Sistemi Operativi

Corso di Laurea in Informatica

a.a. 2020-2021

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Dipartimento di Informatica
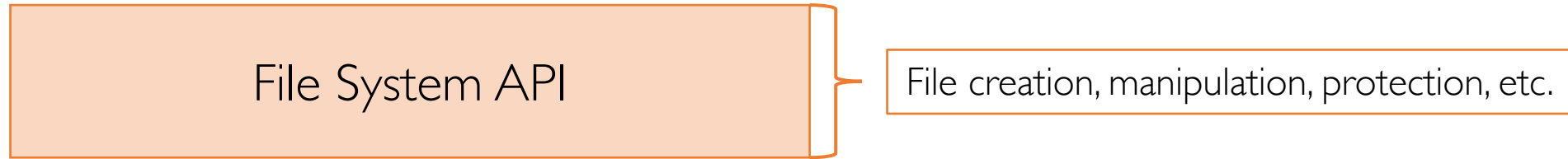
Sapienza Università di Roma

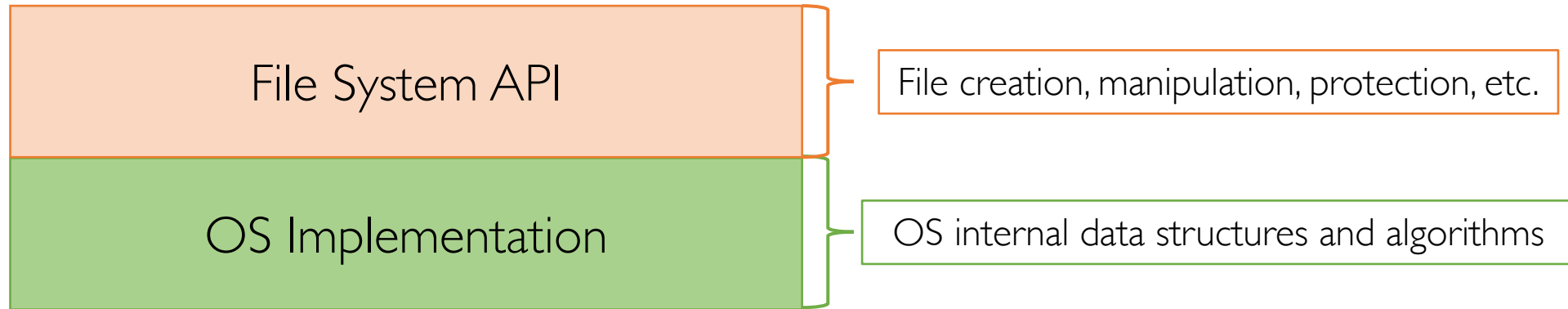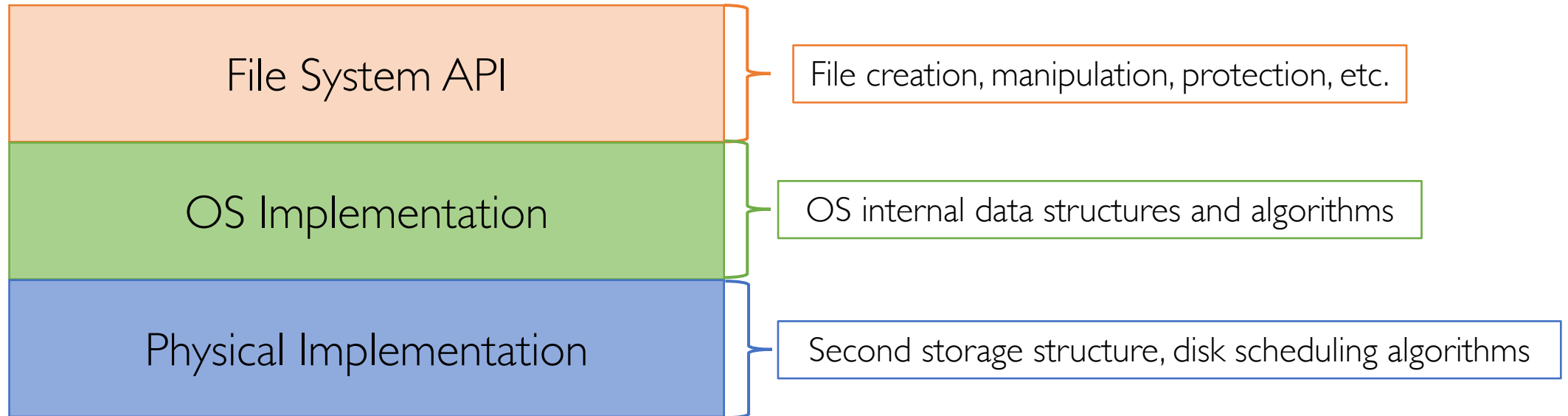tolomei@di.uniroma1.it

File System's Logical View

File System API

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File creation, manipulation, protection, etc.

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Physical Implementation	Second storage structure, disk scheduling algorithms

Overview of Mass-Storage Structure

3 categories of mass-storage devices

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Magnetic Disk

Overview of Mass-Storage Structure

3 categories of mass-storage devices

Magnetic Disk

Solid-State Disk

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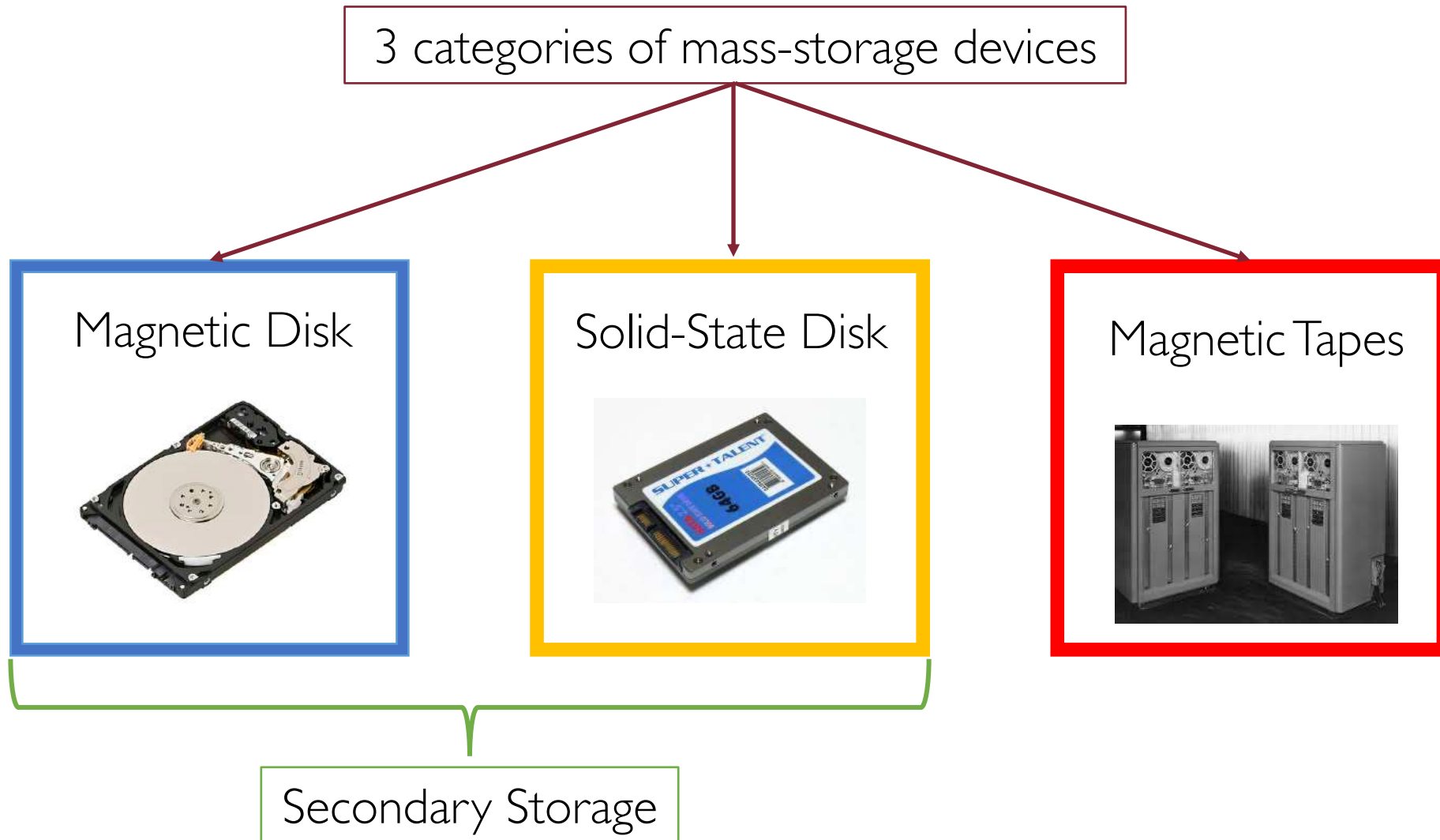
3 categories of mass-storage devices
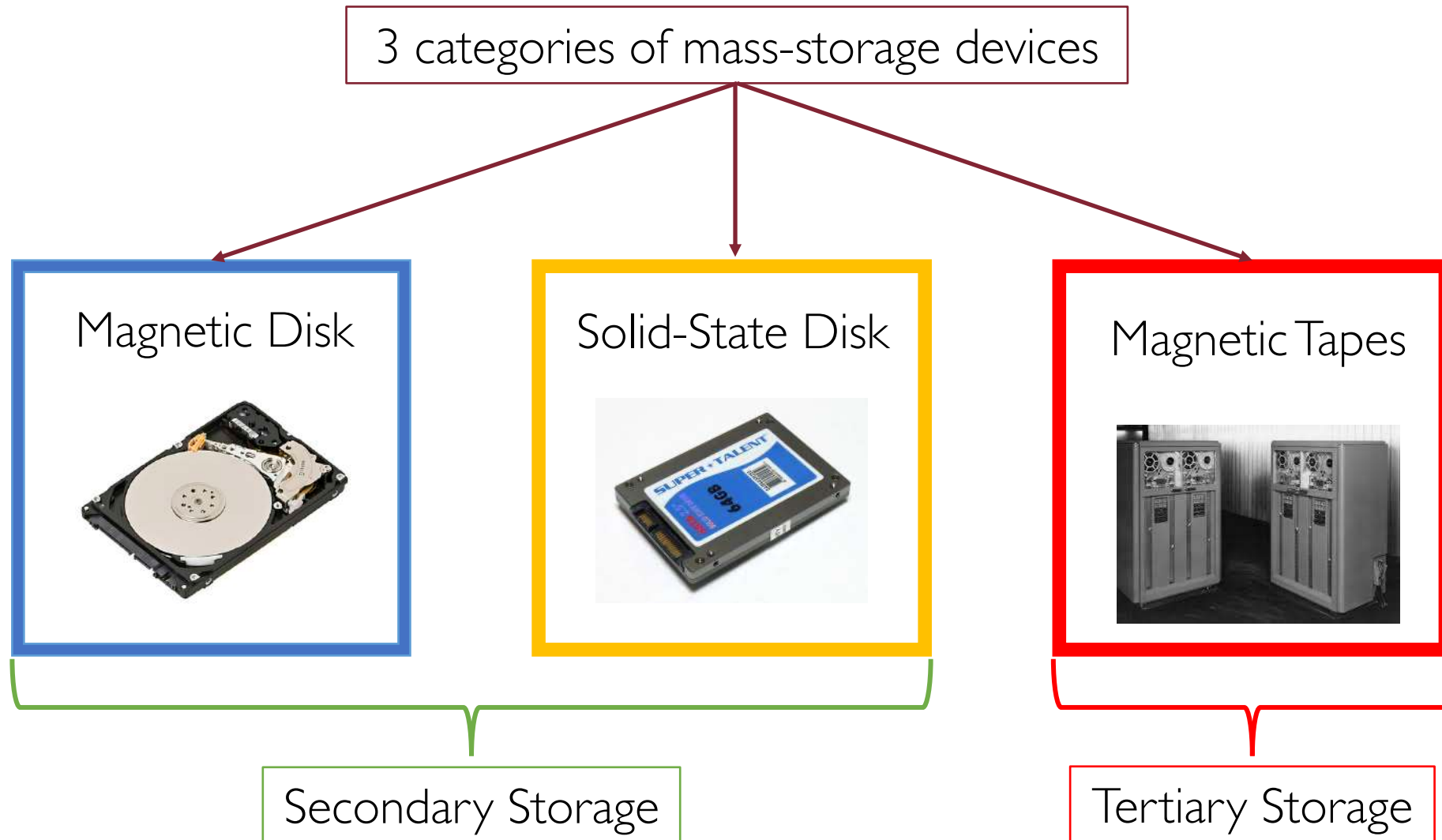

Magnetic Disk

Solid-State Disk

Magnetic Tapes

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3 categories of mass-storage devices

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Secondary Storage

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Secondary Storage

Tertiary Storage

Overview of Mass-Storage Structure

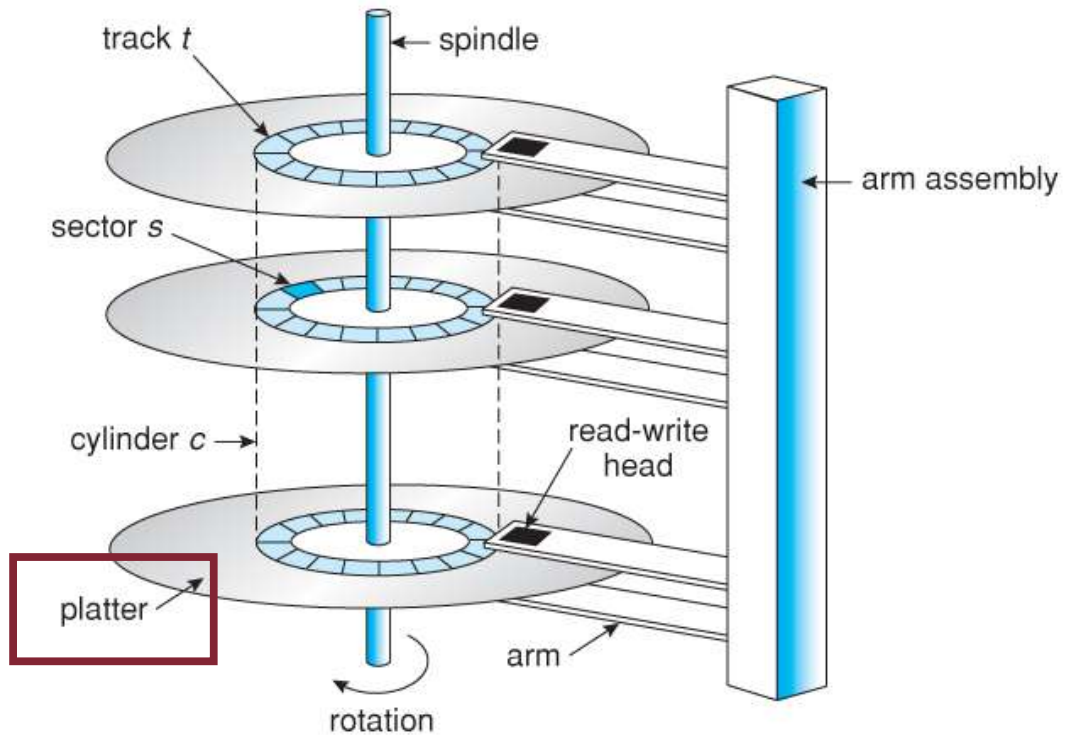3 categories of mass-storage devices
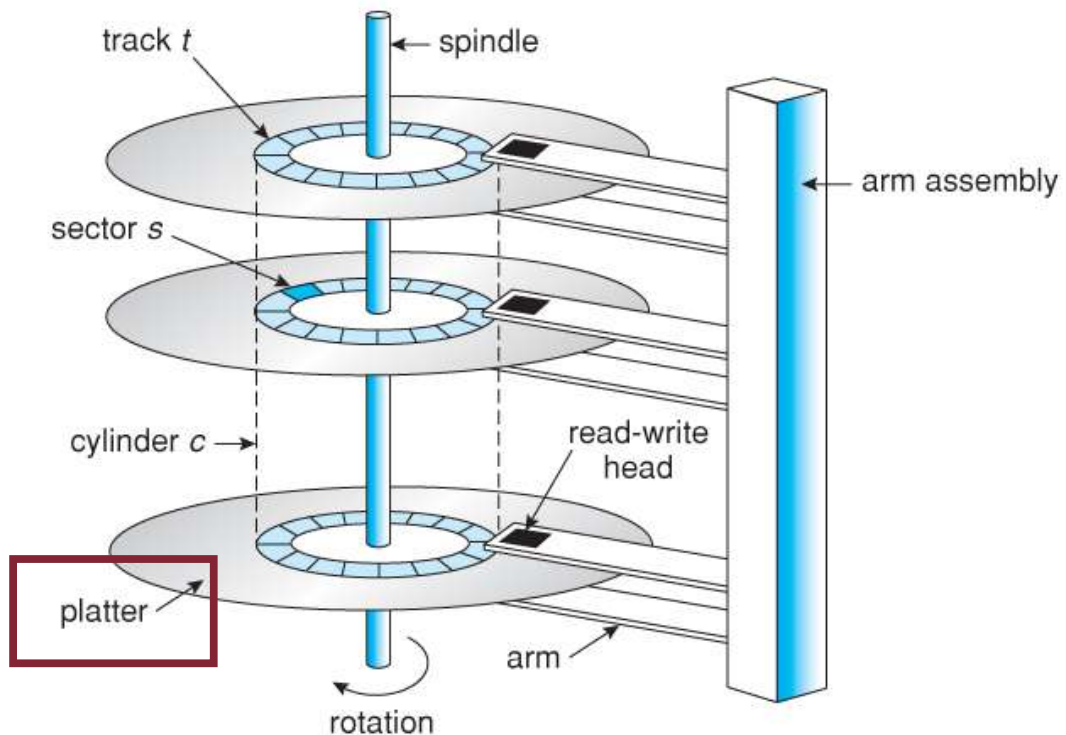
Magnetic Disk

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Magnetic Tapes

Magnetic Disks: Structure

One or more platters covered with magnetic media

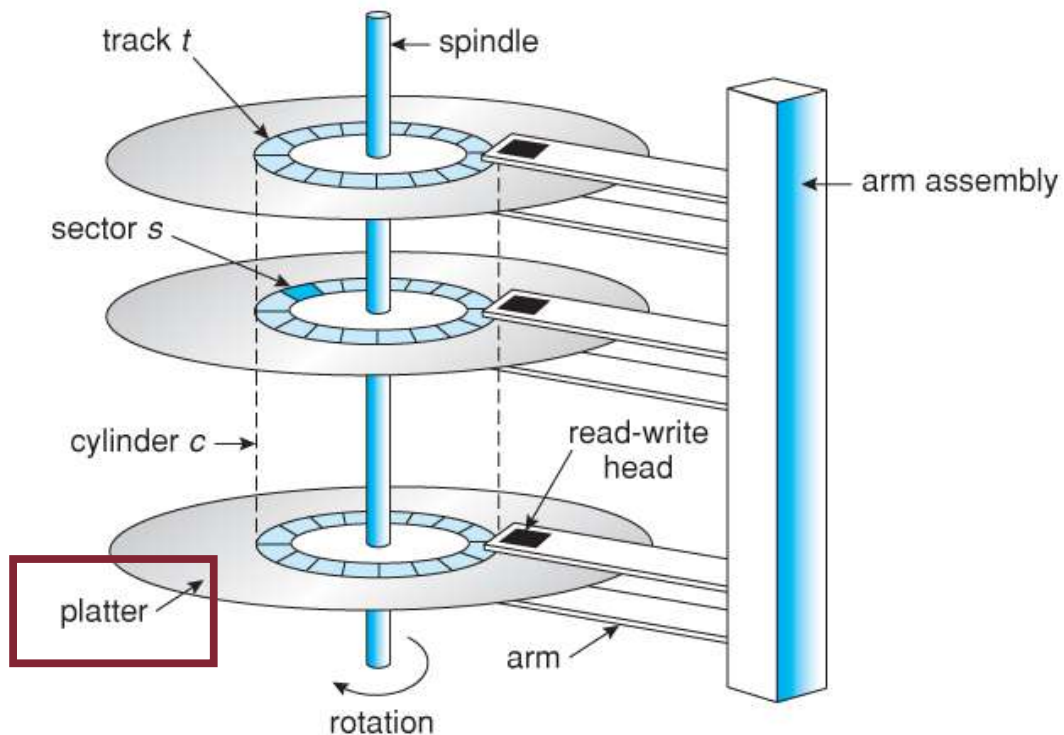# Magnetic Disks: Structure

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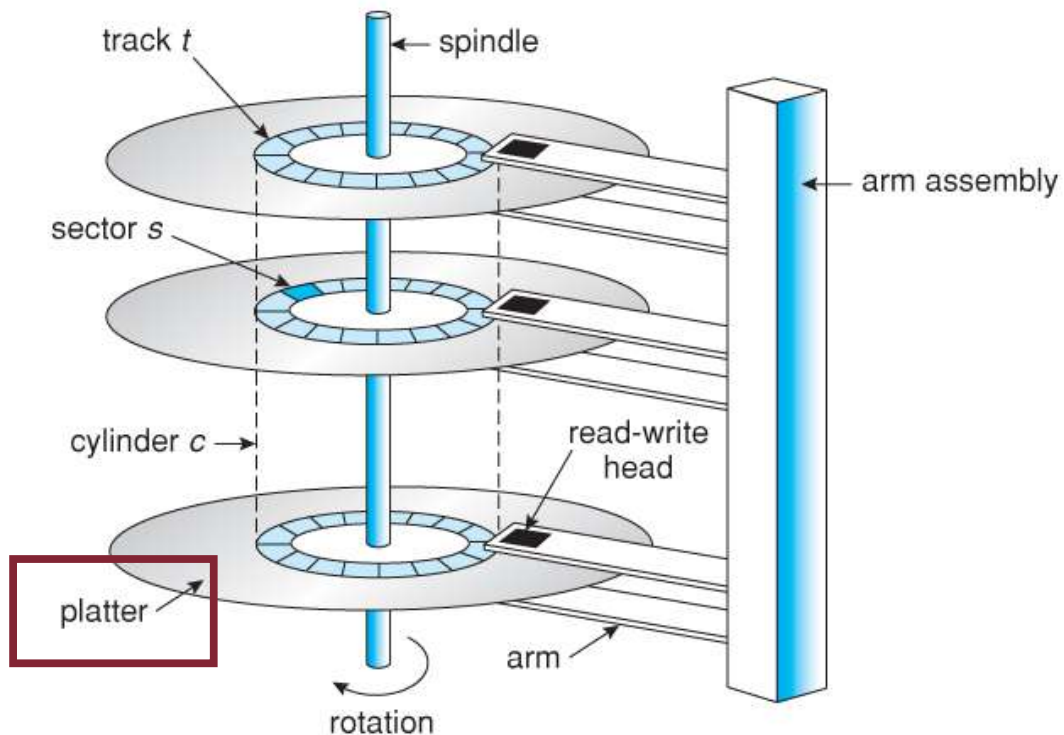
Hard disk
rigid metal

