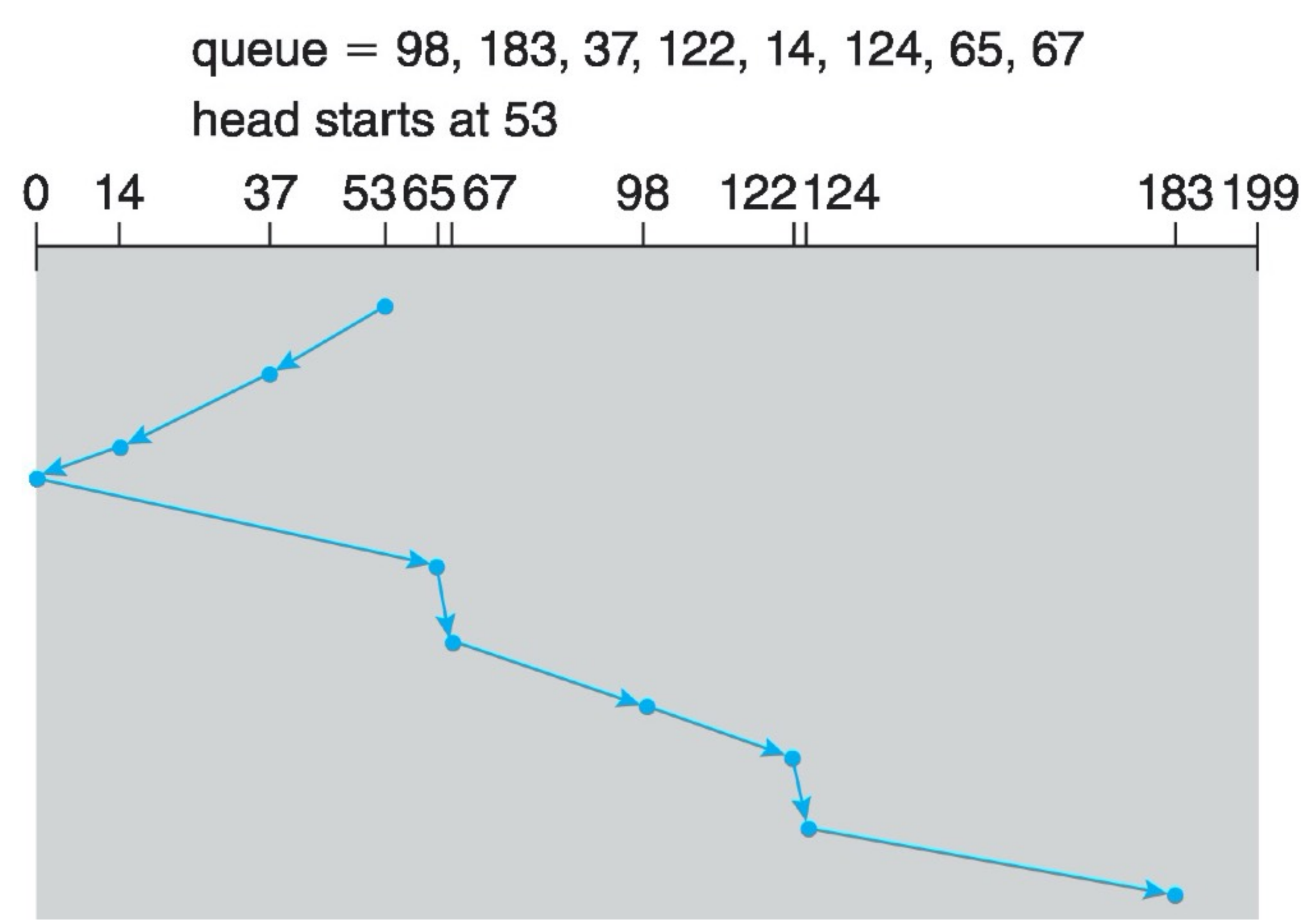

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- if there is no request between current position and the disk end, we can change the direction of movement right away (**LOOK scheduling**)

