Sistemi Operativi

Corso di Laurea in Informatica

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SAPIENZA
UNIVERSITÀ DI ROMA

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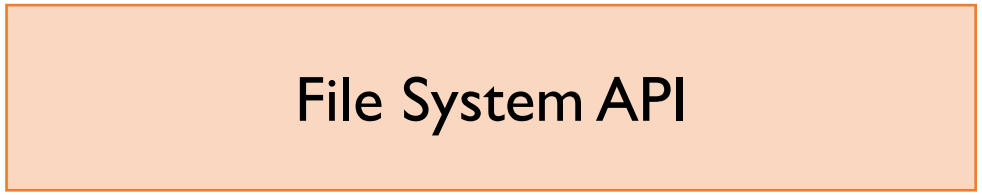
File System's Logical View



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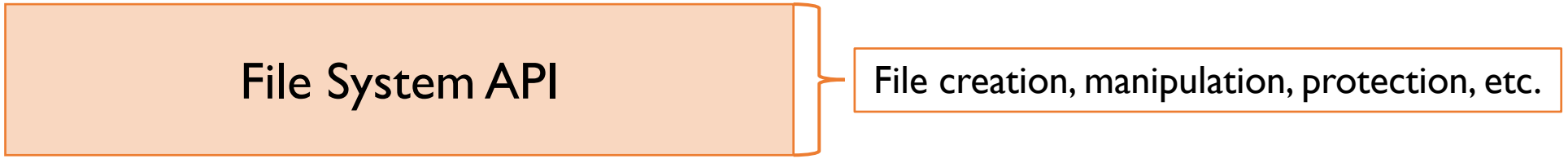

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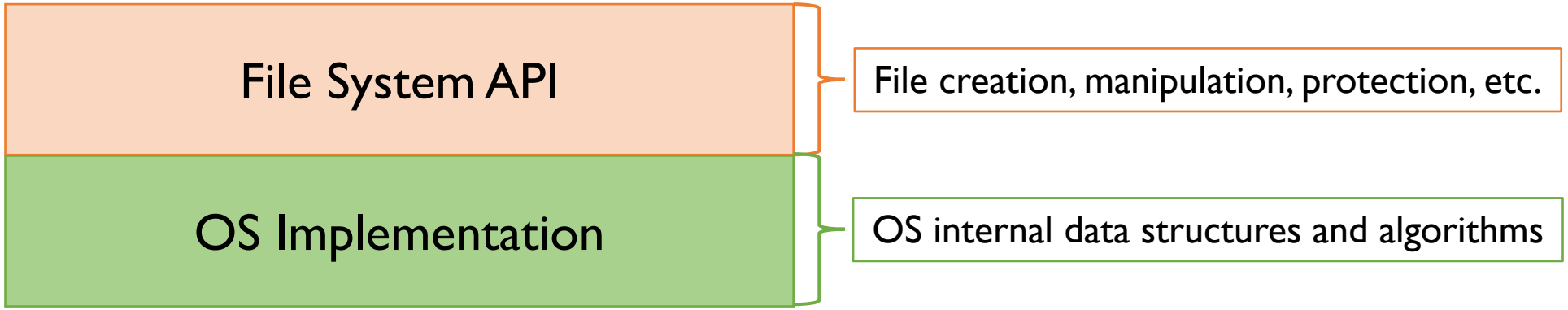

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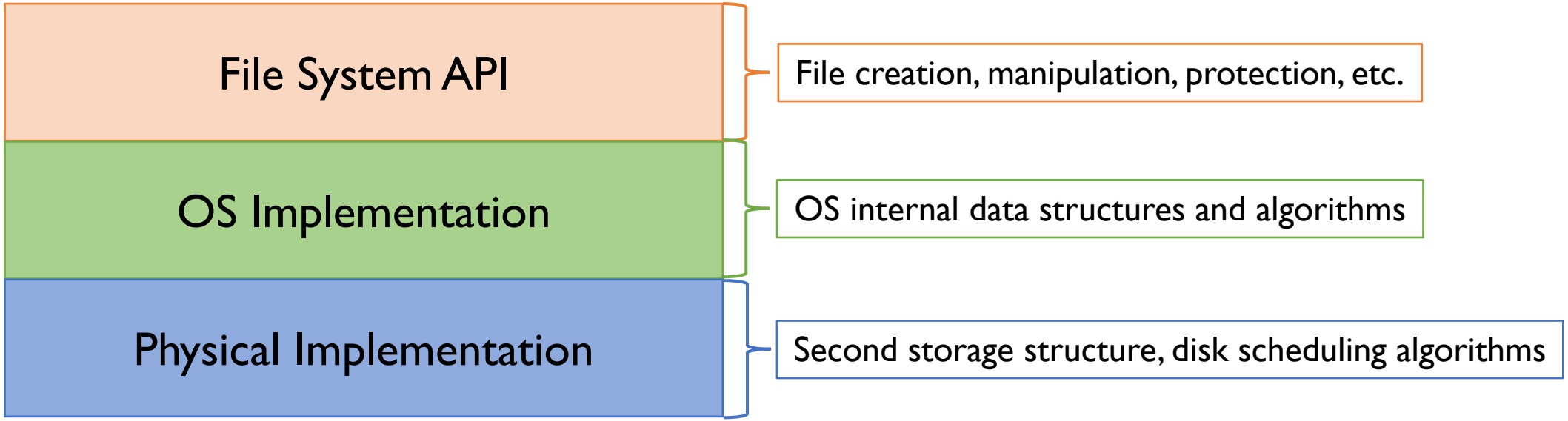

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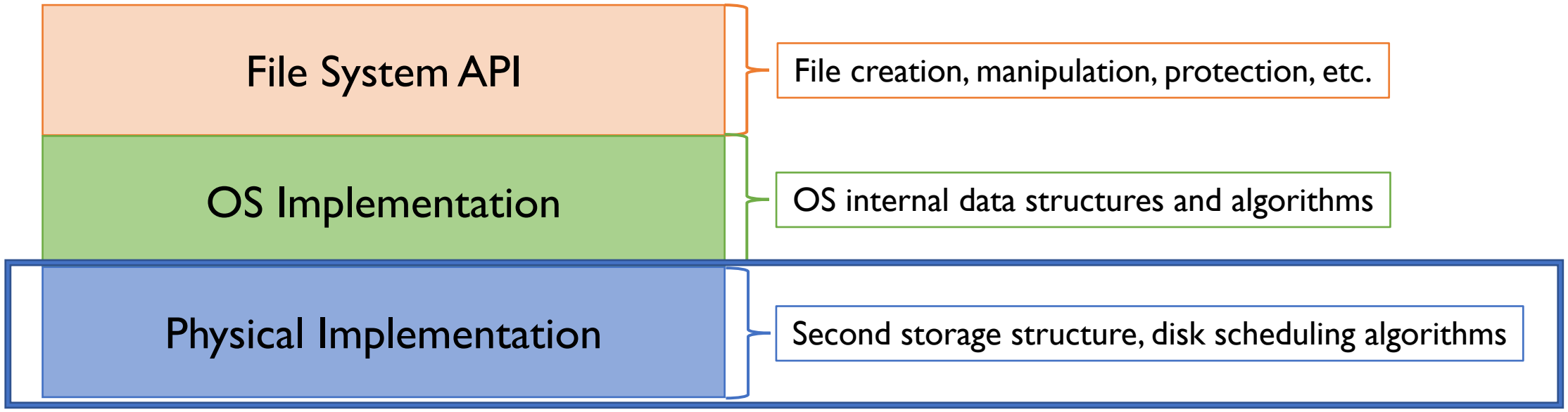

Overview of Mass-Storage Structure

3 categories of mass-storage devices

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Magnetic Disk

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Magnetic Disk

Solid-State Disk

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3 categories of mass-storage devices

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Solid-State Disk

Magnetic Tapes

Overview of Mass-Storage Structure

3 categories of mass-storage devices

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Secondary Storage

Overview of Mass-Storage Structure

3 categories of mass-storage devices

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Secondary Storage

Tertiary Storage

Overview of Mass-Storage Structure

3 categories of mass-storage devices

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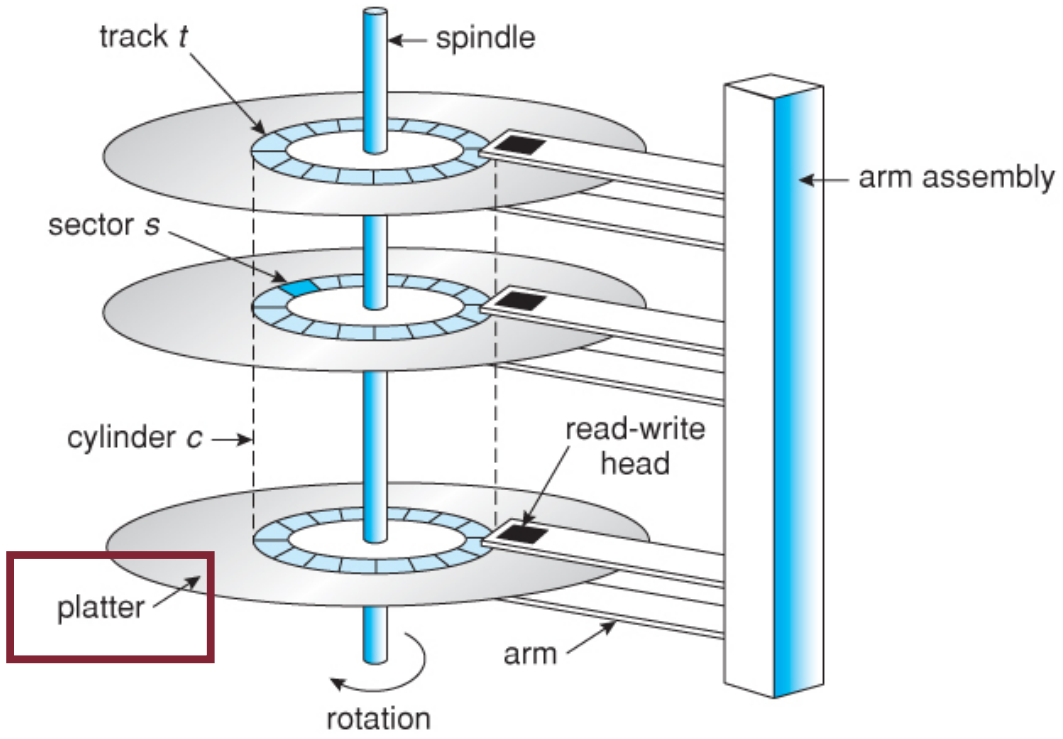
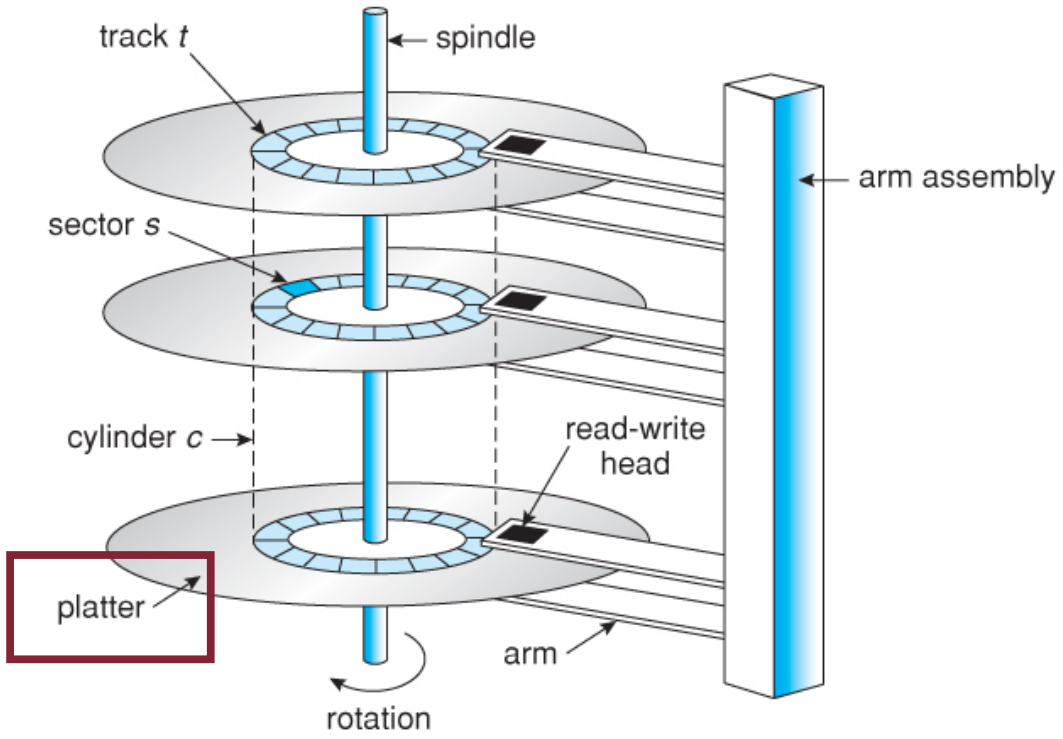
Magnetic Disks: Structure



One or more **platters** covered with **magnetic** media

Magnetic Disks: Structure



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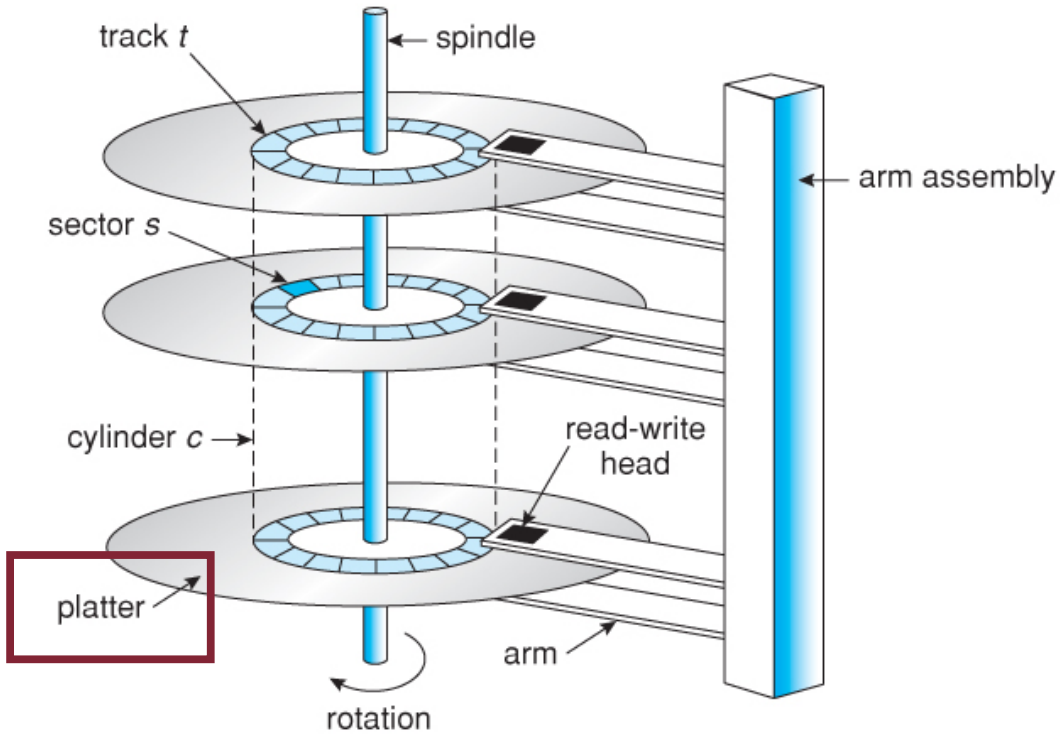

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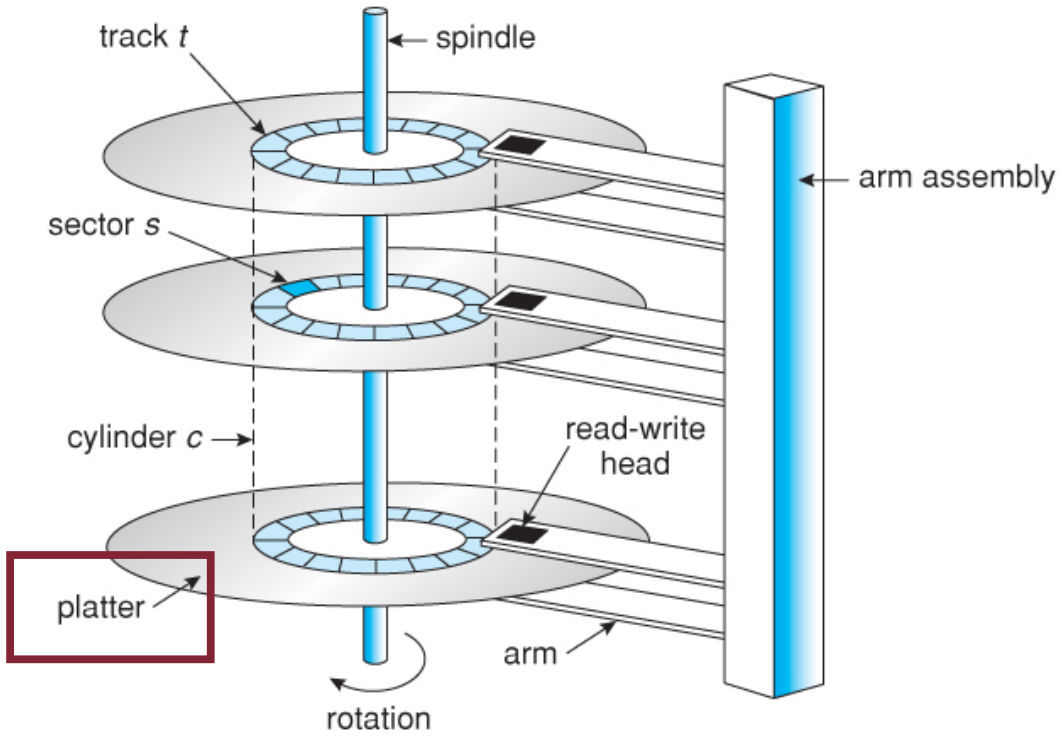
Magnetic Disks: Tracks and Cylinders



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Each platter has **2** working **surfaces**

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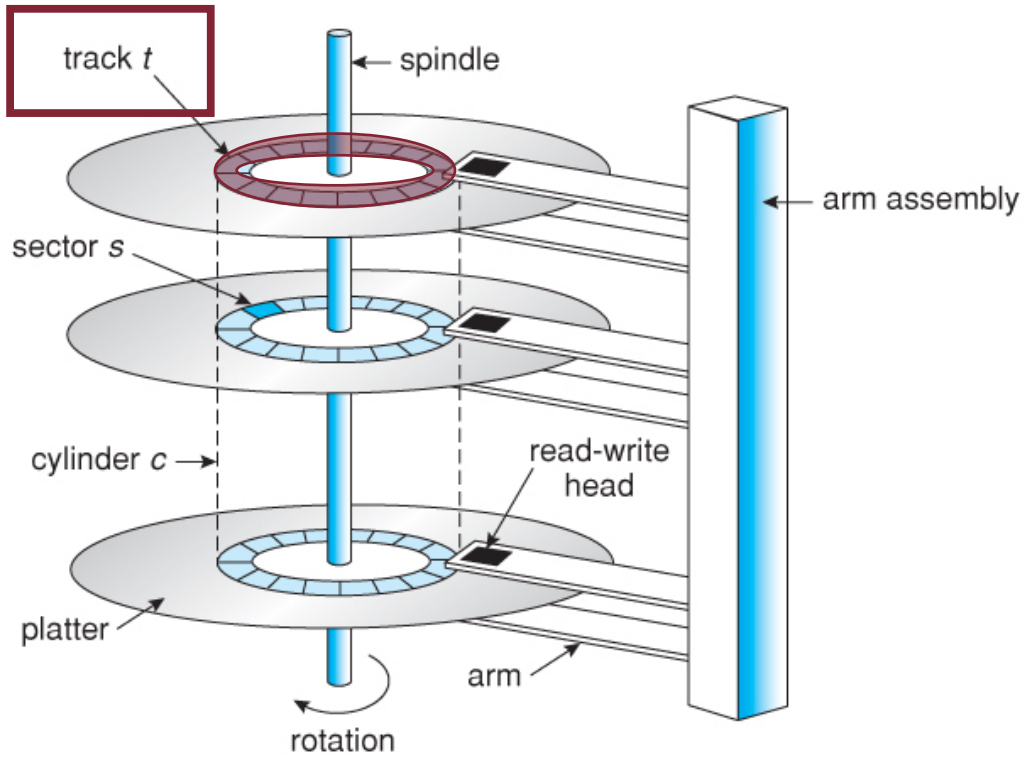

Each surface is divided into a number of concentric rings, called **tracks**

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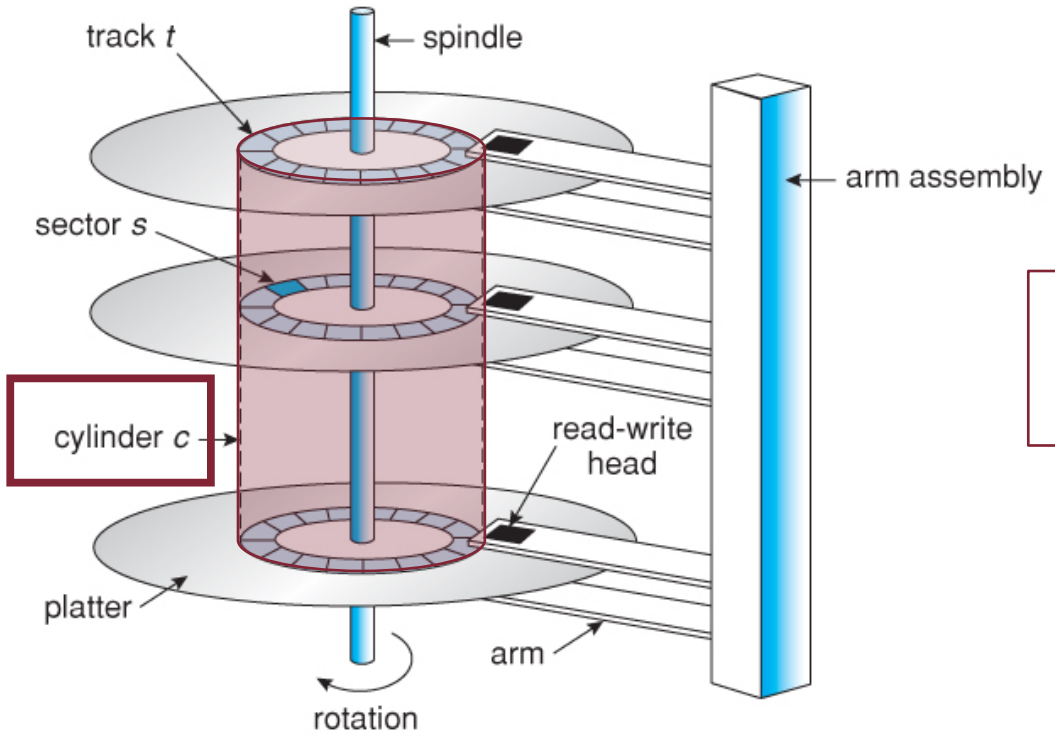
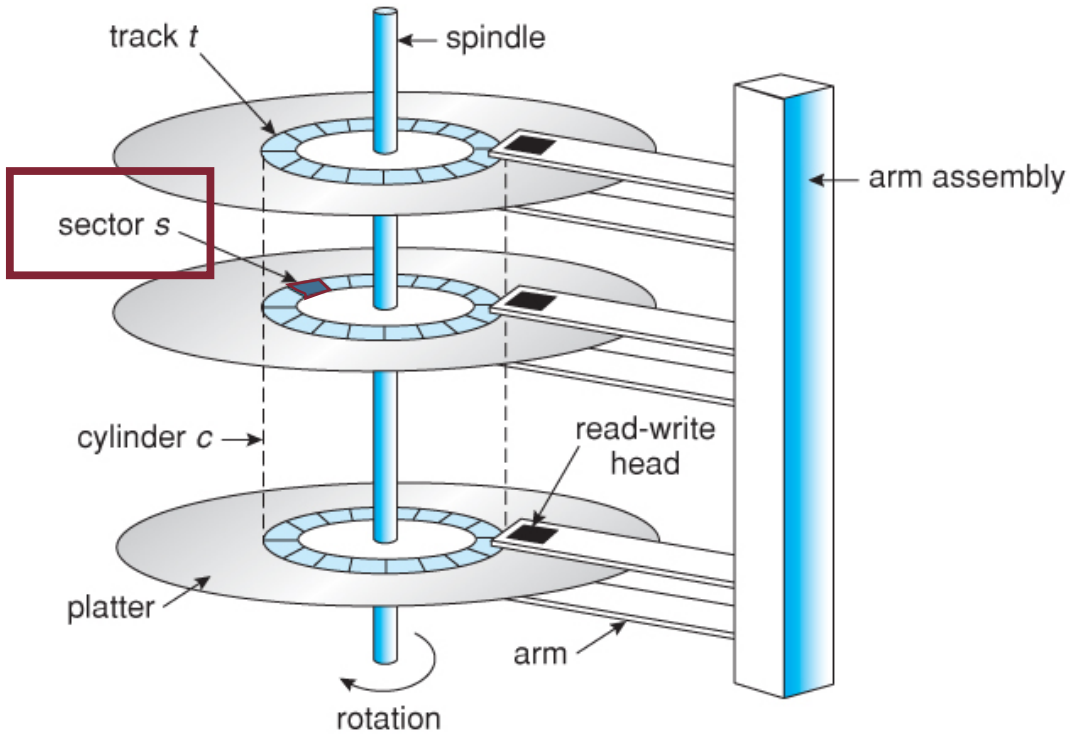


Each surface is divided into a number of concentric rings, called **tracks**

The set of all tracks that are the same distance from the edge of the platter is called a **cylinder**

Magnetic Disks: Sectors



Each track is further divided into **sectors**

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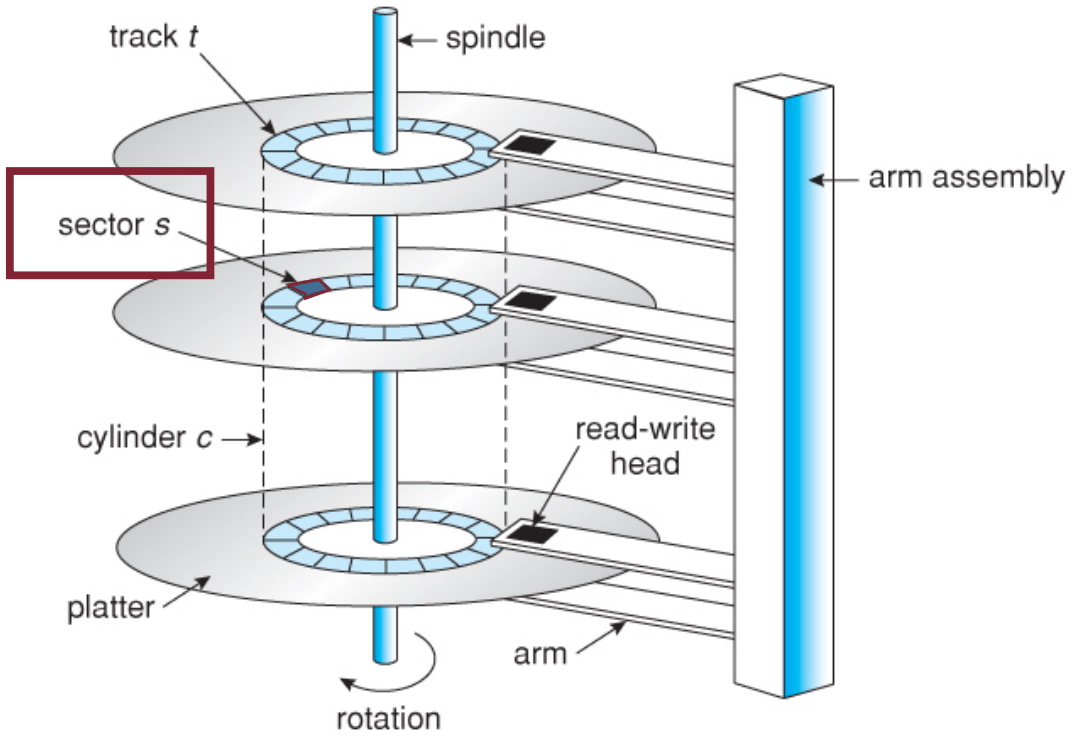

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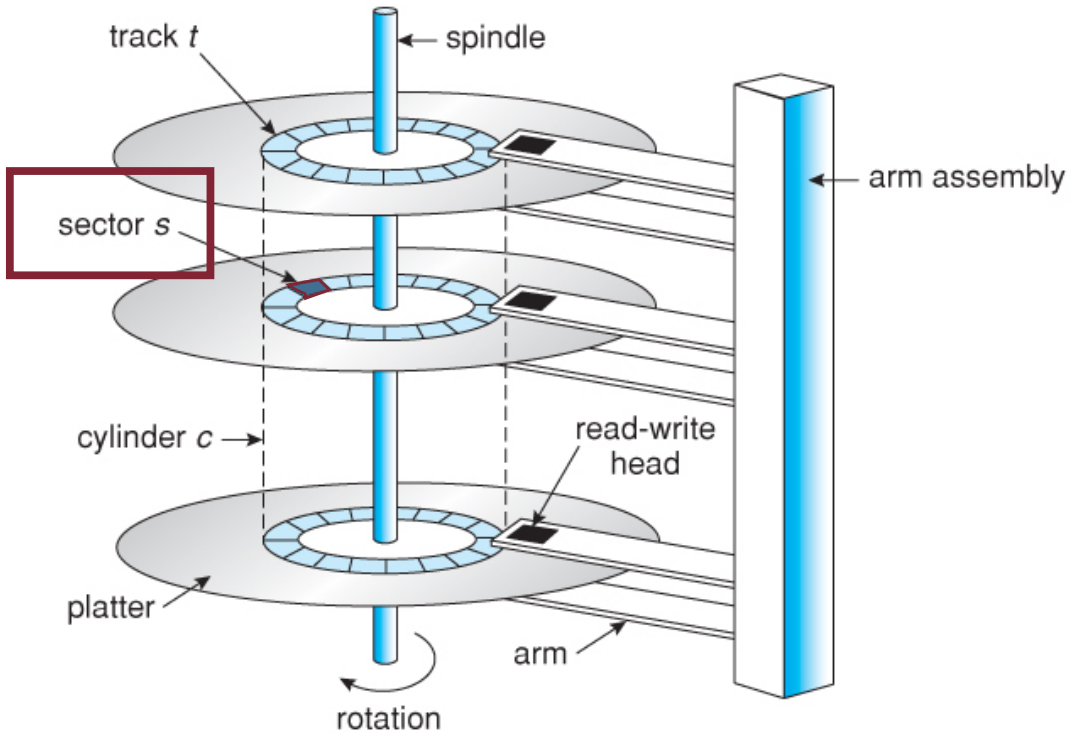