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Floppy disk
flexible plastic
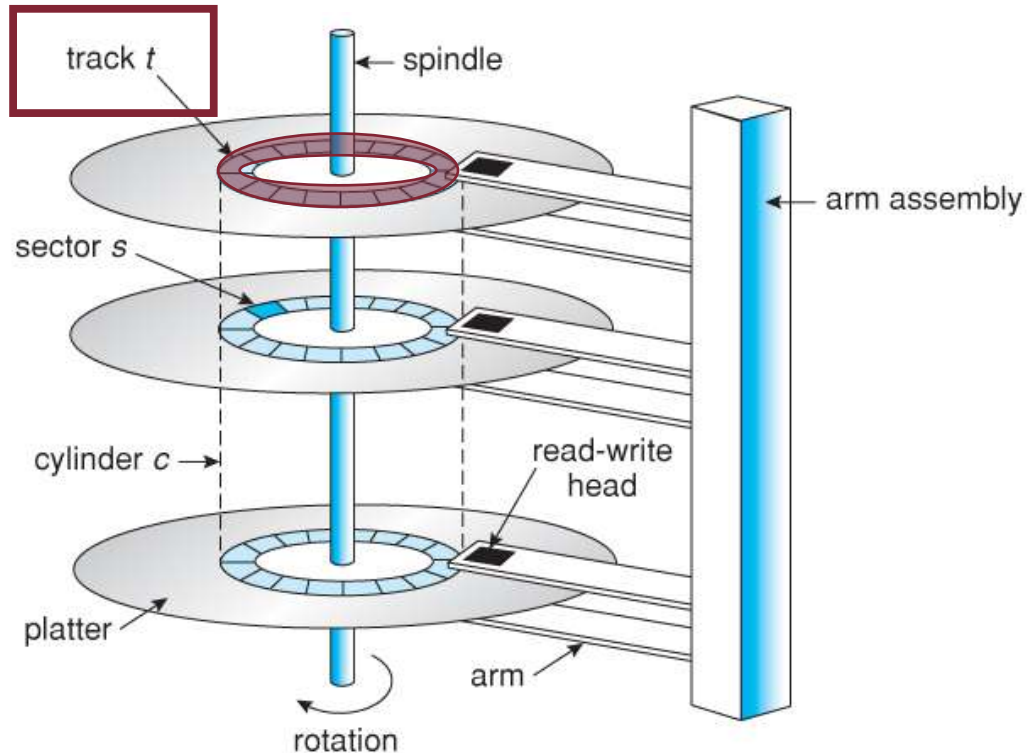
Magnetic Disks: Structure

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

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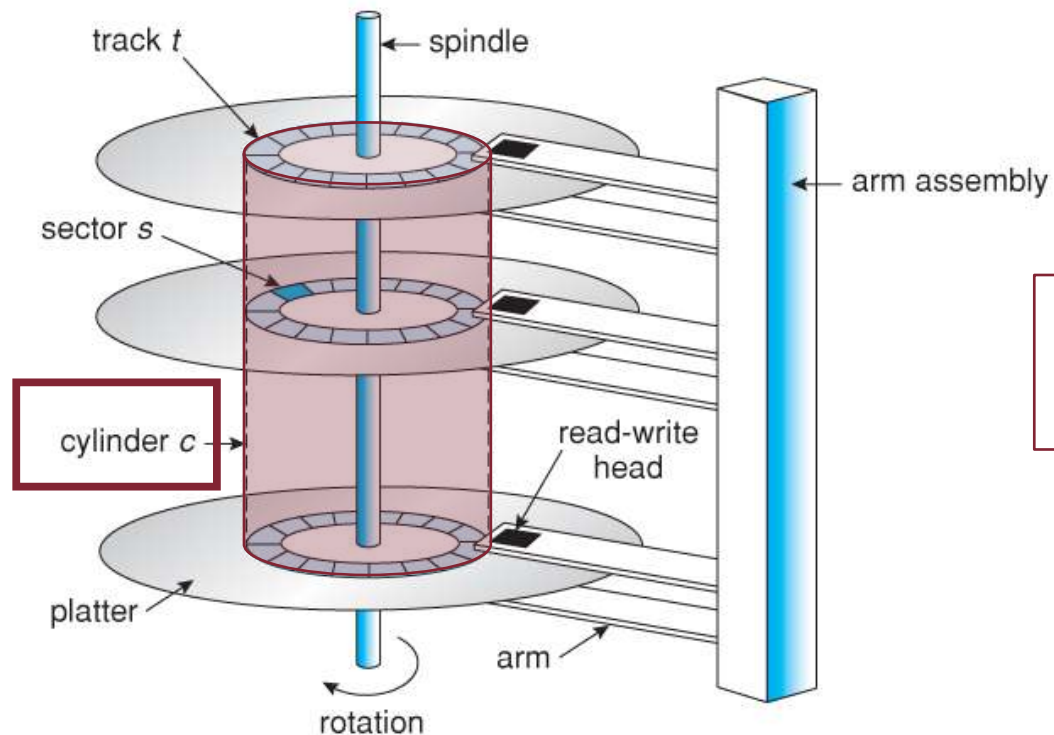Floppy disk
flexible plastic

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

Magnetic Disks: Tracks and Cylinders

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

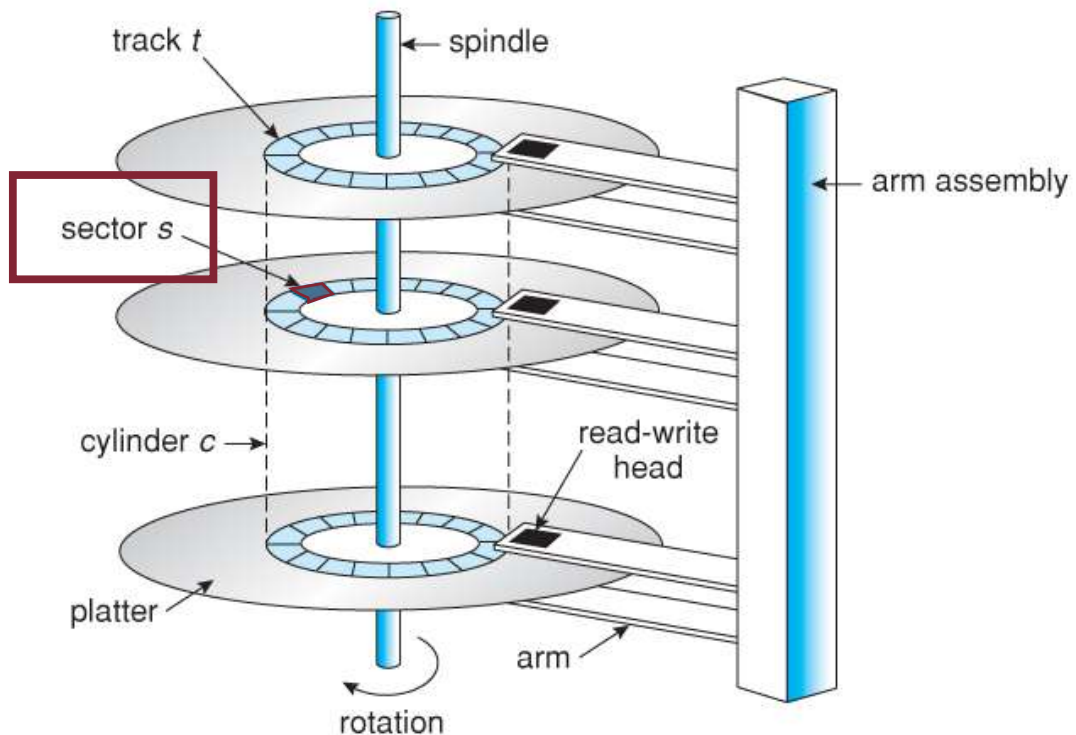# Magnetic Disks: Tracks and Cylinders

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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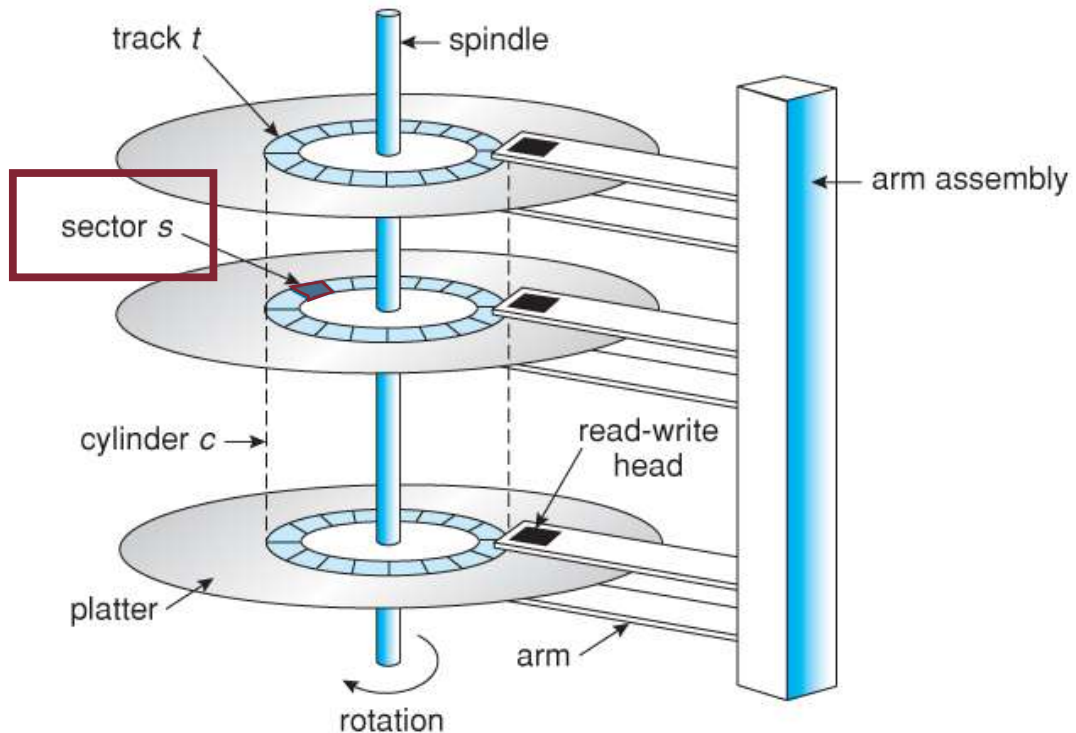
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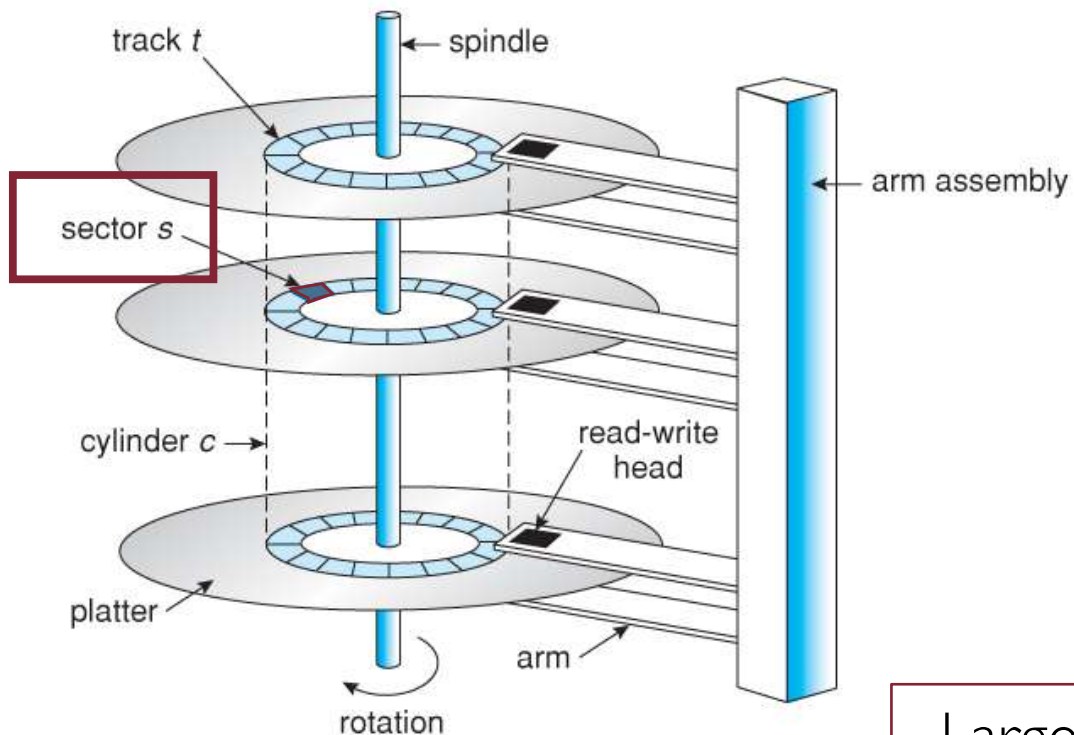
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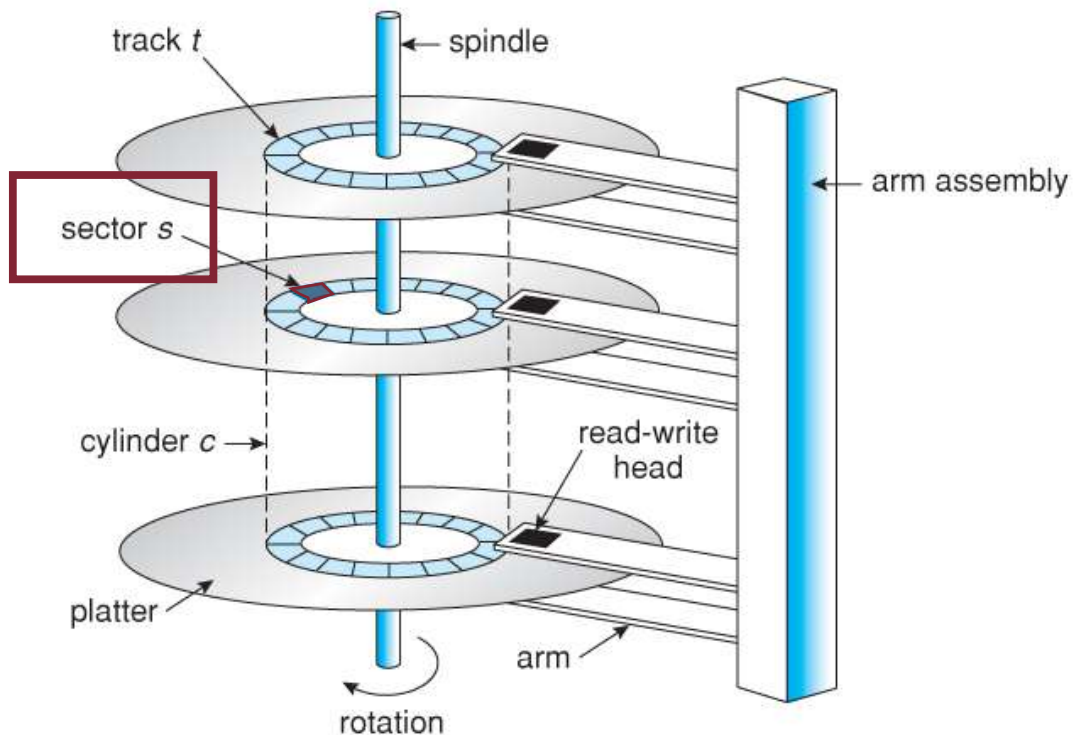Each sector usually contains 512 bytes

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

Magnetic Disks: Heads
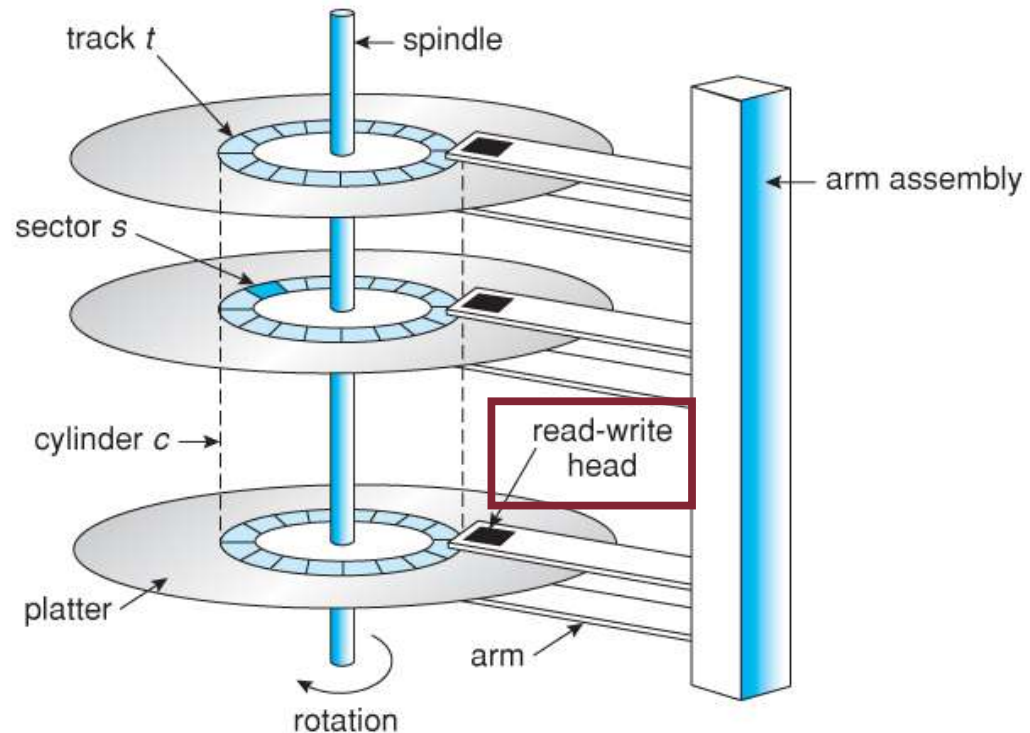
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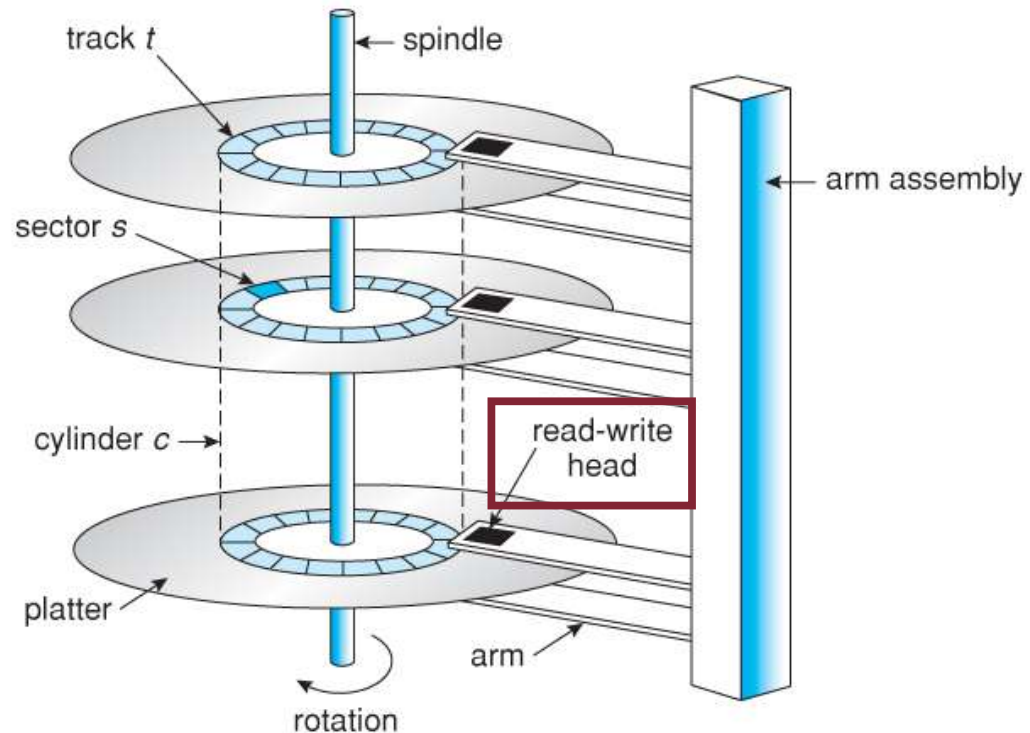
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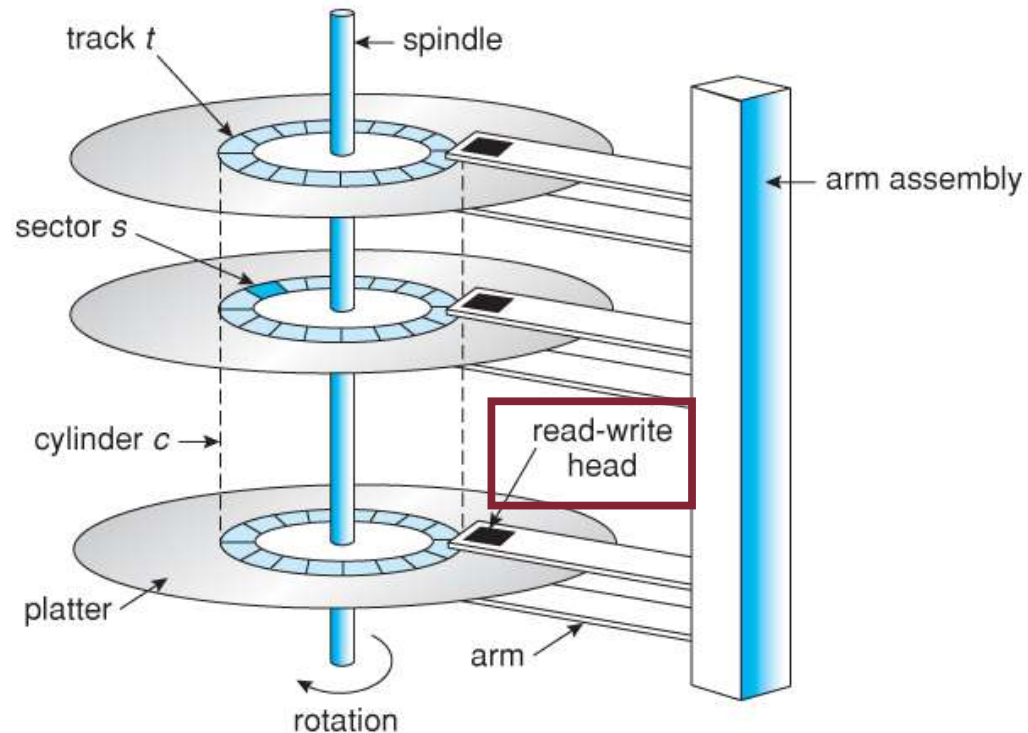
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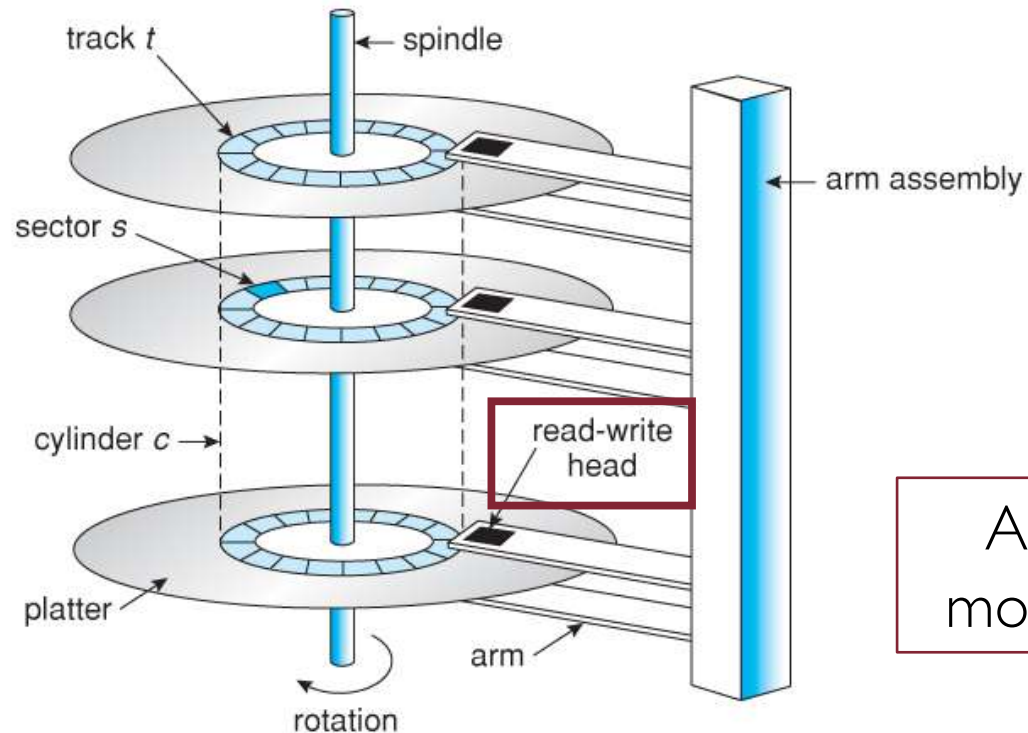
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Each head is placed on a separate **arm**