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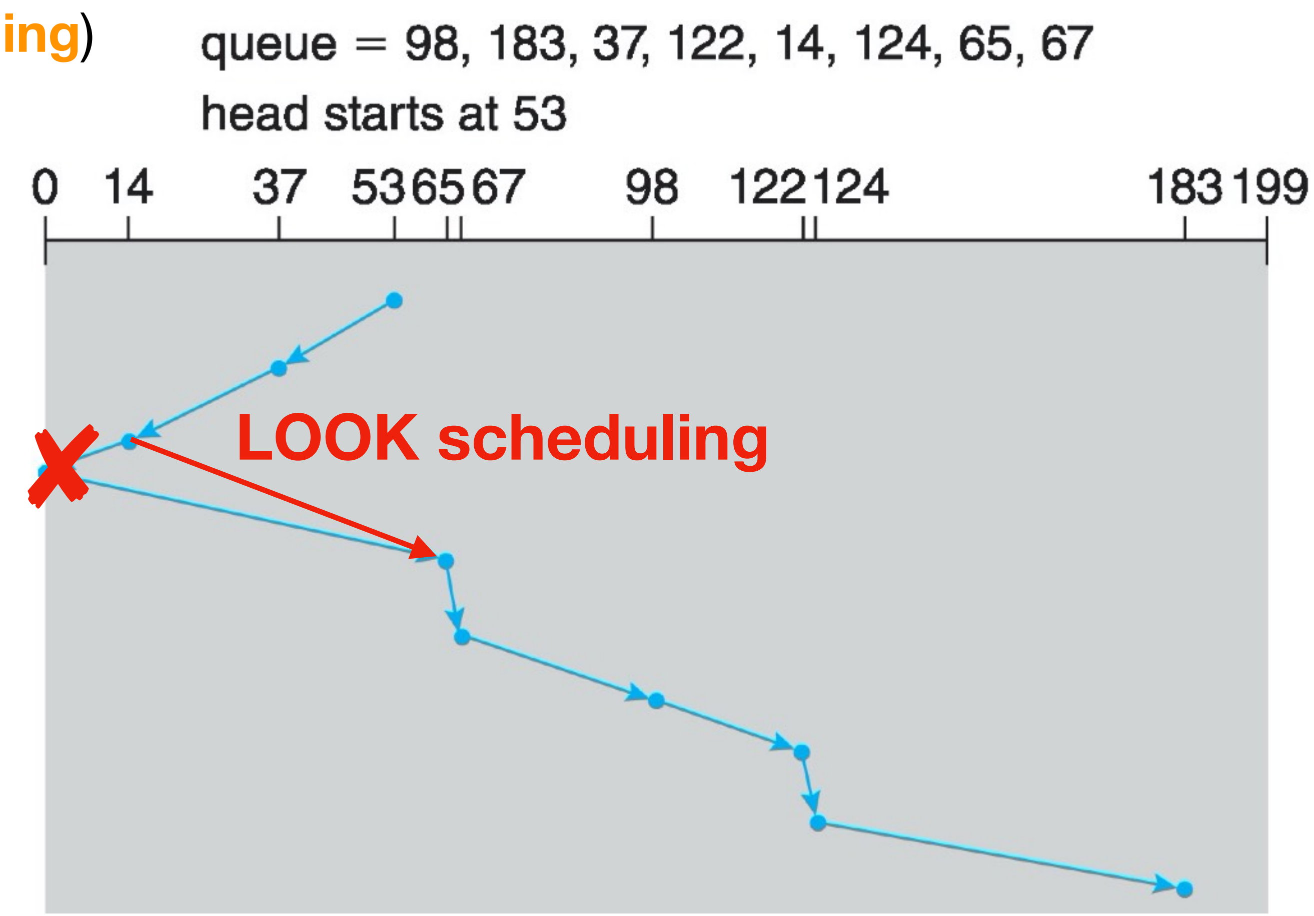
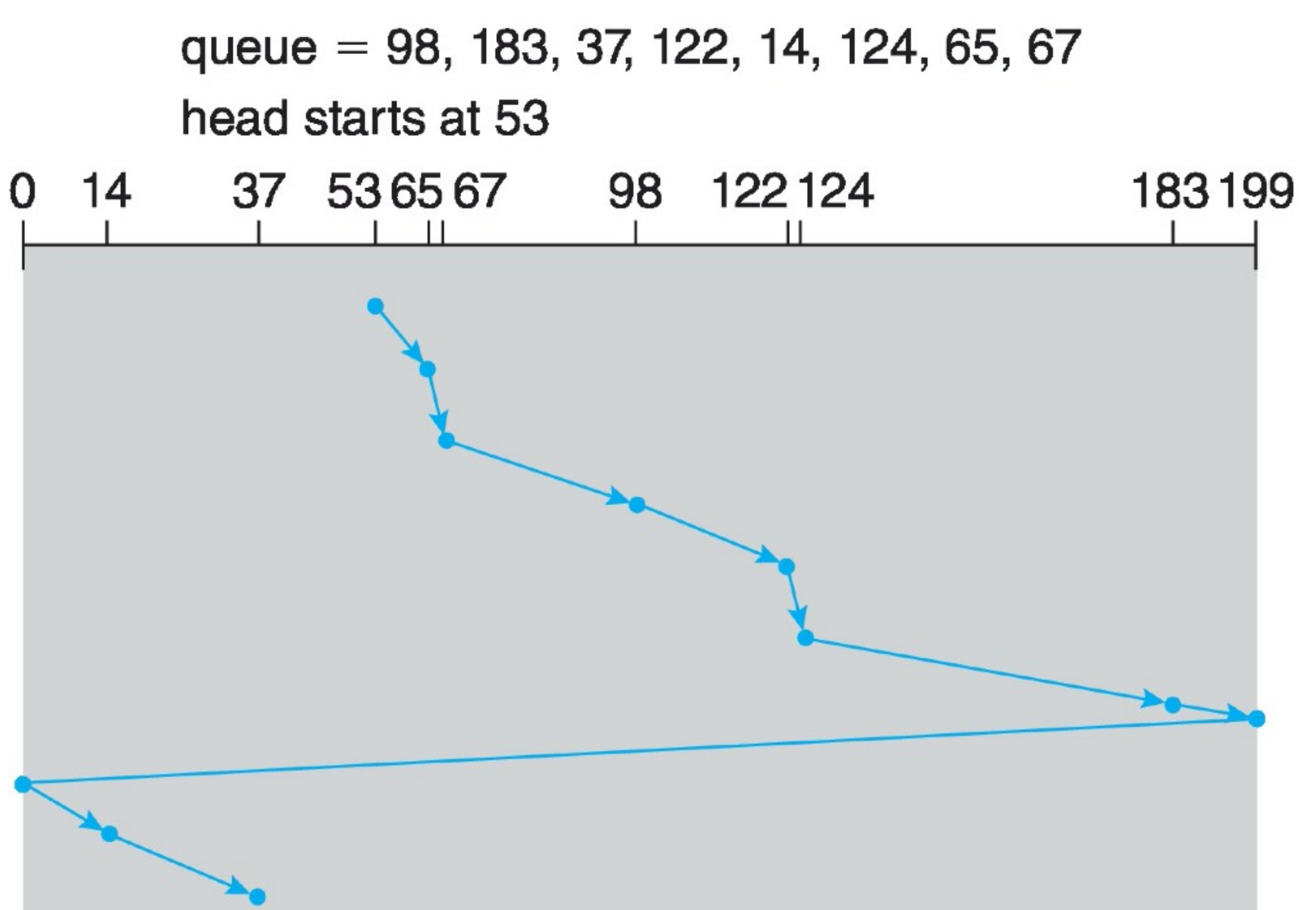