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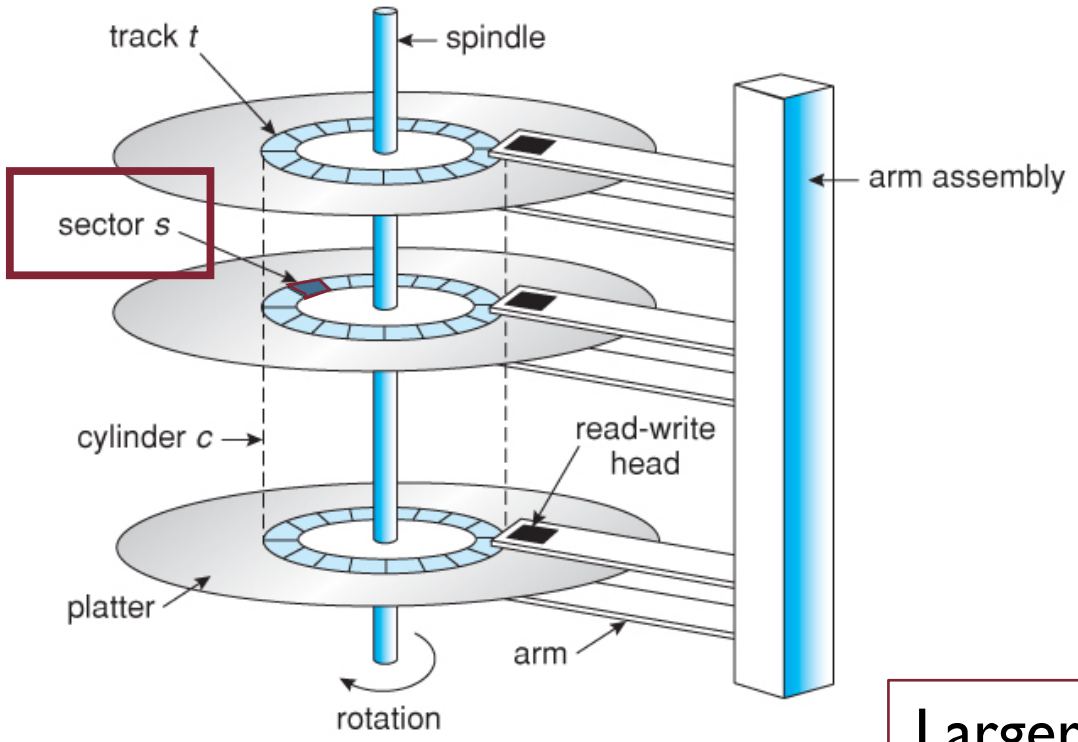

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Larger sector sizes reduce the space wasted by headers and trailers, but increase internal fragmentation

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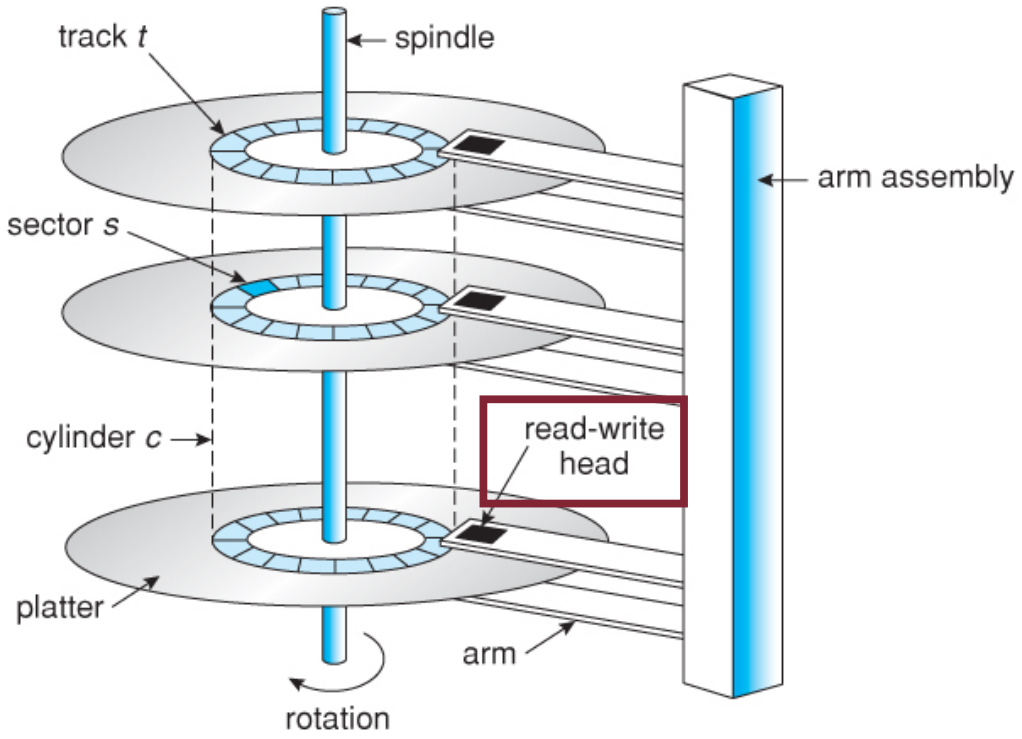

Data on hard drive is read by read-write **heads**

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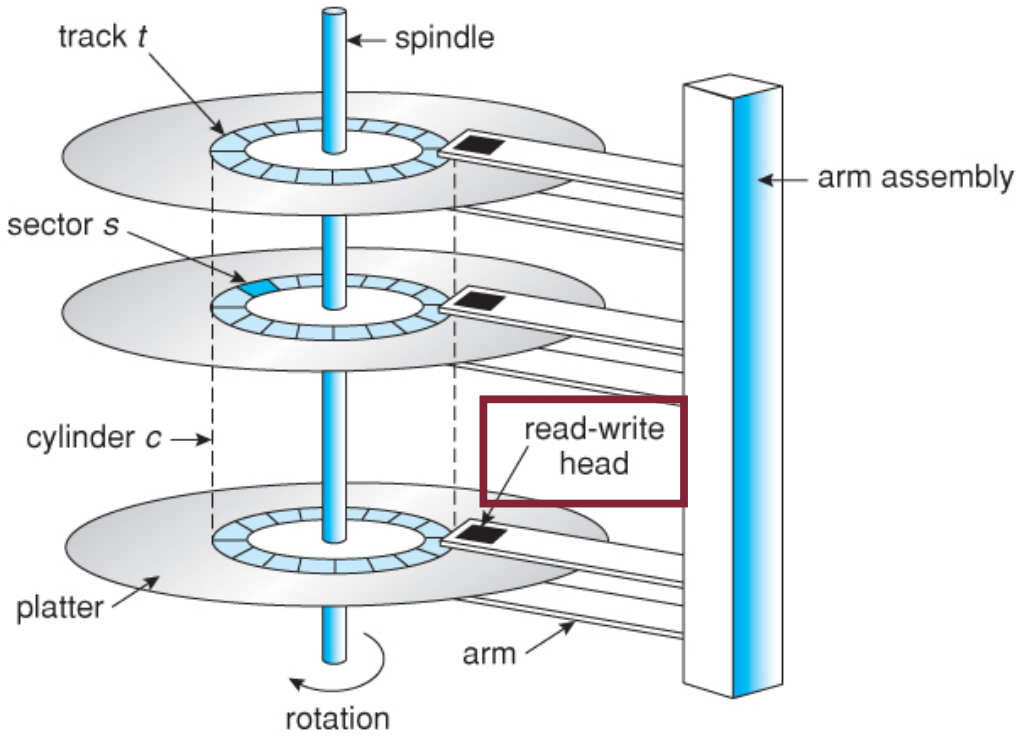

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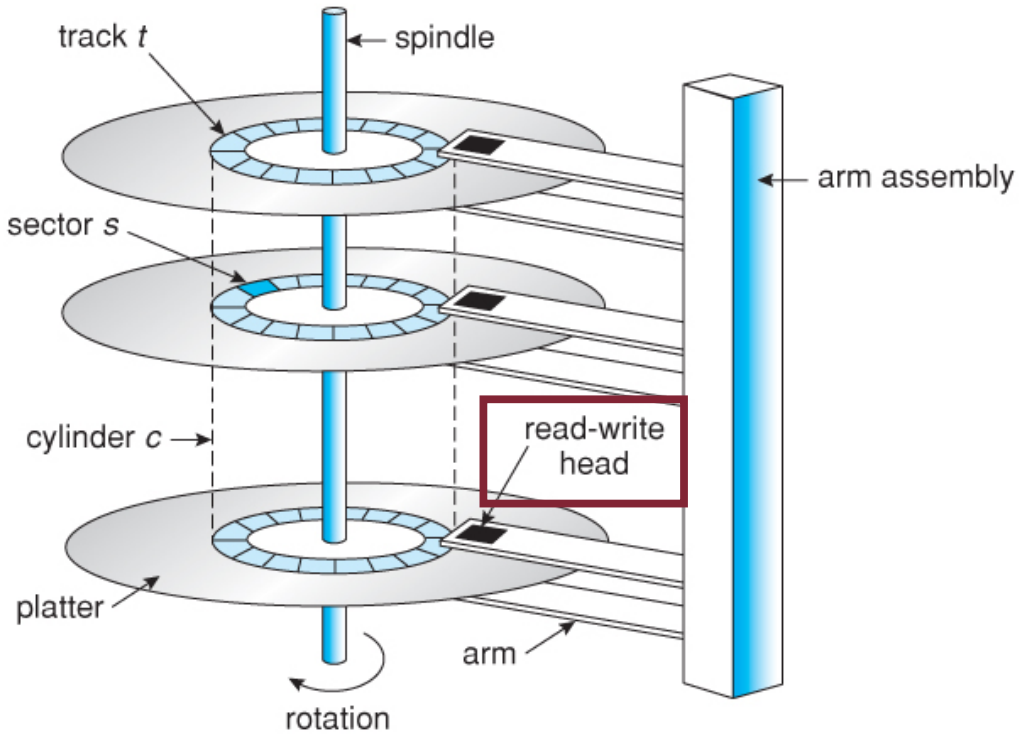

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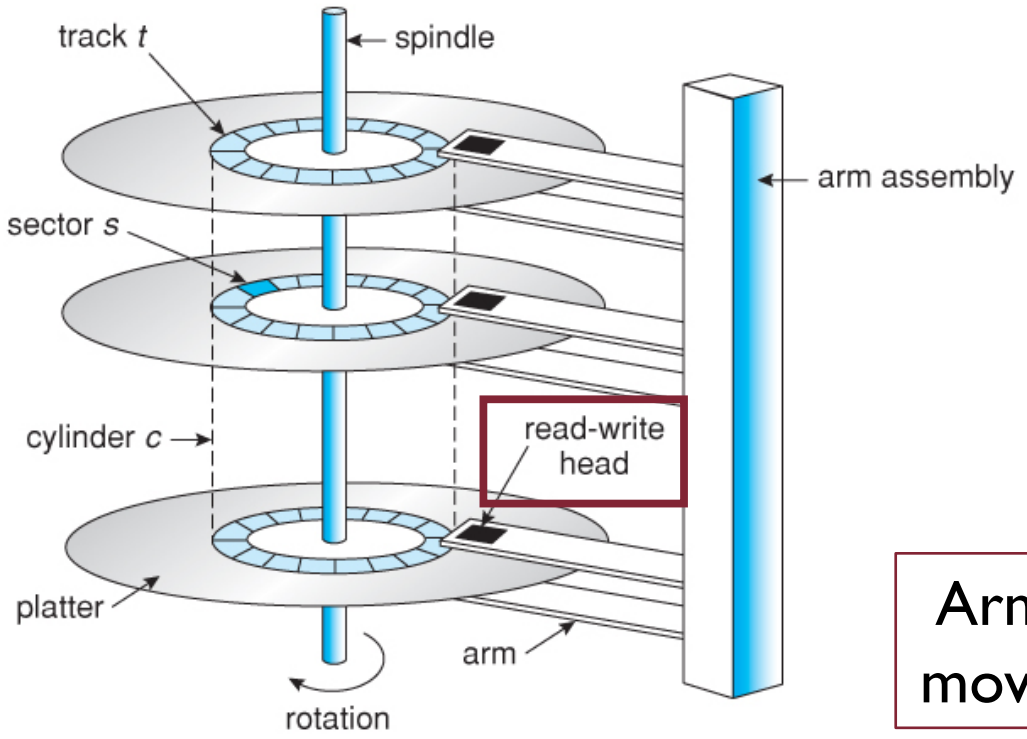

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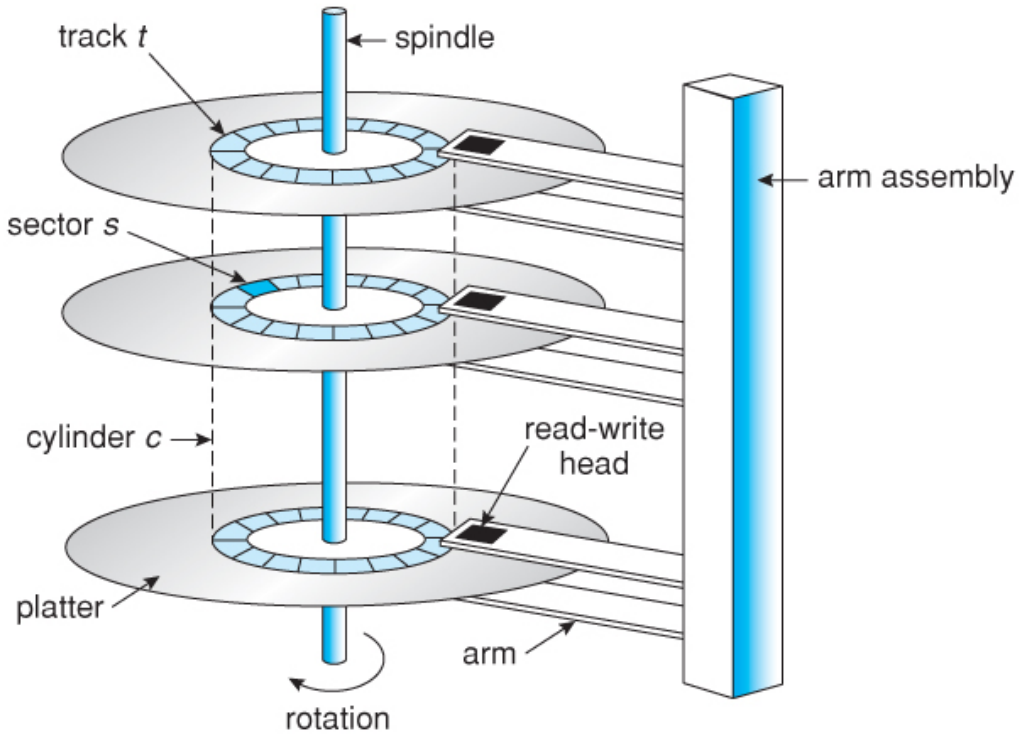
Arms are controlled by a common **arm assembly** moving simultaneously from one cylinder to another

Magnetic Disks: Storage Capacity



H = number of heads (working surfaces)

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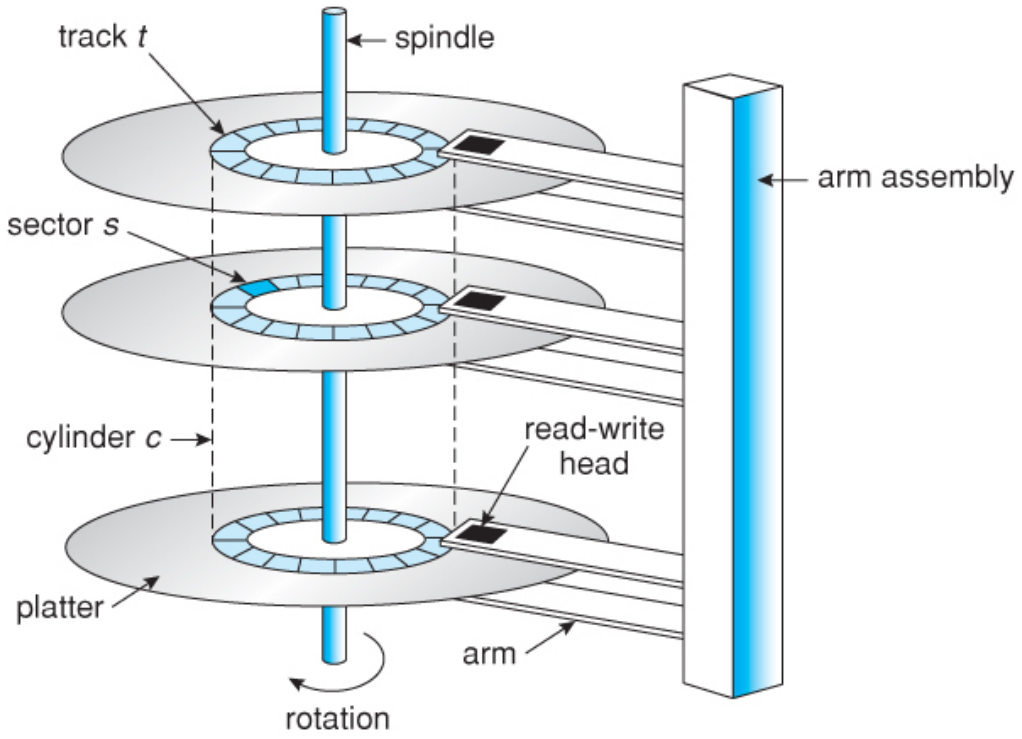

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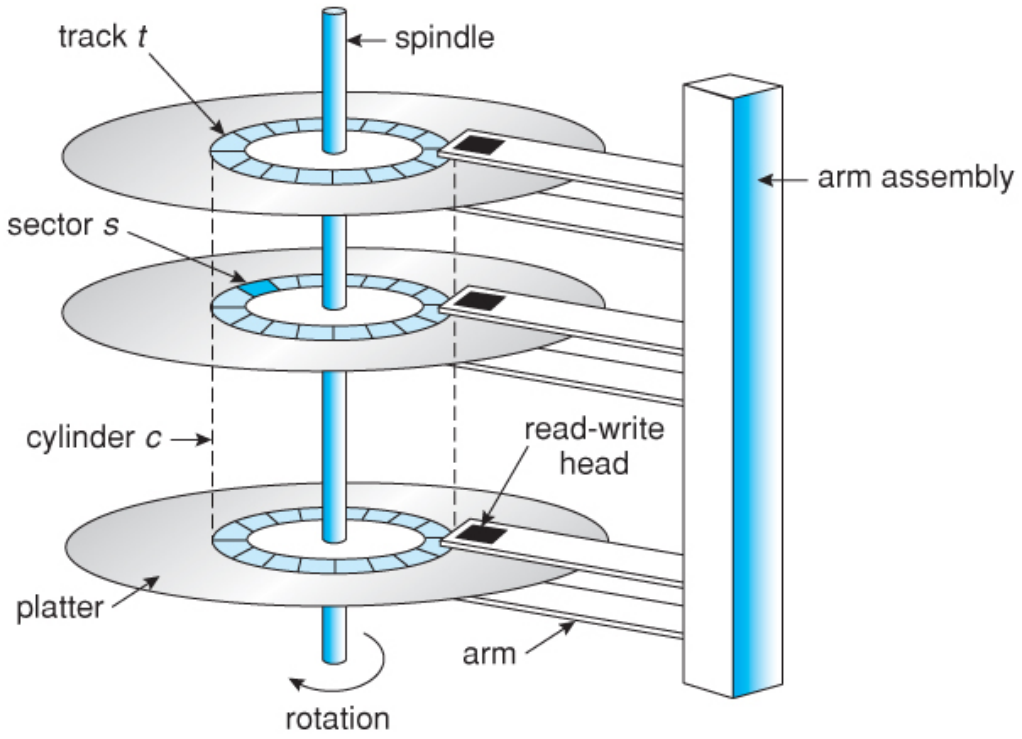

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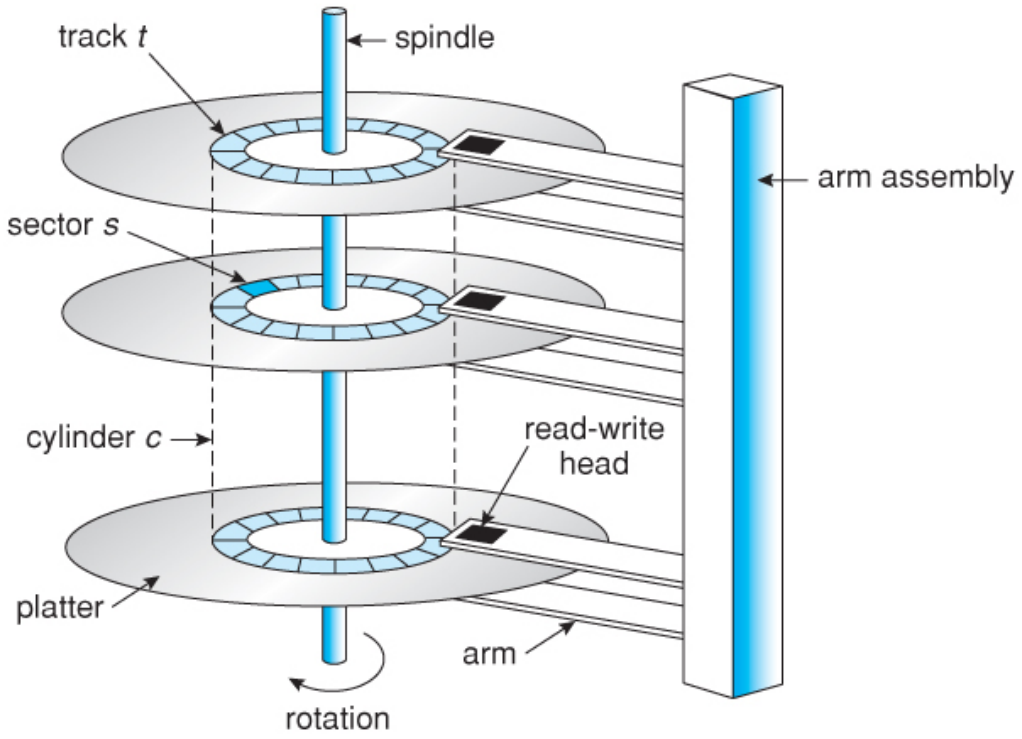

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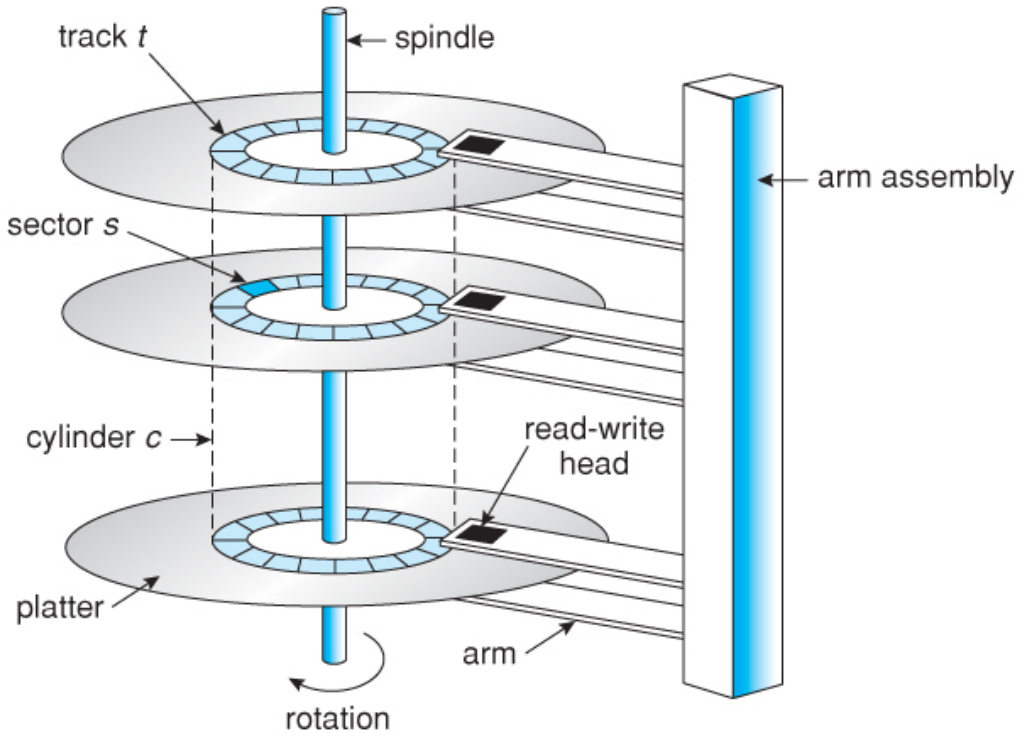

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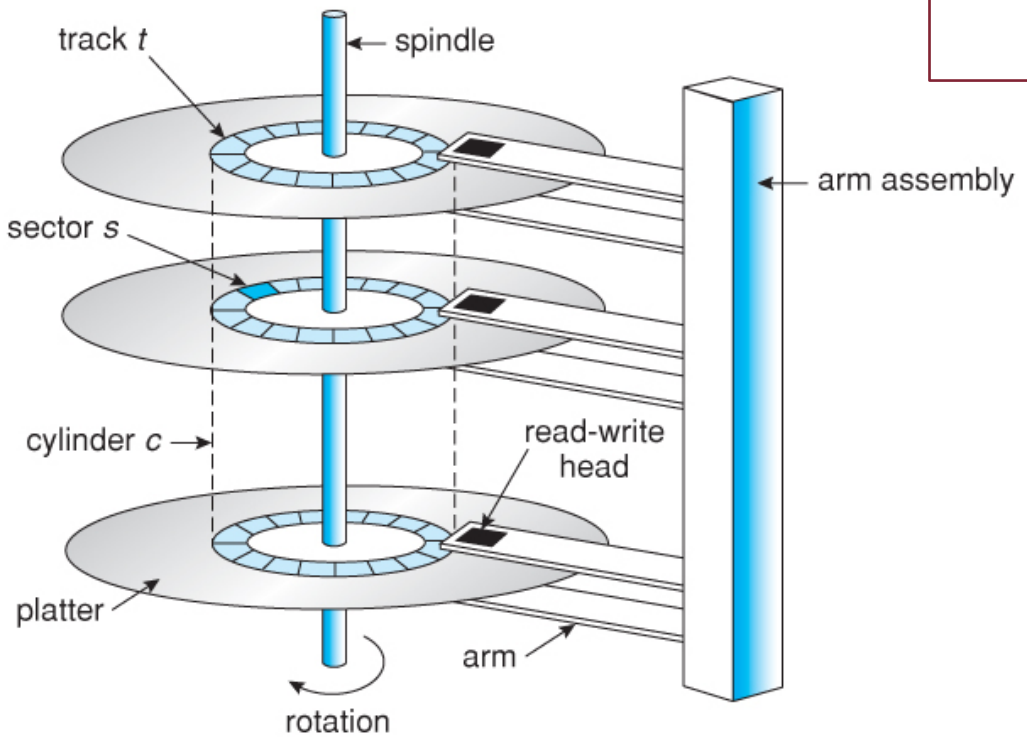
$$C = H * T * S * B$$

OVERALL CAPACITY

Magnetic Disks: Referencing



A physical block of data is specified by the (**head**, **sector**, **cylinder**) number

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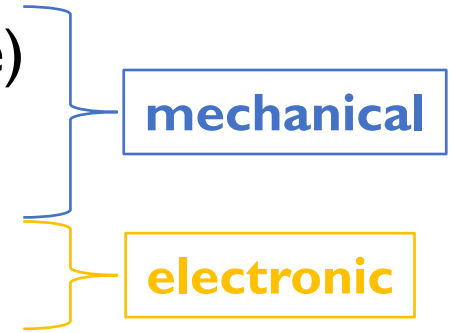

Magnetic Disks: Positioning (Seek) Time

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- Includes the time needed for the heads to settle after the move
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Bottleneck of overall disk data transfer

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The second highest bottleneck

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Data Transfer Time = Seek Time + Rotational Delay + Transfer Time

Sometimes the term **transfer rate** is used to refer to the overall data transfer time

Magnetic Disks: Structure

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- Sector 0 is the first sector of the first track of the outermost cylinder
  - The mapping proceeds in order through that track
  - Then through the rest of tracks in the same cylinder
  - Then through other cylinders (from the outermost to innermost)

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- Parking heads means to move them off the disk or to an area where no data is stored

Magnetic Disks: Interfaces

- Hard drives may be removable as floppy disks, and some are even hot-swappable
  - they can be removed while the computer is running
- Disk drives are connected to the computer via the I/O bus
- Some of the common interface formats include:
  - Enhanced Integrated Drive Electronics (EIDE);
  - Advanced Technology Attachment (ATA) and Serial ATA (SATA);
  - Universal Serial Bus (USB);
  - Fiber Channel (FC);
  - Small Computer Systems Interface (SCSI)

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- Data is transferred between the magnetic surface and onboard **cache** by the disk controller
- Finally, data is transferred from that cache to the host controller and the motherboard memory at electronic speeds

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Hardware Optimization

Minimize Data Transfer Time

- How can the OS help minimize data transfer time?
- Schedule disk operations so as to minimize head movement
- Lay out data on disk so that related data are located on close tracks
- Place commonly-used data on a specific portion of the disk
- Pick carefully the block size contained on each sector:
  - Too small → more seeks are needed to transfer the same amount of data
  - Too large → more internal fragmentation and space wasted

Disk (Head) Scheduling

Setting

The OS is getting constantly read/write disk requests from a bunch of processes, each one having its set of open files