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

Magnetic Disks: Storage Capacity
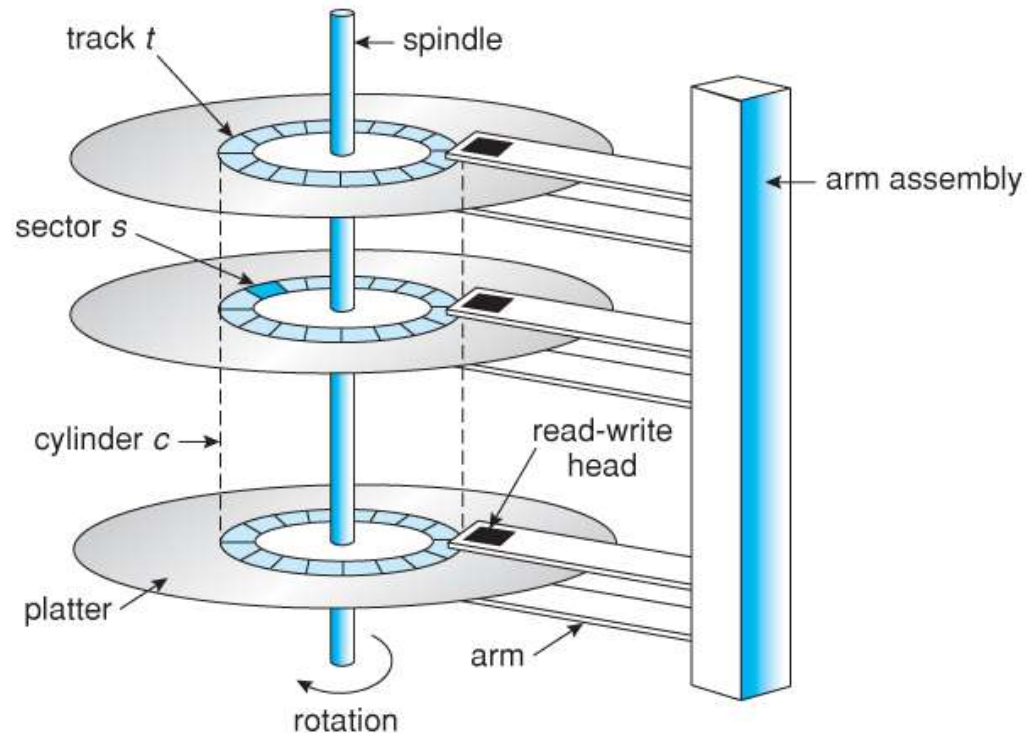
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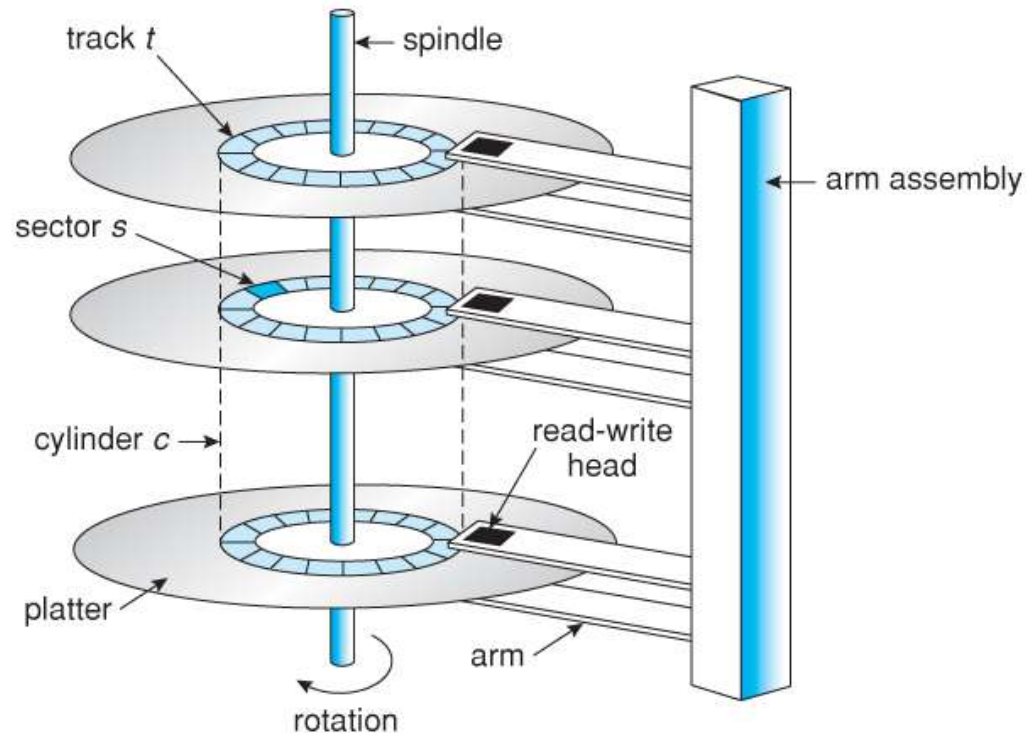
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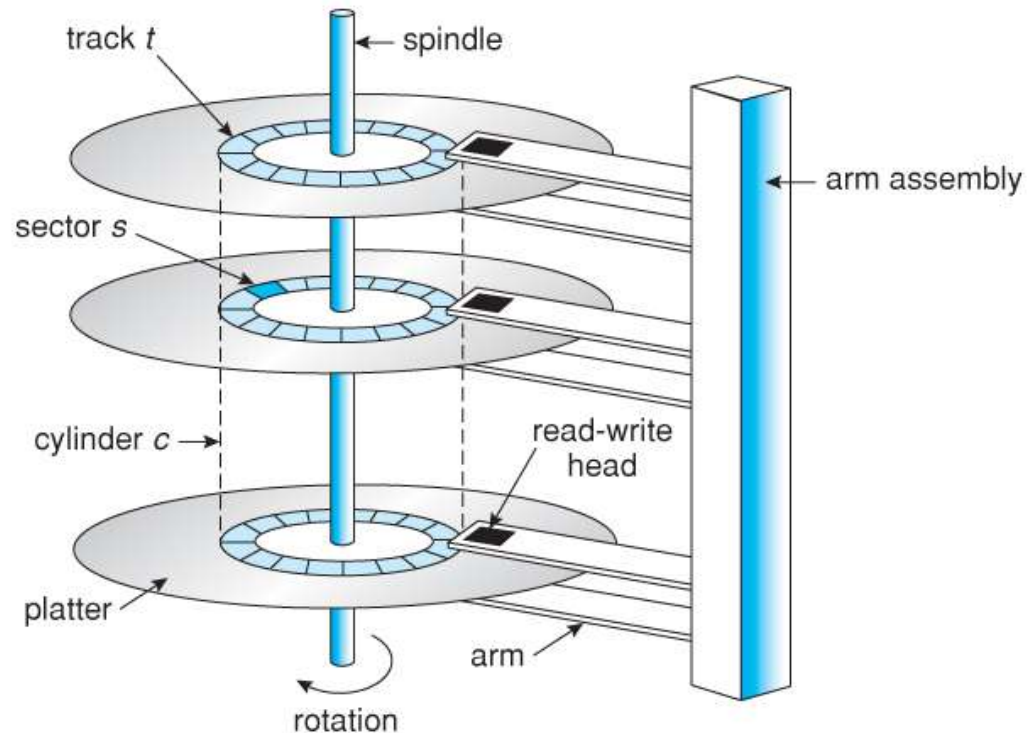
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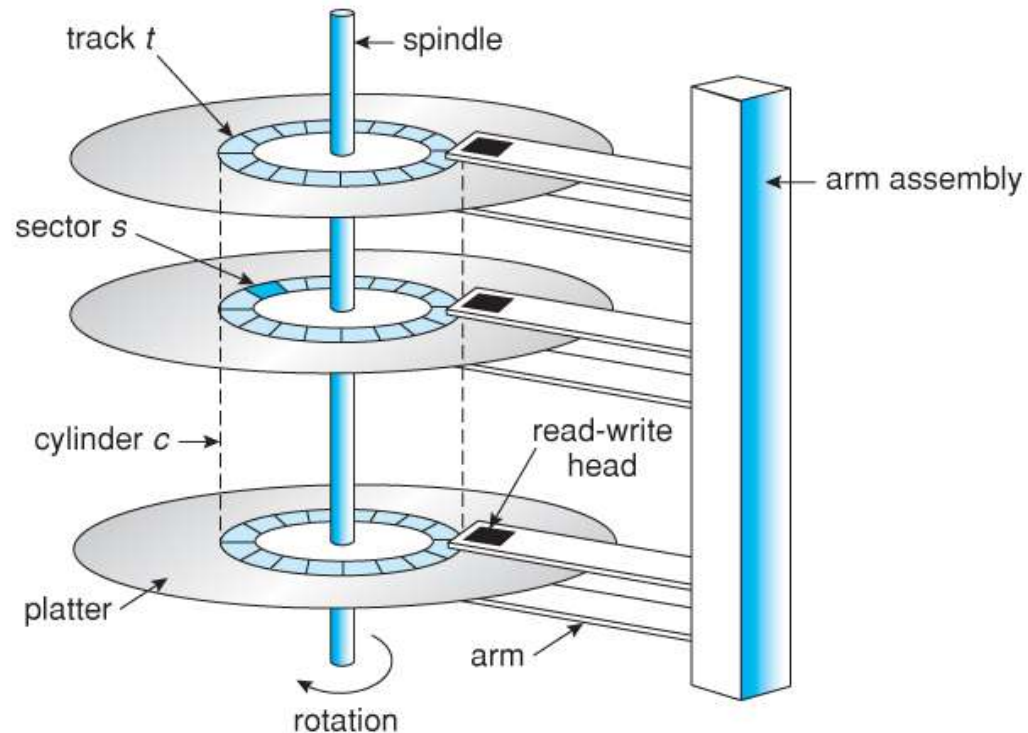
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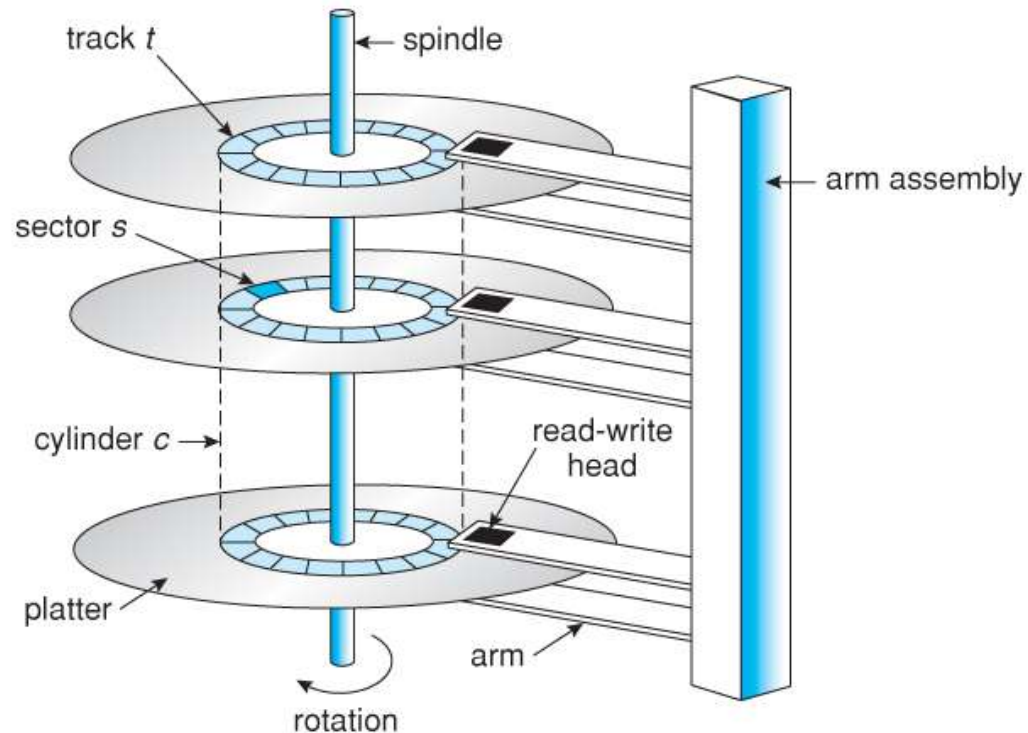
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$C = H * T * S * B$

OVERALL CAPACITY

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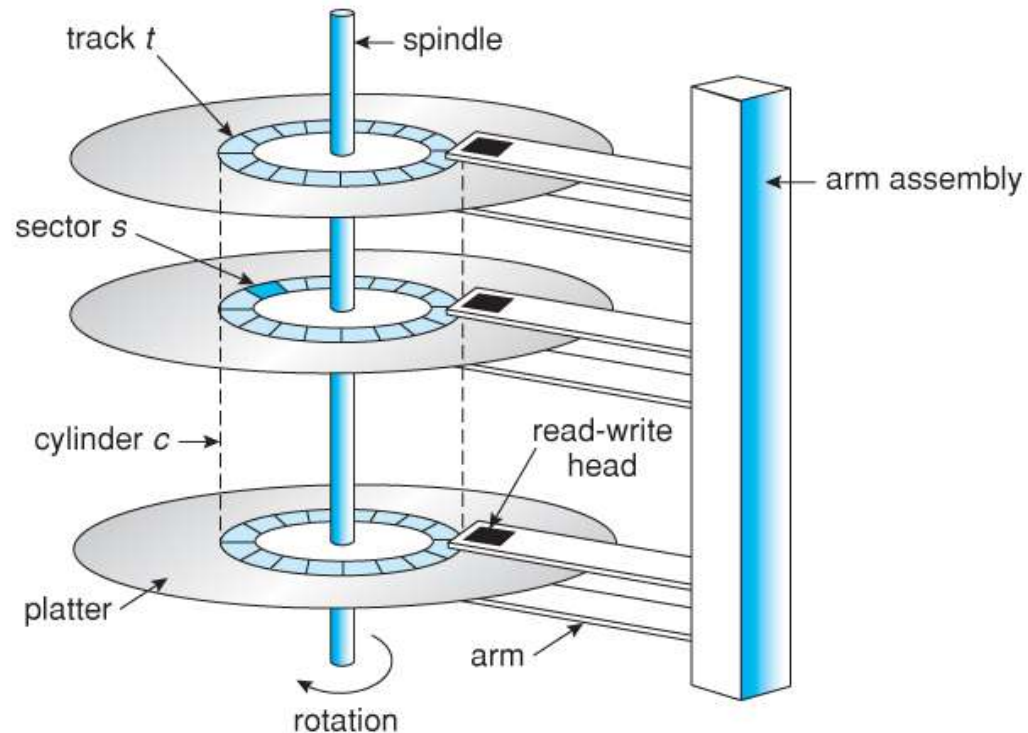
In practice, the number of sectors per track (S) varies with the radius of the track on the platter

The outermost track is larger and can hold more sectors than the inner ones

Magnetic Disks: Referencing
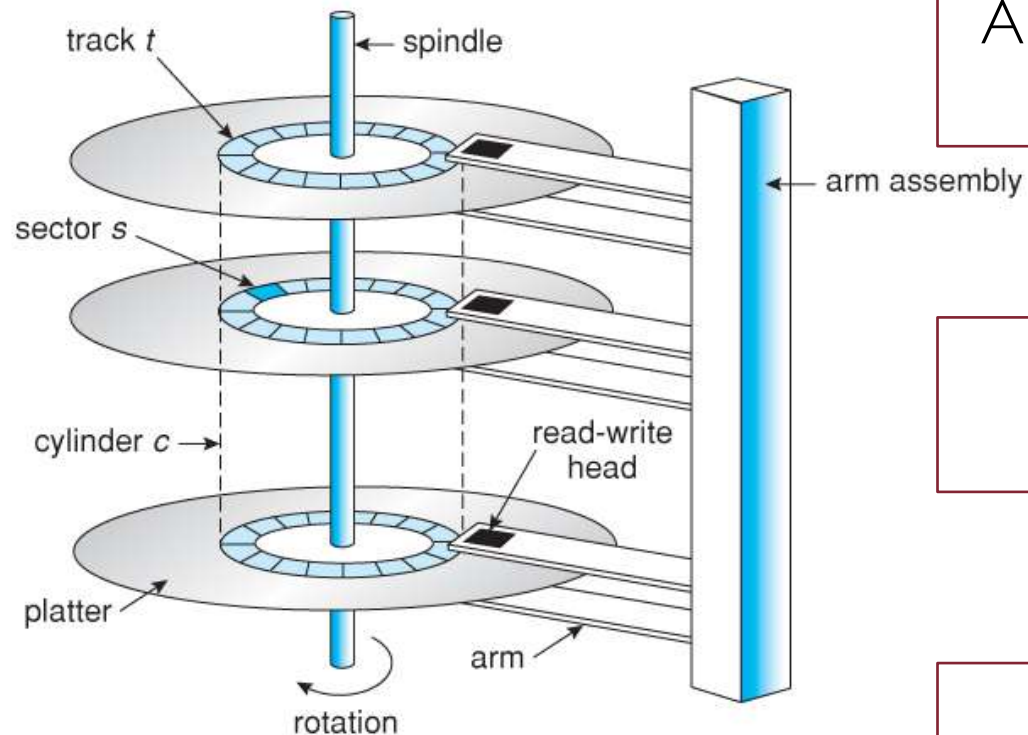
A physical block of data is specified by the (head, cylinder, sector) number

Disk blocks are numbered starting at the outermost cylinder, identified by 0

Note that cylinder coincides with track

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  - transfer time   electronic
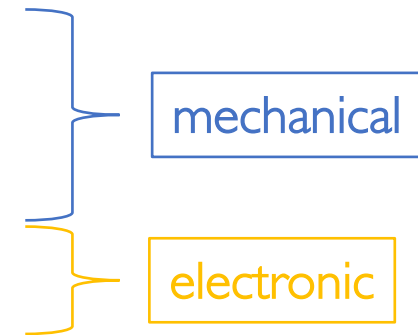
Magnetic Disks: Positioning (Seek) Time

- The time required to move the heads to a specific track/cylinder

- 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

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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)

Magnetic Disks: Risks

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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)

Magnetic Disks: Controllers

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- The CPU issues commands to the host controller (typically via memory-mapped I/O ports)

- 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

Minimize Data Transfer Time

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  - Rotational Delay

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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

<u>Setting</u>

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

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Disk (Head) Scheduling

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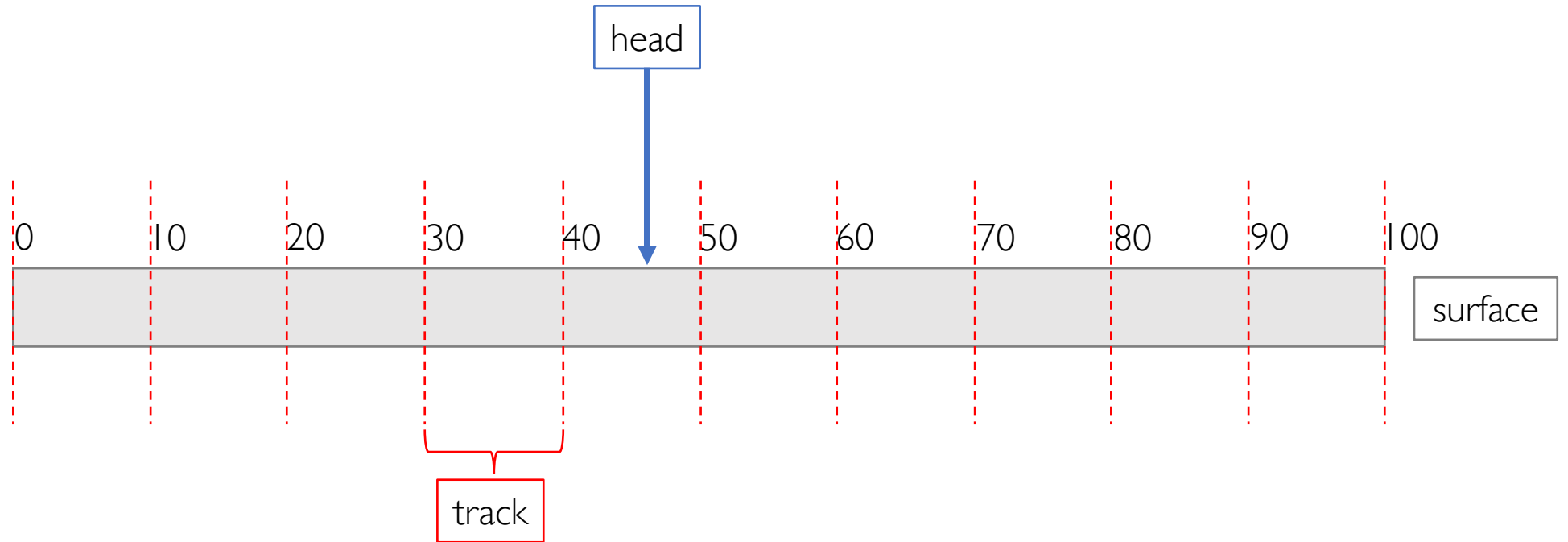
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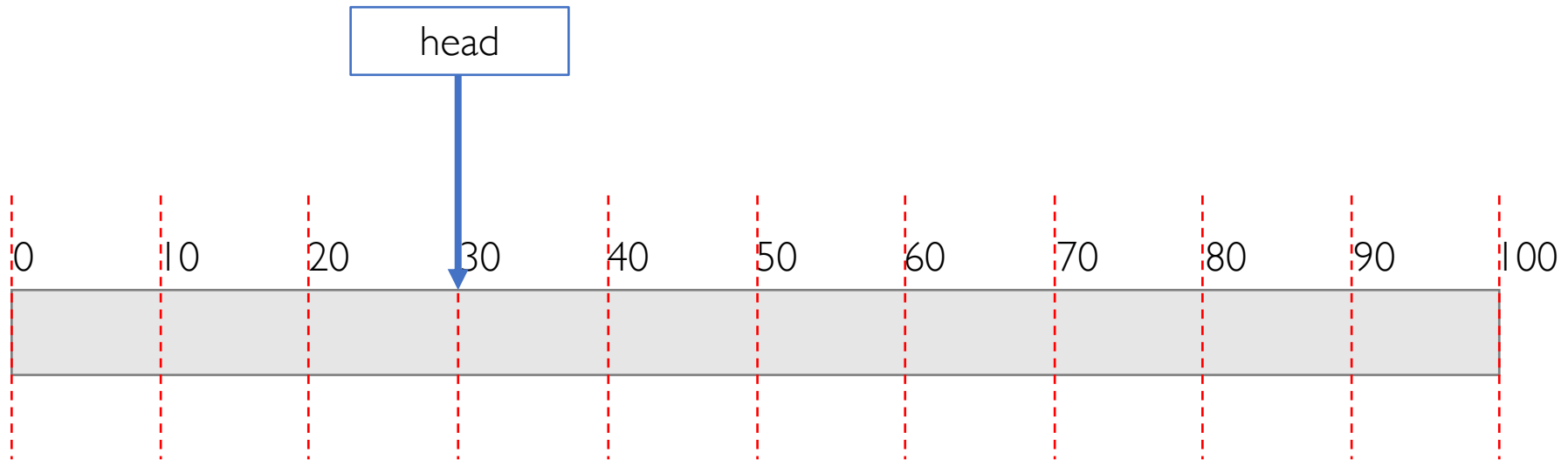We only try minimizing the seek time not the rotational delay