Circular SCAN (C-SCAN) scheduling

- variant of SCAN scheduling with one difference
  - when the head reaches one end of the disk it immediately returns to the other end without servicing any requests on the return path
  - why? assuming uniform distribution of requests, the chance of having requests ahead of the head on the return trip is low as these cylinders have recently been serviced



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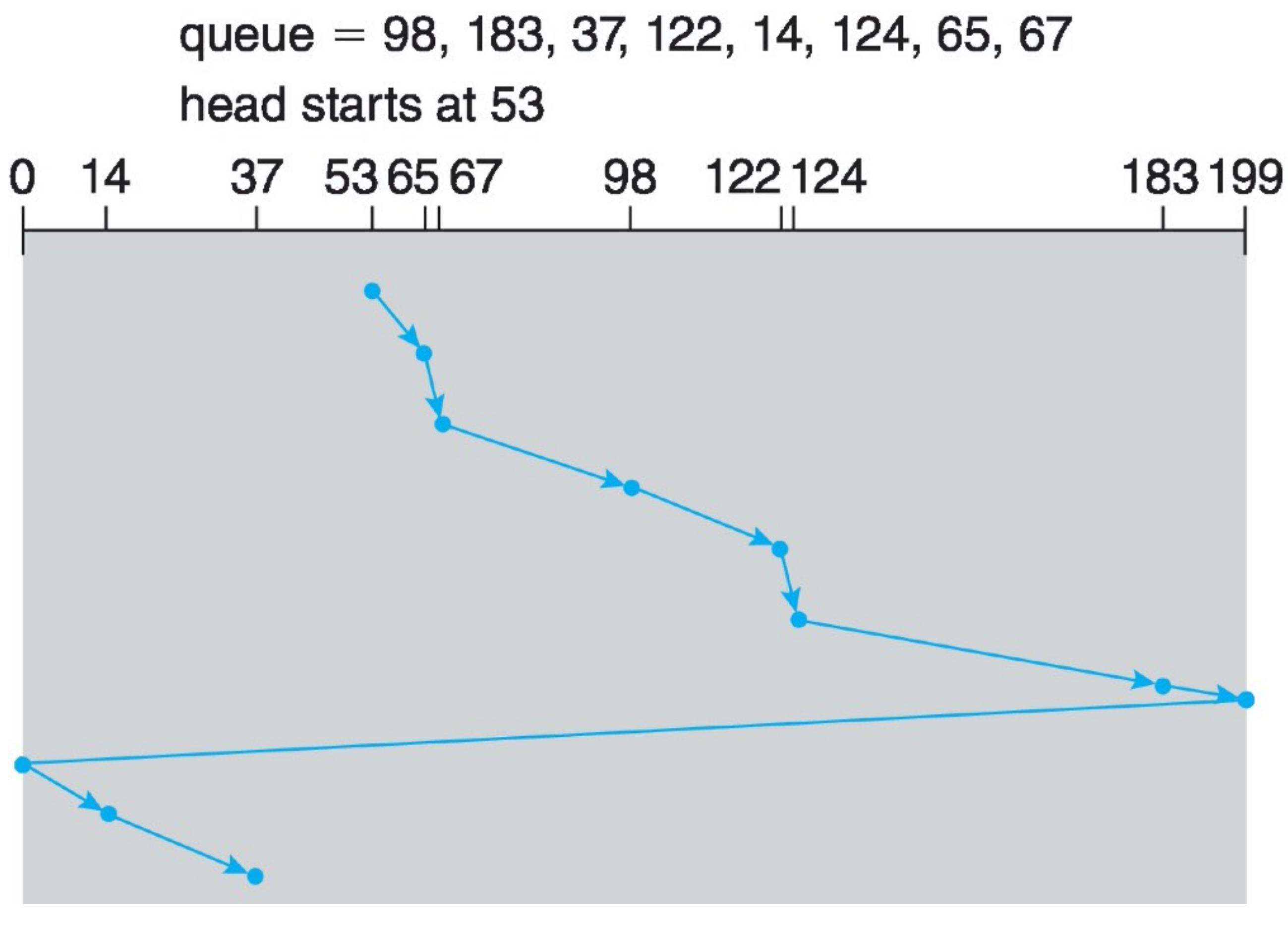