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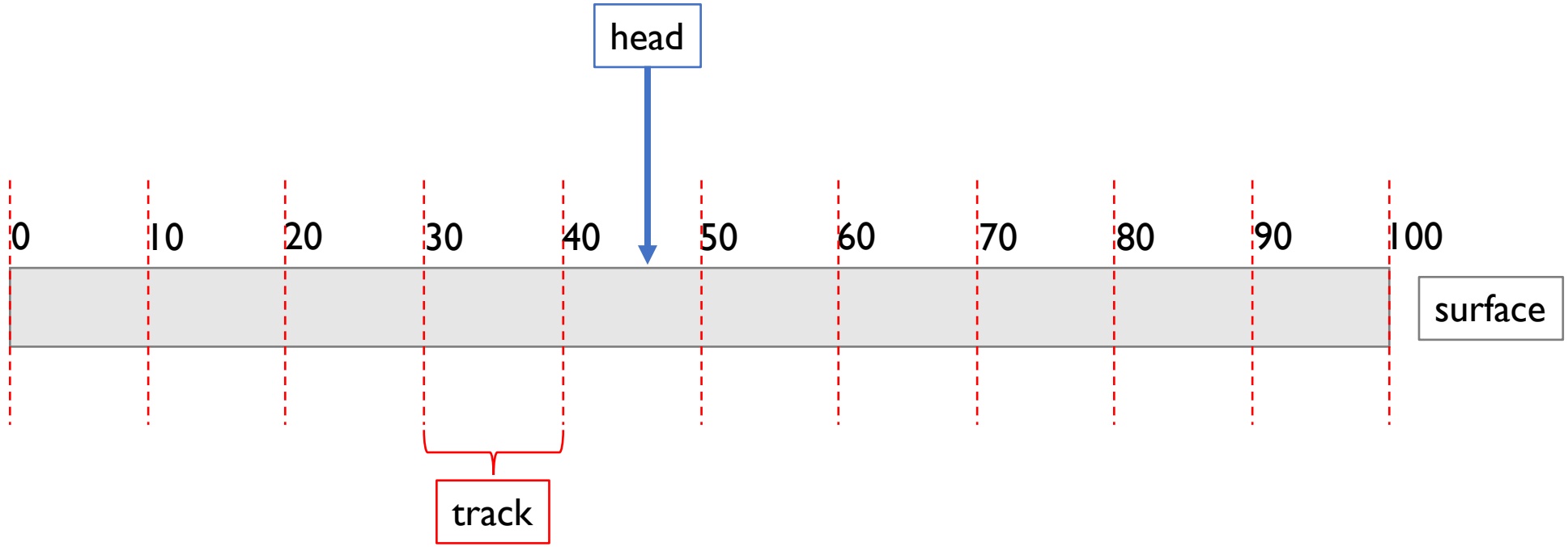
Idea

Permute the order of disk requests from the original order of arrival, so as to reduce the length and number of disk seeks

We only try minimizing the seek time not the rotational delay

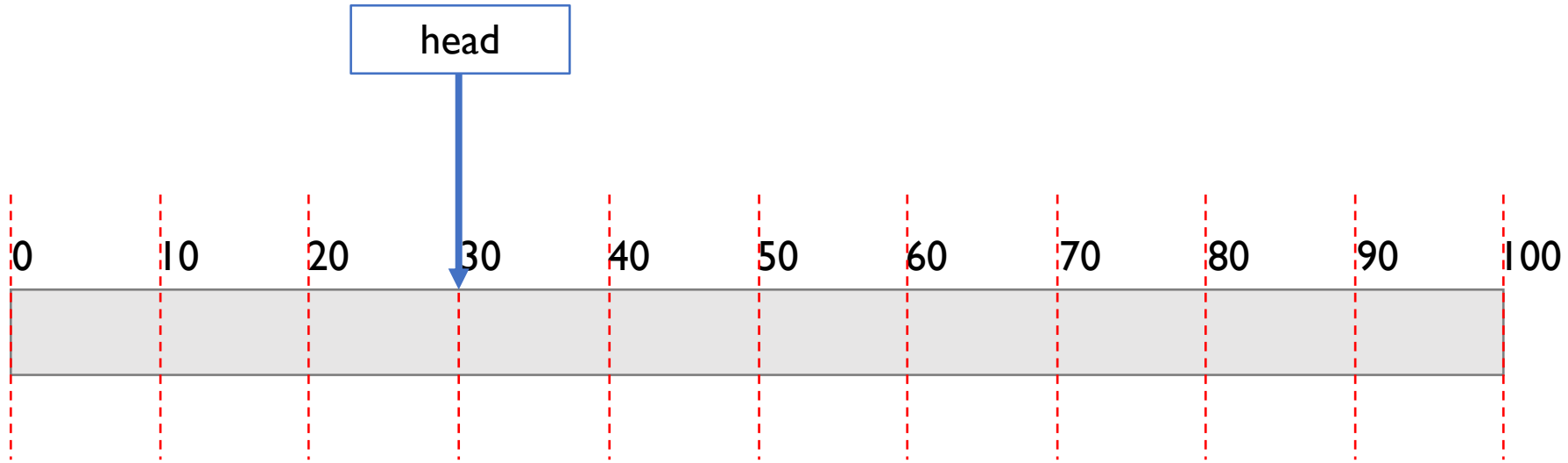
We consider track/cylinder independently of the sector

Disk Scheduling: Model



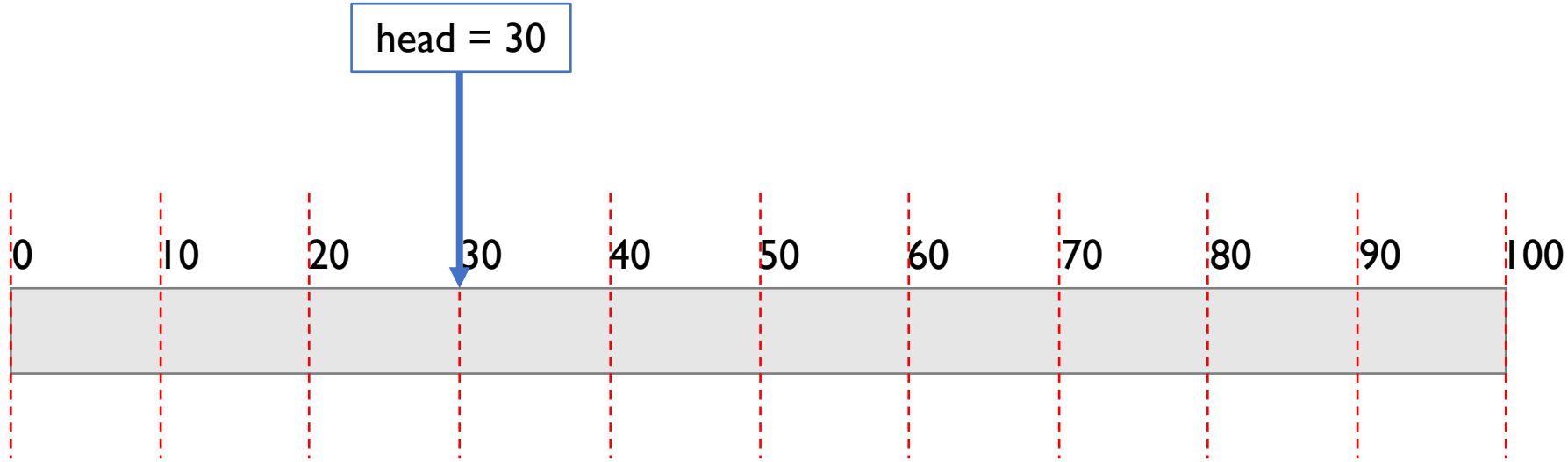
Disk Scheduling: First Come First Served (FCFS)

Serve the requests in the exact same order they arrive



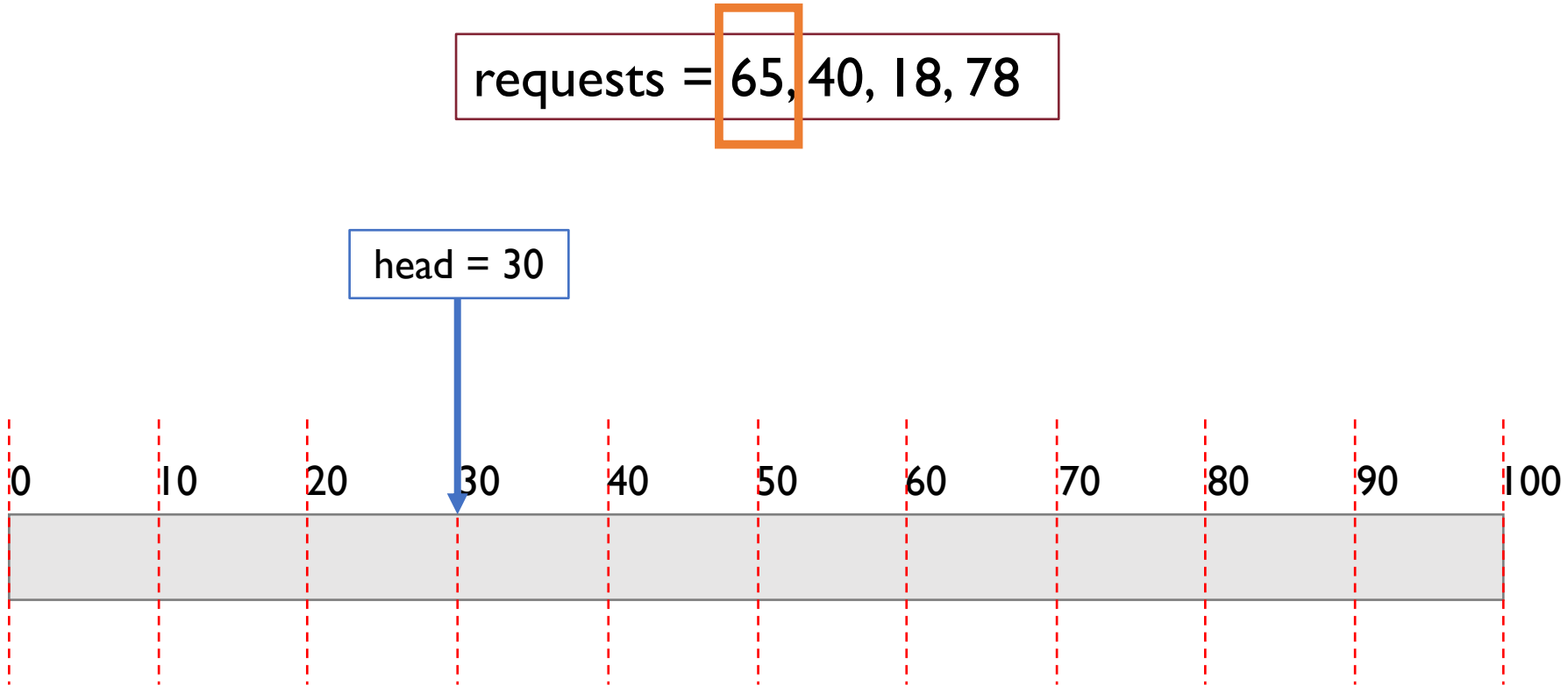
Disk Scheduling: First Come First Served (FCFS)

requests = 65, 40, 18, 78



Distance travelled = 0

Disk Scheduling: First Come First Served (FCFS)



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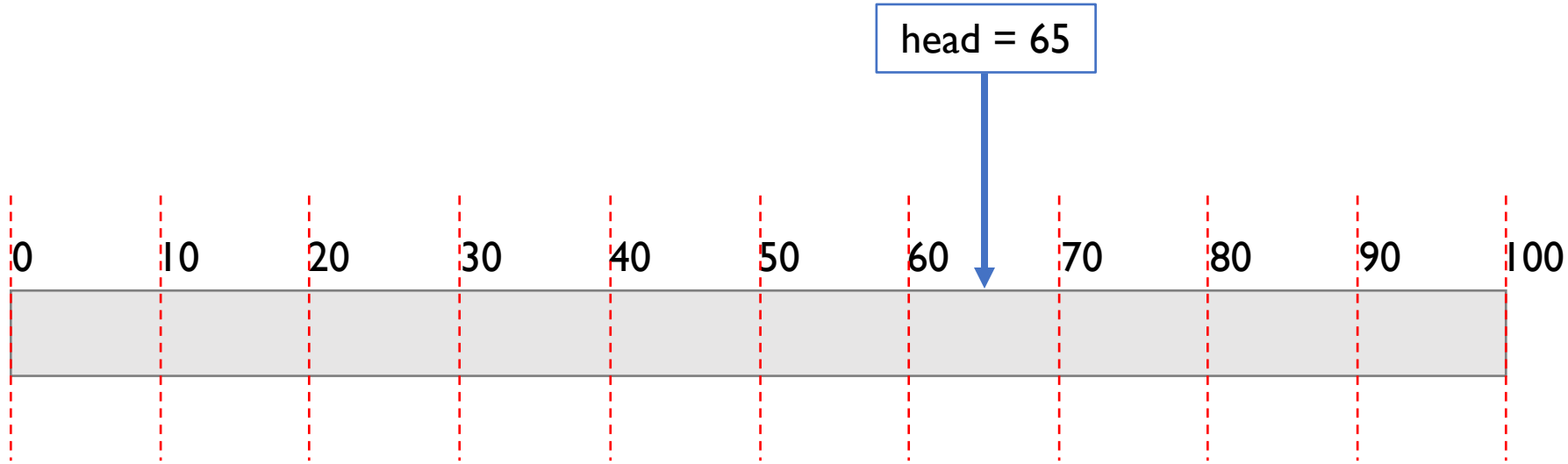

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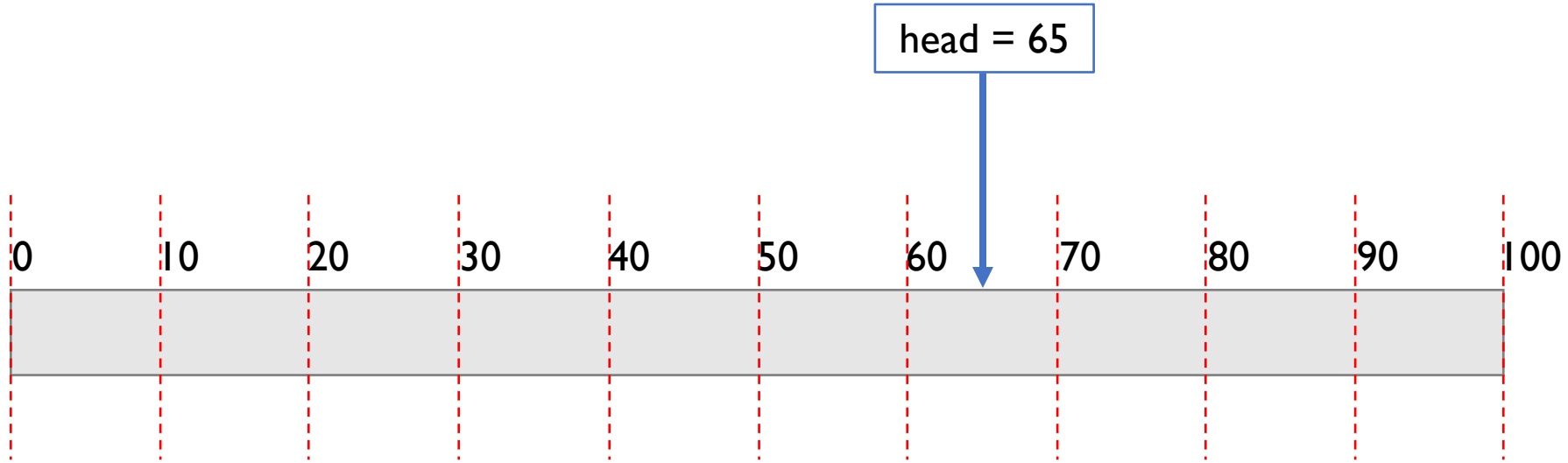
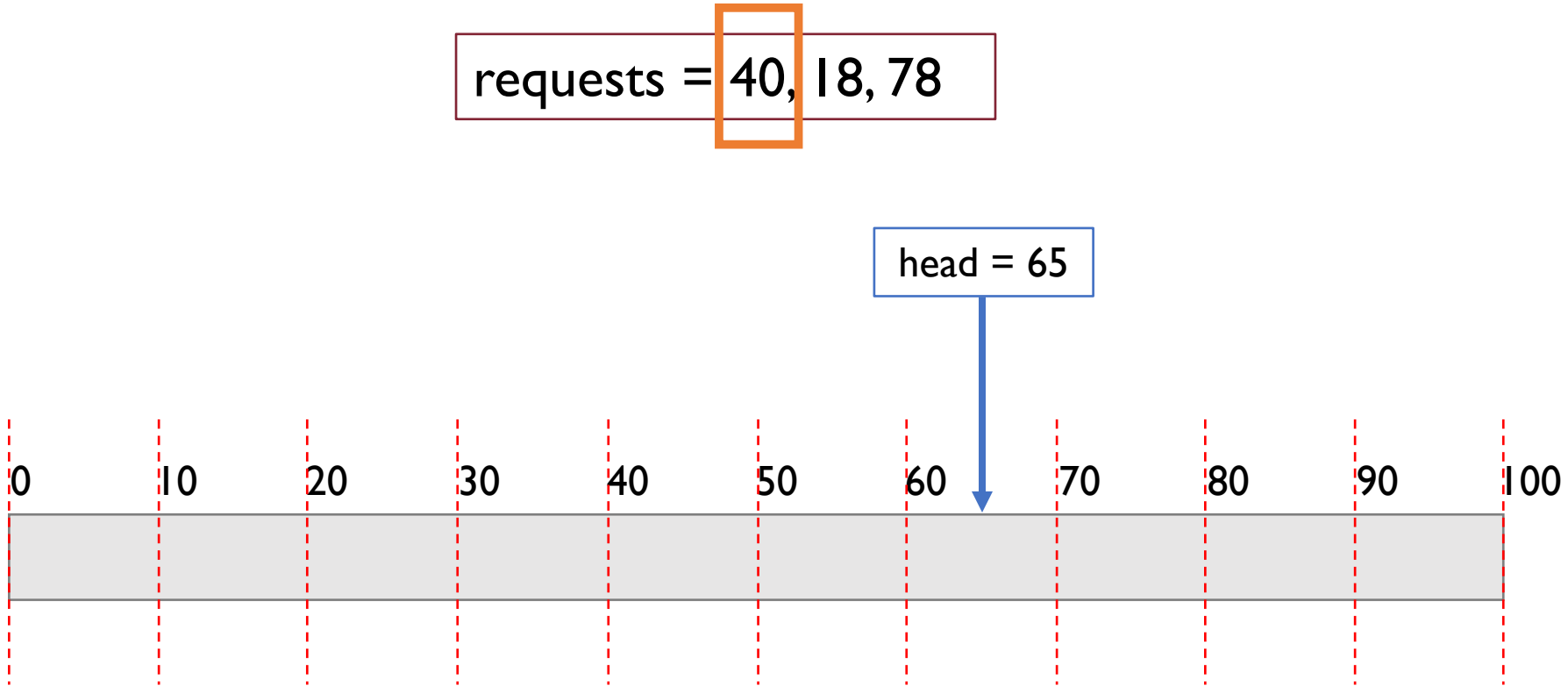


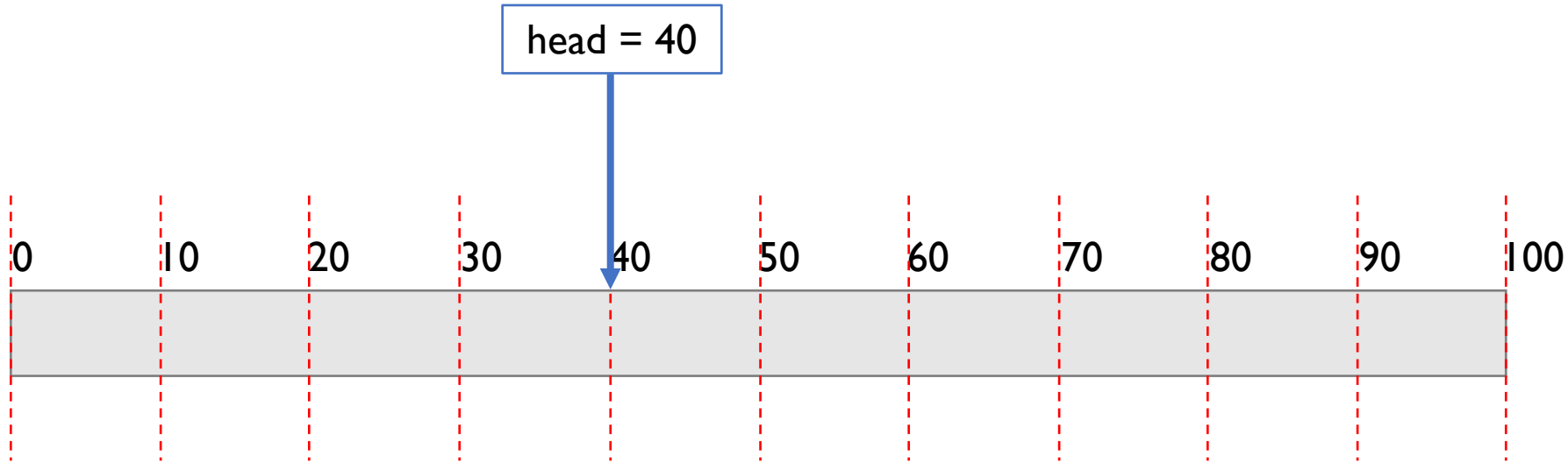
Distance travelled = 0 + |65 – 30| = 35

Disk Scheduling: First Come First Served (FCFS)



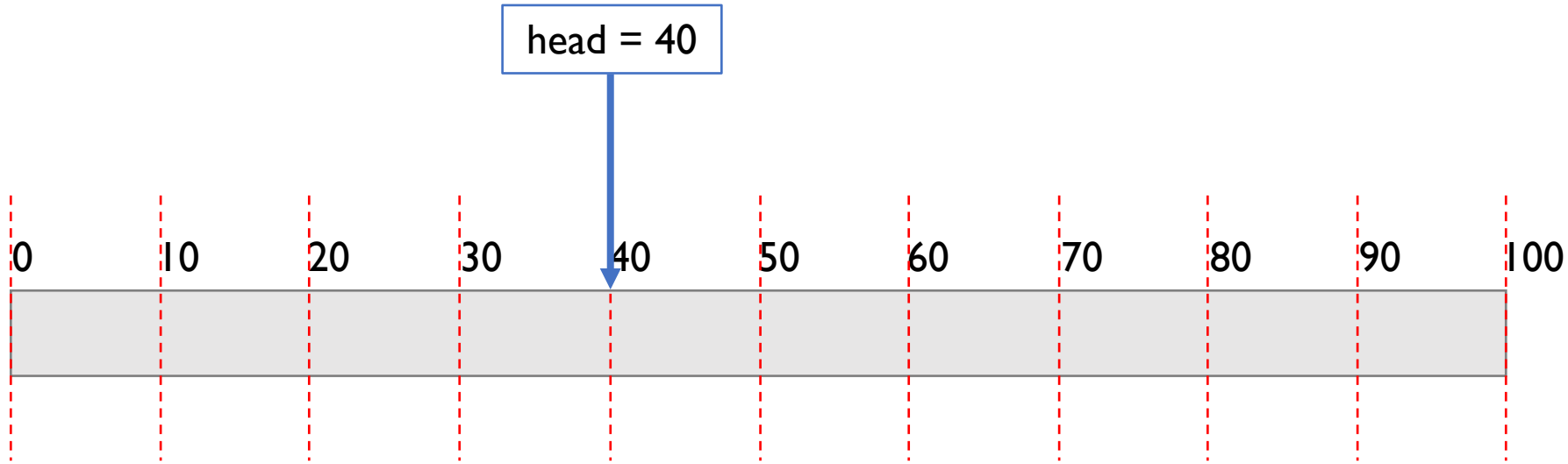
Disk Scheduling: First Come First Served (FCFS)

requests = 40, 18, 78



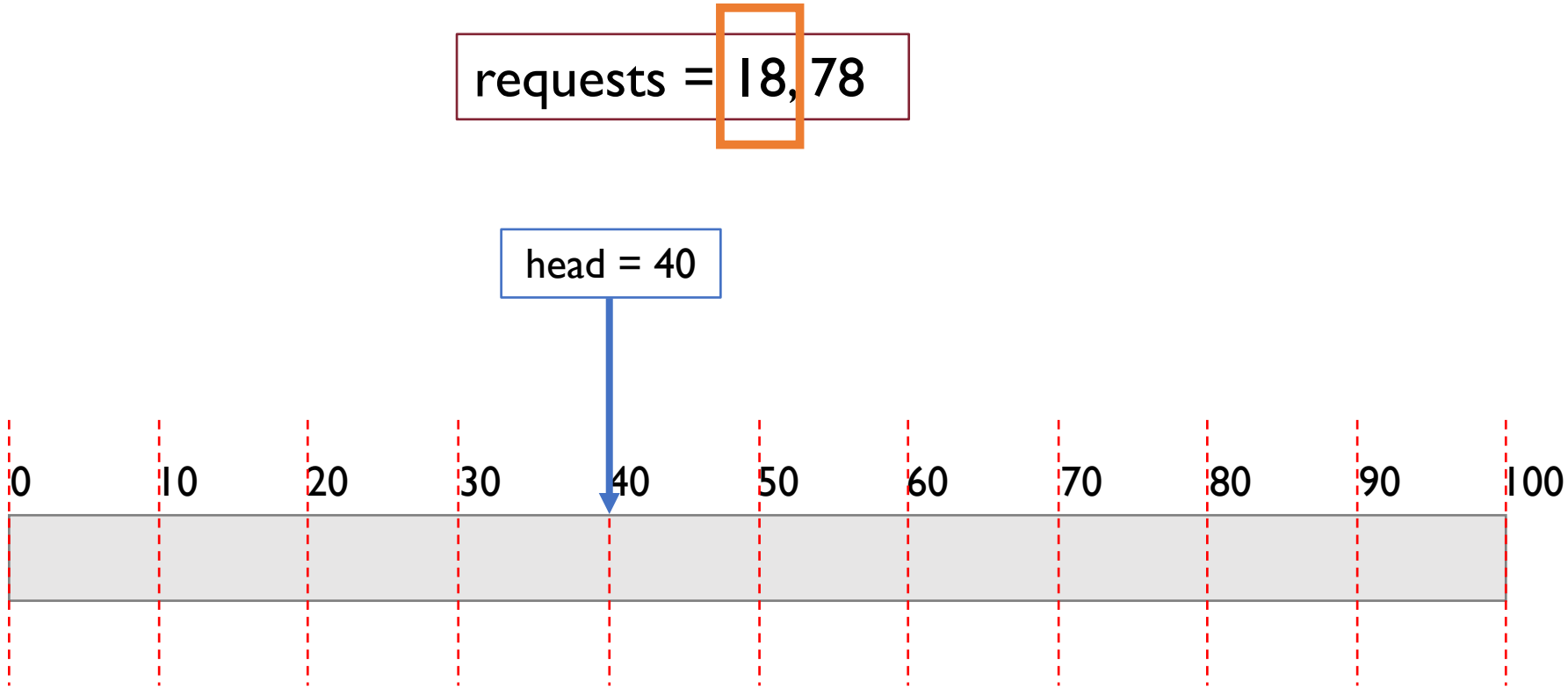
Disk Scheduling: First Come First Served (FCFS)

requests = 40, 18, 78



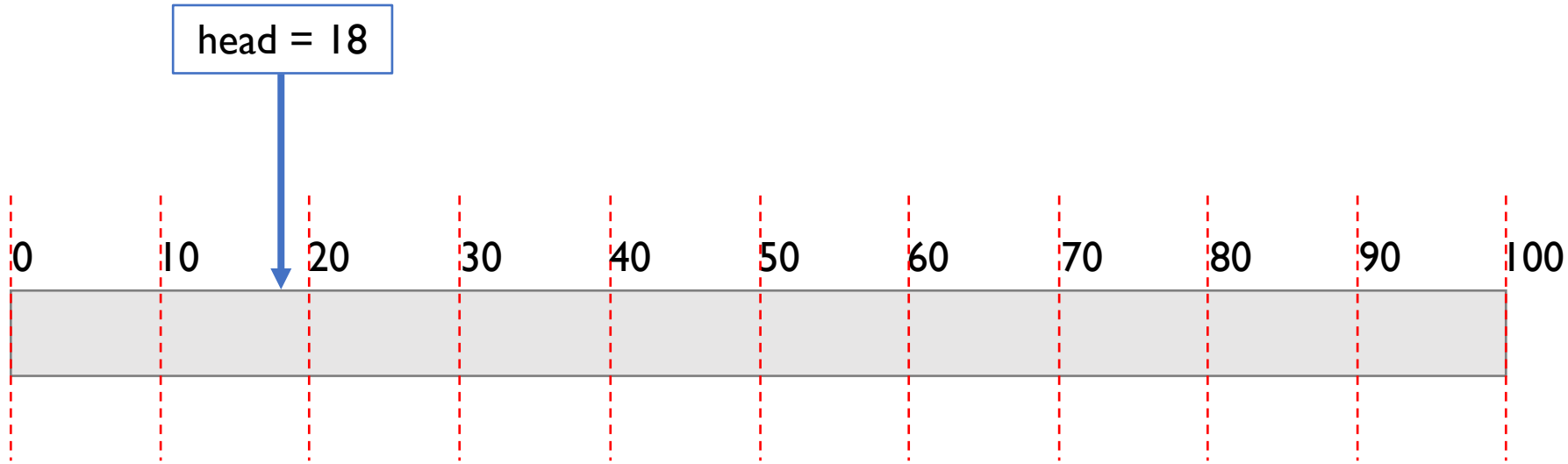
Distance travelled = 35 + |40 – 65| = 60

Disk Scheduling: First Come First Served (FCFS)