We consider track/cylinder independently of the sector

Disk Scheduling: Model

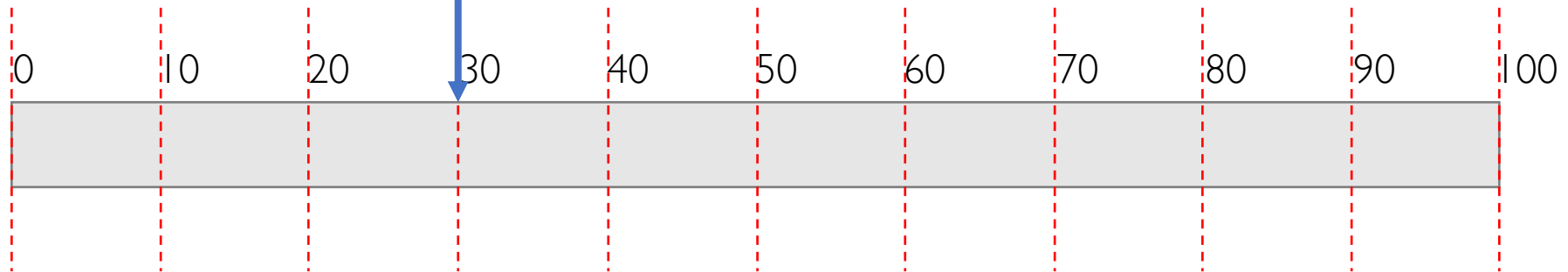# Disk Scheduling: First Come First Serve (FCFS)

Serve the requests in the exact same order they arrive

head

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: First Come First Serve (FCFS)

requests = 65, 40, 18, 78

head = 30

0   10   20   30   40   50   60   70   80   90   100

Distance travelled = 0

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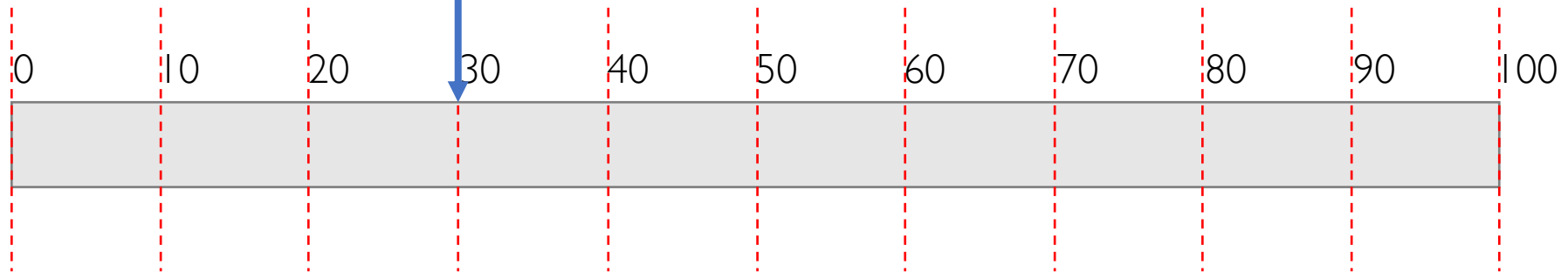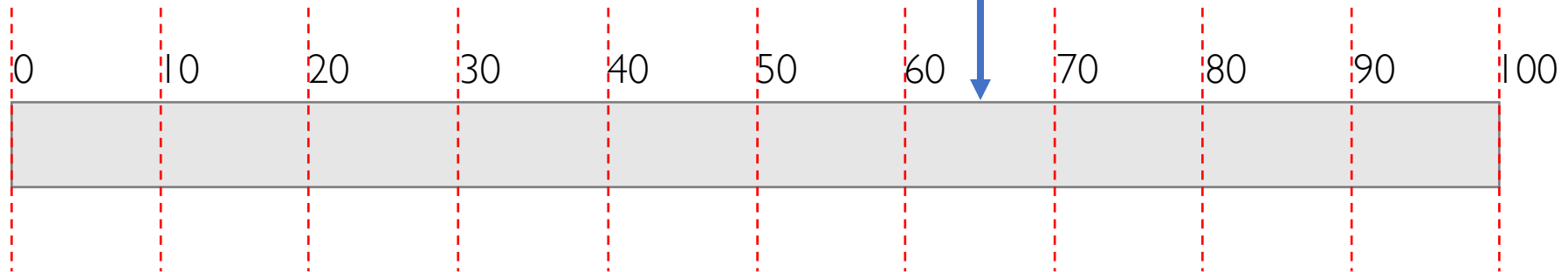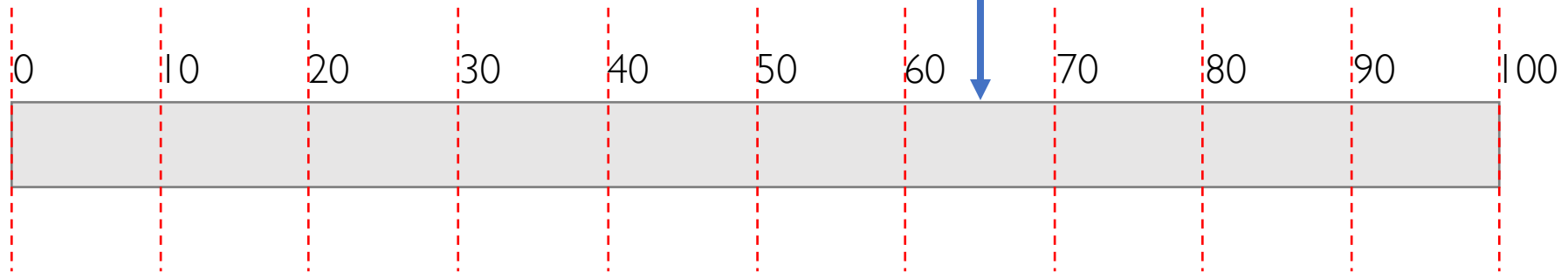
Distance travelled = 0 + |65 − 30| = 35

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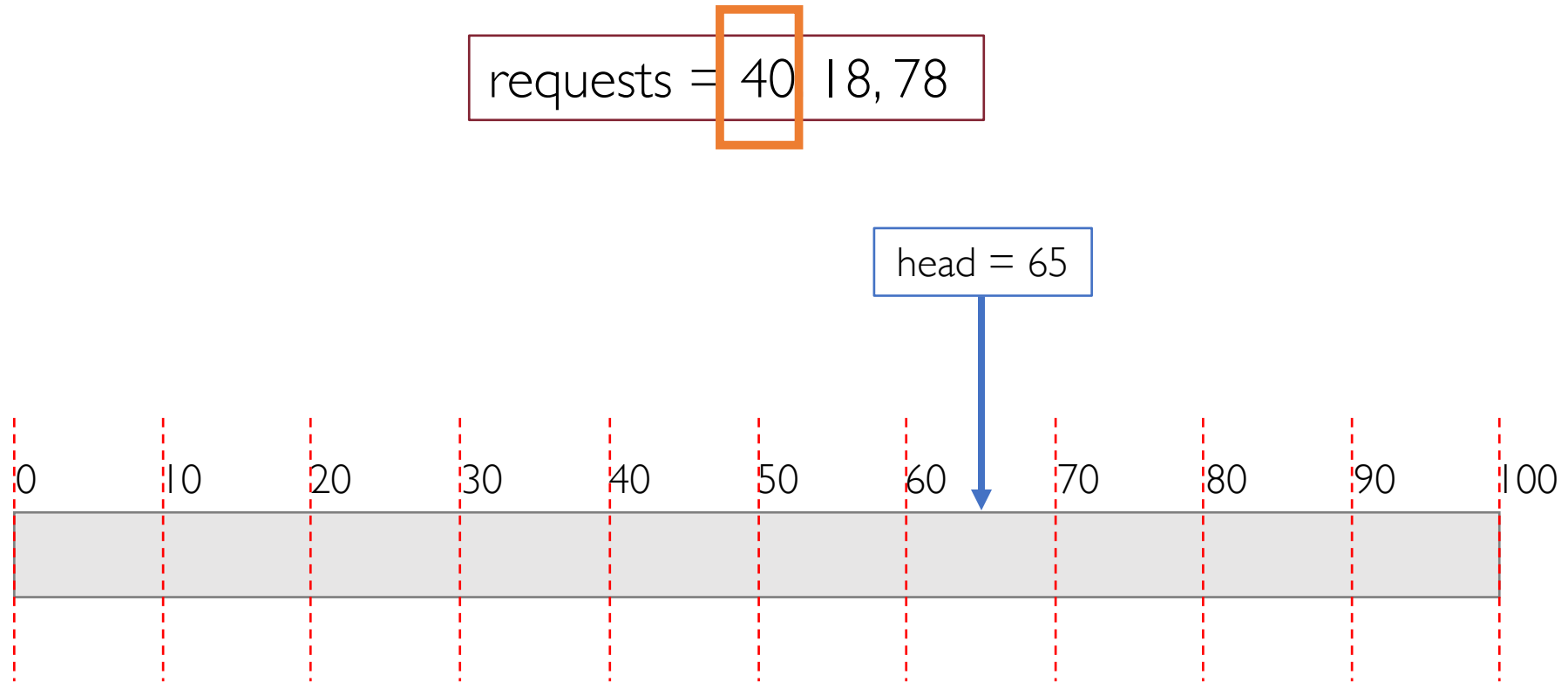
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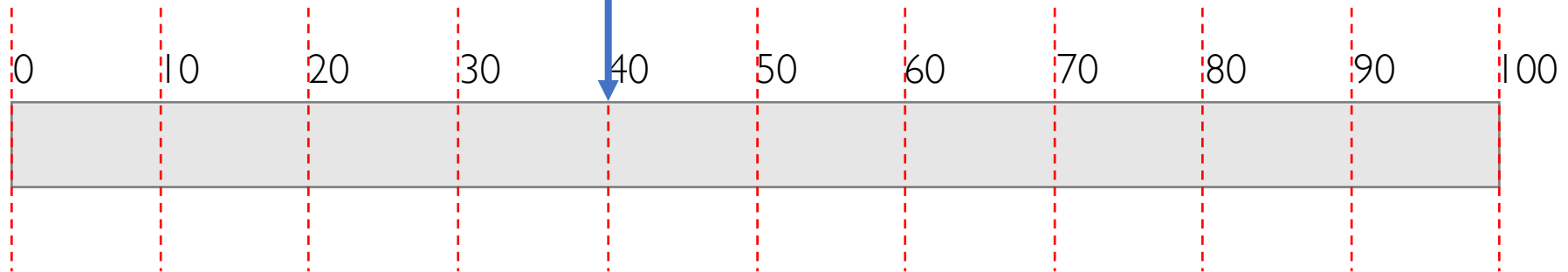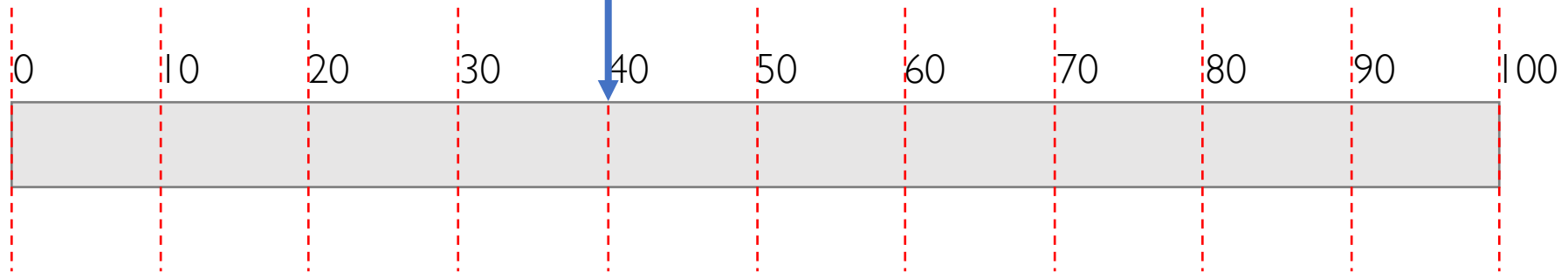
Distance travelled = 35 + |40 − 65| = 60

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0   10   20   30   40   50   60   70   80   90   100

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0   10   20   30   40   50   60   70   80   90   100

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| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
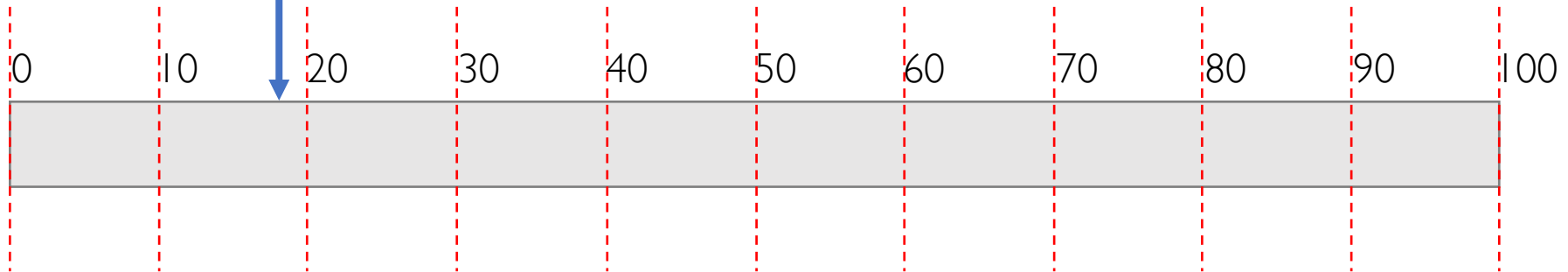
Distance travelled = 60 + |18 − 40| = 82

Disk Scheduling: First Come First Serve (FCFS)

requests = 78

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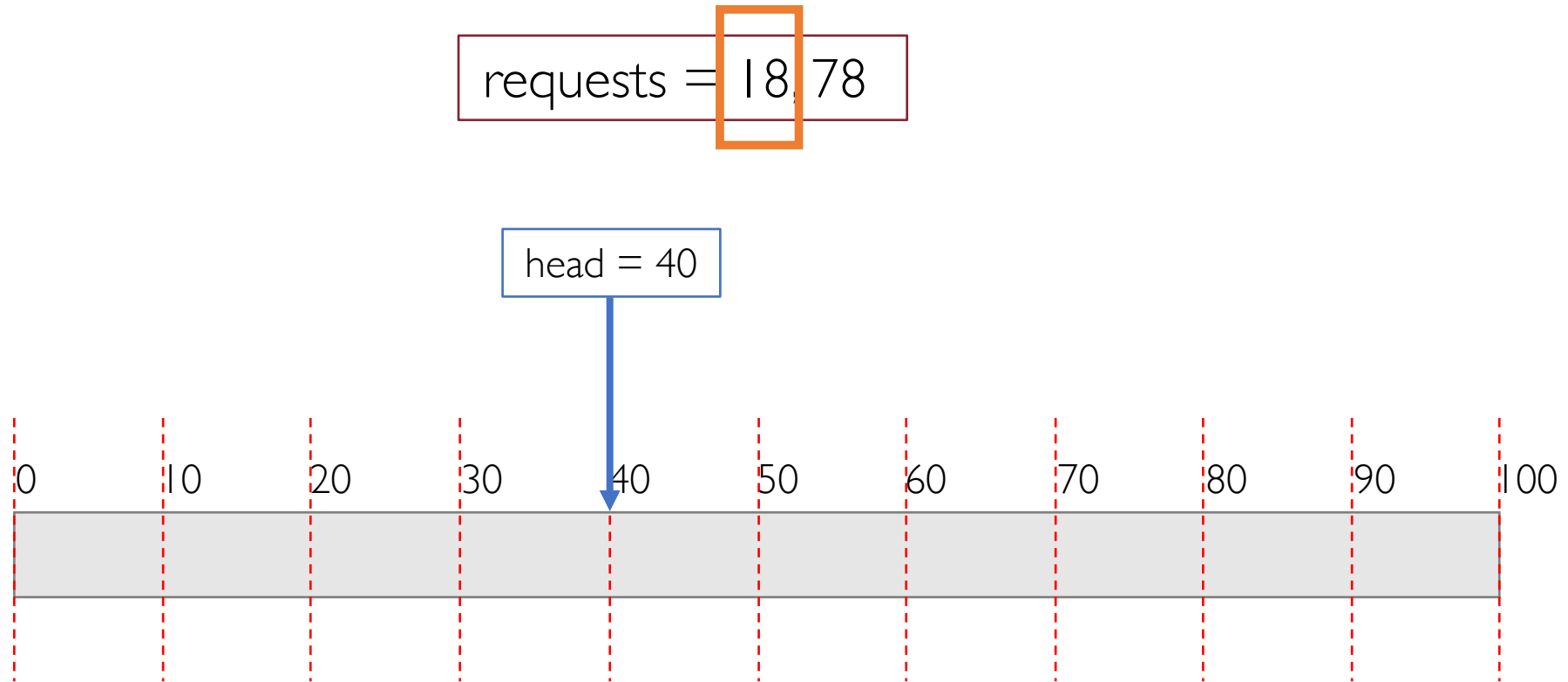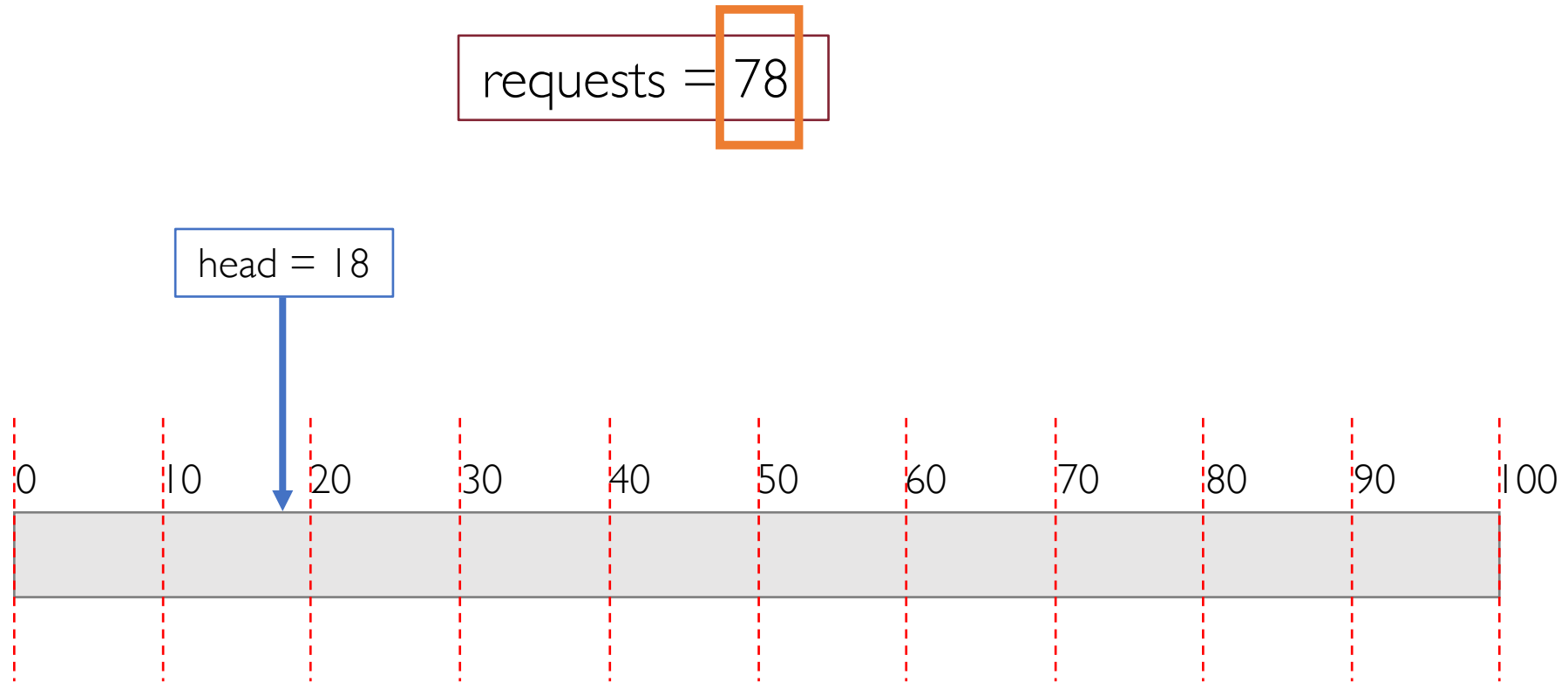
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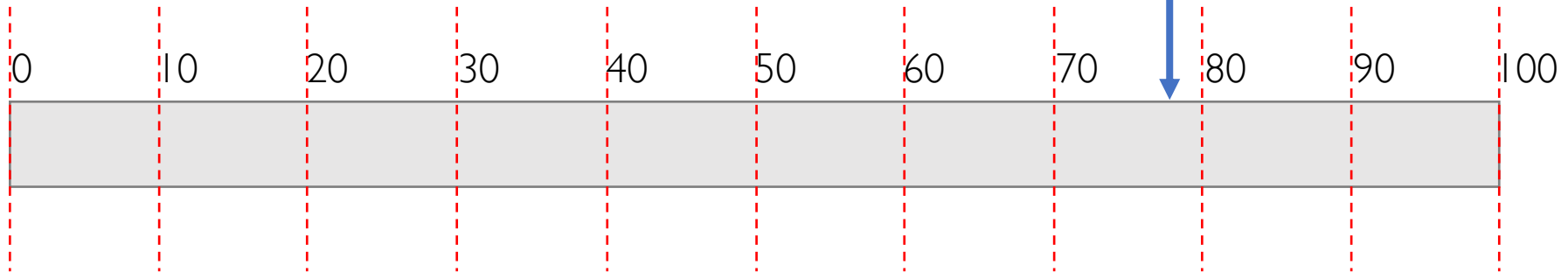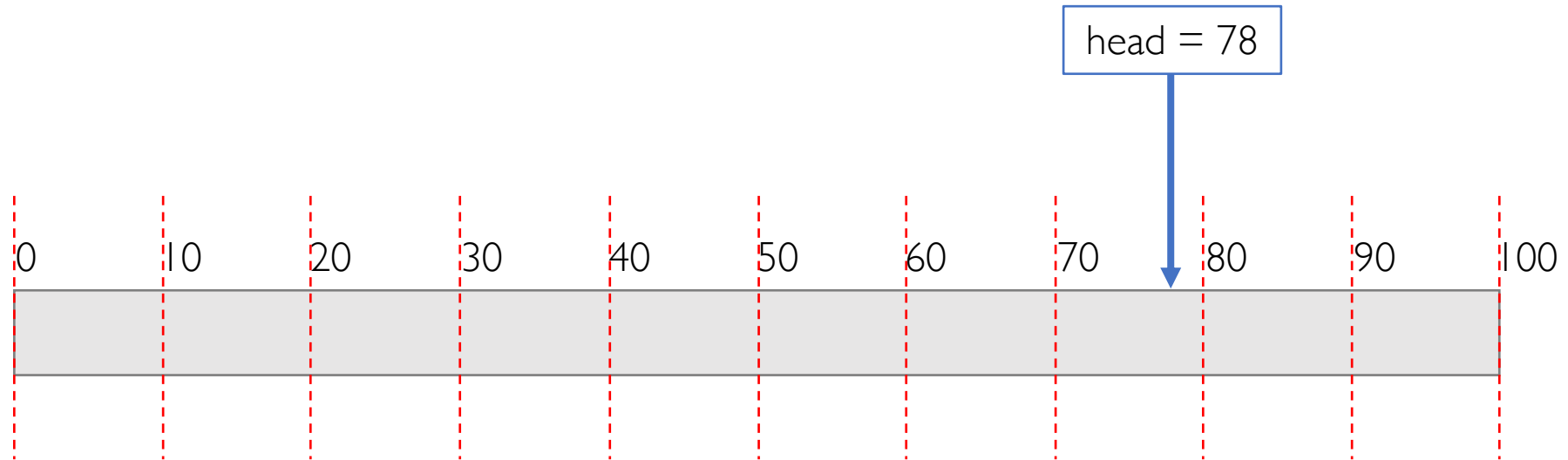
Distance travelled = 82 + |78 − 18| = 142