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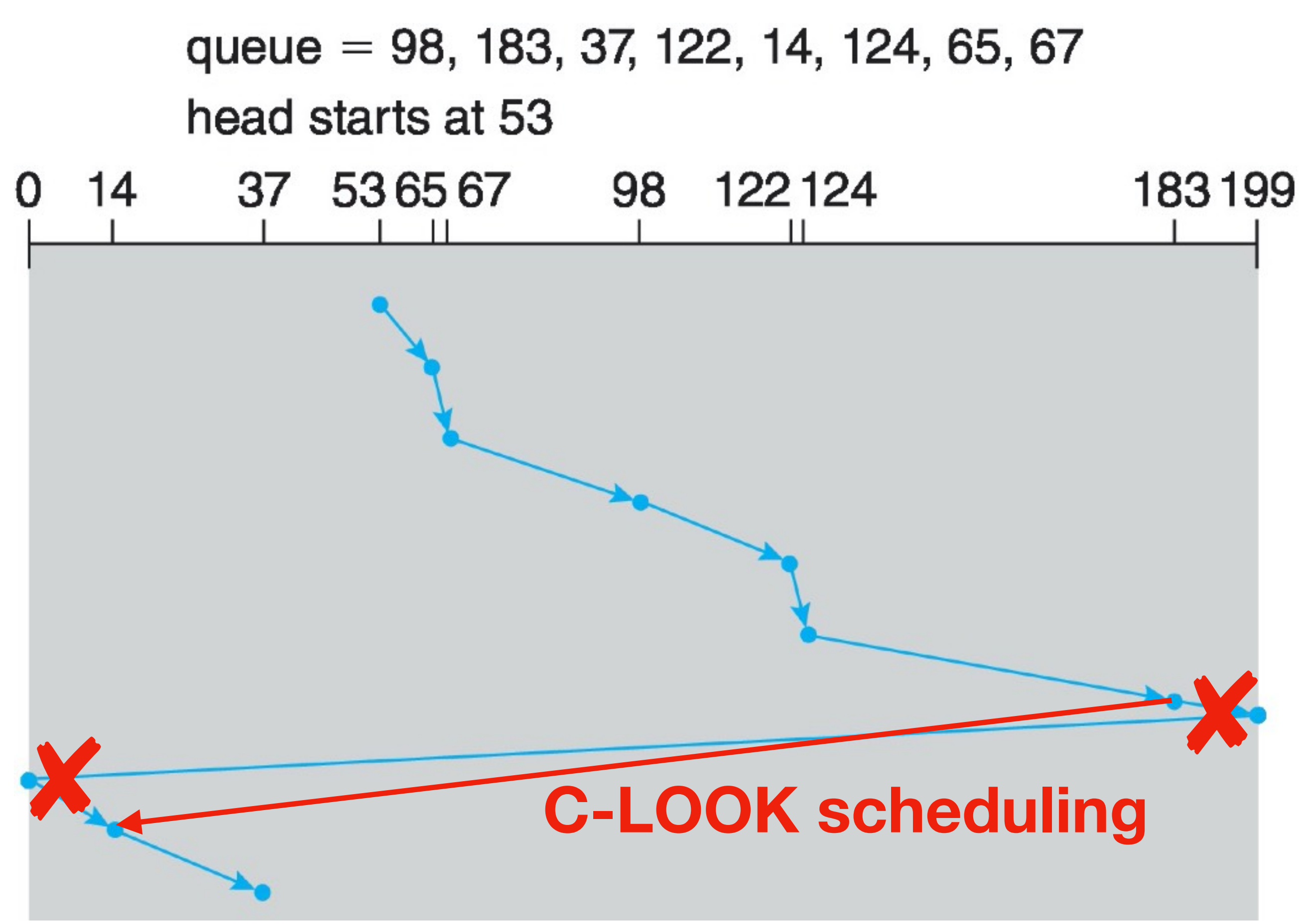

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- SCAN favors the middle tracks compared to C-SCAN because it passes through the middle twice before coming back to the outer track
- all these algorithms ignore rotation delay and optimize for seek delay only
  - makes sense if seek delay is much higher than rotational delay
  - but what if it is not the case for some storage technology?

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- analogous to Traveling Salesman Problem (TSP)
- in modern systems, disks have sophisticated internal schedulers themselves
  - so the OS scheduler usually issues a small batch of I/O requests that thinks are the best
  - internal disk scheduler services these requests in the SATF order

Improving disk performance using read ahead

- to reduce the number of seeks, we can read blocks that will probably be used while you have them under the head
- read blocks from the disk ahead of user's request and place in buffer on disk controller
- can we predict which disk blocks will be needed? with sequential access?

Deadline scheduler in Linux

- maintain separate read and write queues (specifically two read queues and two write queues) and give read requests a higher priority
  - because processes are more likely to block on read than write (write-back is often used)
  - requests are submitted to queues in batch
- one read queue and one write queue are kept sorted by logical block address order
  - it is similar to C-SCAN as both queues are kept sorted in logical block address order
- one read queue and one write queue are kept sorted by FCFS
- for each batch, if there are requests in FCFS queues older than some predefined age, they are serviced first (**fairness**)
  - otherwise, requests in queues sorted by logical block address are serviced