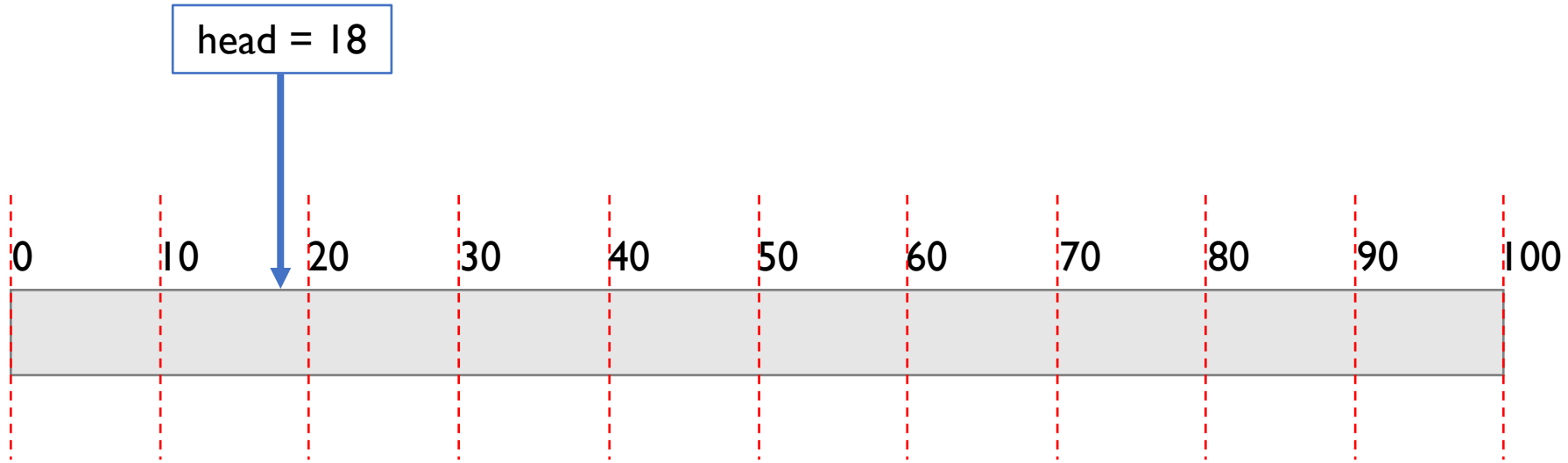
Disk Scheduling: First Come First Served (FCFS)

requests = 18, 78



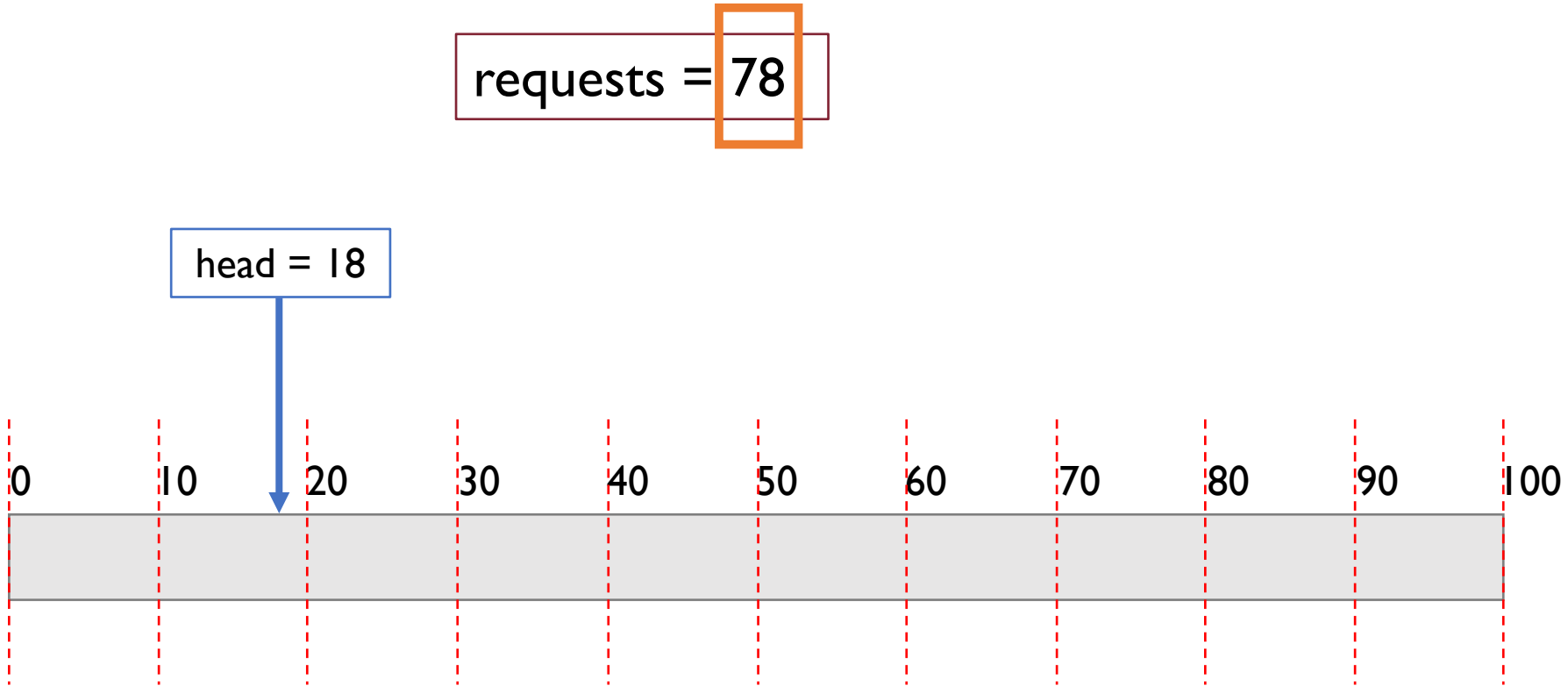
Disk Scheduling: First Come First Served (FCFS)

requests = 18, 78

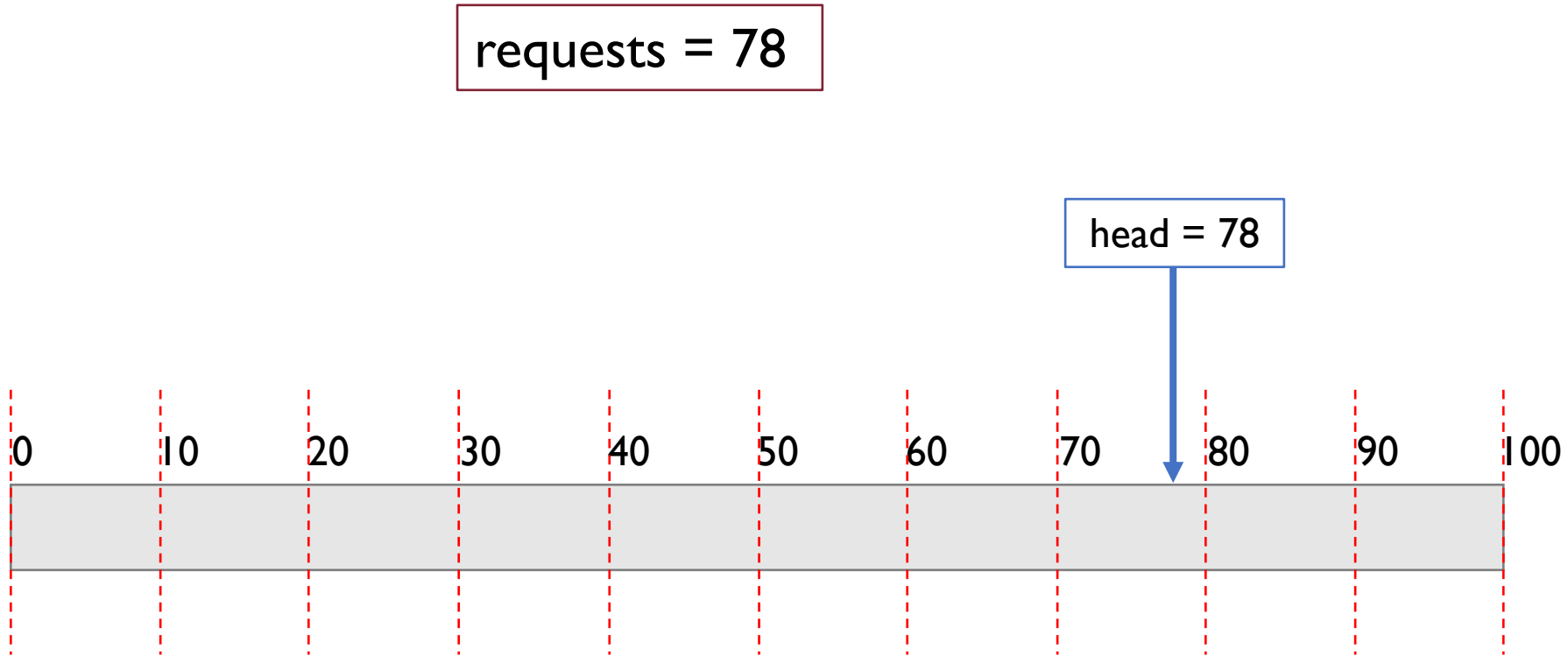


Distance travelled = 60 + |18 – 40| = 82

Disk Scheduling: First Come First Served (FCFS)

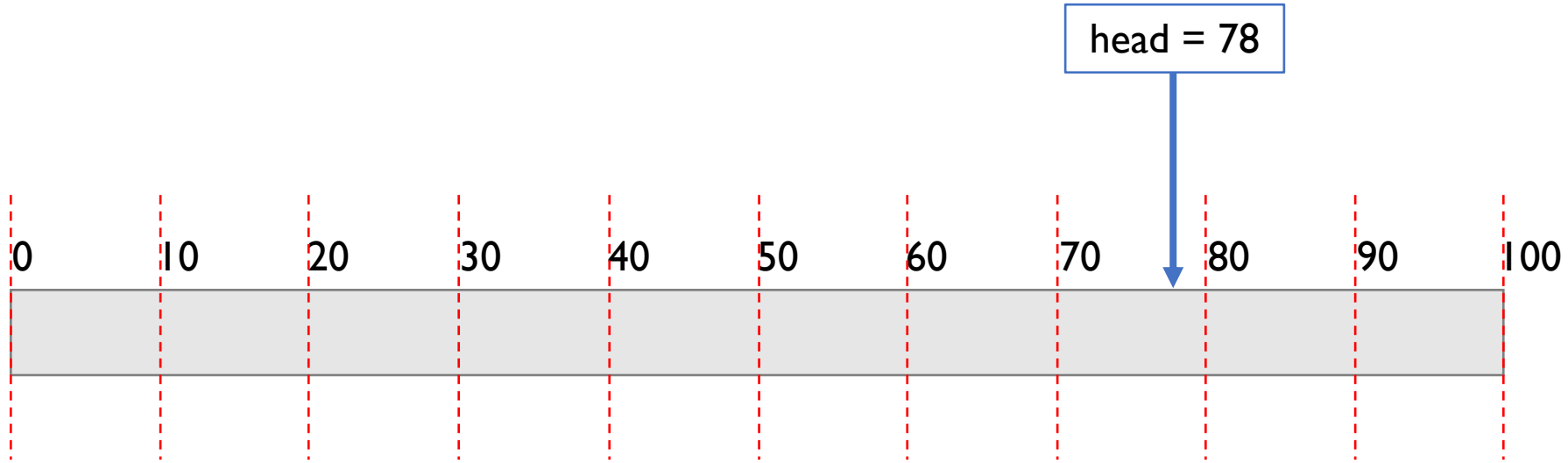


Disk Scheduling: First Come First Served (FCFS)



Disk Scheduling: First Come First Served (FCFS)

requests = 78



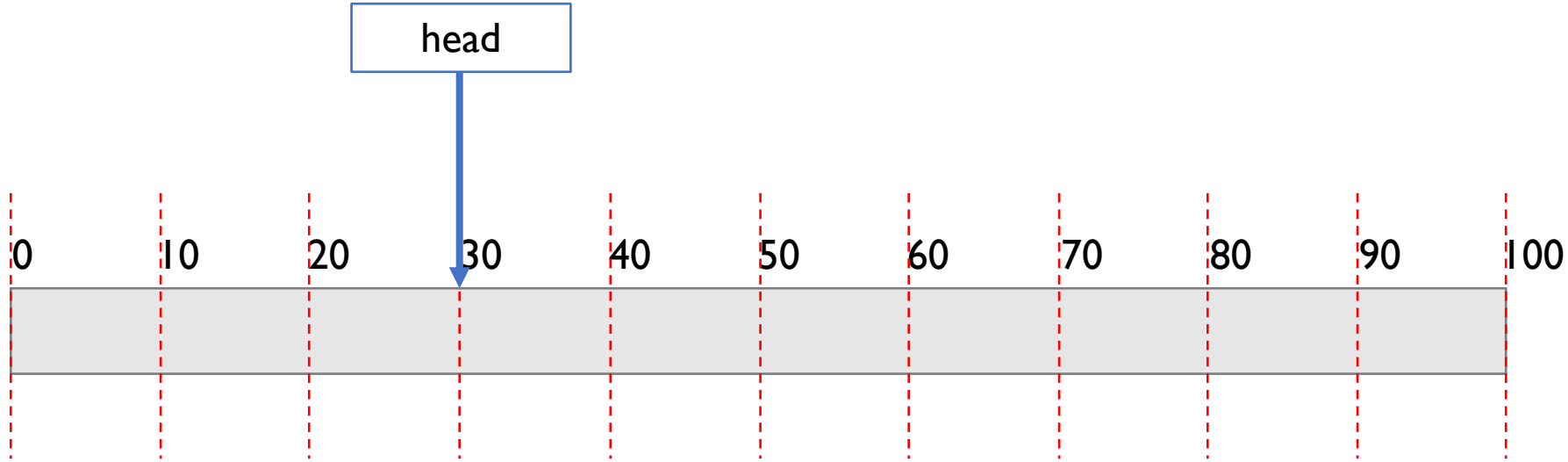
Distance travelled = 82 + |78 – 18| = **142**

FCFS: Considerations

- Easy to implement and fair
- Works quite well when systems are underloaded
- Performance may quickly deteriorate as requests increase
- Used also by SSD drives because accesses there do not require any mechanical movement
  - It's like random access to main memory

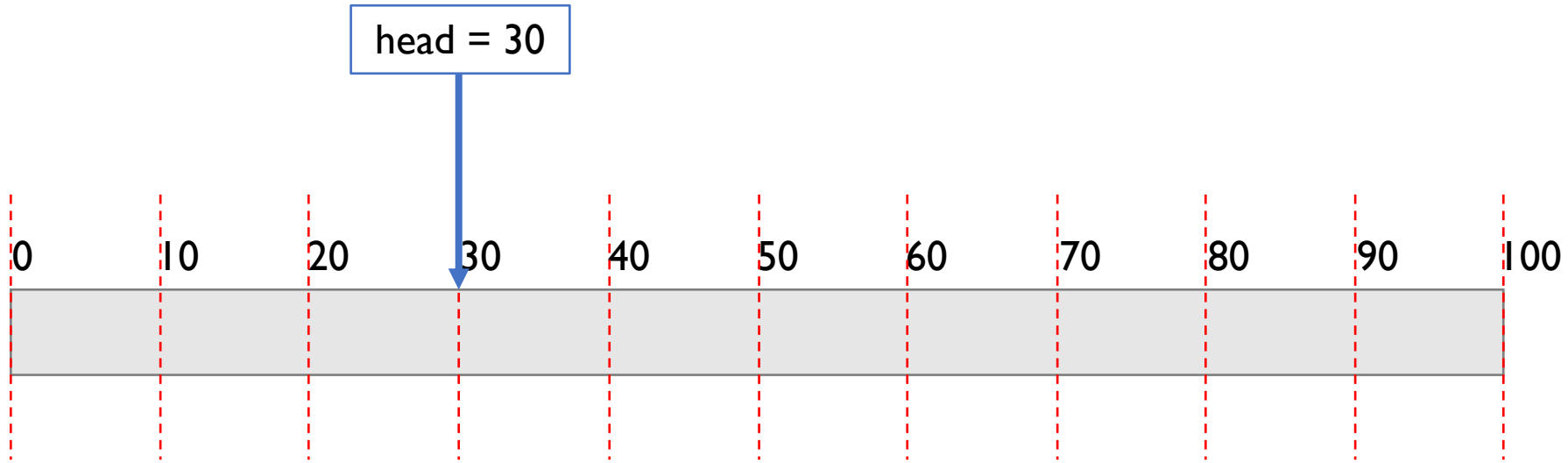
Disk Scheduling: Shortest Seek Time First (SSTF)

Greedily select the next closest request



Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 40, 18, 78

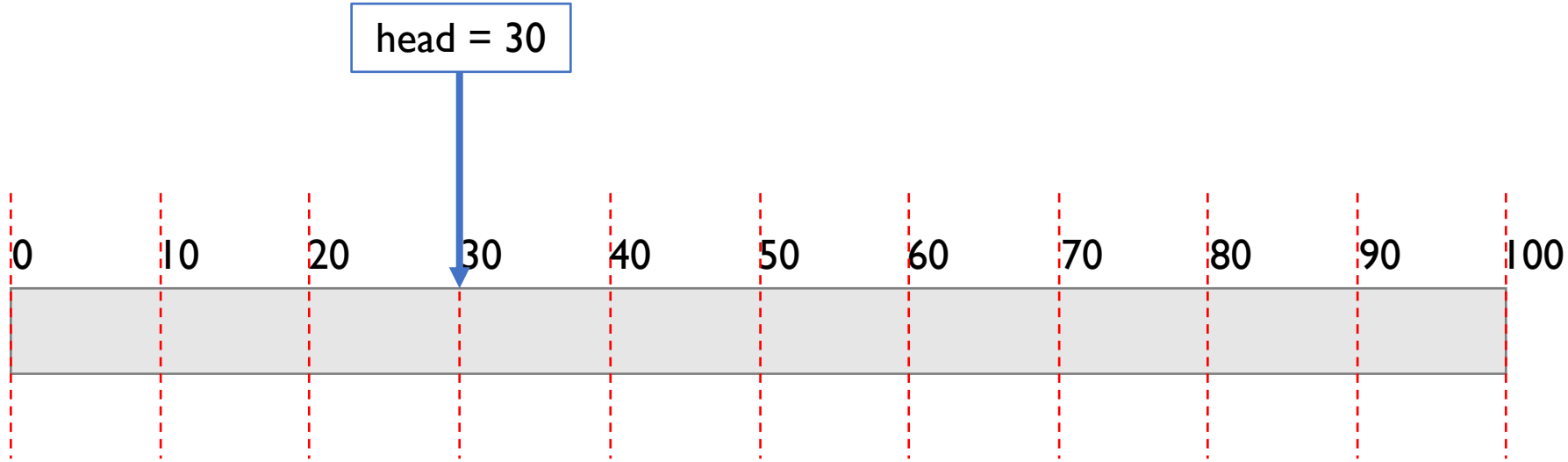


Distance travelled = 0

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 40, 18, 78

Closest request = 40



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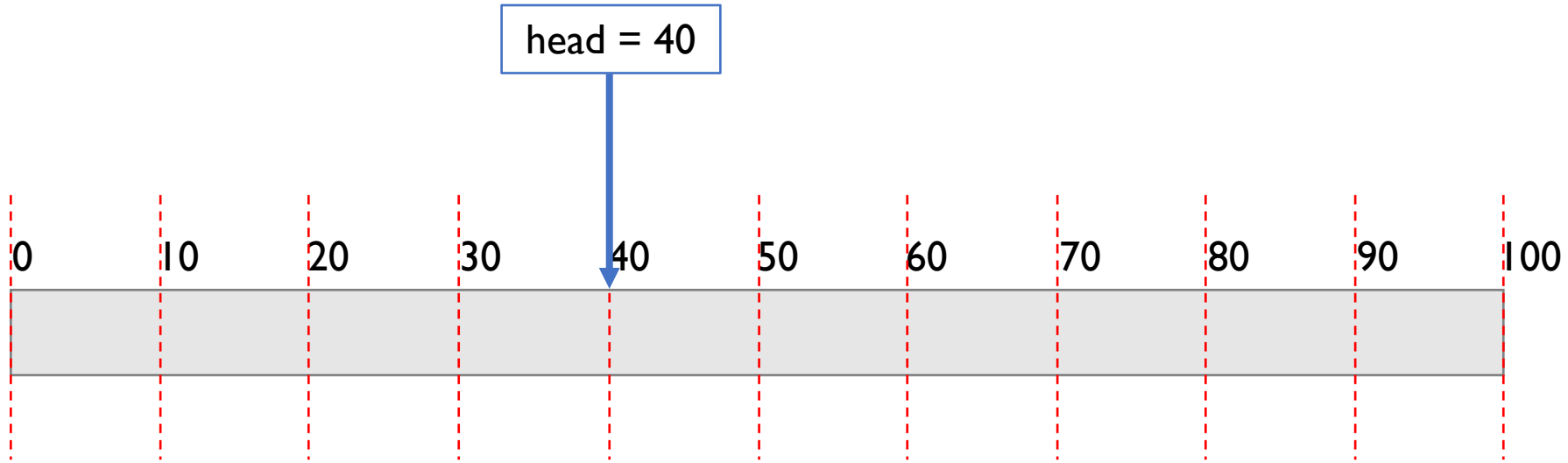

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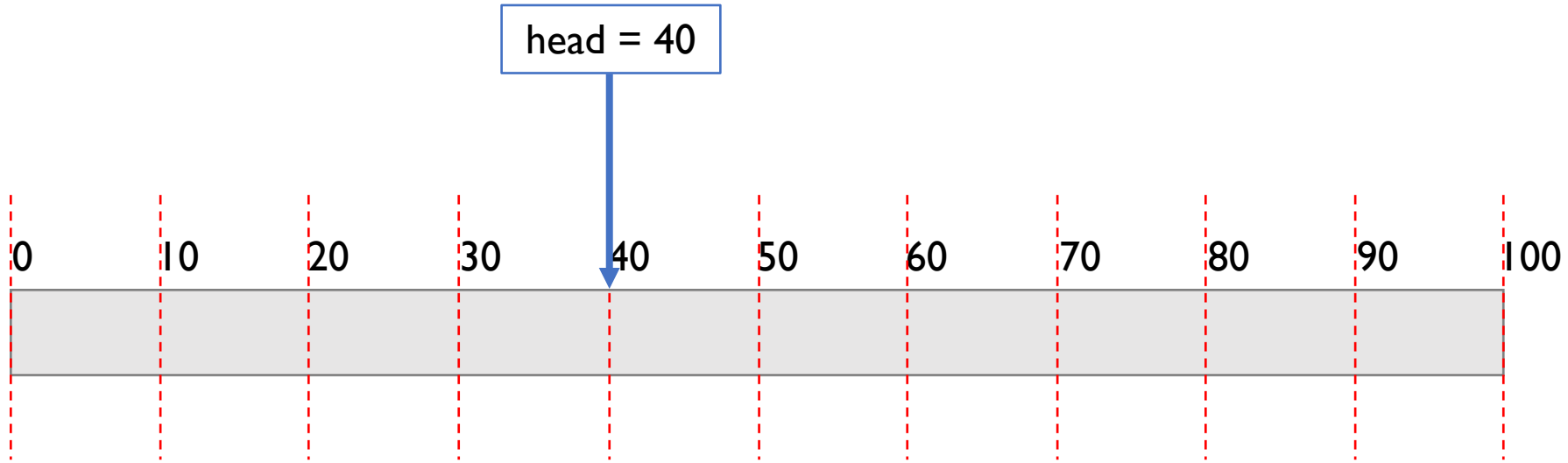
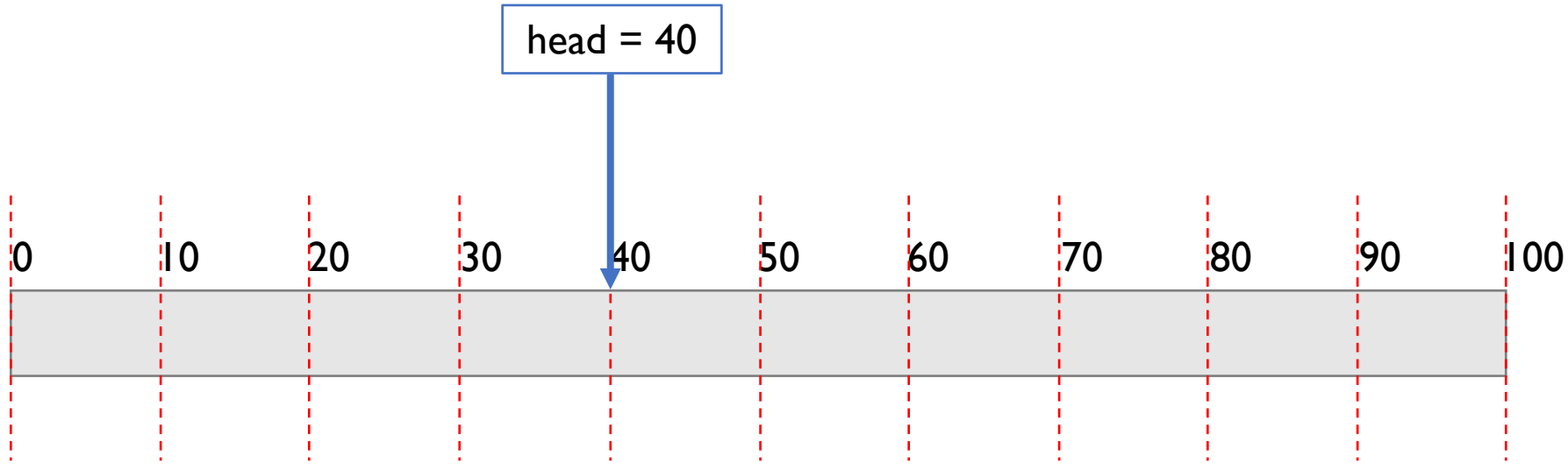


Distance travelled = 0 + |40 – 30| = 10

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 18, 78

Closest request = 18



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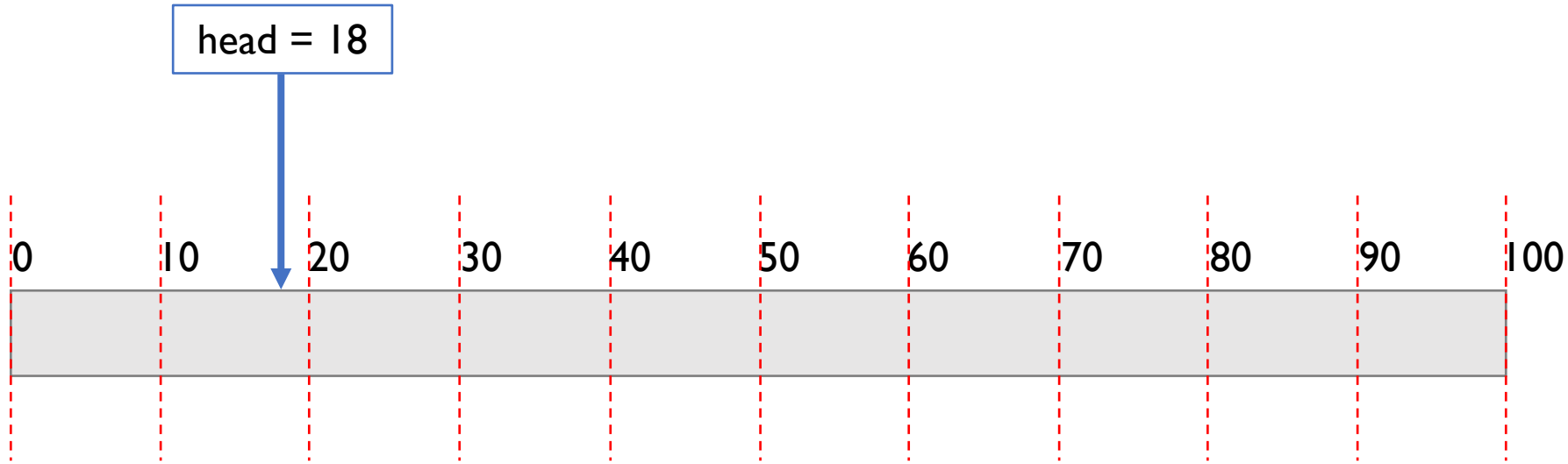

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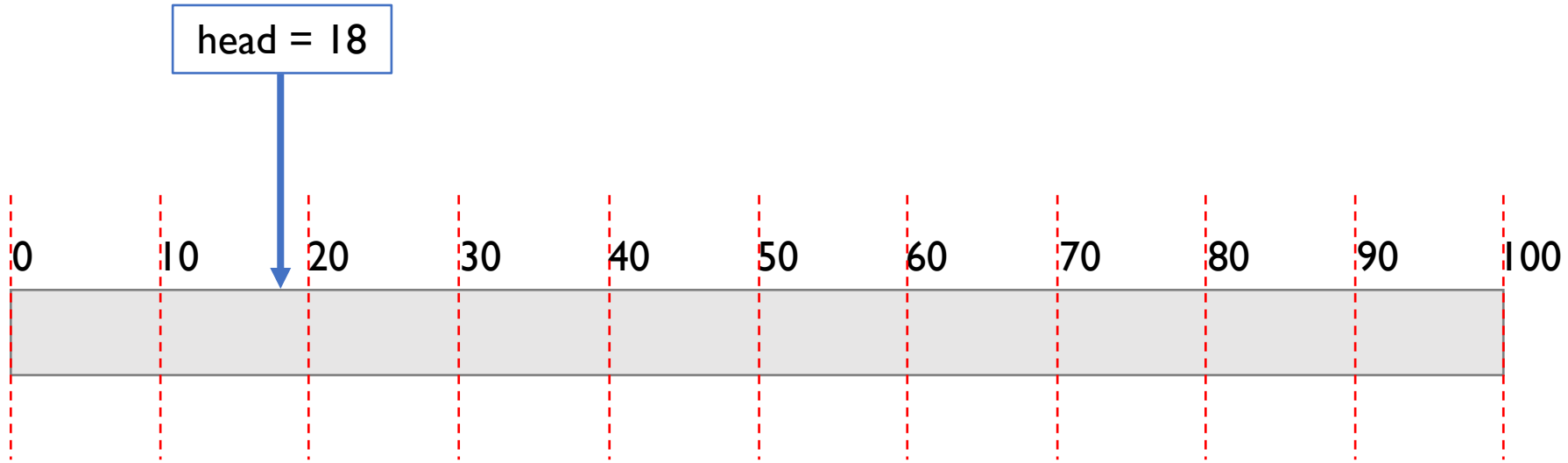
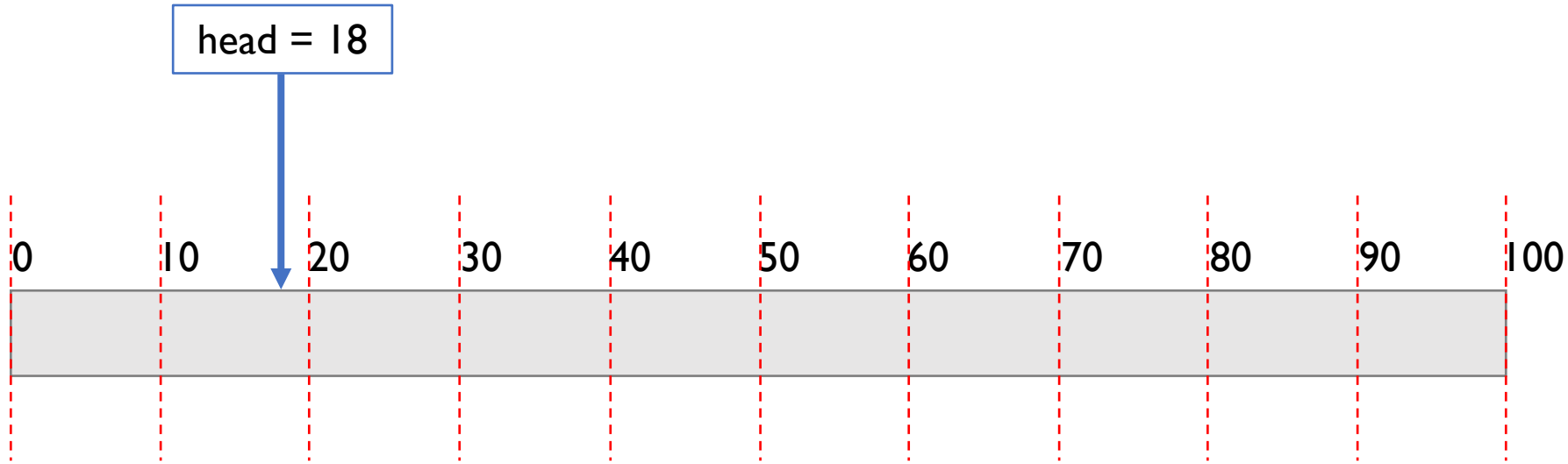