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
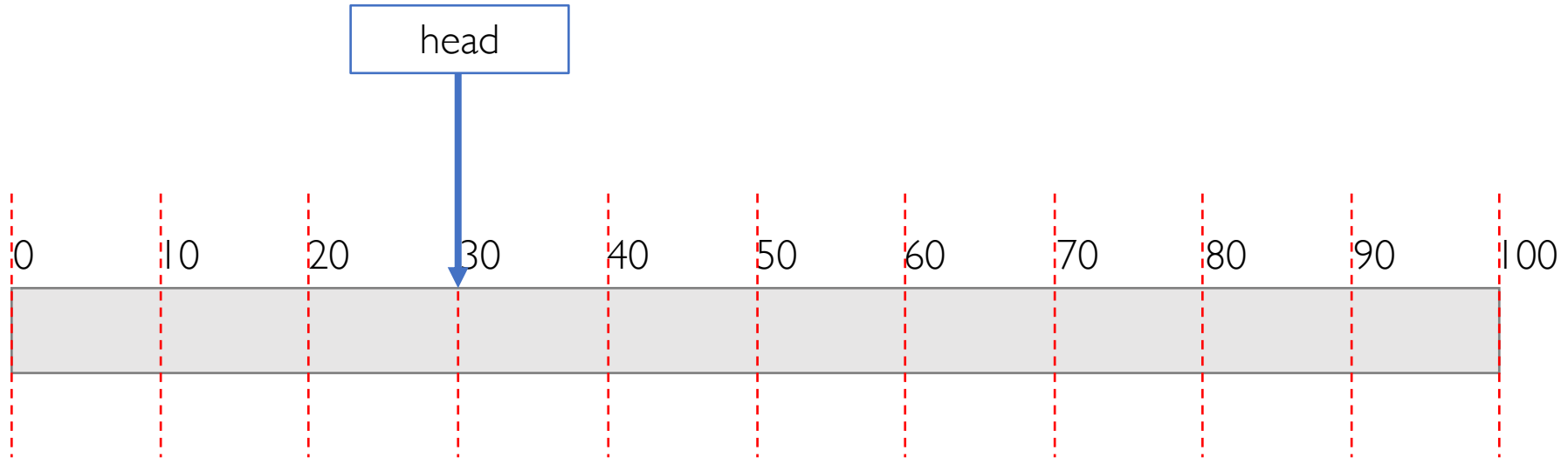
head

0 10 20 30 40 50 60 70 80 90 100

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 40, 18, 78

head = 30

0   10   20   30   40   50   60   70   80   90   100
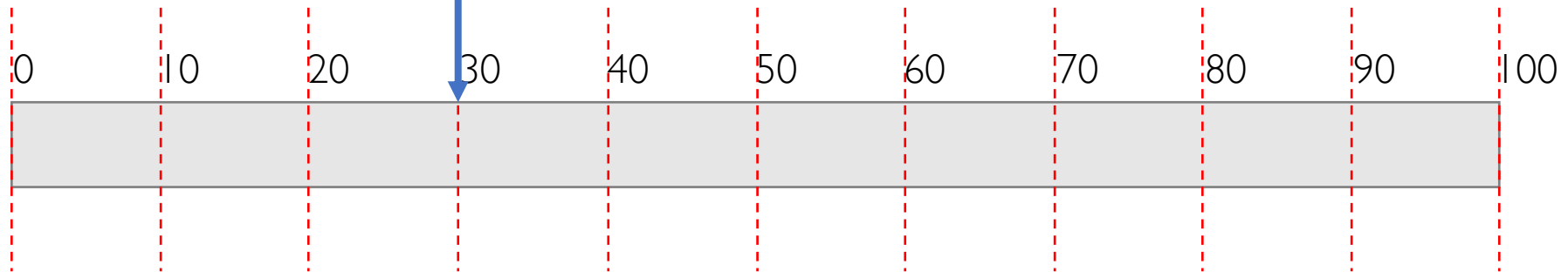
Distance travelled = 0

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 40, 18, 78

Closest request = 40
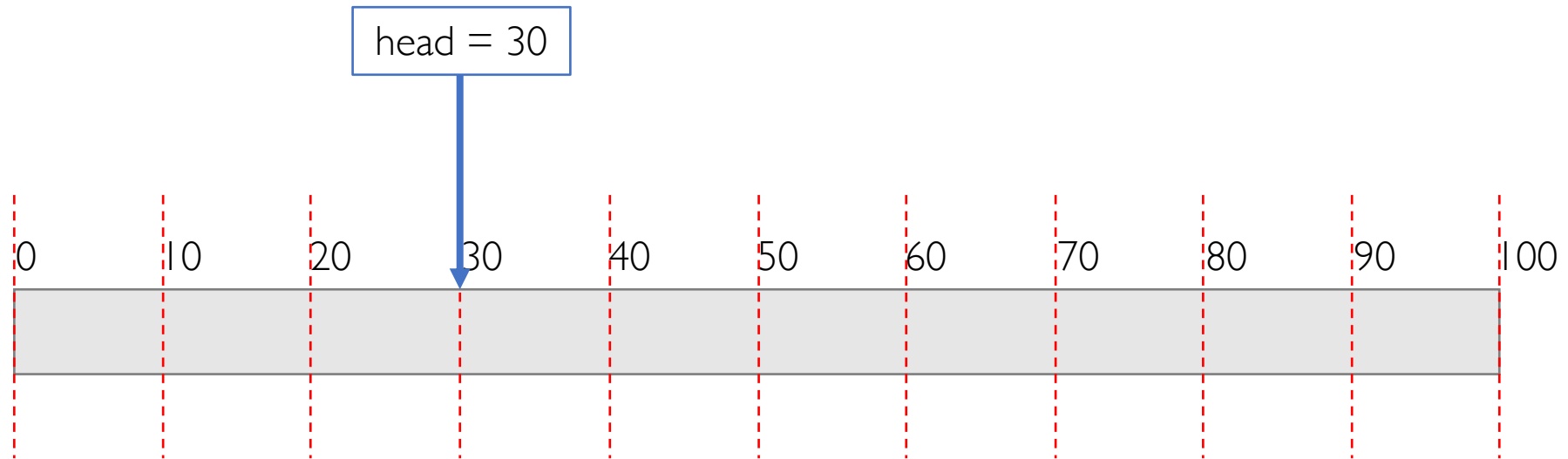
head = 30

```
0    10   20   30   40   50   60   70   80   90   100
```

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 40, 18, 78

head = 40

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 40, 18, 78

head = 40

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
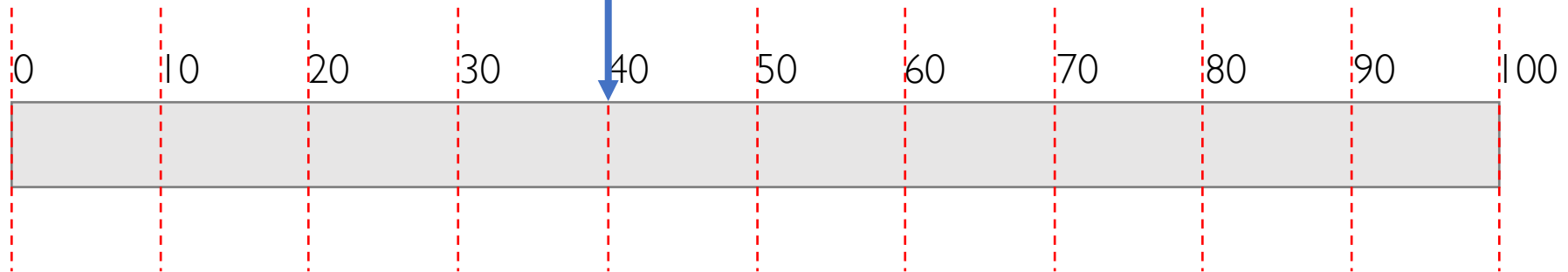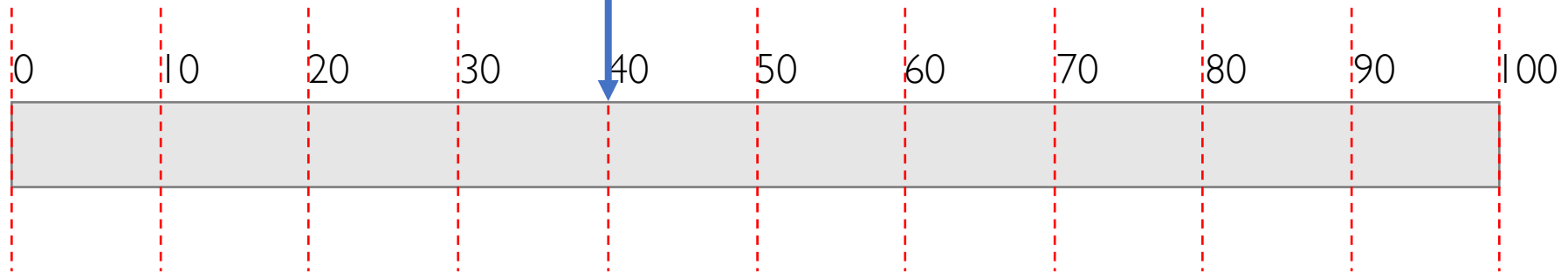
Distance travelled = 0 + |40 – 30| = 10

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65,18,78

Closest request = 18

head = 40
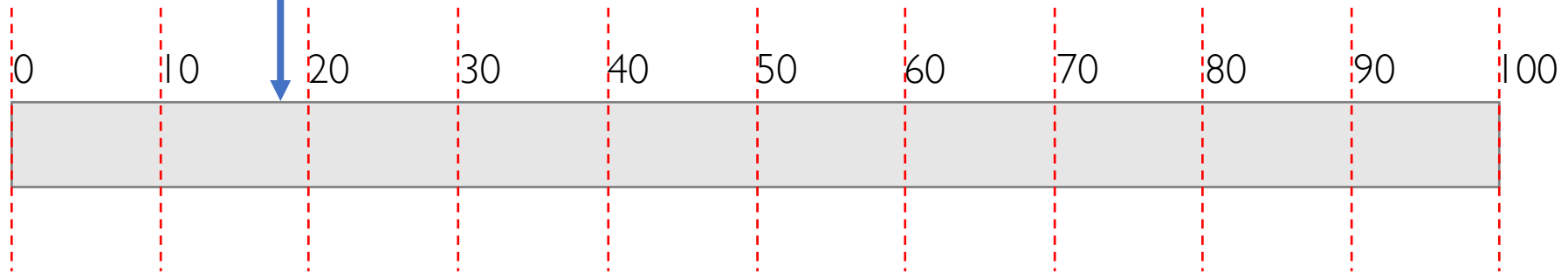
0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 18, 78

head = 18

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 18, 78

head = 18

0   10   20   30   40   50   60   70   80   90   100

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

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 78

Closest request = 65
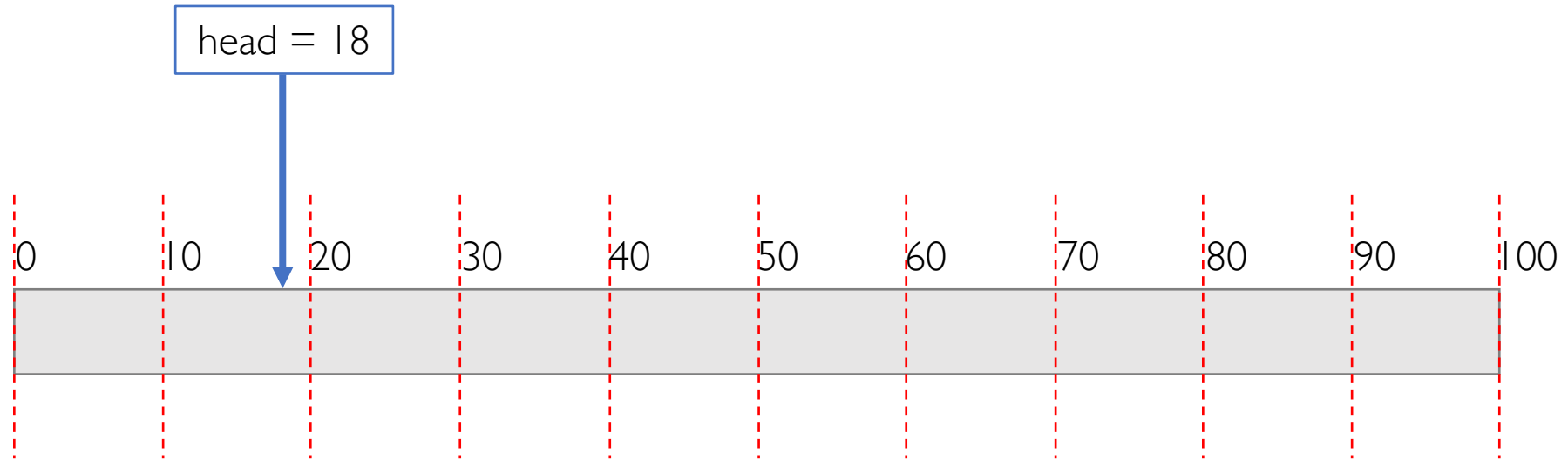
head = 18

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 78

head = 65

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 65, 78

head = 65

0 10 20 30 40 50 60 70 80 90 100
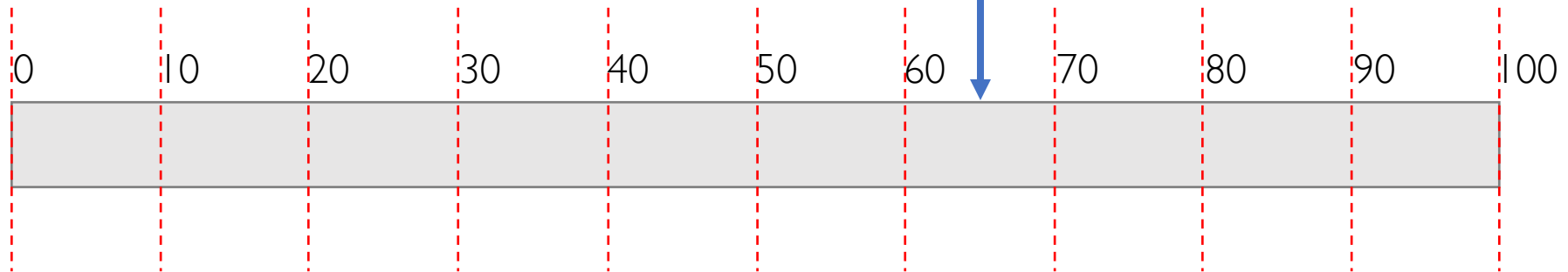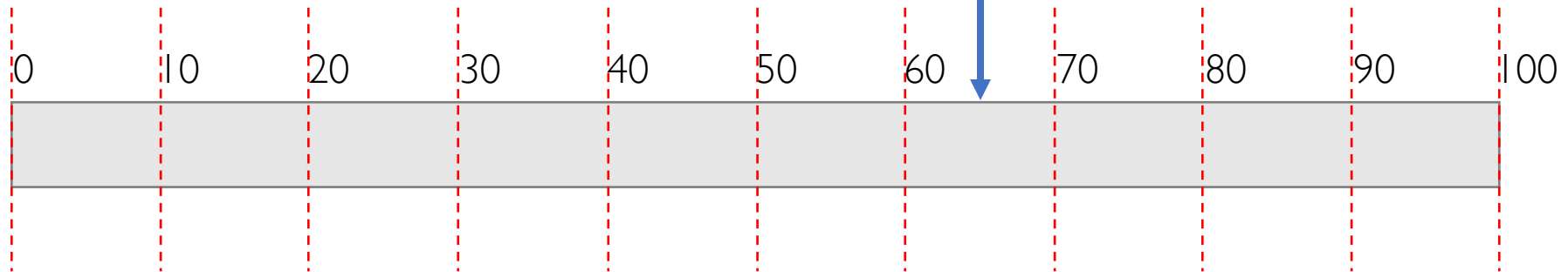
Distance travelled = 32 + |65 − 18| = 79

Disk Scheduling: Shortest Seek Time First (SSTF)
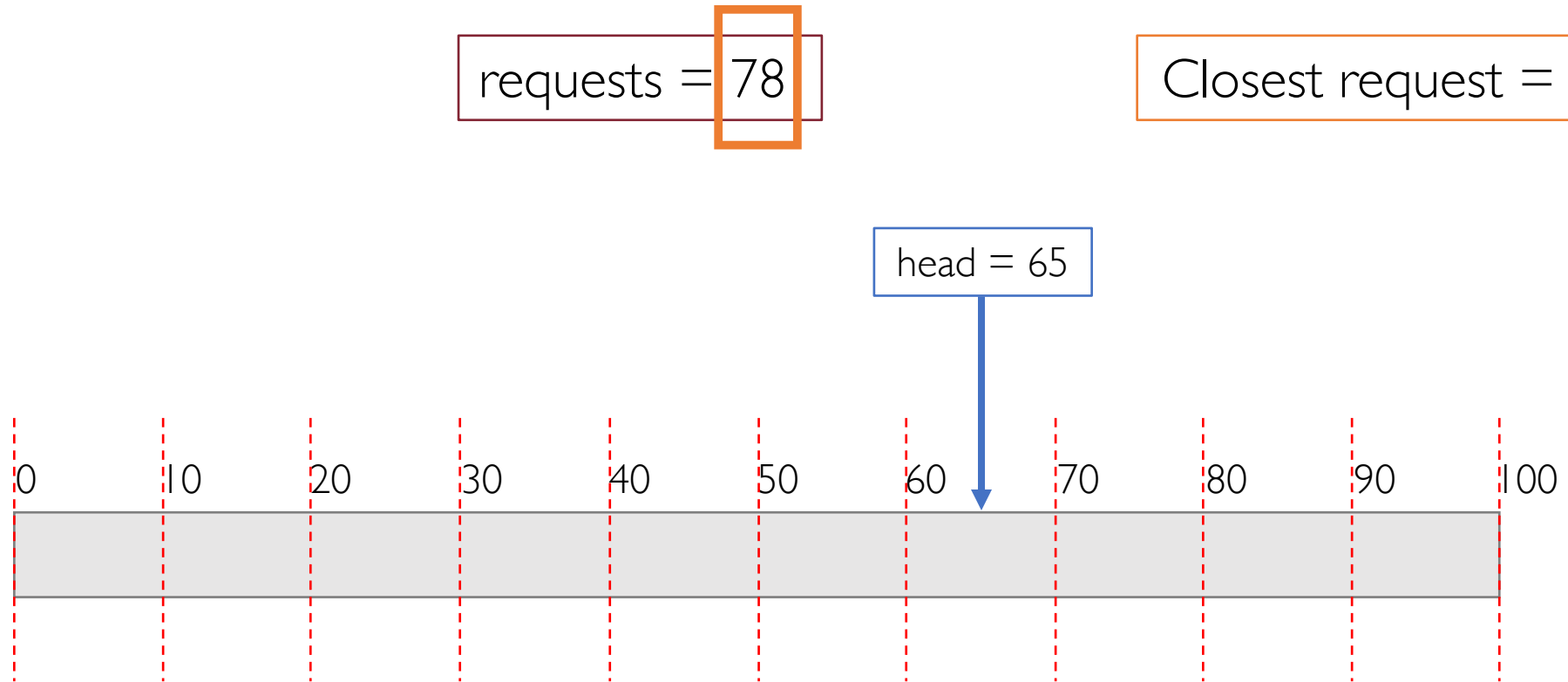
requests = 78

Closest request = 78

head = 65

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: Shortest Seek Time First (SSTF)

requests = 78

head = 78

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: Shortest Seek Time First (SSTF)
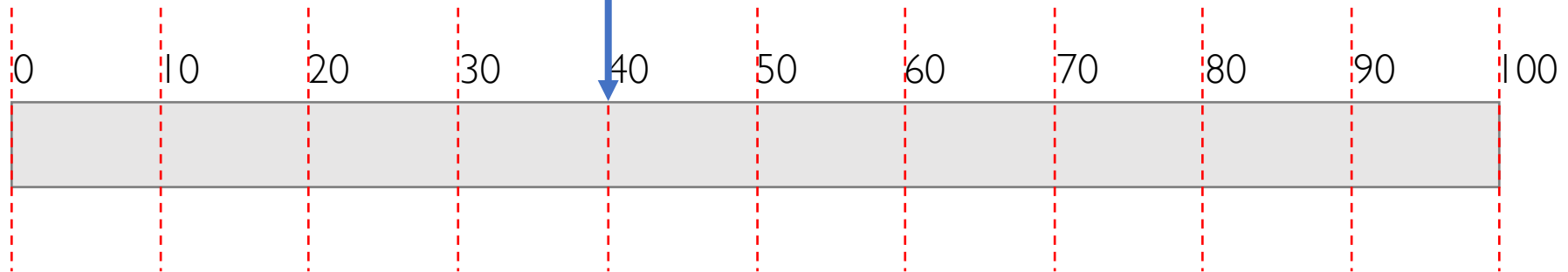
requests = 78

head = 78

0 10 20 30 40 50 60 70 80 90 100
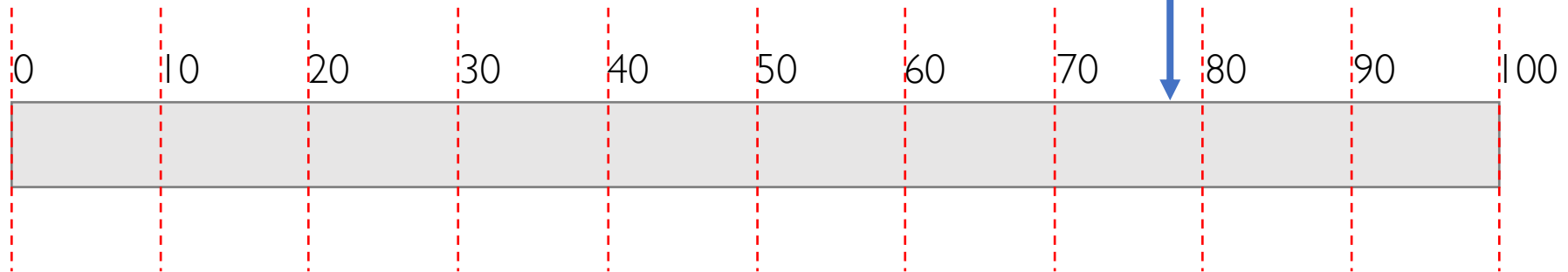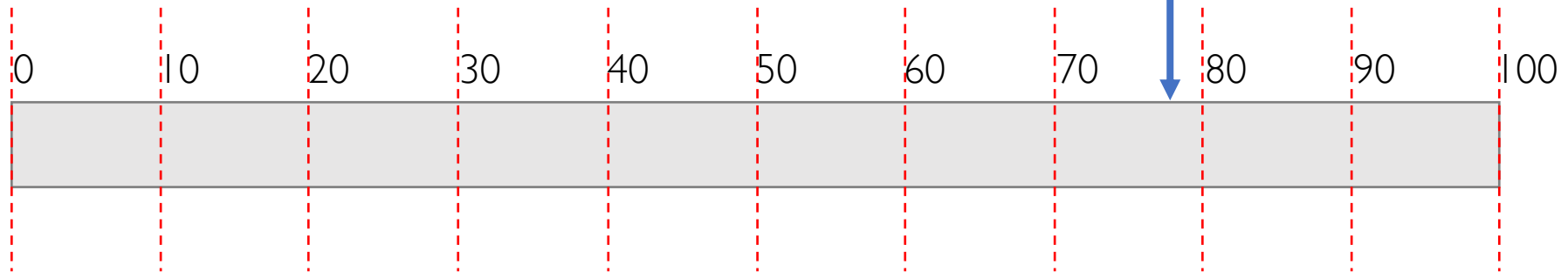
Distance travelled = 79 + |78 − 65| = 92

SSTF: Considerations

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

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- It is not overall optimal as greedily minimizes seek time (locally)

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

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- It is not overall optimal as greedily minimizes seek time (locally)

  - 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)
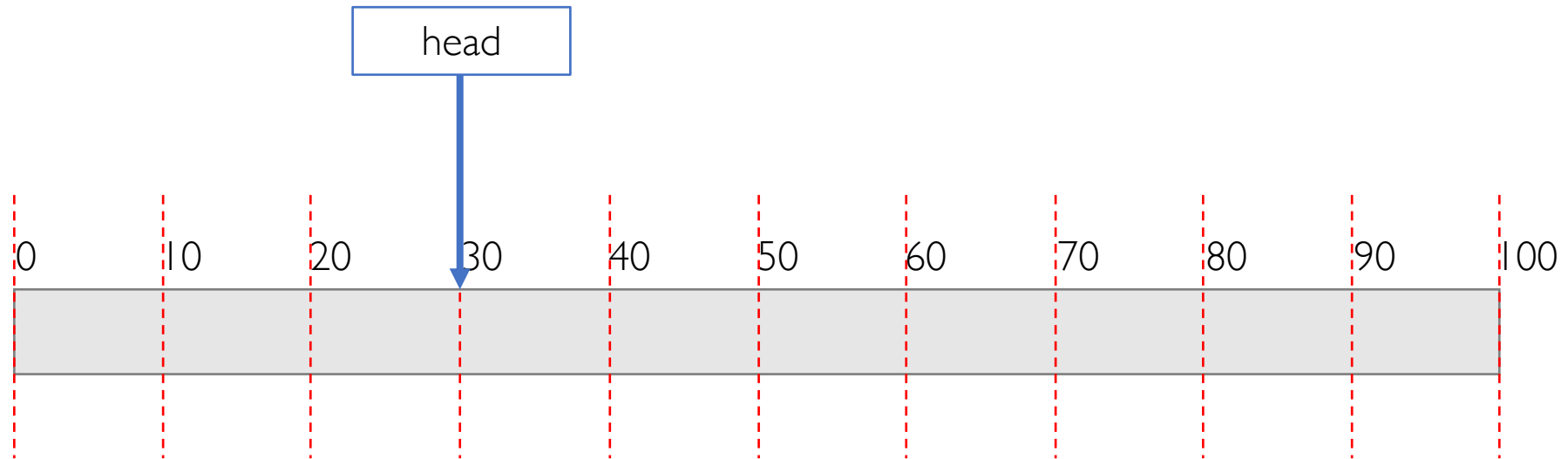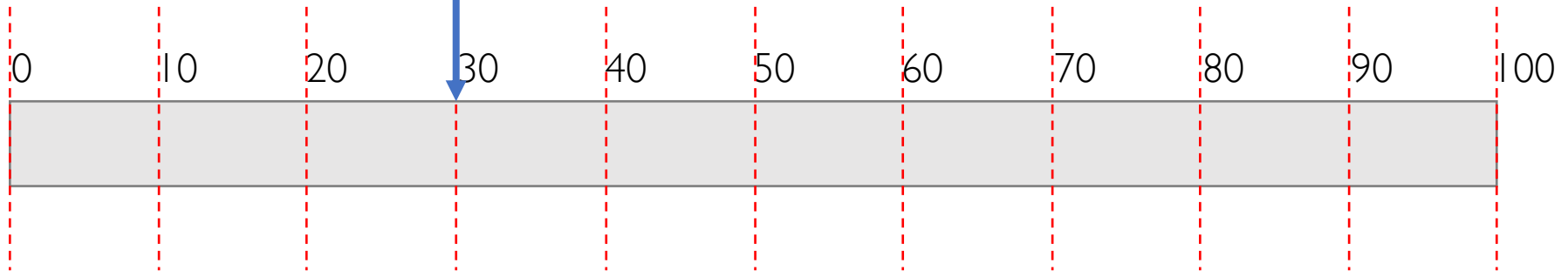
head

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: SCAN

requests = 65, 40, 18, 78

head = 30

0   10   20   30   40   50   60   70   80   90   100

Distance travelled = 0

Disk Scheduling: SCAN

requests = 65, 40, 18, 78

head = 30

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: SCAN

requests = 65, 40, 18, 78

head = 18

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: SCAN

requests = 65, 40, 18, 78

head = 18

0 10 20 30 40 50 60 70 80 90 100

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

Disk Scheduling: SCAN

requests = 65, 40, 78

head = 18

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: SCAN

requests = 65, 40, 78

head = 0

0   10   20   30   40   50   60   70   80   90   100

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

Disk Scheduling: SCAN

requests = 65, 40, 78

head = 0

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: SCAN

requests = 65, 40, 78

head = 40

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: SCAN

requests = 65, 40, 78

head = 40

0   10   20   30   40   50   60   70   80   90   100
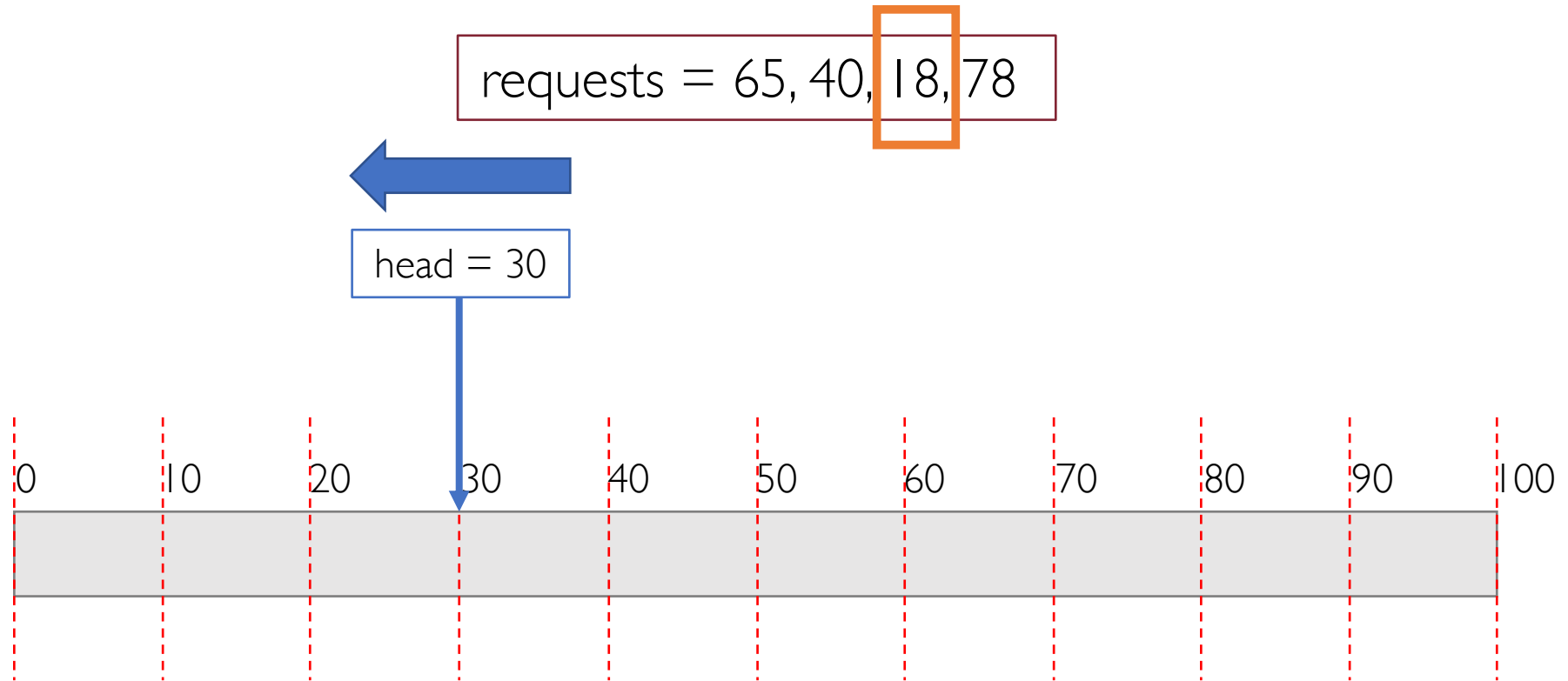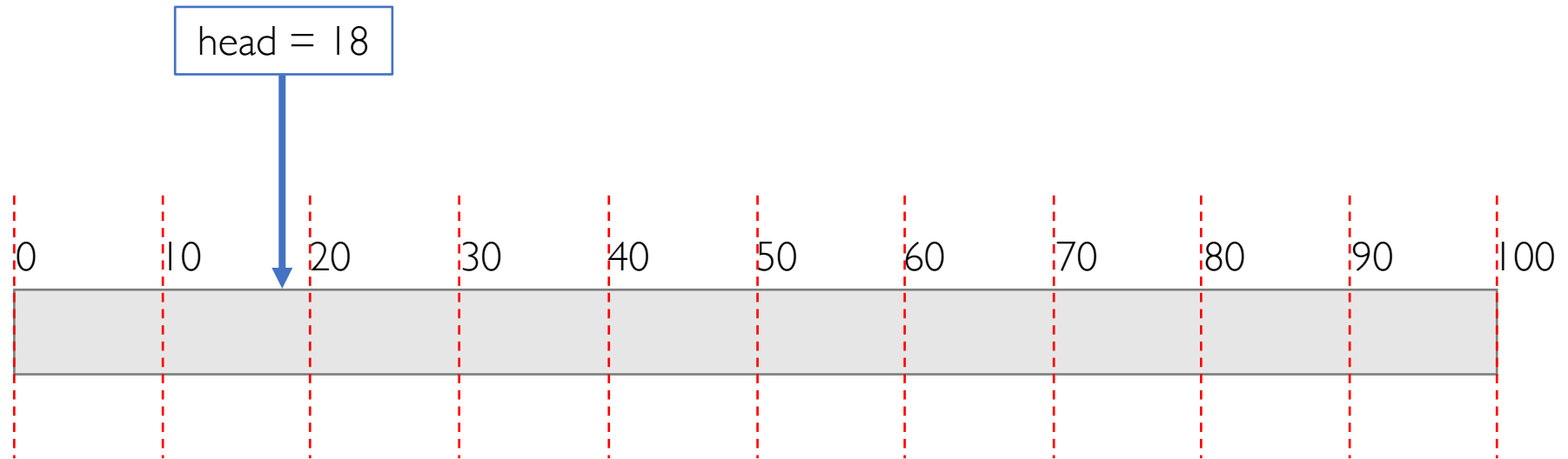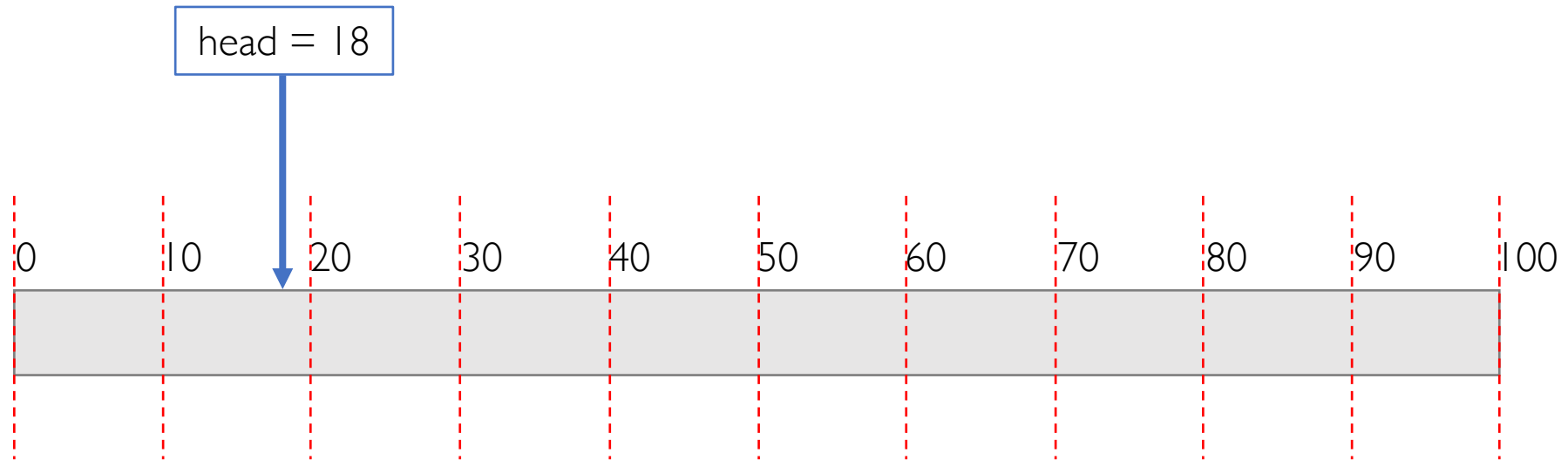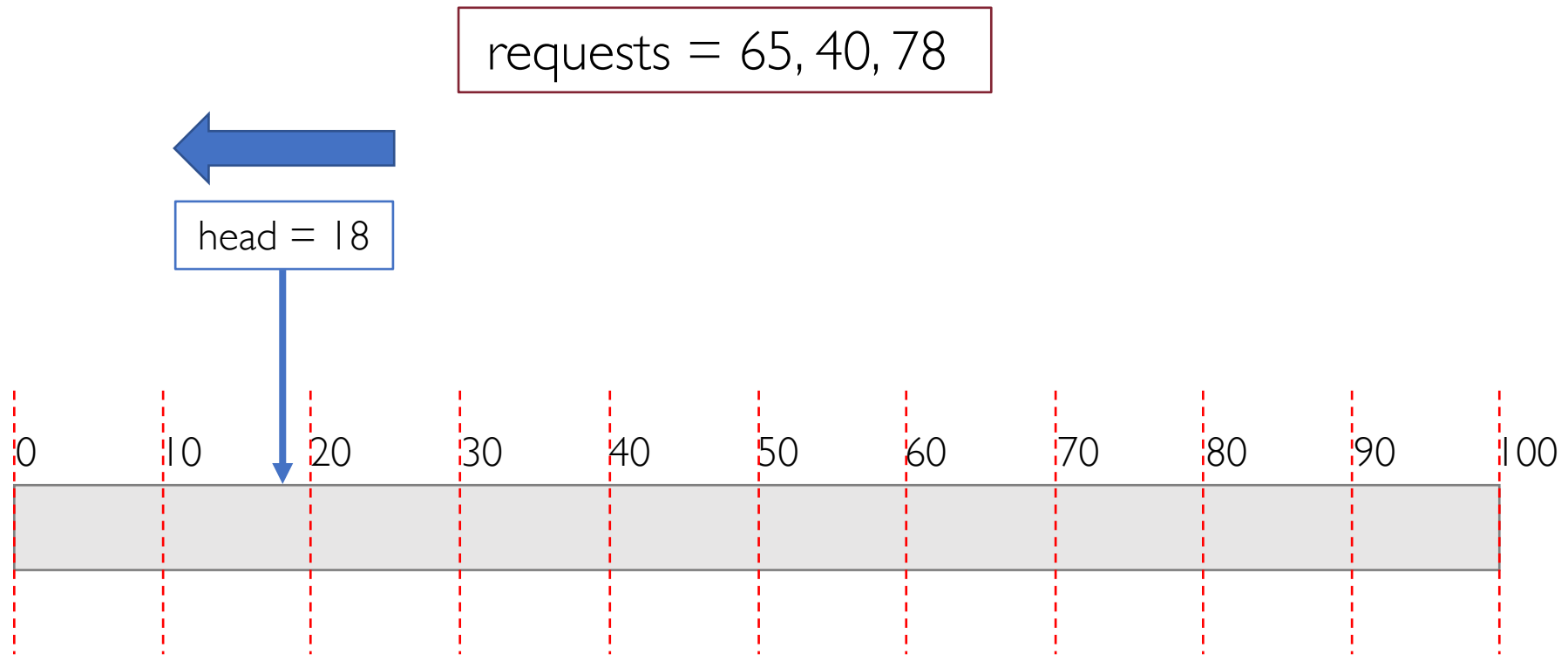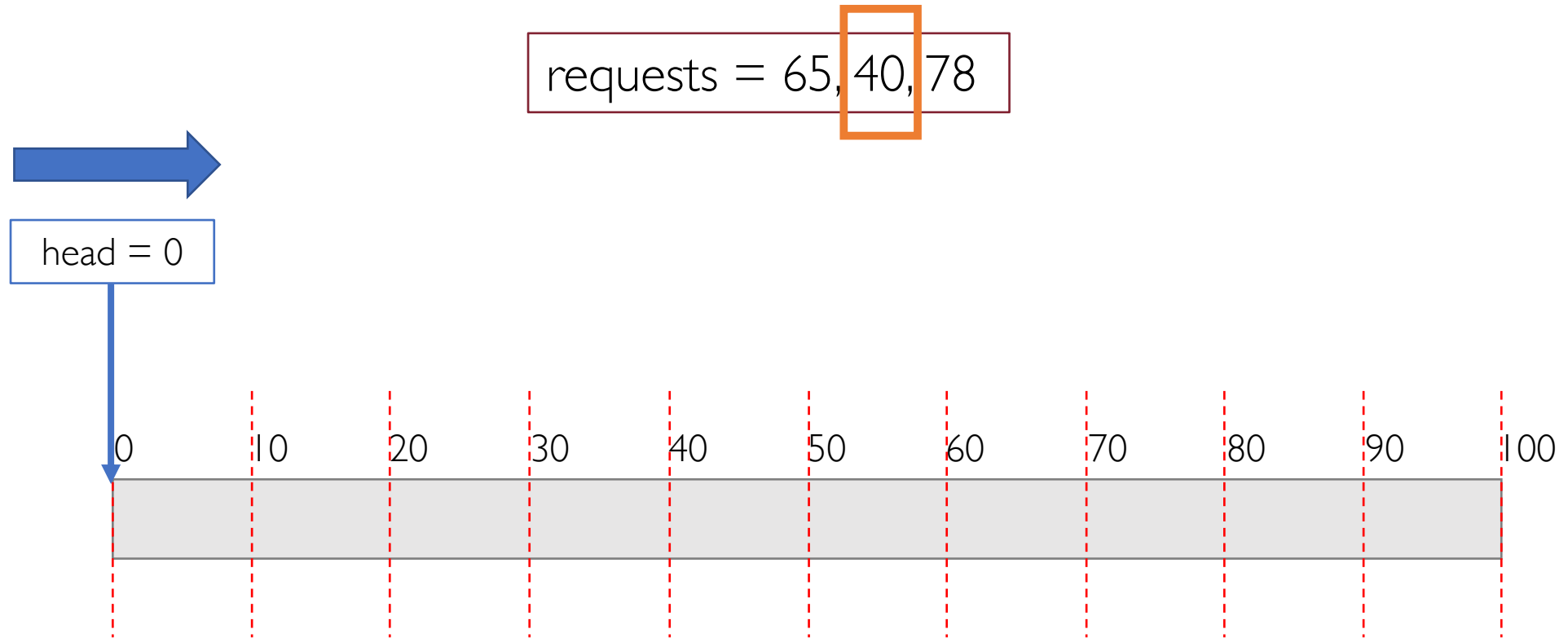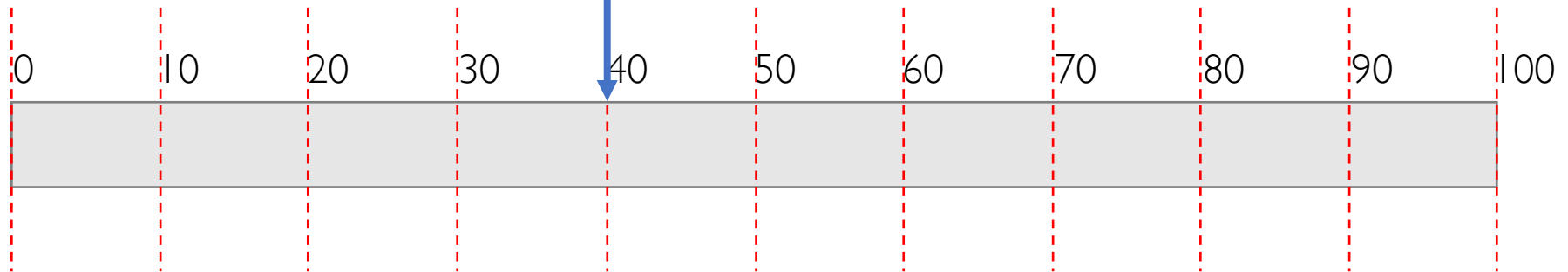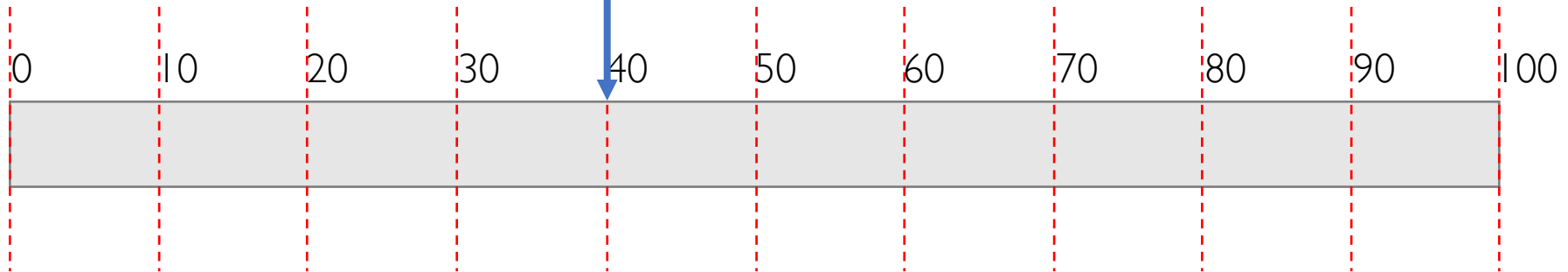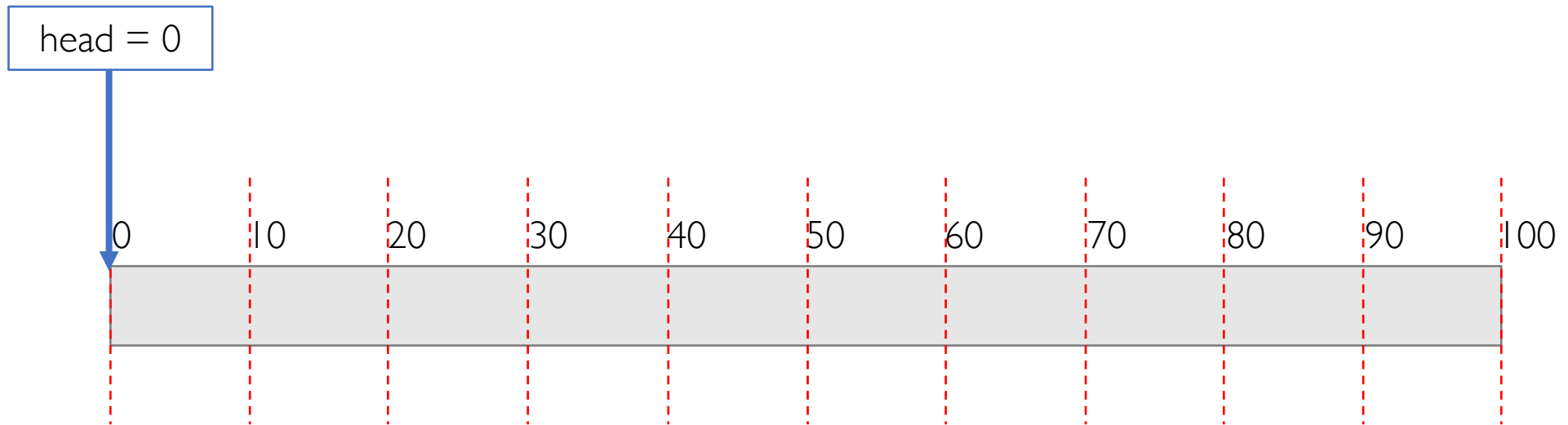
Distance travelled = 30 + |40 – 0| = 70