Distance travelled = 10 + |18 – 40| = 32

Disk Scheduling: Shortest Seek Time First (SSTF)

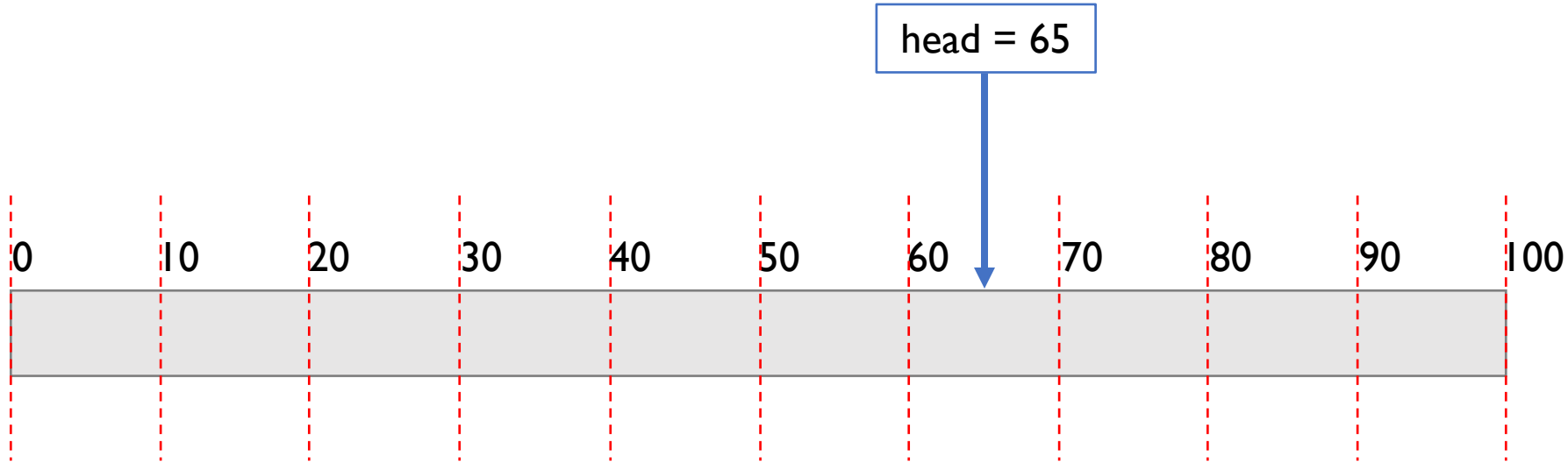
requests = 65, 78

Closest request = 65



Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 78



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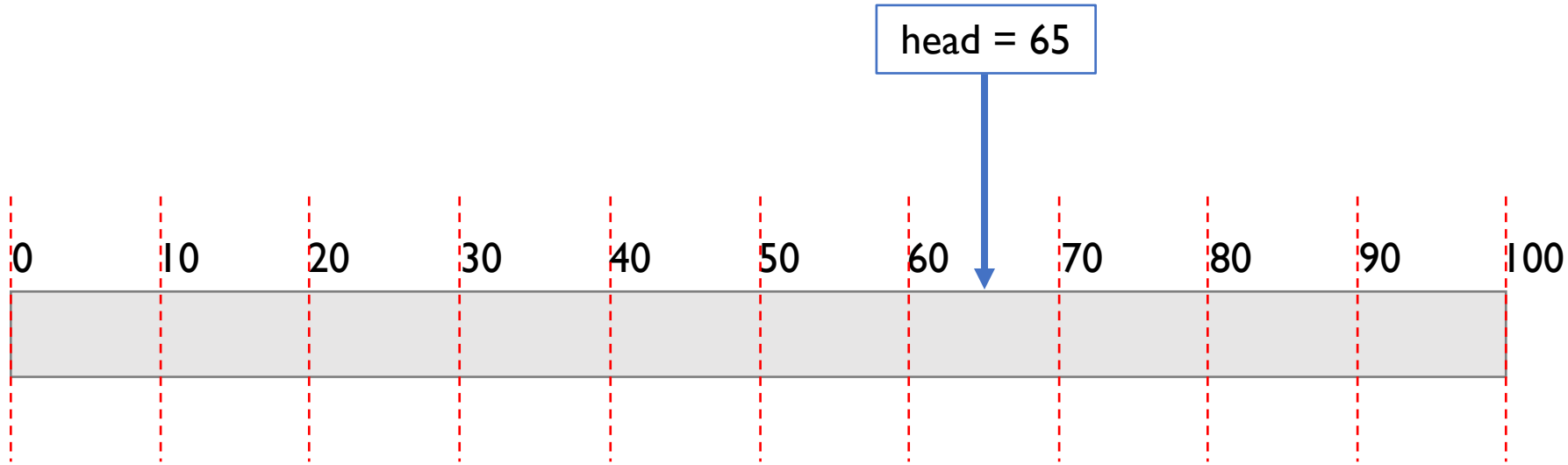
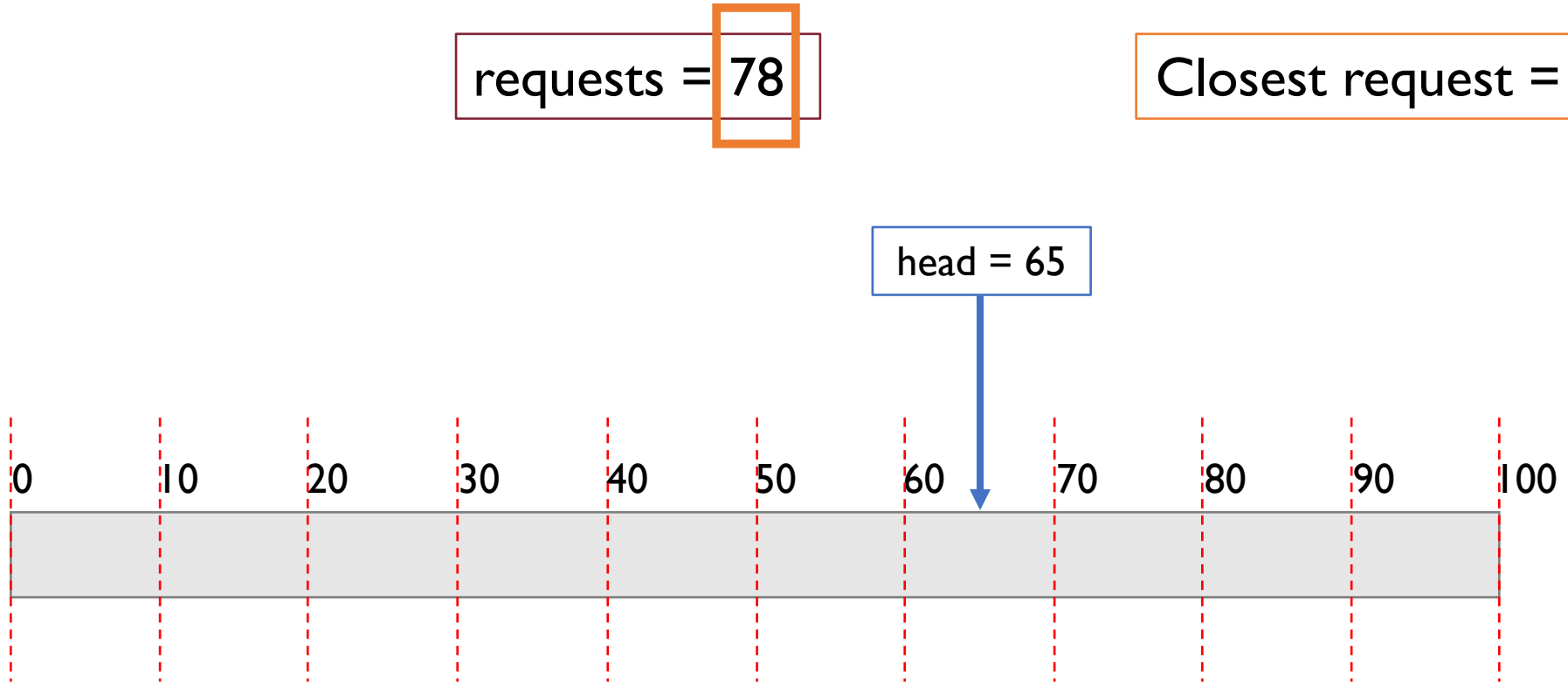
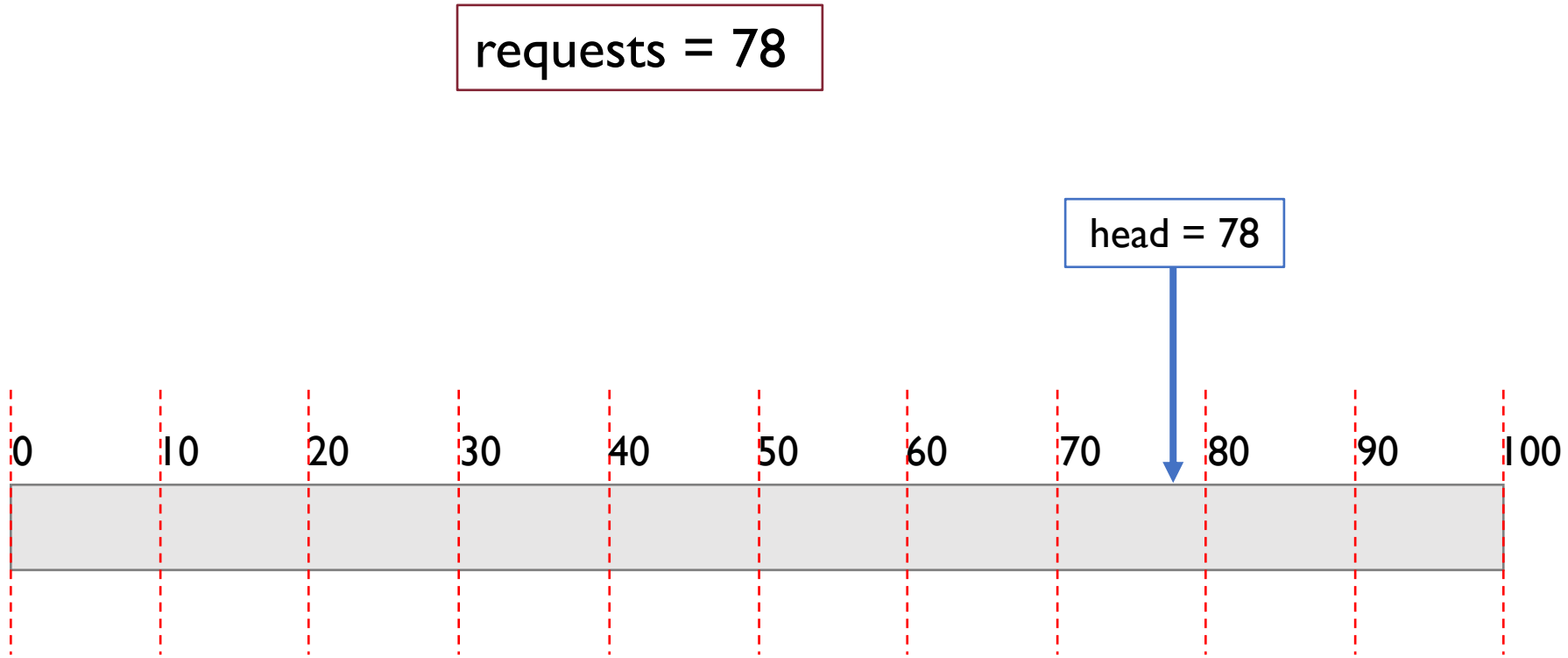


Distance travelled = 32 + |65 – 18| = 79

Disk Scheduling: Shortest Seek Time First (SSTF)

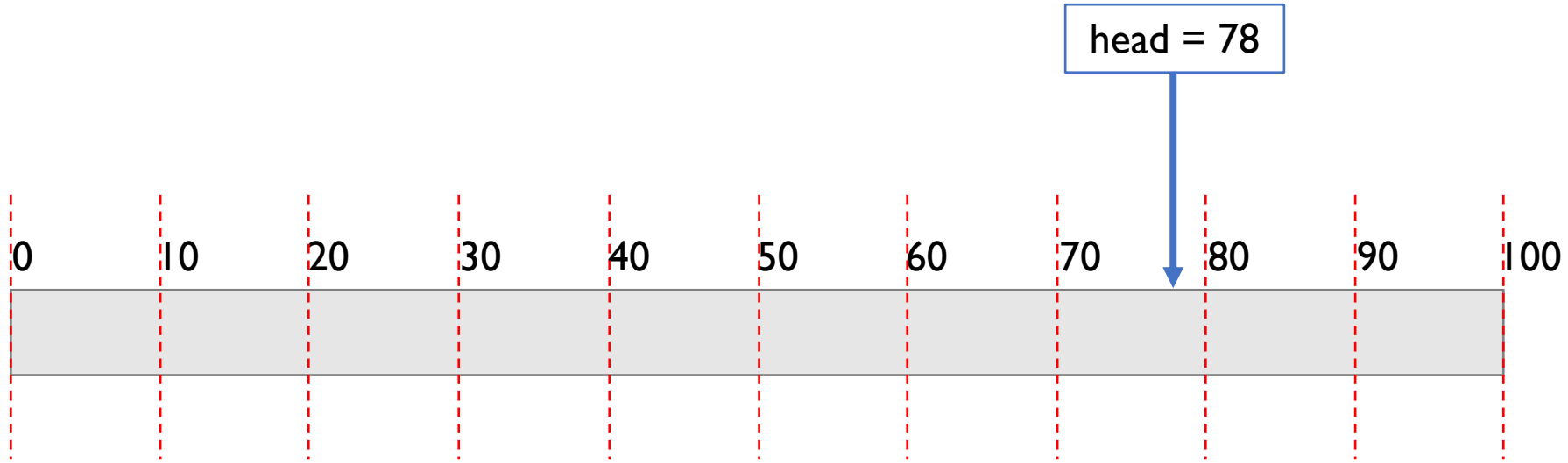


Disk Scheduling: Shortest Seek Time First (SSTF)



Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 78



Distance travelled = 79 + |78 – 65| = **92**

SSTF: Considerations

- Implemented by keeping a doubly-linked list of requests (sorted)

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  - Example: head = 50; requests = 10, 20, 30, 40, 61

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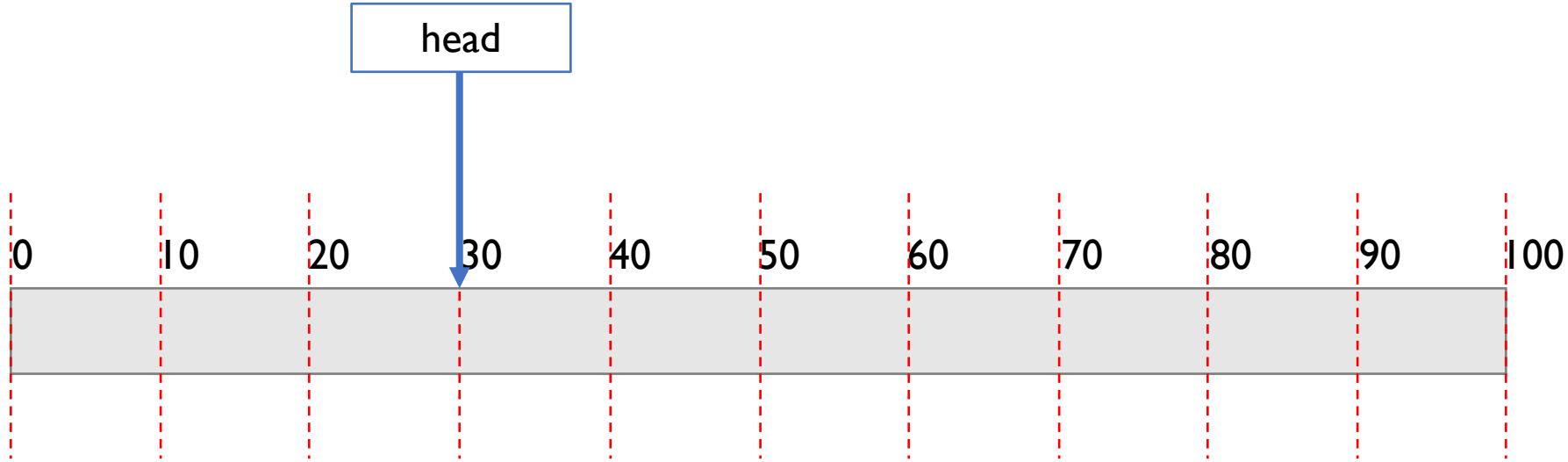
  - Example: head = 50; requests = 10, 20, 30, 40, 61

SSTF only looks one step ahead

Disk Scheduling: SCAN

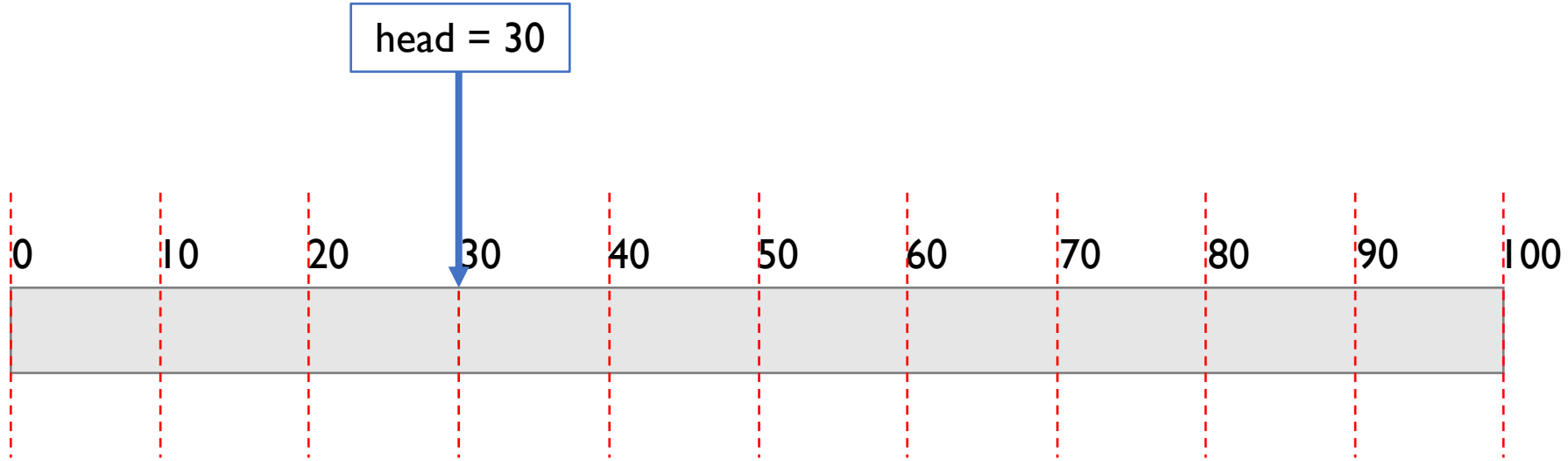
Head moves back and forth acoss the disk (e.g., track 0 to 100, 100 to 0, etc.)

Requests are served as the head passes (**elevator**)



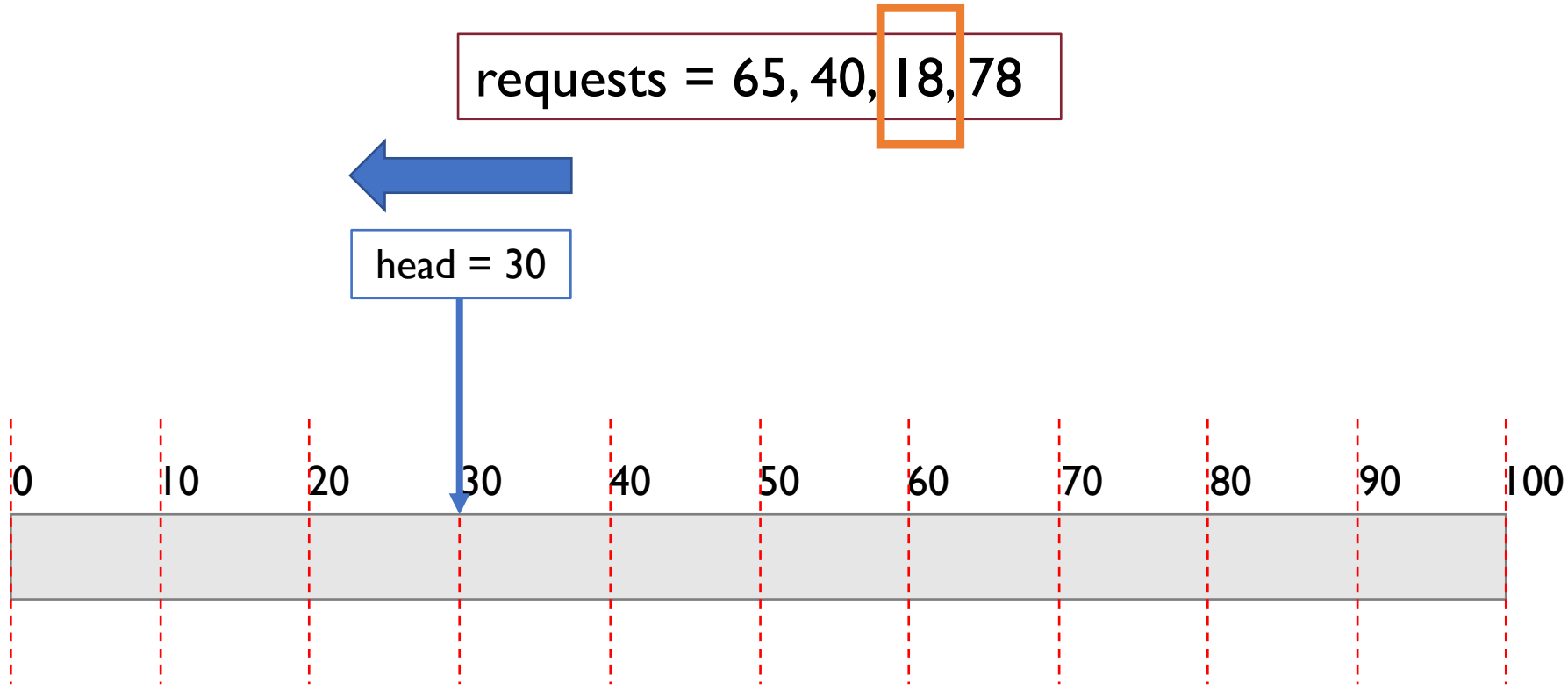
Disk Scheduling: SCAN

requests = 65, 40, 18, 78



Distance travelled = 0

Disk Scheduling: SCAN



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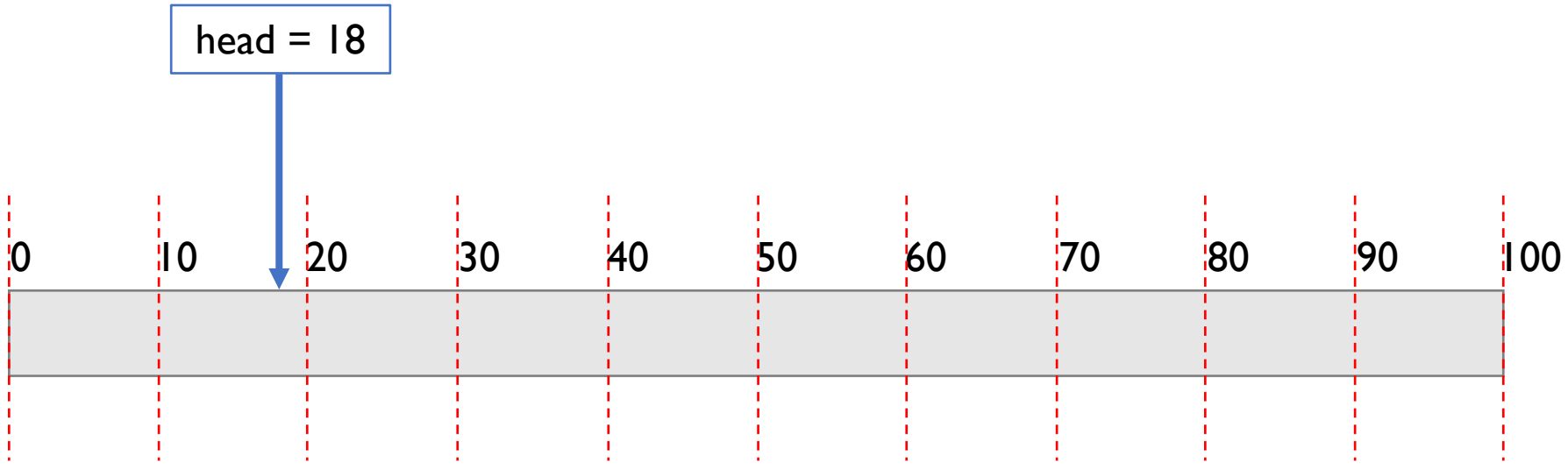
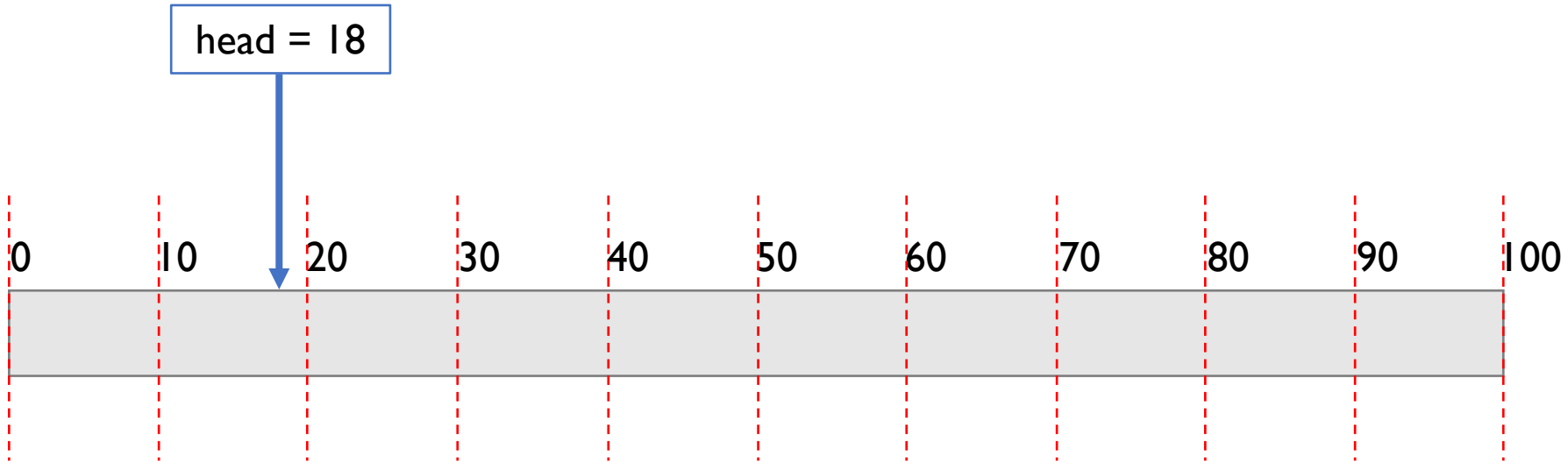