Disk Scheduling: SCAN
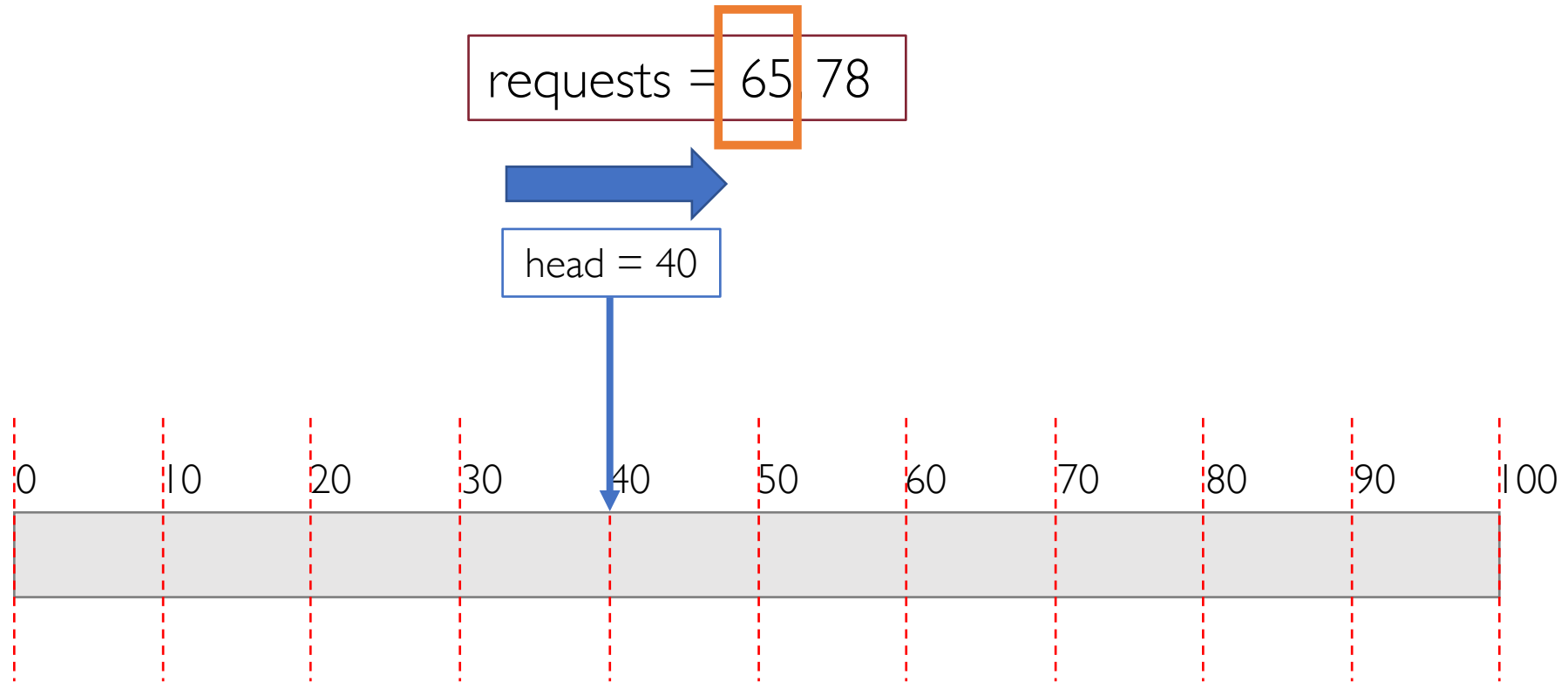
requests = 65, 78

head = 40

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: SCAN

requests = 65, 78

head = 65

0 10 20 30 40 50 60 70 80 90 100

Disk Scheduling: SCAN

requests = 65, 78

head = 65

0   10   20   30   40   50   60   70   80   90   100
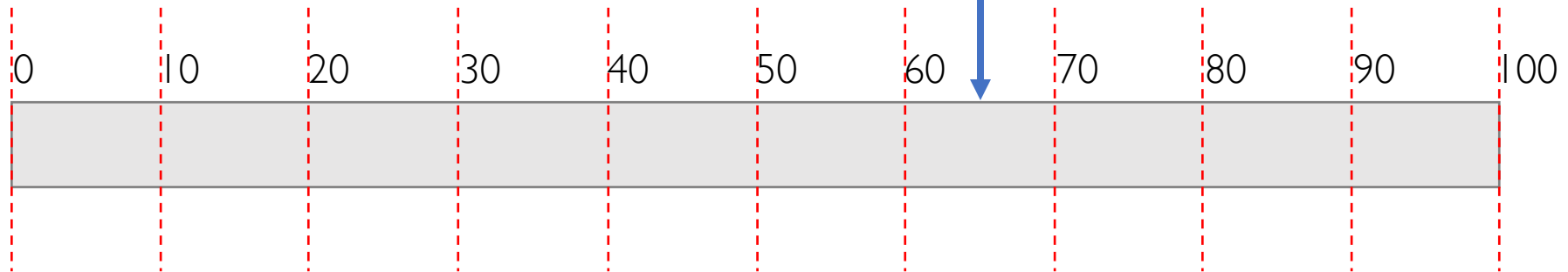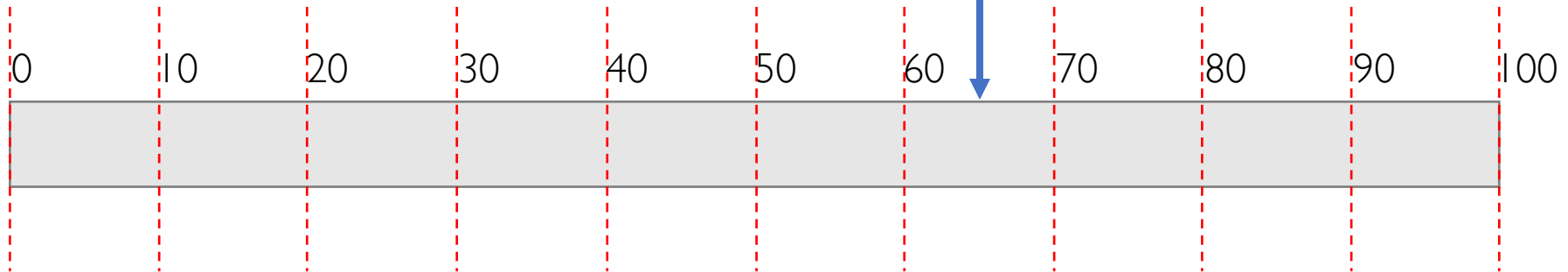
Distance travelled = 70 + |65 − 40| = 95

Disk Scheduling: SCAN
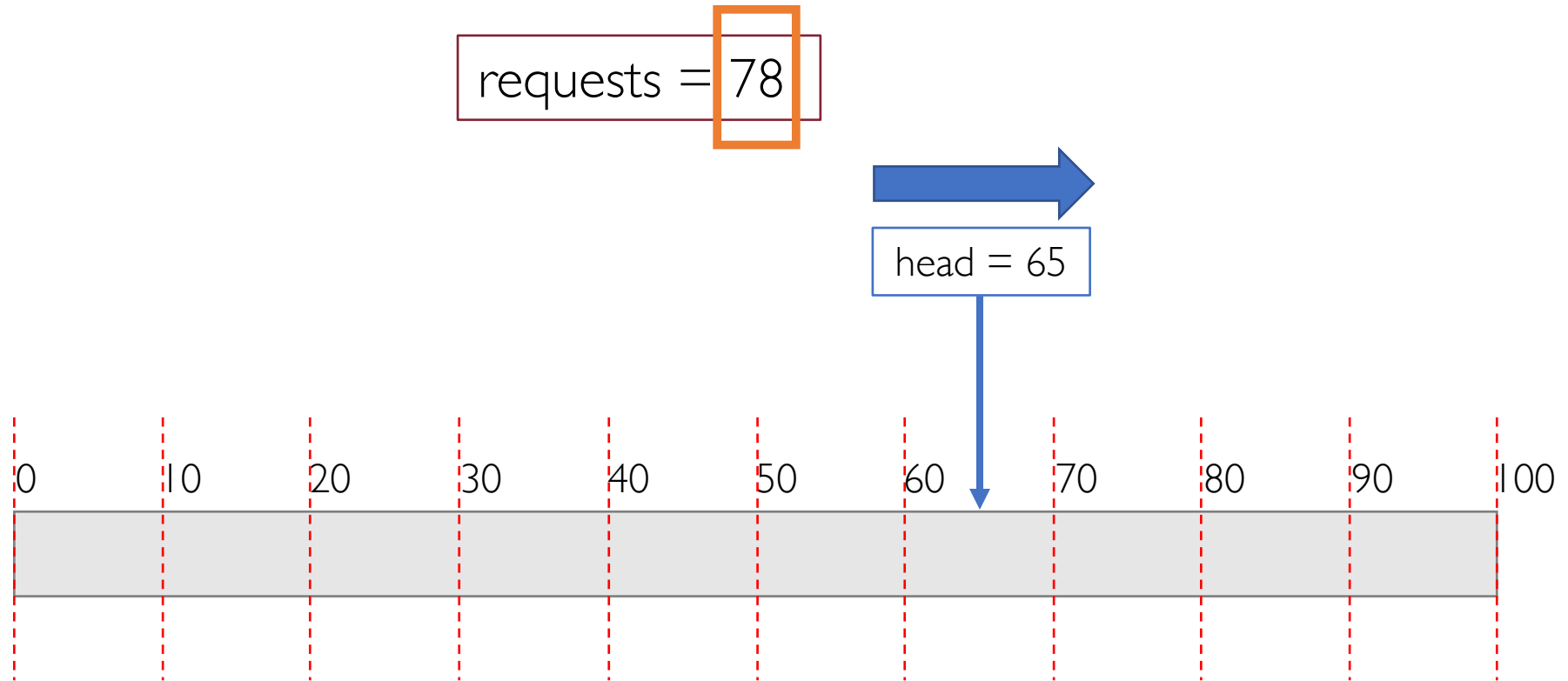
requests = 78

head = 65

0 10 20 30 40 50 60 70 80 90 100

Disk Scheduling: SCAN

requests = 78

head = 78

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: SCAN

requests = 78

head = 78

0   10   20   30   40   50   60   70   80   90   100
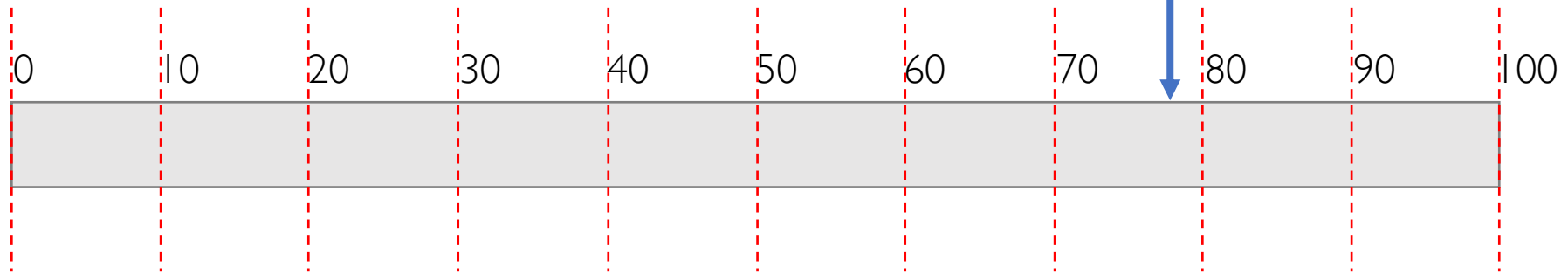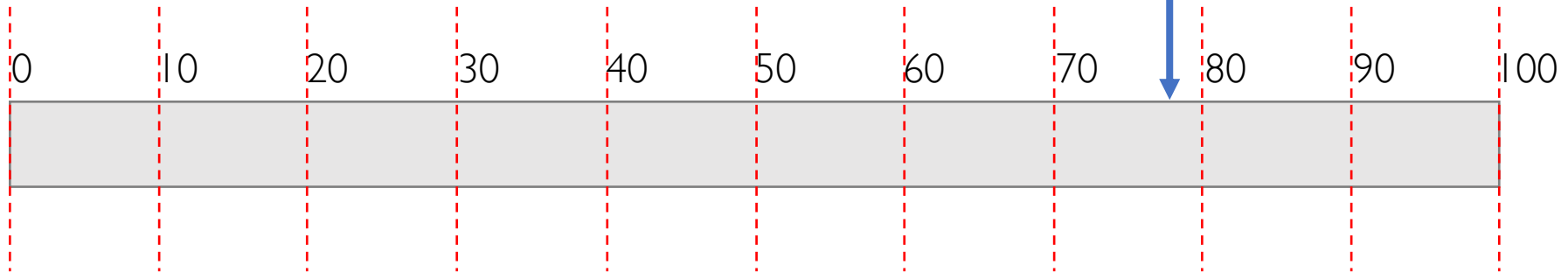
Distance travelled = 95 + |78 − 65| = 108

SCAN: Considerations

- Requires to keep a sorted list of requests

SCAN: Considerations

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- 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

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  - 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)

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)

- However, this is not the case! Remember that this is all mechanical!

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)

- 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
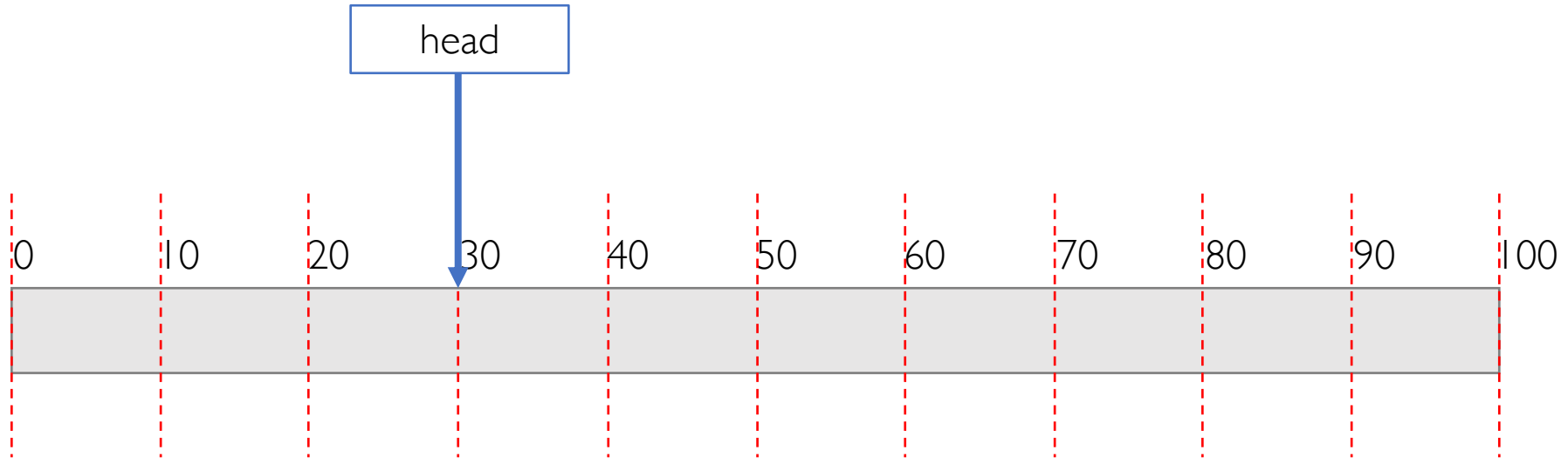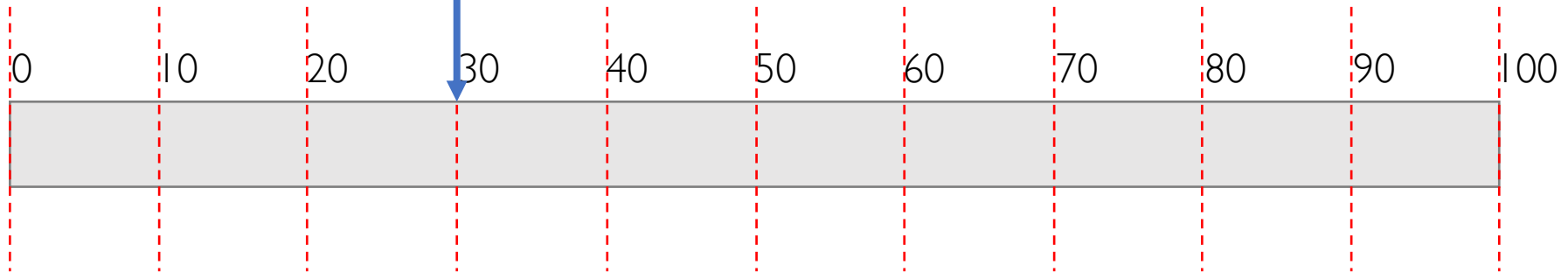
head