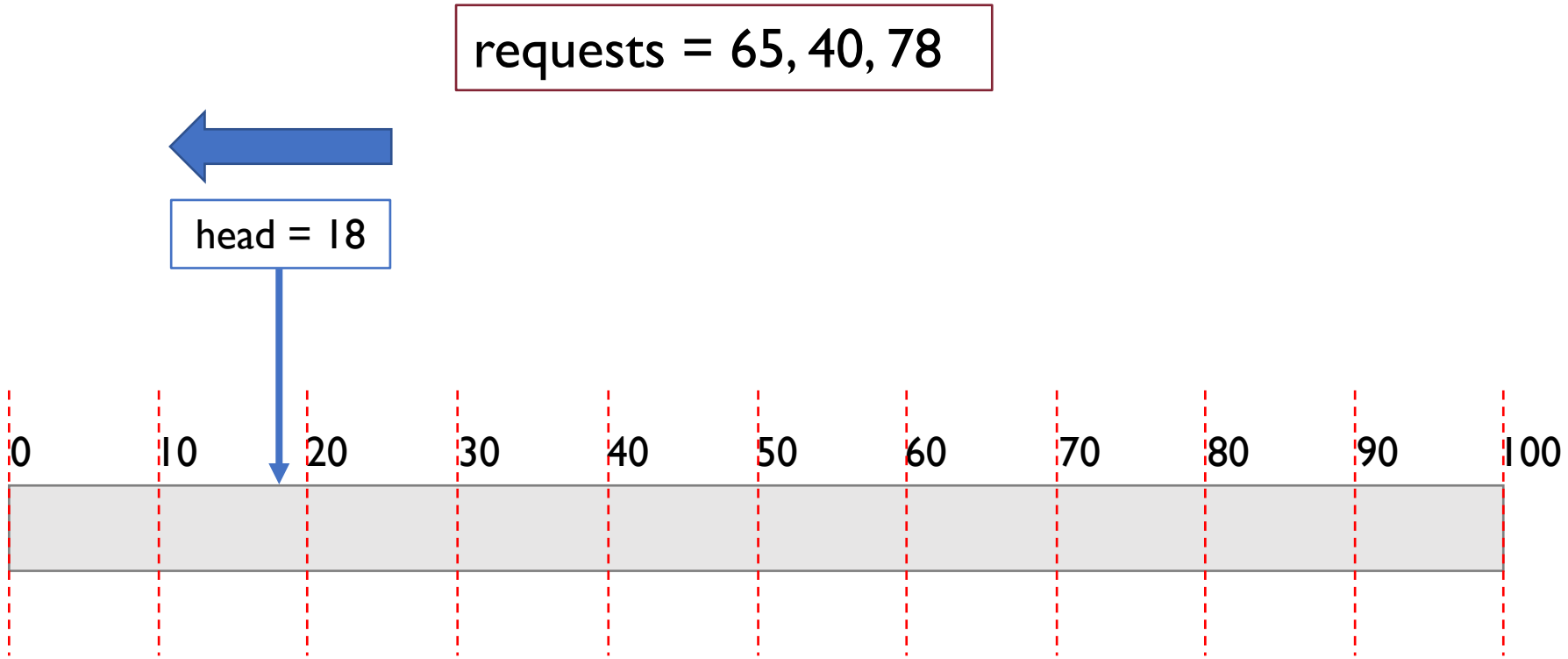
Disk Scheduling: SCAN

requests = 65, 40, 18, 78



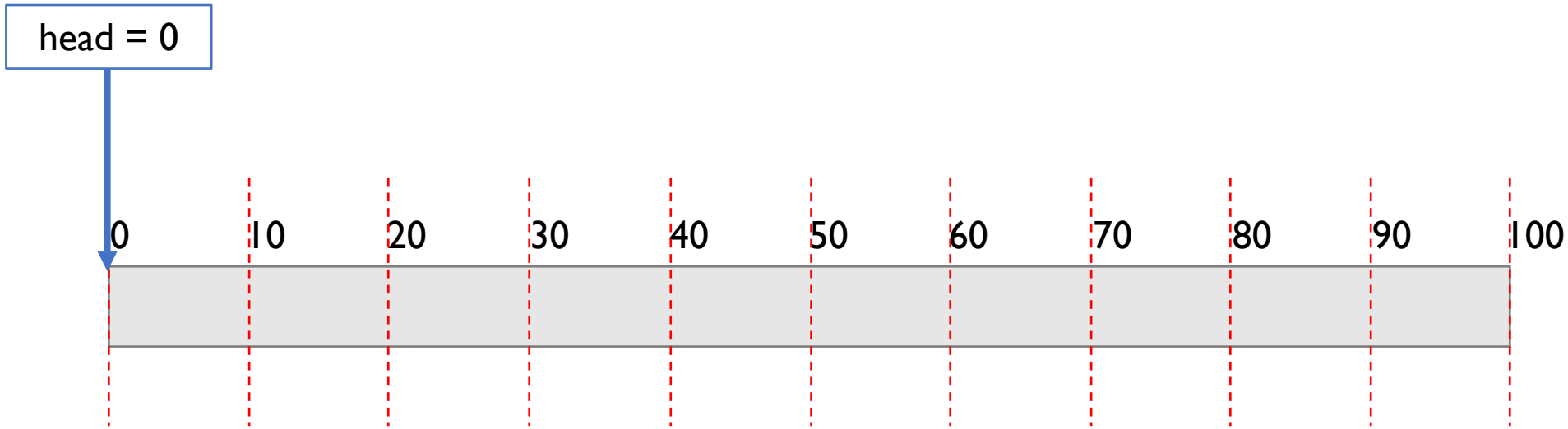
Distance travelled = 0 + |18 – 30| = 12

Disk Scheduling: SCAN



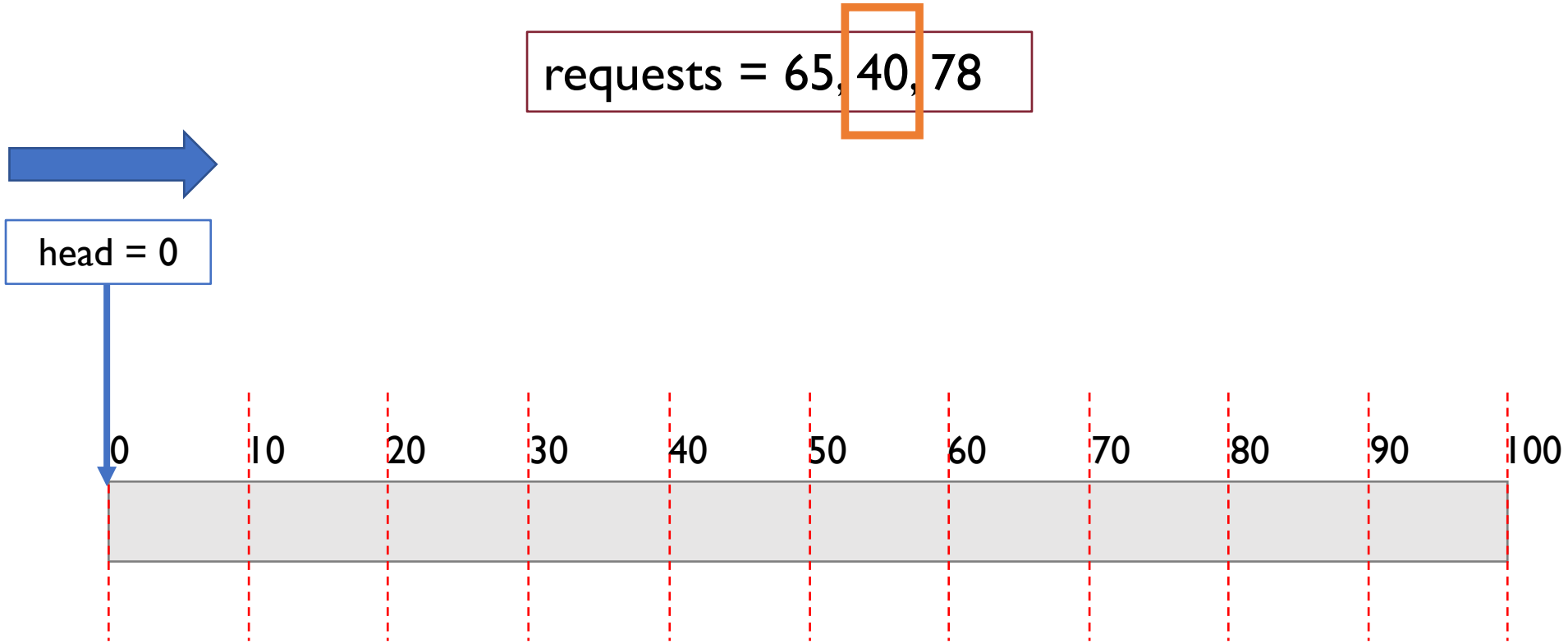
Disk Scheduling: SCAN

requests = 65, 40, 78

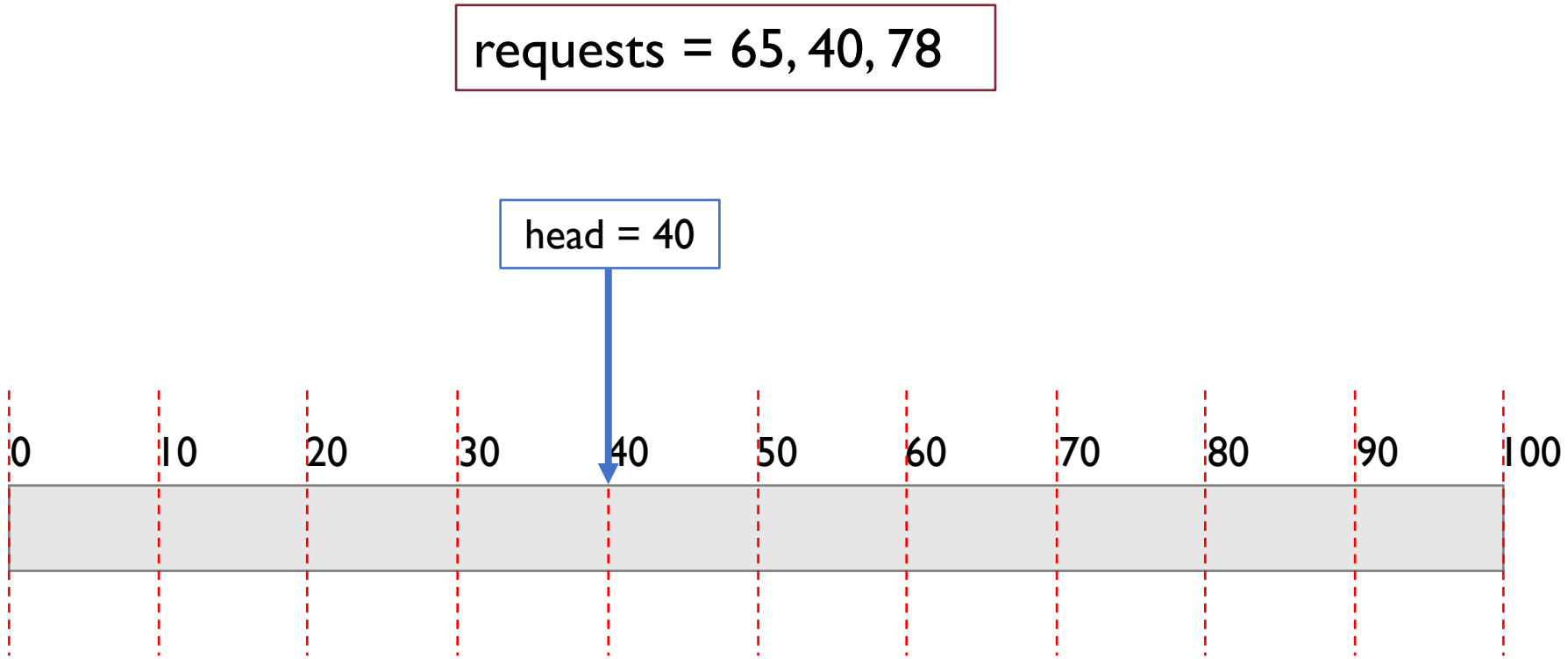


Distance travelled = 12 + |0 – 18| = 30

Disk Scheduling: SCAN

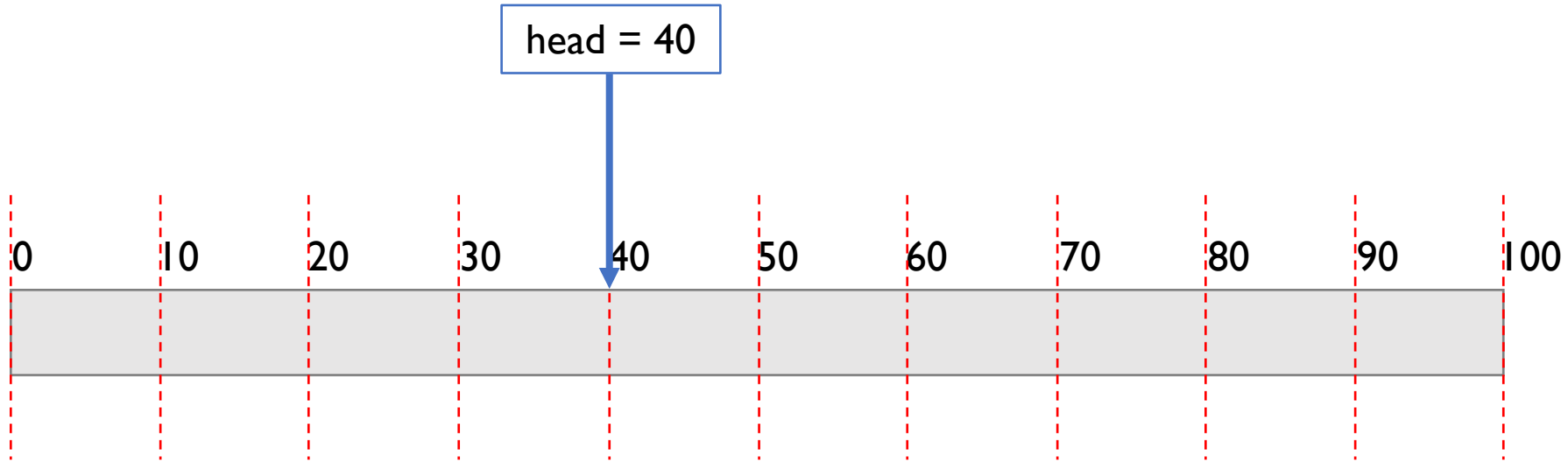


Disk Scheduling: SCAN



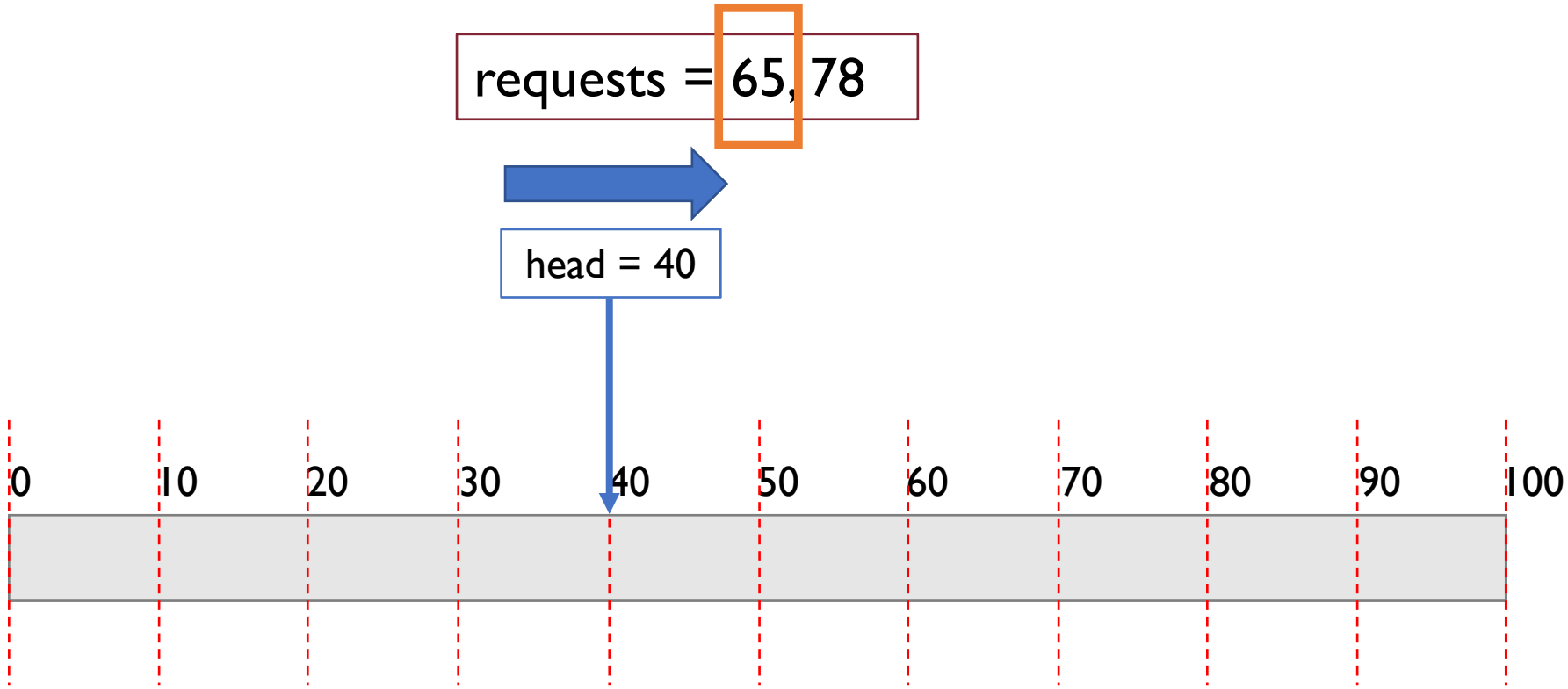
Disk Scheduling: SCAN

requests = 65, 40, 78



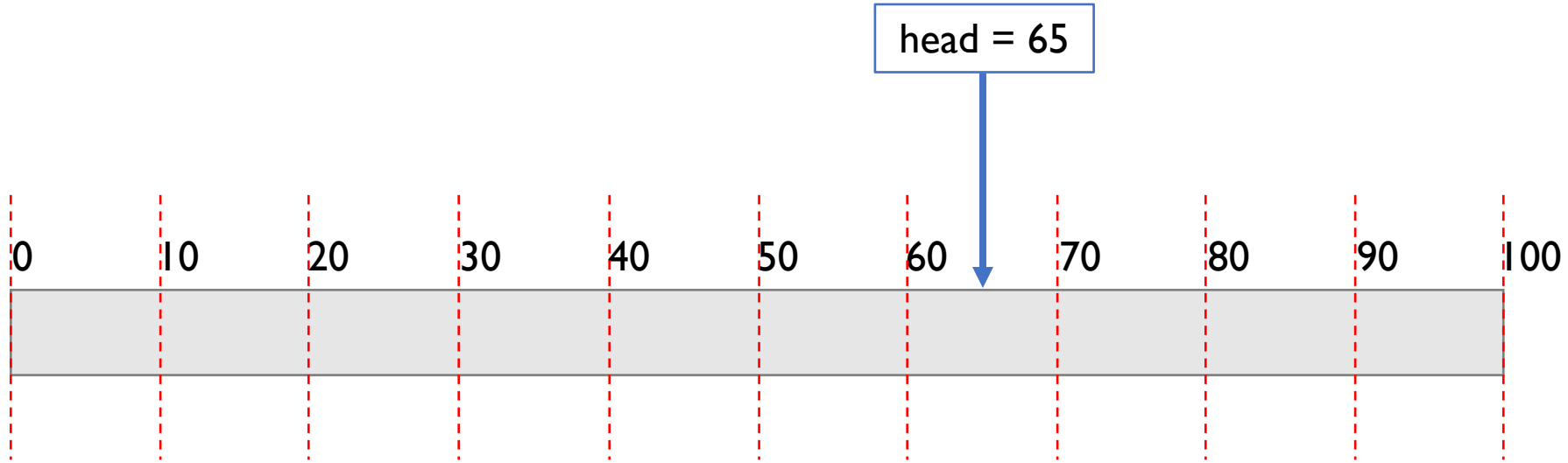
Distance travelled = 30 + |40 – 0| = 70

Disk Scheduling: SCAN



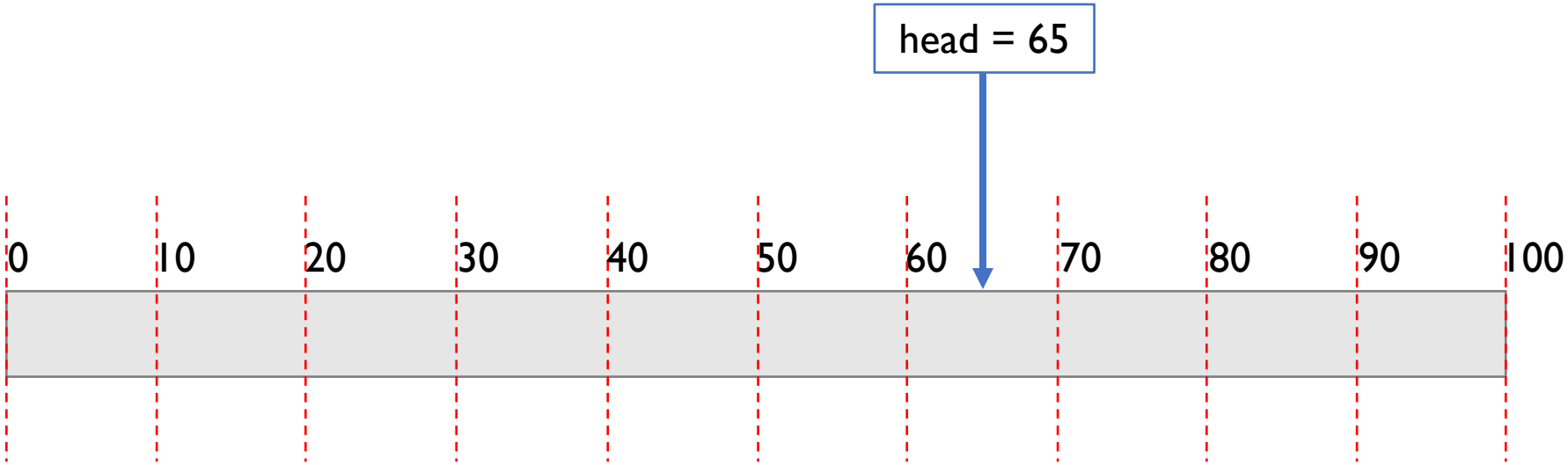
Disk Scheduling: SCAN

requests = 65, 78



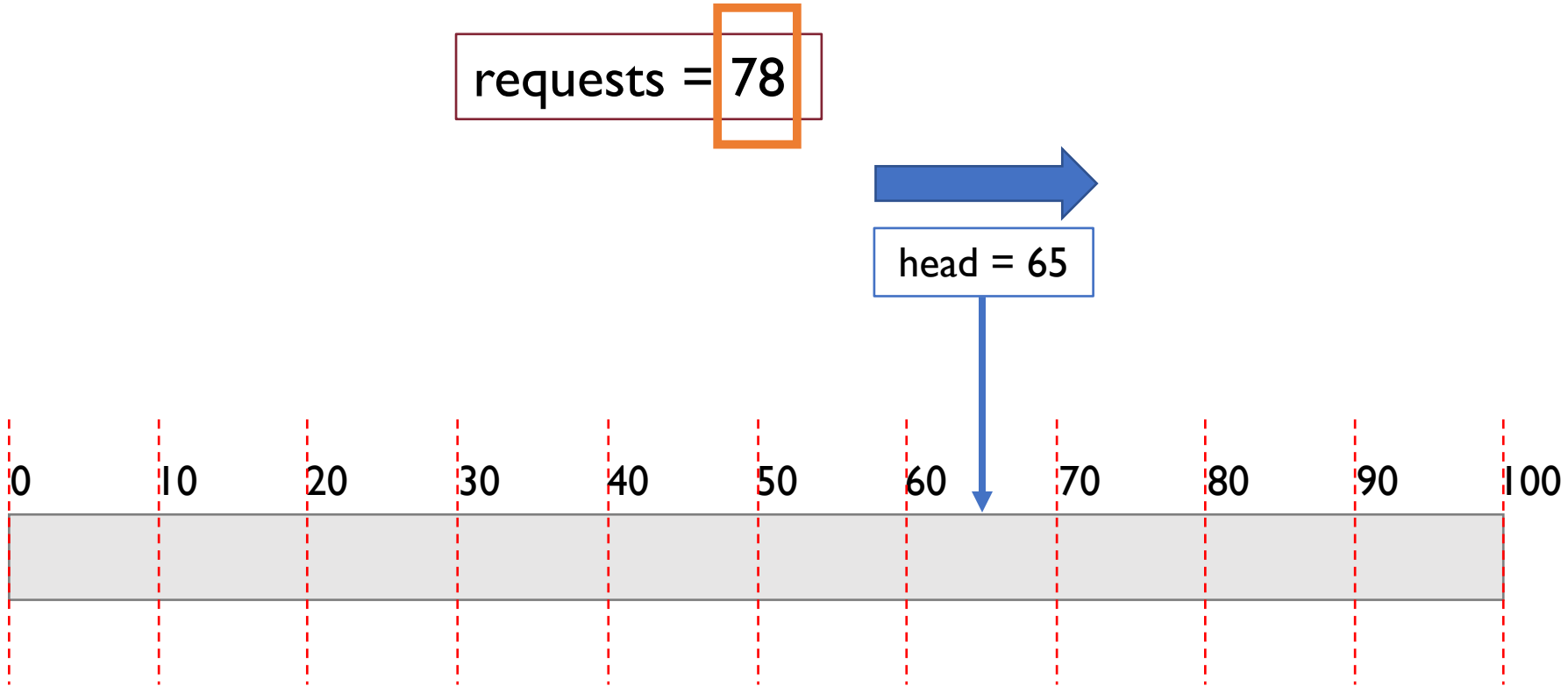
Disk Scheduling: SCAN

requests = 65, 78

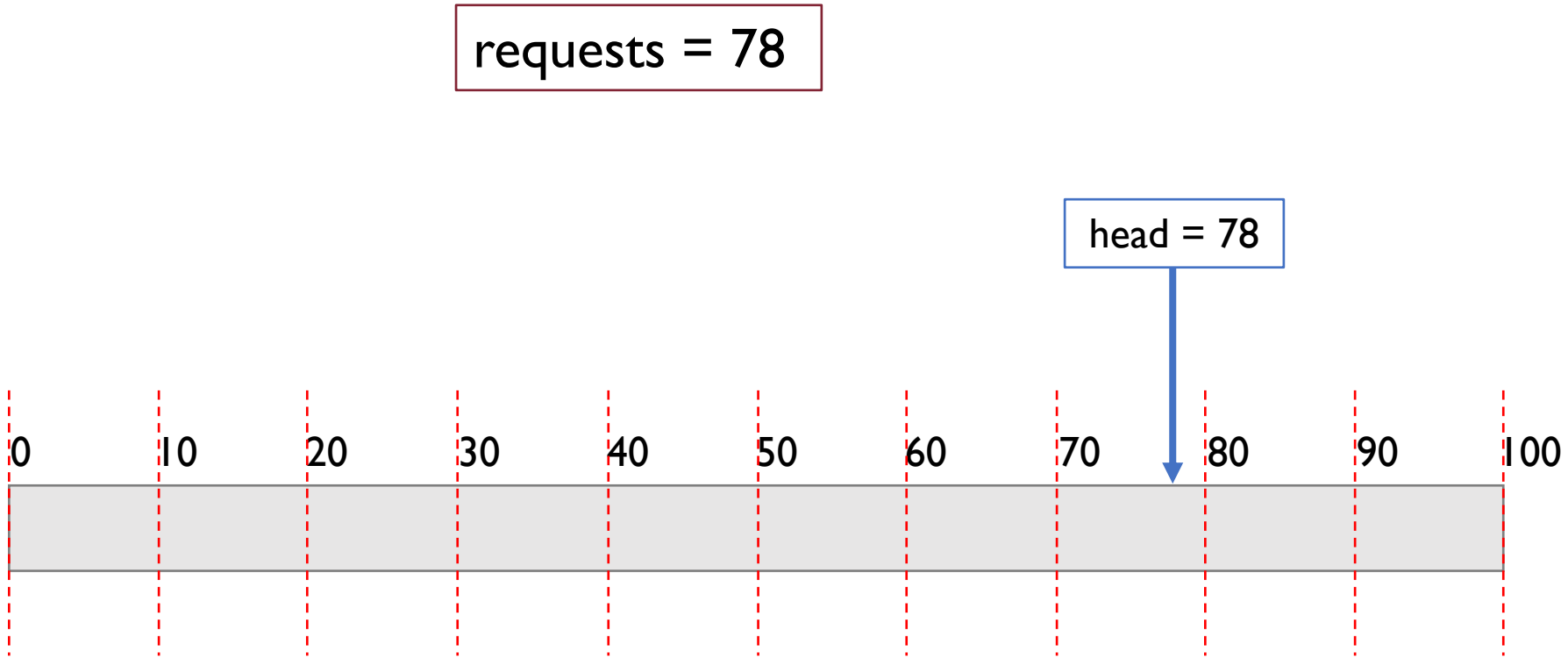


Distance travelled = 70 + |65 – 40| = 95

Disk Scheduling: SCAN

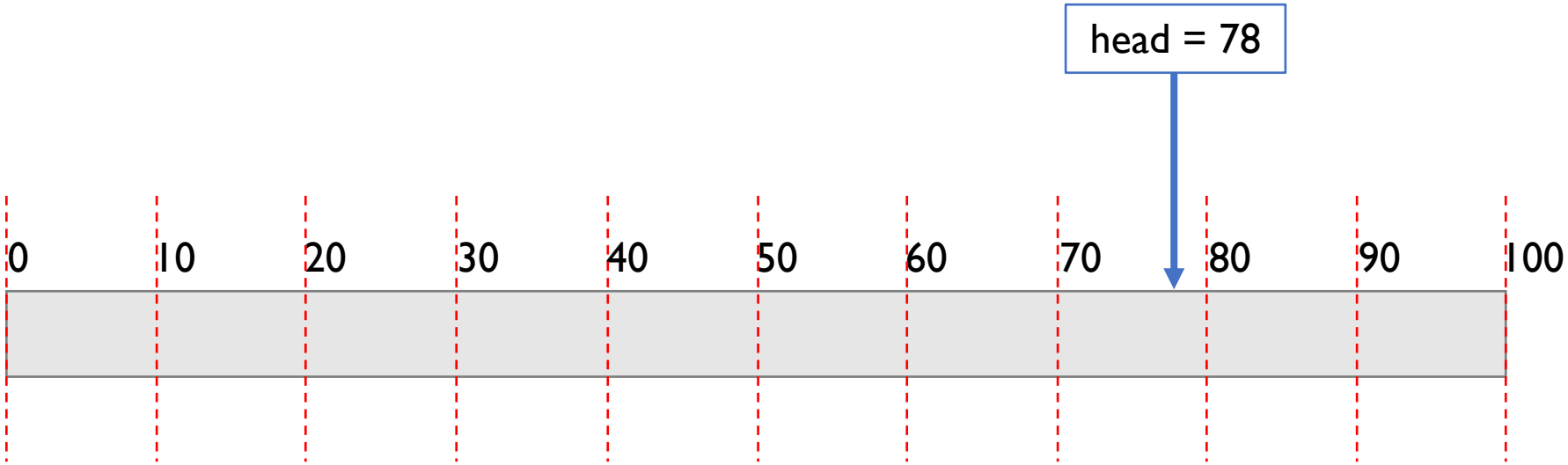


Disk Scheduling: SCAN



Disk Scheduling: SCAN

requests = 78



Distance travelled = 95 + |78 – 65| = **108**

SCAN: Considerations

- Requires to keep a sorted list of requests

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- Requires to keep a sorted list of requests
- Simple optimization (LOOK)
  - Do not go all the way to the edge of the disk each time
  - Just go as far as the last request to be served
  - In the example: no need to go from 18 to 0! Just stop at 18 (first request)
  - Total distance goes from **108** down to **72** (saving 18-0 and 0-18 movements)

SCAN vs. SSTF

- SCAN does not suffer from possible starvation as SSTF does
  - We are guaranteed each request will be served eventually

SCAN vs. SSTF

- SCAN does not suffer from possible starvation as SSTF does
  - We are guaranteed each request will be served eventually
- However, seek time might be larger with SCAN than SSTF when:
  - New requests are coming in immediately after SCAN has passed
  - In such cases, SSTF will serve "closer" request first, whilst SCAN will complete the whole pass to the opposite edge before going back
  - E.g., SCAN is going upwards and just passes track 50, then request 49 comes in

SCAN vs. SSTF

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  - E.g., SCAN is going upwards and just passes track 50, then request 49 comes in
- SCAN may prioritize serving more recent requests than older ones

Appendix: Arm Speed

- We assumed the time it takes to the head to move from track to track is a linear function of the traversed tracks
  - i.e., moving from track 10 to 20 takes as twice as much time than moving from track 10 to 15 (10 vs. 5 tracks traversed)

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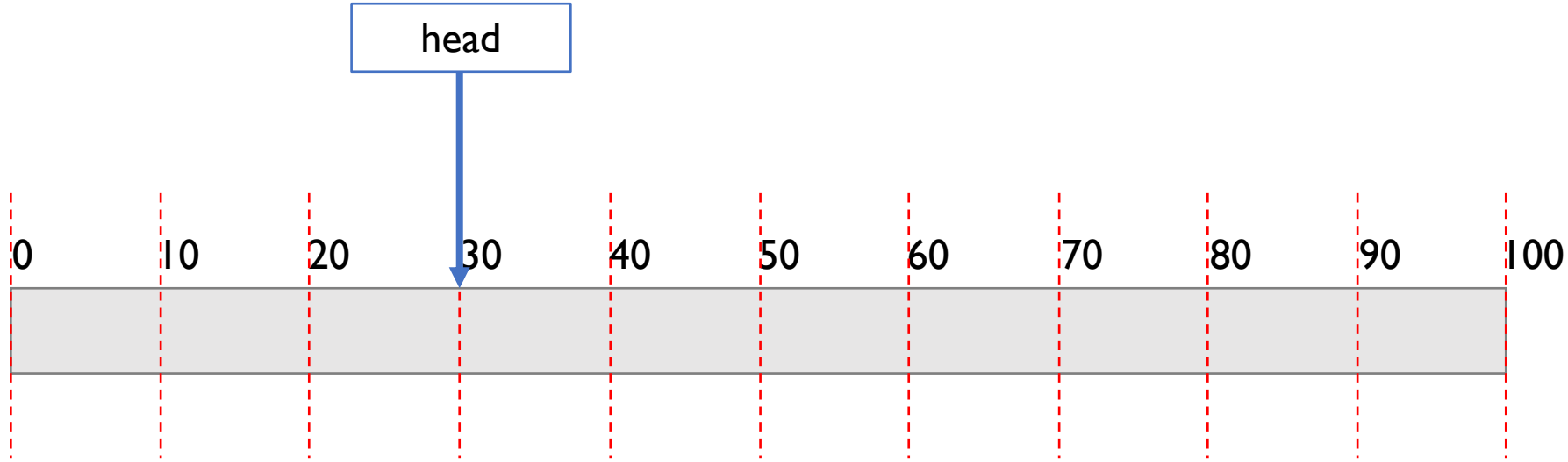
  - i.e., moving from track 10 to 20 takes as twice as much time than moving from track 10 to 15 (10 vs. 5 tracks traversed)
- However, this is not the case! Remember that this is all mechanical!
- Disk arms are subject to acceleration and deceleration, and their speed is not constant (as opposed to rotational speed)

Disk Scheduling: C-SCAN

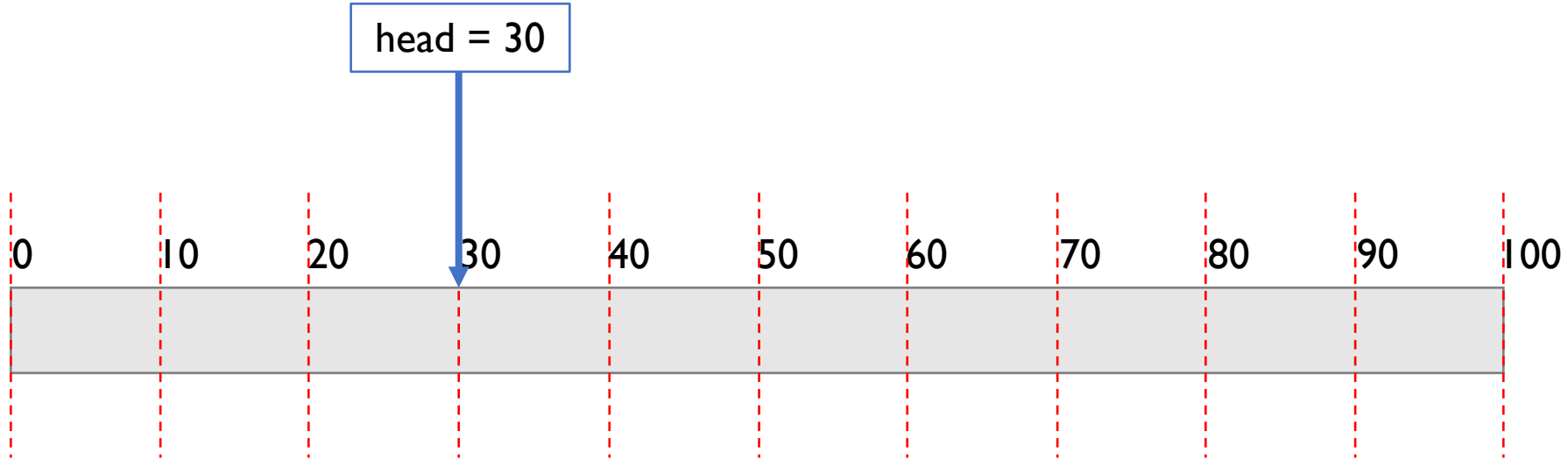
Head makes circular scan of the disk (requests are in a circular queue)

Each time the head reaches an end it is reset to the opposite end



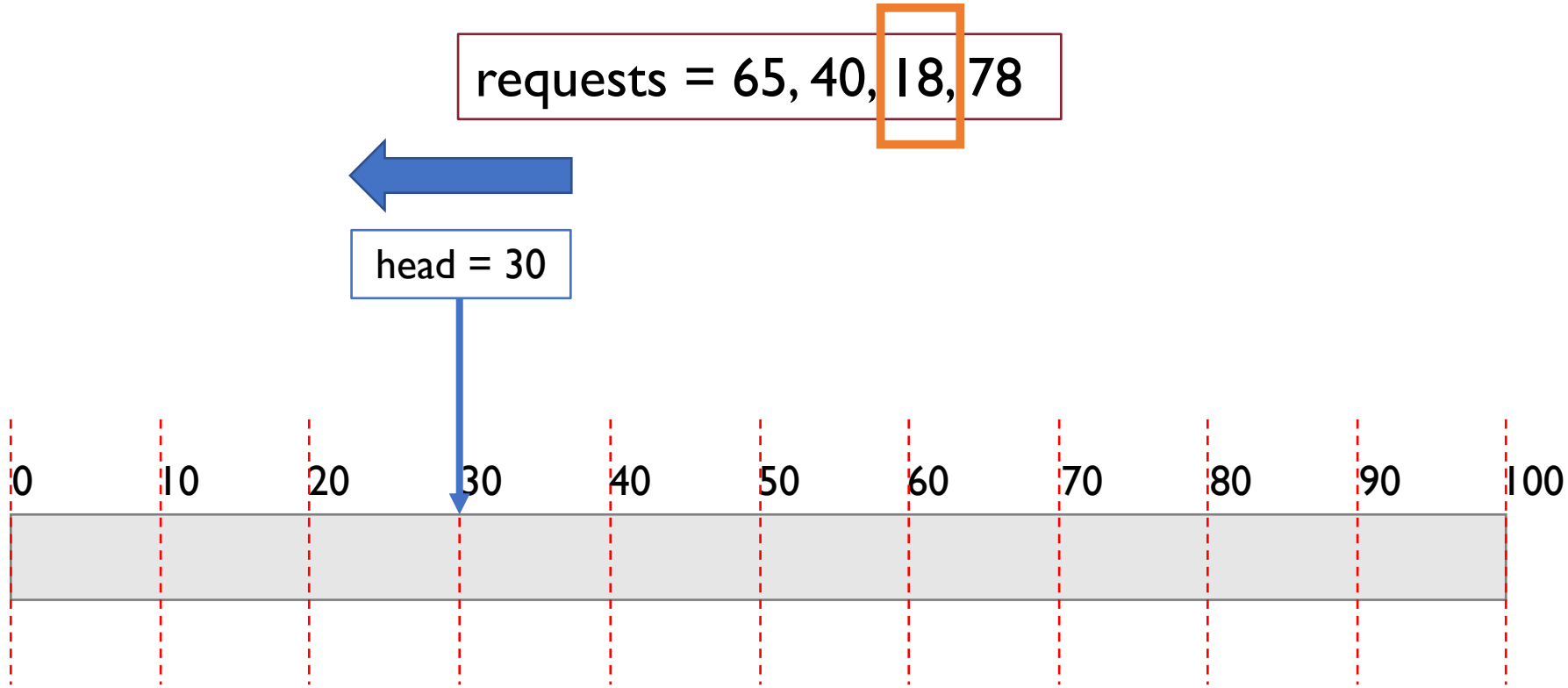
Disk Scheduling: C-SCAN

requests = 65, 40, 18, 78



Distance travelled = 0

Disk Scheduling: C-SCAN



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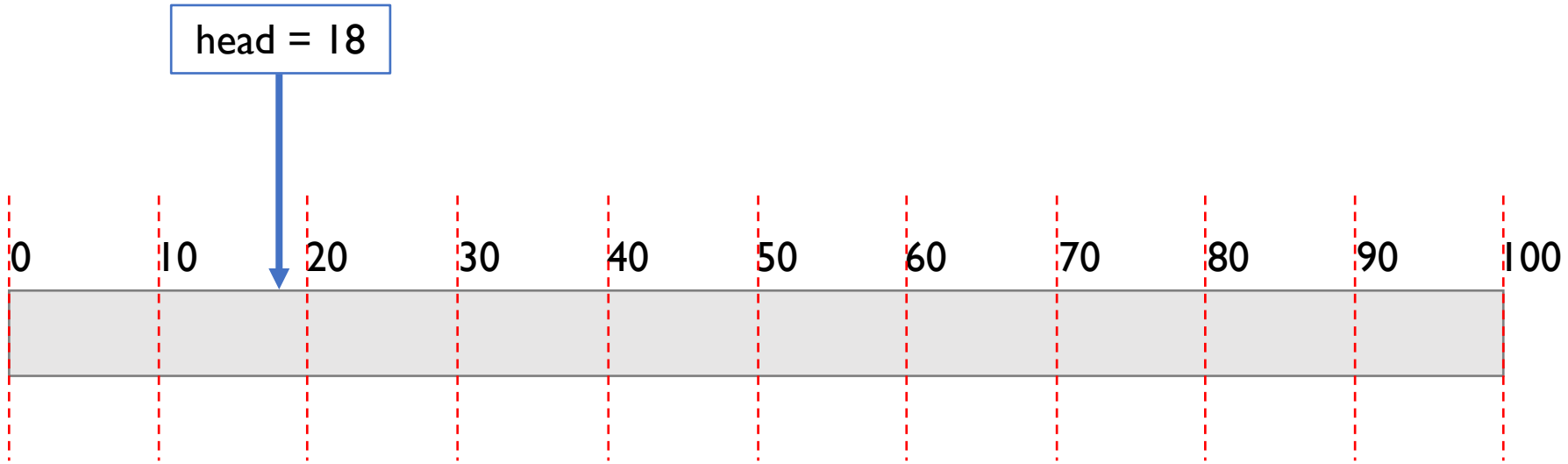

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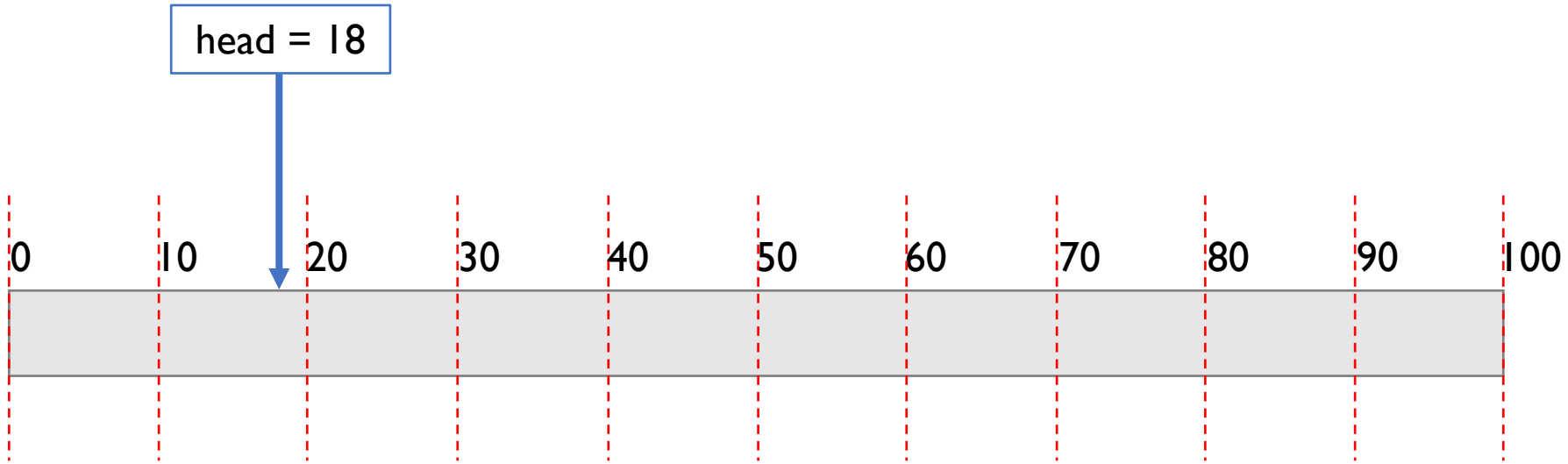
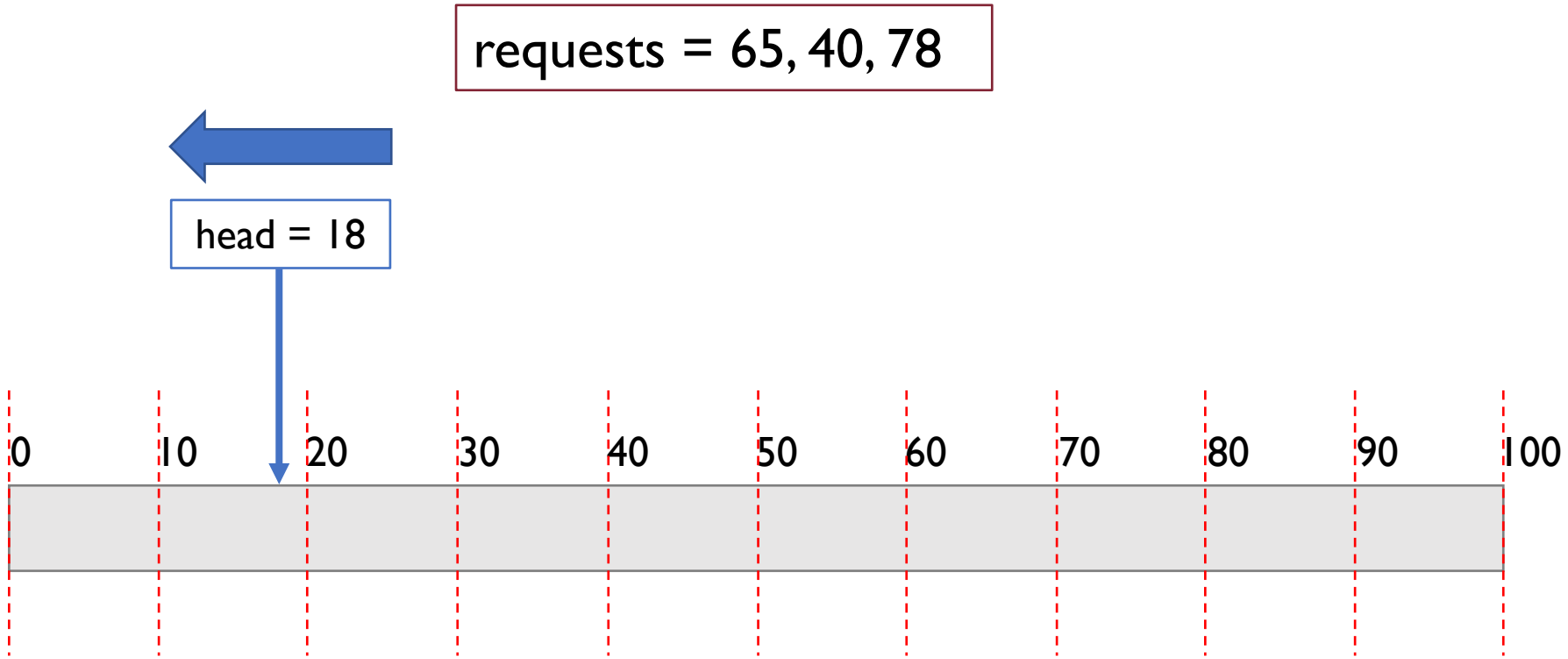


Distance travelled = 0 + |18 – 30| = 12

Disk Scheduling: C-SCAN



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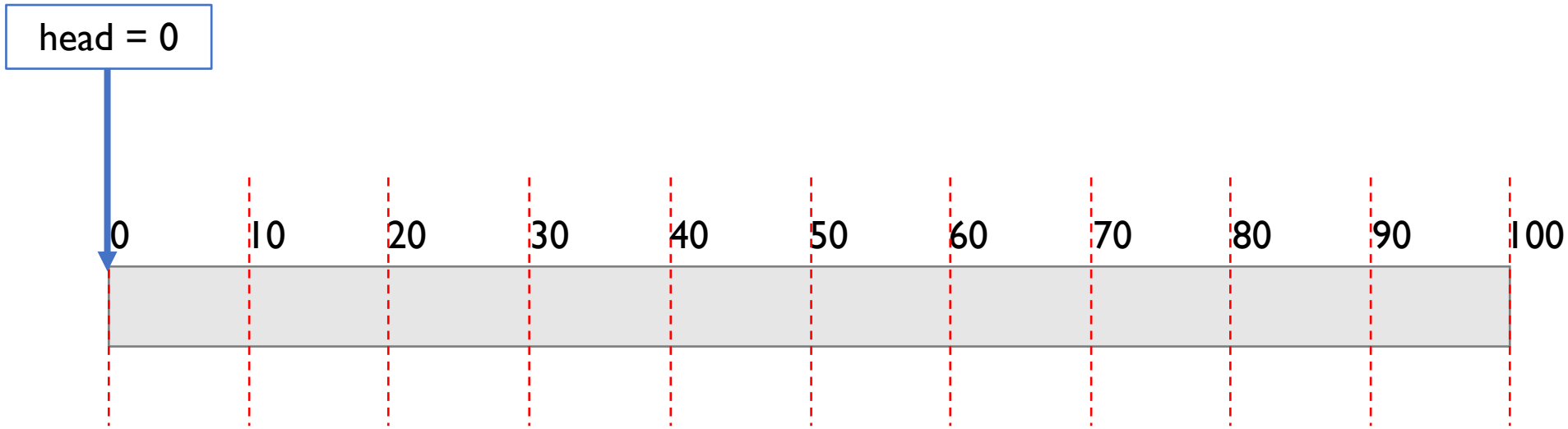

Distance travelled = 12 + |0 – 18| = 30

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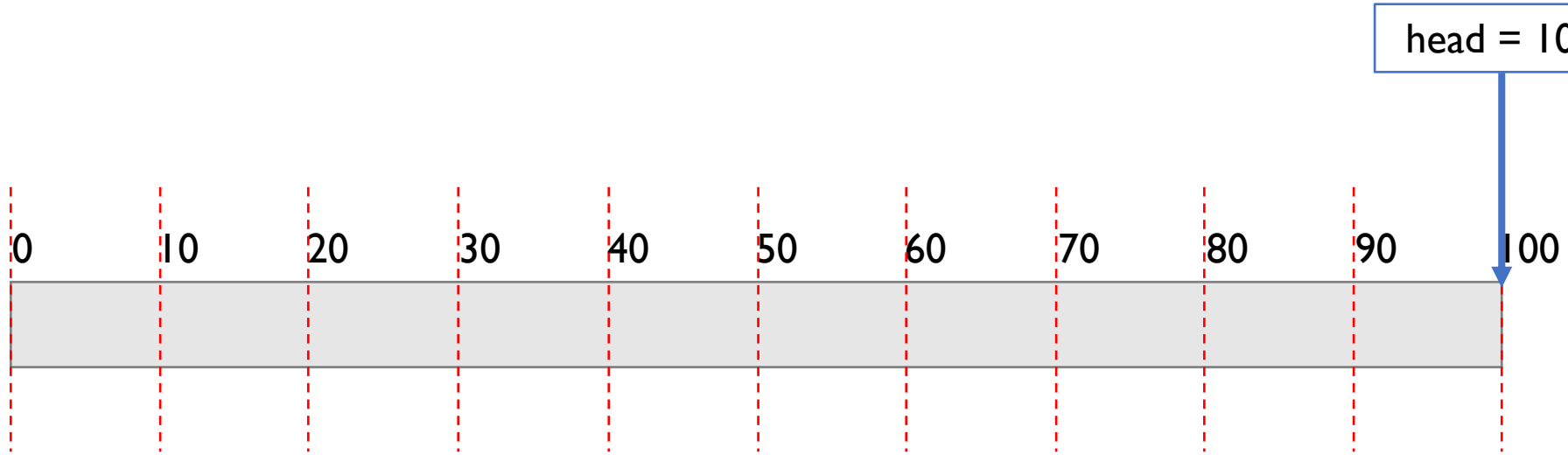
Head reset



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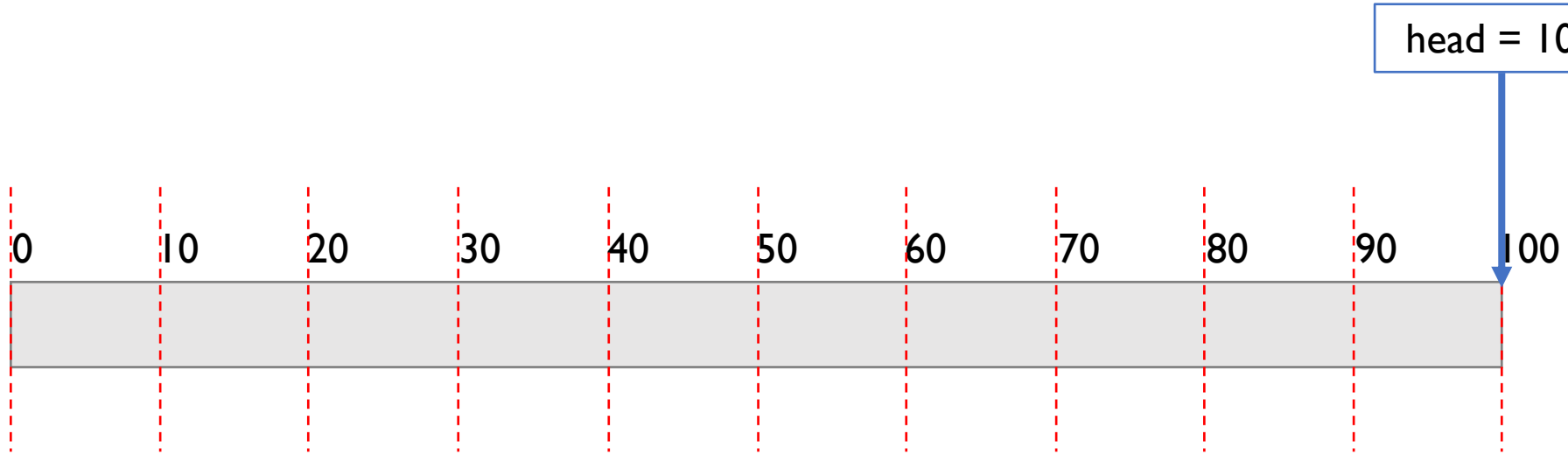

Distance travelled = 30 + |100 – 0| = 130

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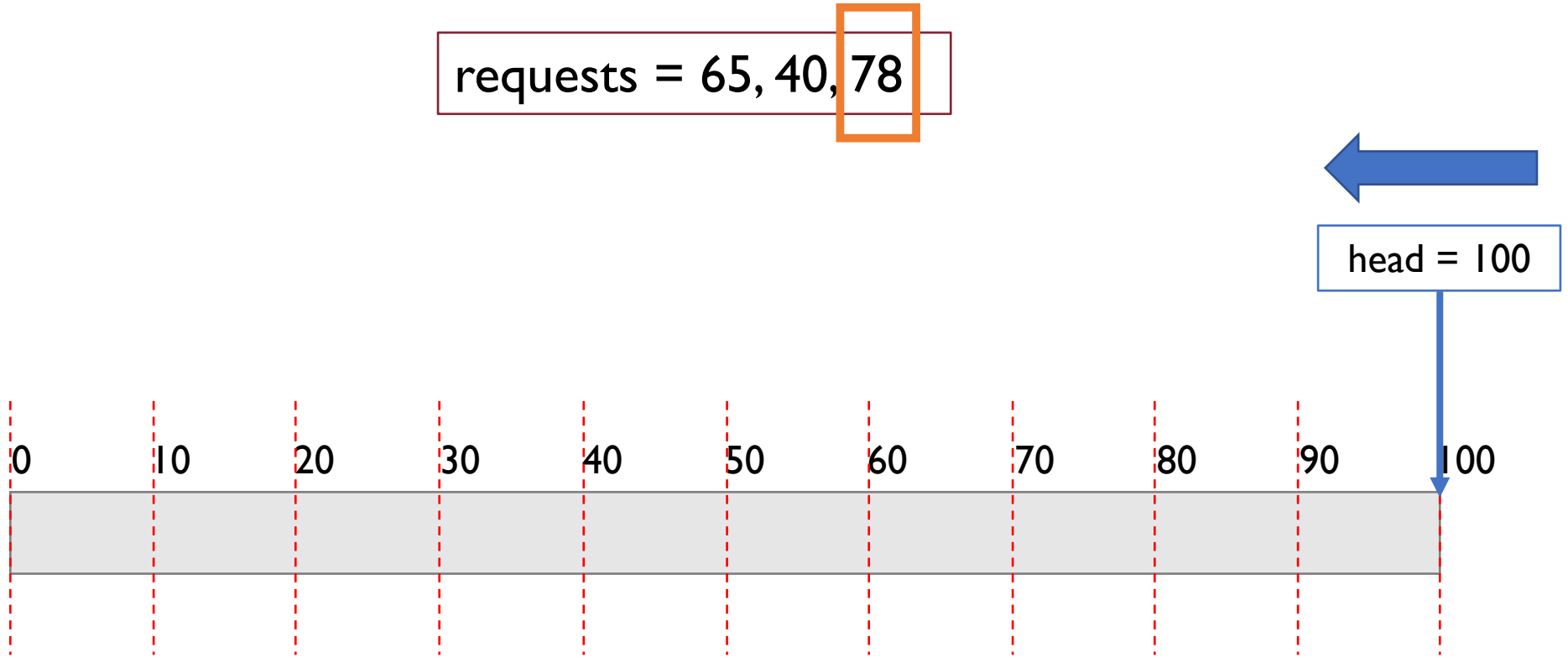

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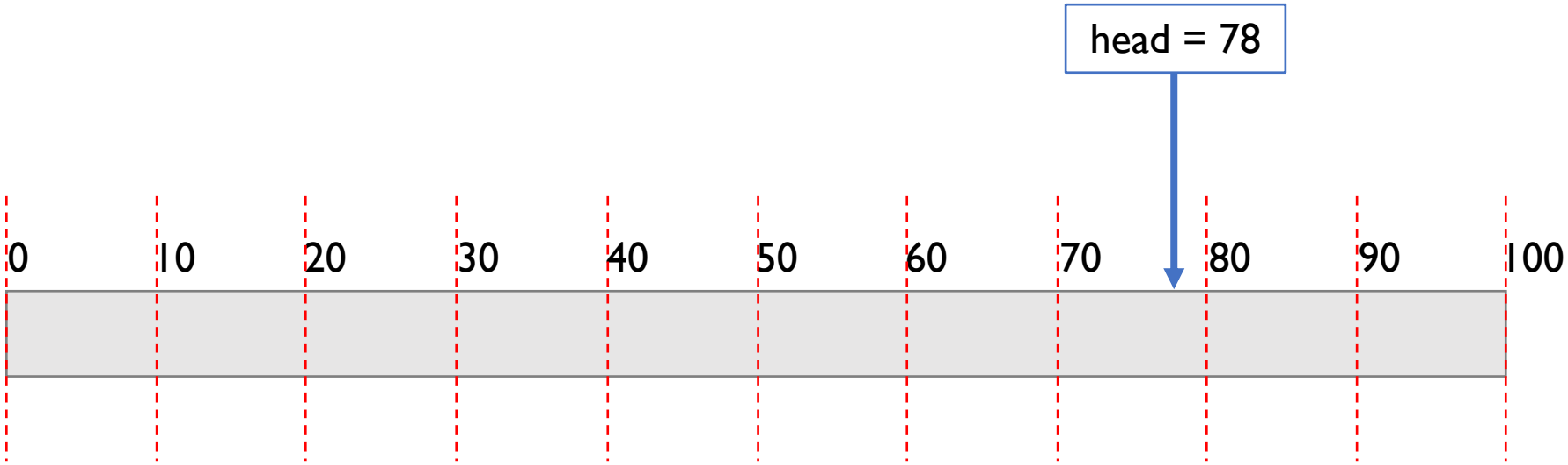

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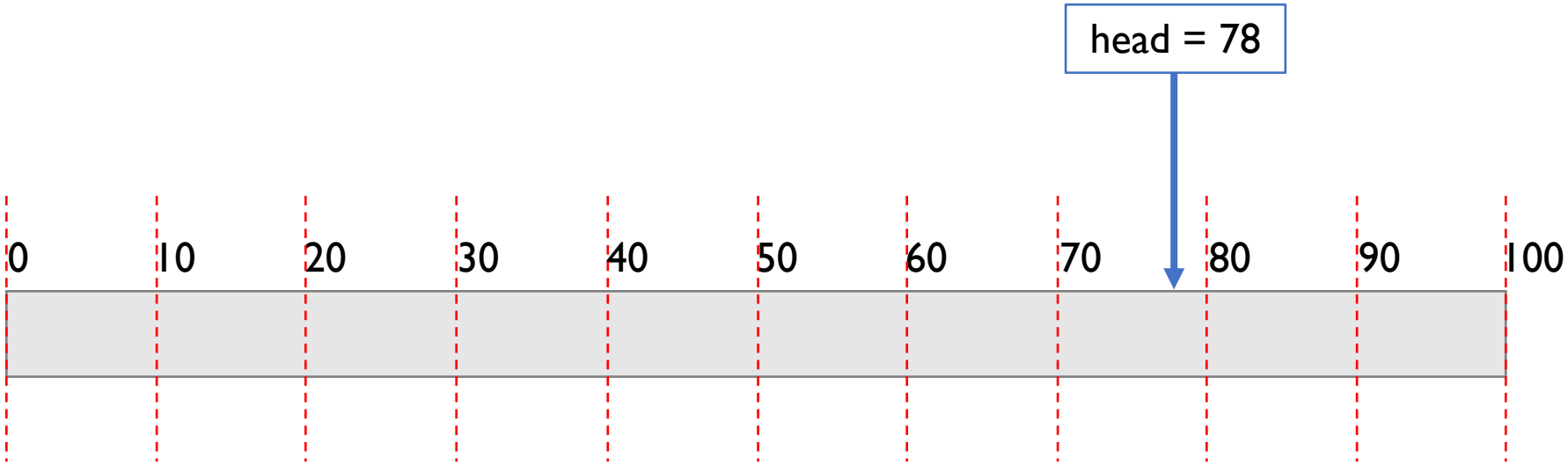

Distance travelled = 130 + |78 – 100| = 152

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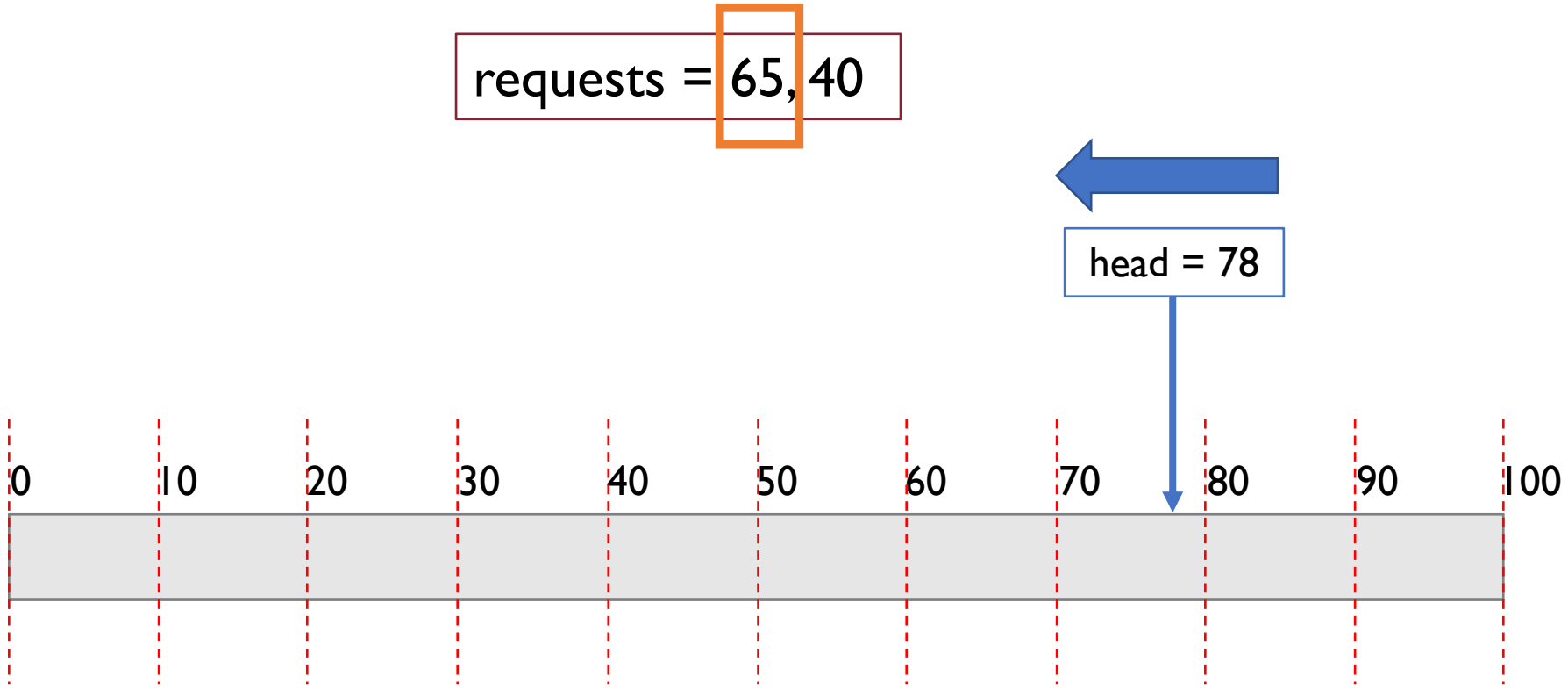

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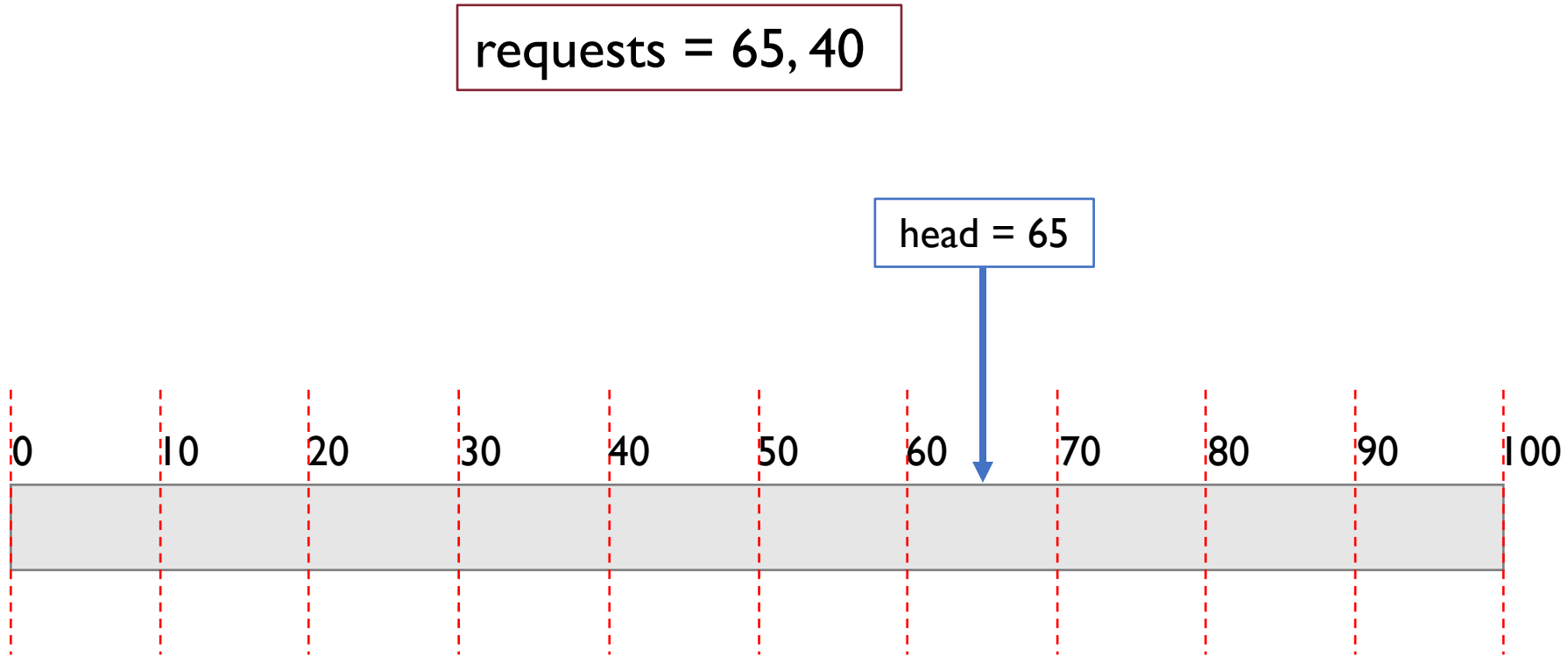

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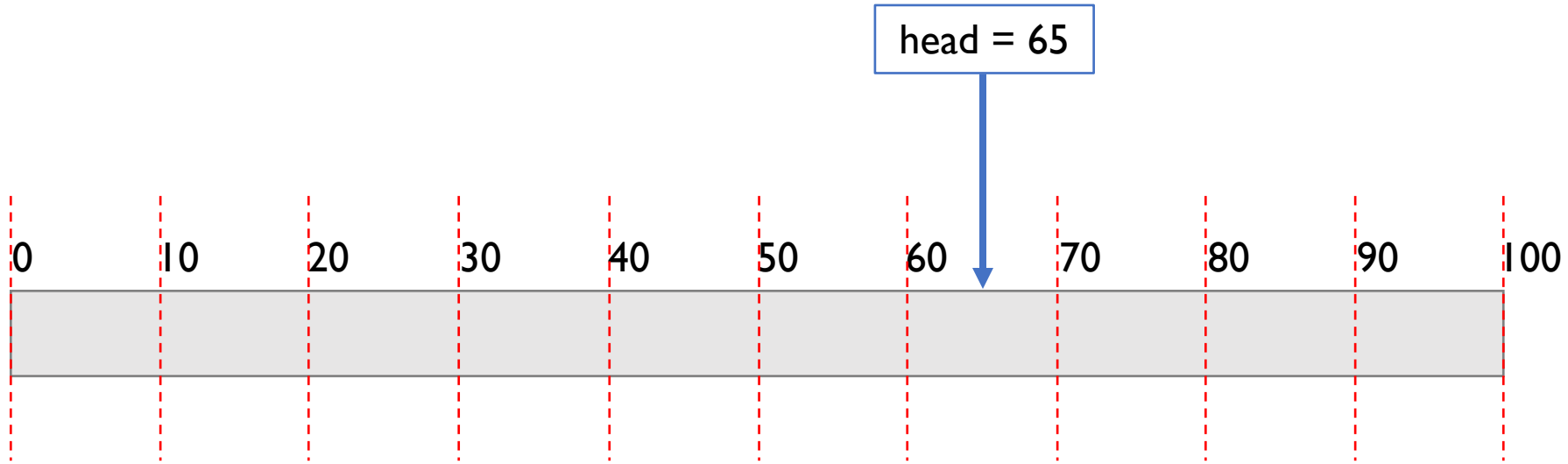

Distance travelled = 152 + |65 – 78| = 165

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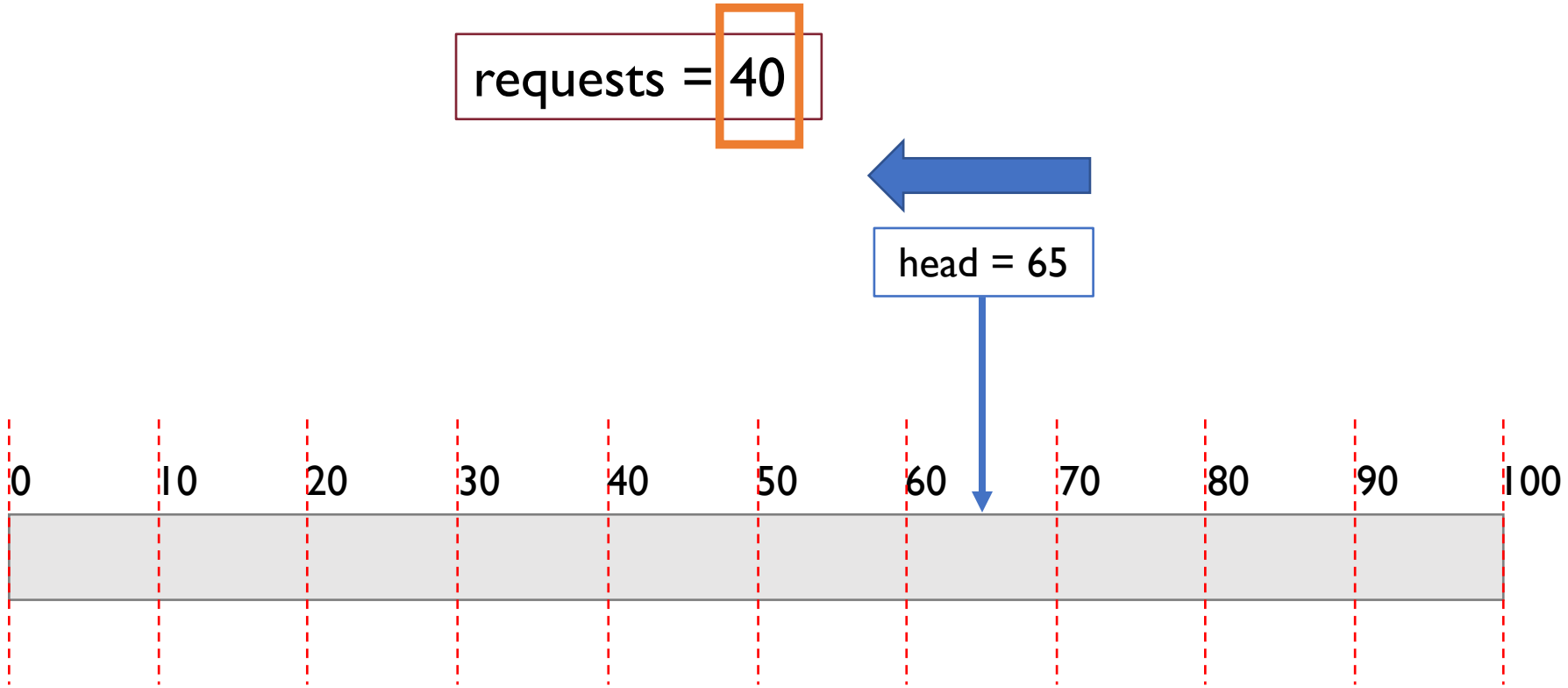

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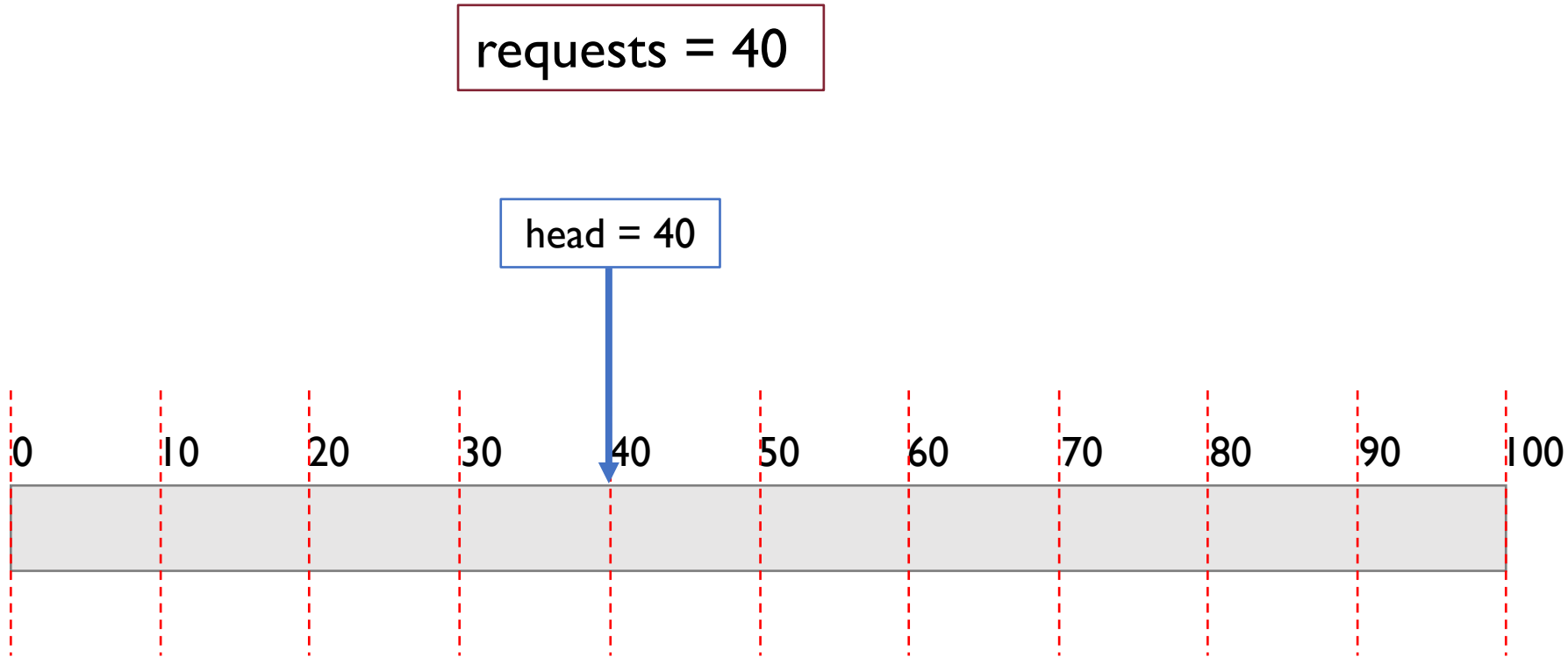

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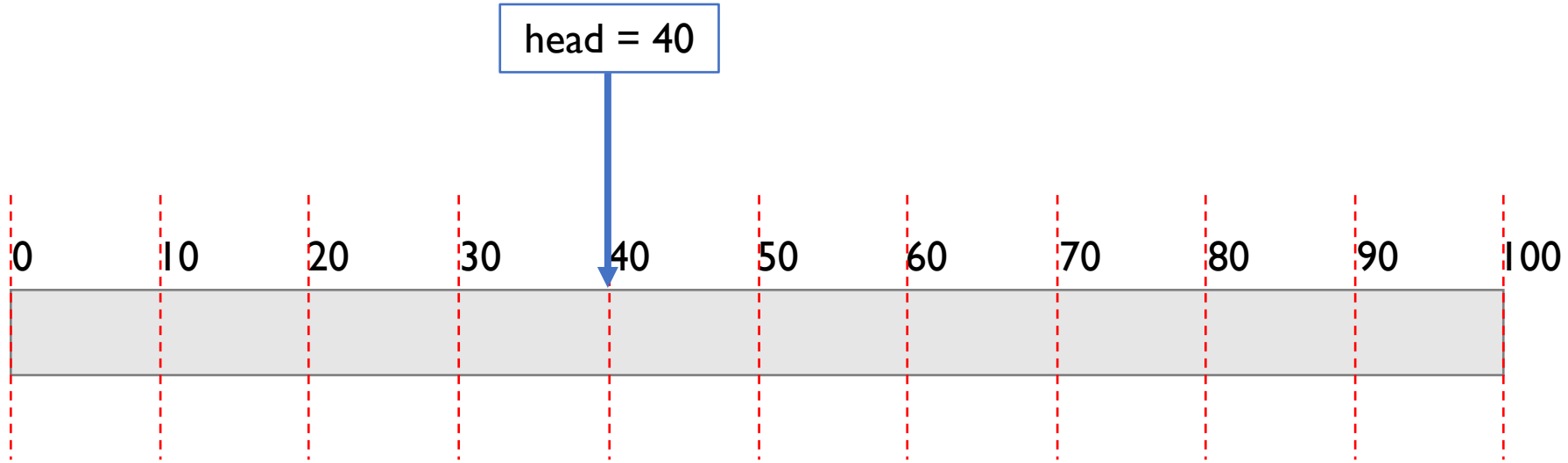
requests = 40



Distance travelled = 165 + |40 – 65| = **190**

C-SCAN: Considerations

- C-LOOK: similar optimization to LOOK
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    - no need to go from 18 to 0! Just stop at 18 (first request)
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- C-SCAN does not prioritize serving more recent requests
- Avoid start/stop of mechanical head movements

Where Are Those Algorithms Implemented?

- Disk scheduling algorithms are typically implemented on the disk controller itself
- Disk drives are shipped with one of these algorithms ready
- More complex scheduling algorithms can be designed (e.g., optimizing the overall access time)
- Complex logic should be instead moved to the disk driver (OS kernel)

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Filesystem-level optimization

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Pre-fetching can be done both at the Disk-level and Filesystem-level

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- ECC is done with every disk read/write, and if damage is detected and recoverable, the disk controller handles itself a **soft error**

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- After partitioning, then the filesystems must be **logically formatted** (more on this later)

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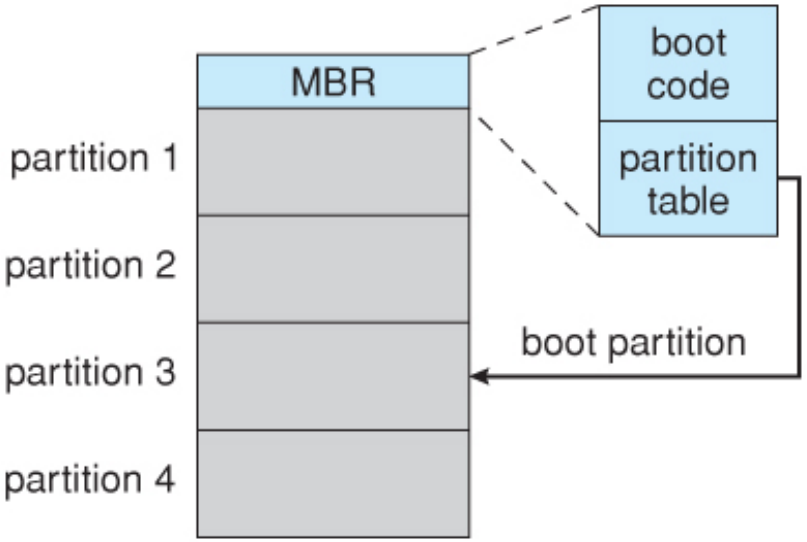

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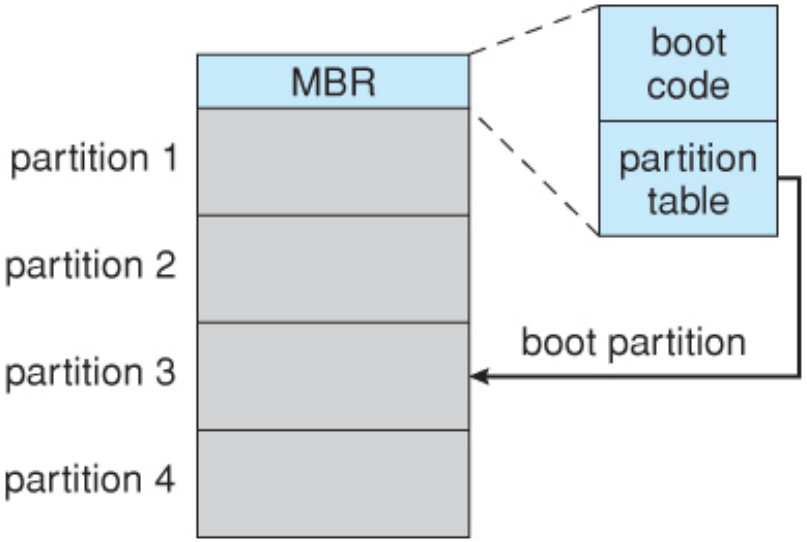

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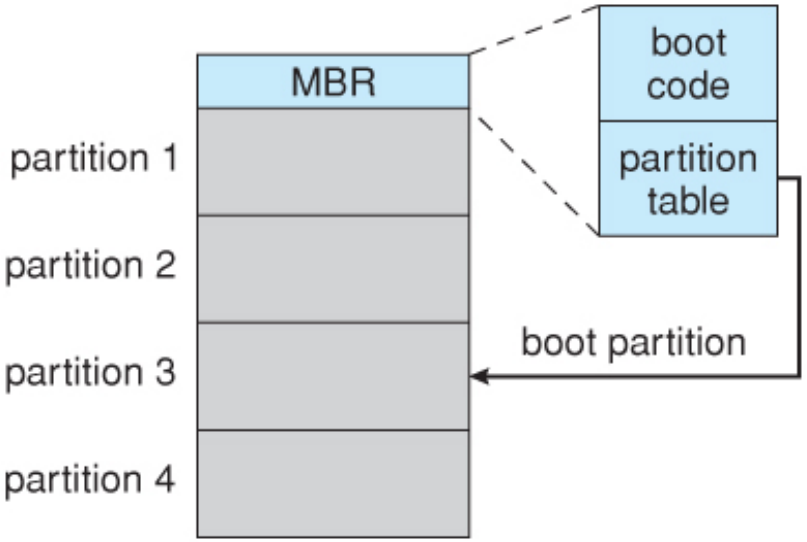

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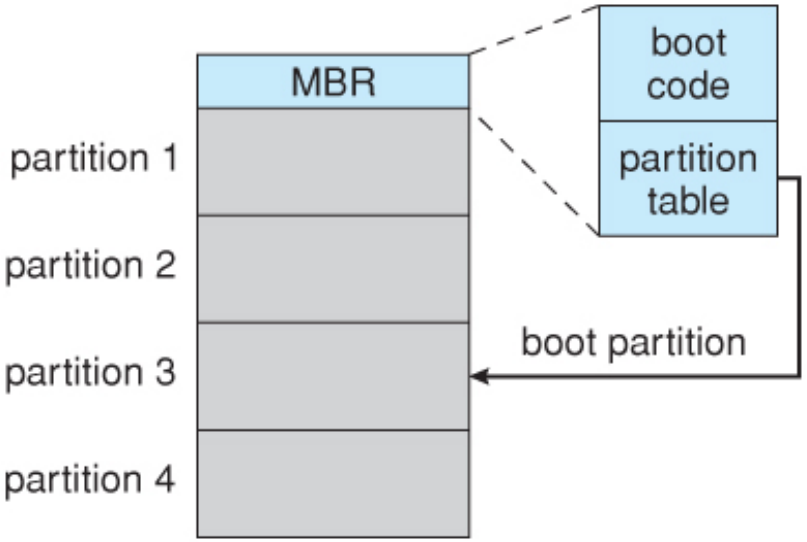

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Once the kernel is found, it is loaded into memory and then control is transferred over to the OS, which initializes all important kernel data structures and system services

Overview of Mass-Storage Structure

3 categories of mass-storage devices

Magnetic Disk

Solid-State Disk

Magnetic Tapes

Solid-State Disks (SSDs): Overview

- SSDs use memory technology as a small fast hard disk
- Specific implementations may use either flash memory or DRAM chips protected by a battery
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No need for disk scheduling

Solid-State Disks: Overview

- Read operations are very fast
- Write operations are slower as they need a slower erease cycle (cannot overwrite directly)
- Unreferenced blocks instead of overwriting (garbage collection)
- Limited number of writes per block (over lifetime)
- SSD controller needs to count how many times a block gets overwritten, so as to keep this balanced

Solid-State Disks: Overview

- SSDs are more expensive than hard drives, generally not as large, and may have shorter life spans
- SSDs are especially useful as a high-speed cache of hard-disk information that must be accessed quickly
- For example, they can use to store:
  - File system meta-data, e.g., directory and inode information (more on this later)
  - The OS bootloader and some application executables, but no vital user data

Solid-State Disks: Overview

- SSDs are also used in laptops to make them smaller, faster, and lighter
- Since SSDs are so much faster than traditional hard disks, the throughput of the I/O bus can become a limiting factor
- Some SSDs are therefore connected directly to the system PCI bus

Overview of Mass-Storage Structure

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Magnetic Tapes

- Primarily used for backups
- Accessing a particular spot on a magnetic tape can be slow
- No random/direct access, only sequential!
- After reading or writing starts, access speeds are comparable to disk drives
- Capacities of tape drives can range from 20 to 200 GB
- Today replaced by disks

Advanced Topic: RAID Structure

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- Today RAID systems employ large possibly expensive disks as their components, switching the definition to **Independent** disks

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- The more disks a system has, the greater the likelihood that one of them will go bad at any given time
- Hence, increasing disks on a system actually decreases the **Mean Time To Failure** (**MTTF**) of the system

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$$E[T] = Np$$

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- Things are not so infrequent when we deal with several disks:
  - 1 (expected) failure per day with N = 4,000 disks
  - 100 (expected) failures per day with N = 400,000 disks

Improvement of Reliability via Redundancy

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$$p^N$$

Improvement of Performance via Parallelism

- Mirroring also improves performance, particularly with respect to read operations
- Every block of data is duplicated on multiple disks, and read operations can be satisfied from any available copy
- Multiple disks can be reading different data blocks simultaneously in parallel
- Writes could also be speed up through careful scheduling algorithms, but it would be complicated in practice

Improvement of Performance via Parallelism

- Another way of improving disk access time is with **striping**
- This means spreading data out across multiple disks that can be accessed simultaneously
- Striped disks are logically seen as a single storage unit

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- A number of different schemes combine try to balance between the 2
  - RAID Level 0 → striping only, no mirroring
  - RAID Level 1 → mirroring only, no striping
  - …
  - RAID Level 6 → striping + mirroring + parity bit

RAID Levels

(a) RAID 0: non-redundant striping.

(b) RAID 1: mirrored disks.

(c) RAID 2: memory-style error-correcting codes.

(d) RAID 3: bit-interleaved parity.

(e) RAID 4: block-interleaved parity.

(f) RAID 5: block-interleaved distributed parity.

(g) RAID 6: P + Q redundancy.

Summary

- Disks are slow devices compared to CPUs (and main memory)
- Manage those device efficiently is crucial
- Adding complexity to the OS in exchange for better I/O performance
- The same applies to other I/O devices