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: C-SCAN

requests = 65, 40, 18, 78

head = 30

0   10   20   30   40   50   60   70   80   90   100

Distance travelled = 0

Disk Scheduling: C-SCAN

requests = 65, 40, 18, 78

head = 30

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: C-SCAN

requests = 65, 40, 18, 78

head = 18

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: C-SCAN

requests = 65, 40, 18, 78

head = 18

0   10   20   30   40   50   60   70   80   90   100

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

Disk Scheduling: C-SCAN

requests = 65, 40, 78

head = 18

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: C-SCAN

requests = 65, 40, 78

head = 0

| | | | | | | | | | | |
| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |

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

Disk Scheduling: C-SCAN

requests = 65, 40, 78

Head reset

head = 100

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: C-SCAN

requests = 65, 40, 78

Head reset

head = 100

0   10   20   30   40   50   60   70   80   90   100
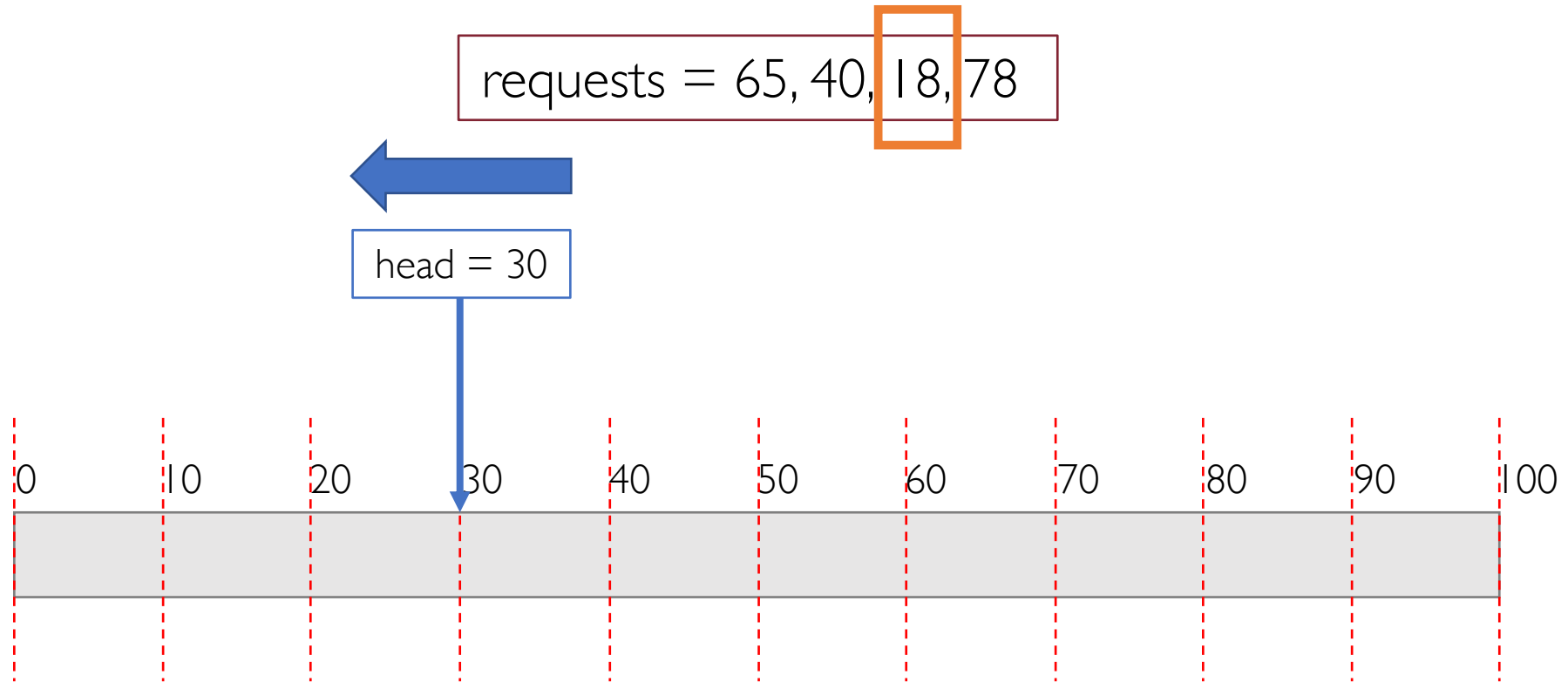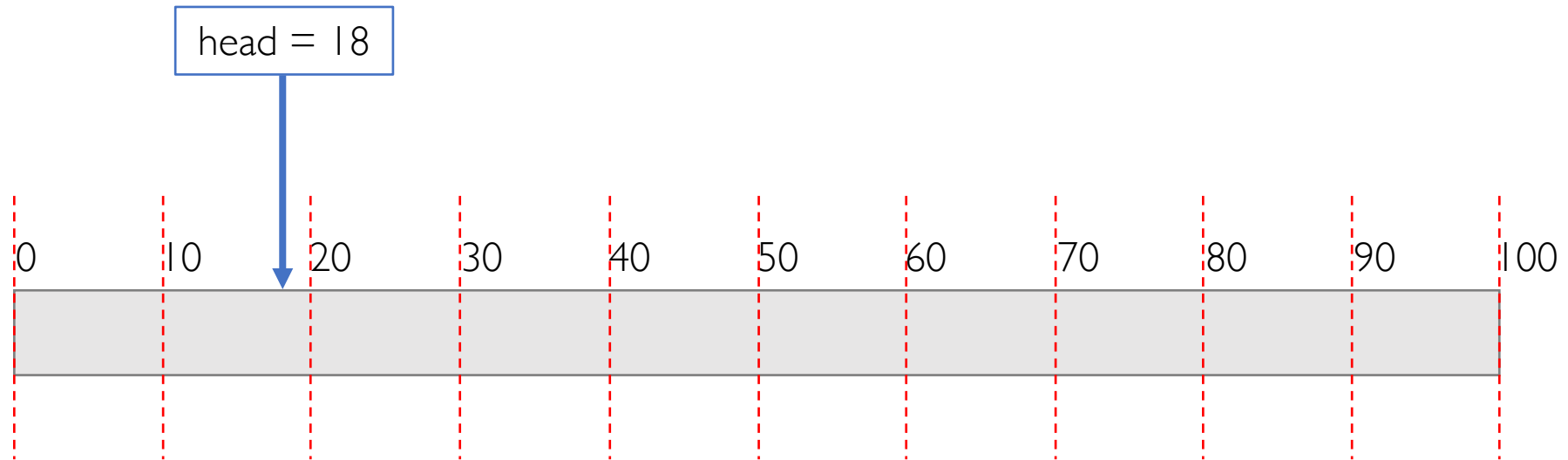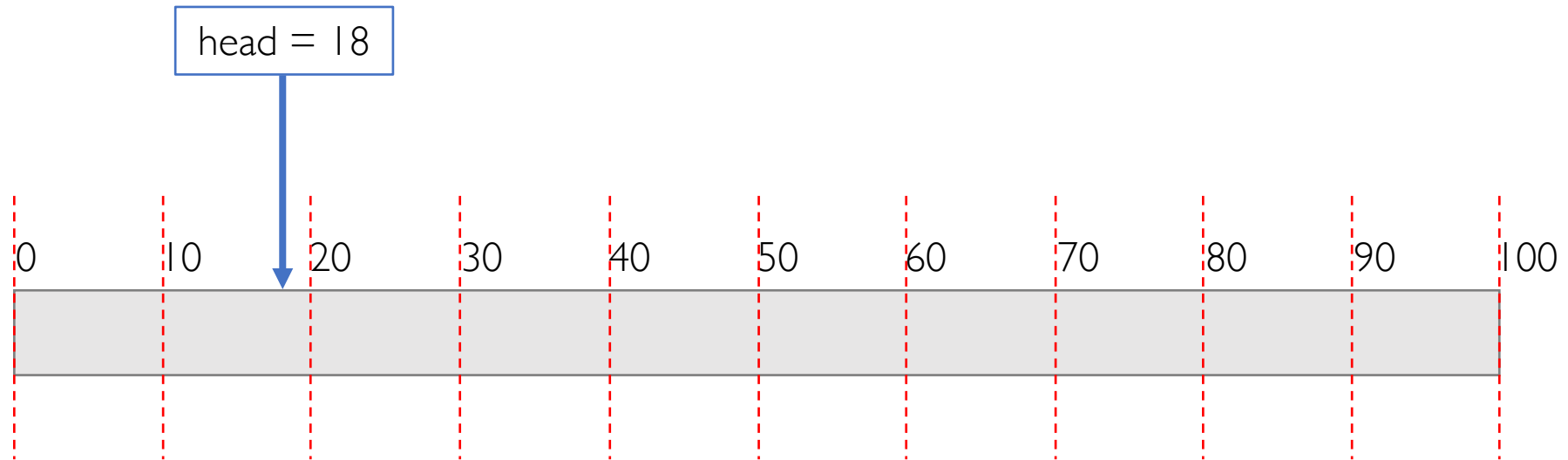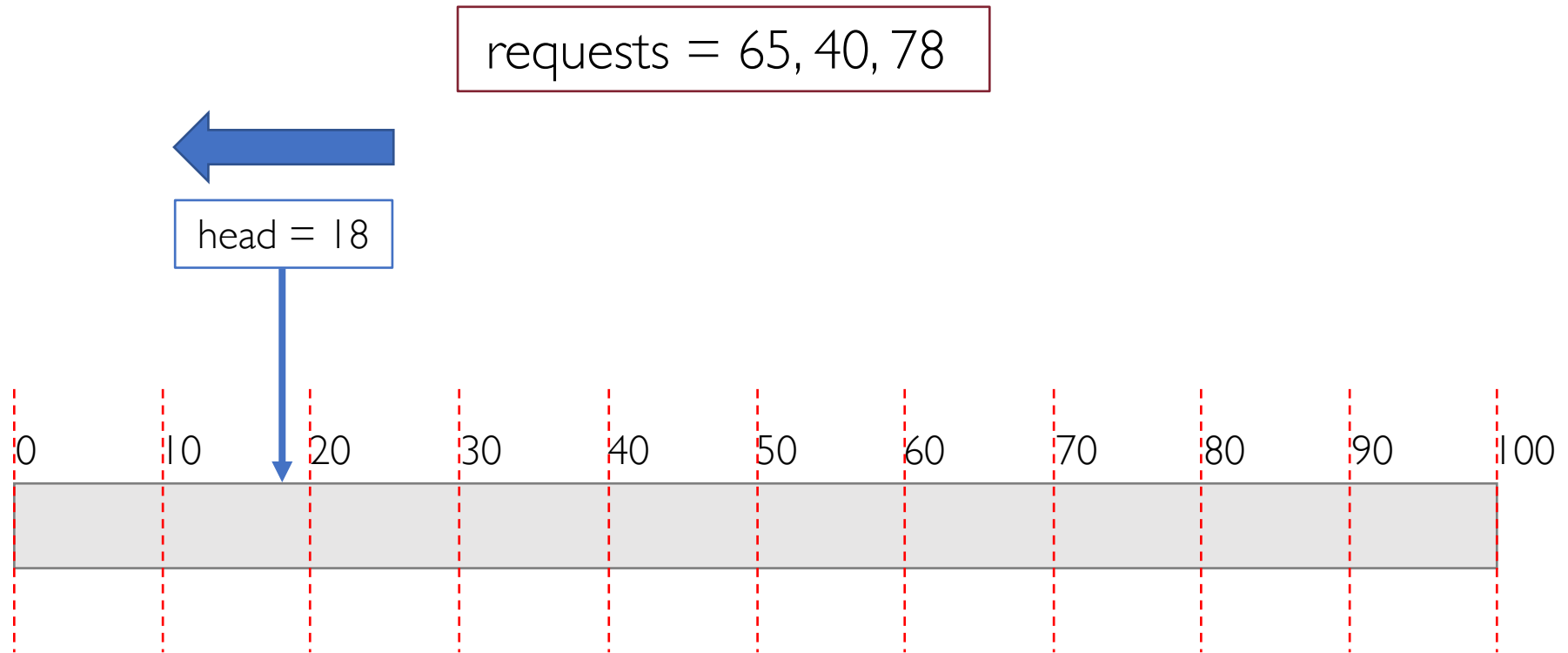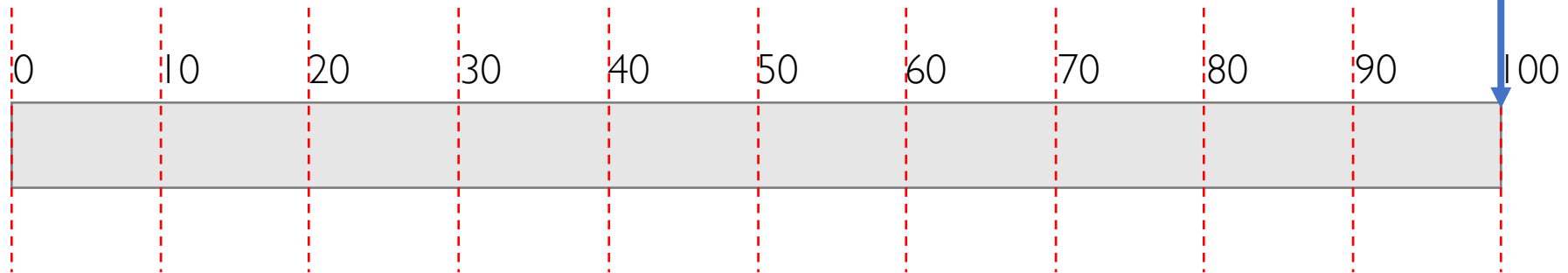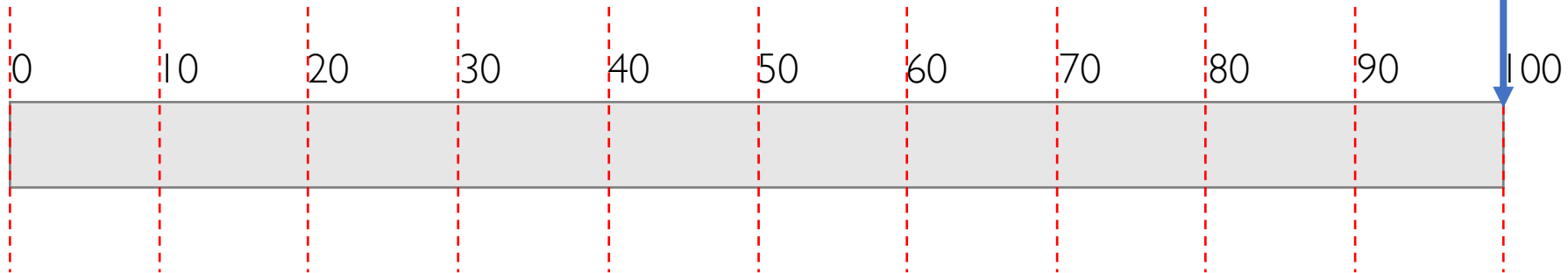
Distance travelled = 30 + |100 − 0| = 130

Disk Scheduling: C-SCAN

requests = 65, 40, 78

head = 100
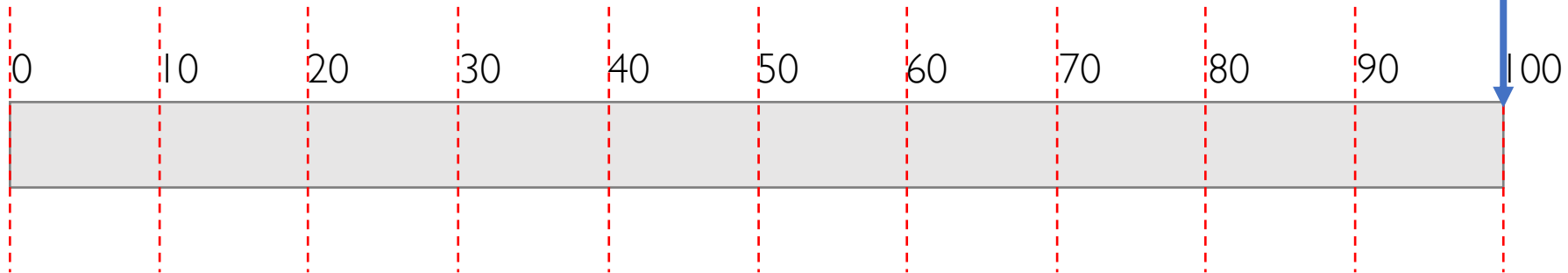
0 10 20 30 40 50 60 70 80 90 100

Disk Scheduling: C-SCAN

requests = 65, 40, 78

head = 78

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: C-SCAN

requests = 65, 40, 78

head = 78

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
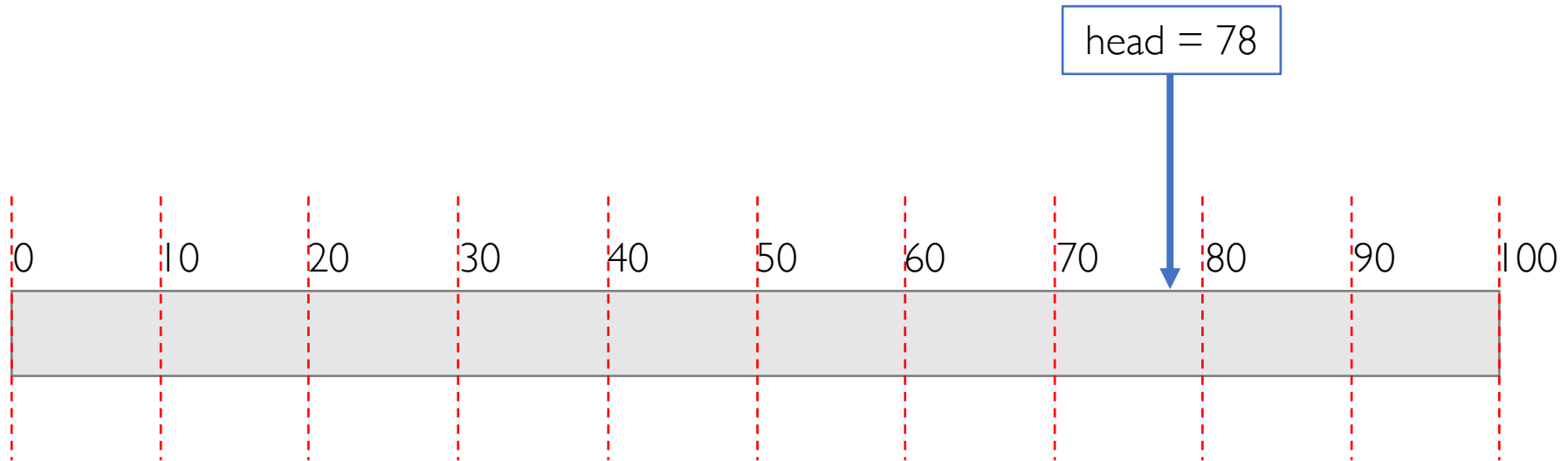
Distance travelled = 130 + |78 − 100| = 152

Disk Scheduling: C-SCAN

requests = 65, 40

head = 78

0 10 20 30 40 50 60 70 80 90 100

Disk Scheduling: C-SCAN

requests = 65, 40

head = 65

0   10   20   30   40   50   60   70   80   90   100
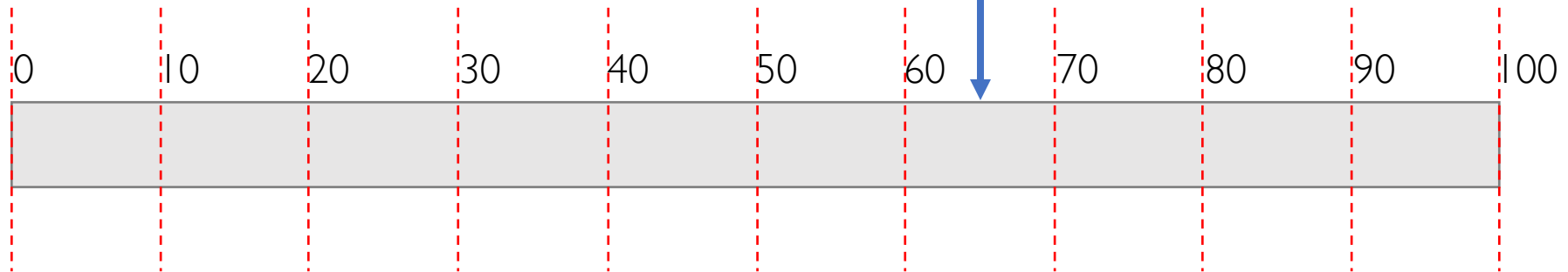
Disk Scheduling: C-SCAN

requests = 65, 40

head = 65
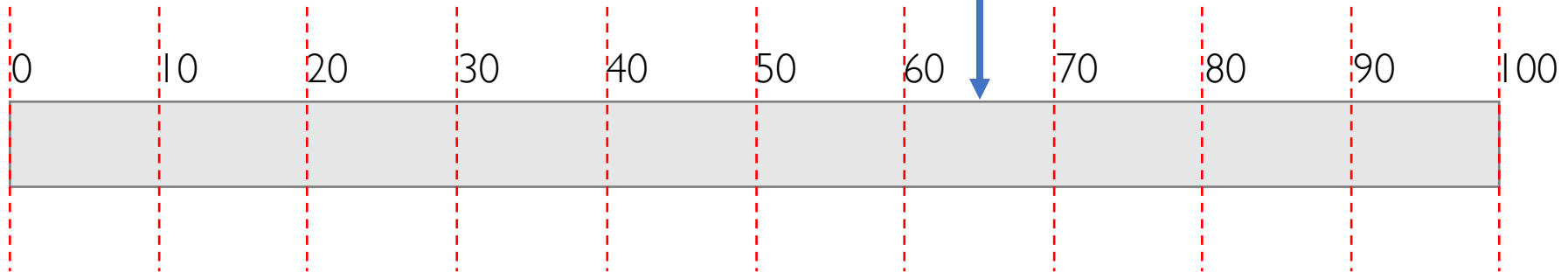
Distance travelled = 152 + |65 − 78| = 165

Disk Scheduling: C-SCAN
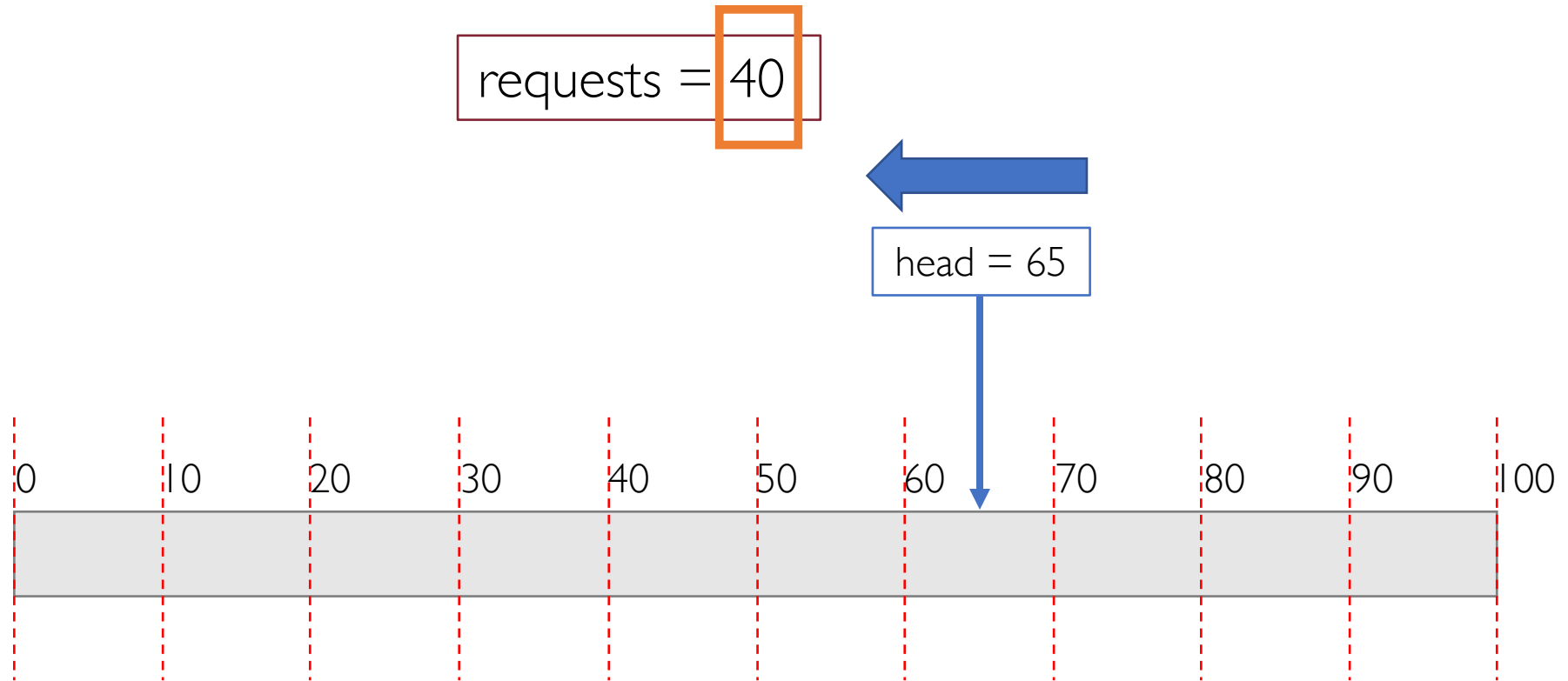
requests = 40

head = 65

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: C-SCAN

requests = 40

head = 40

0   10   20   30   40   50   60   70   80   90   100

Disk Scheduling: C-SCAN

requests = 40

head = 40

0   10   20   30   40   50   60   70   80   90   100
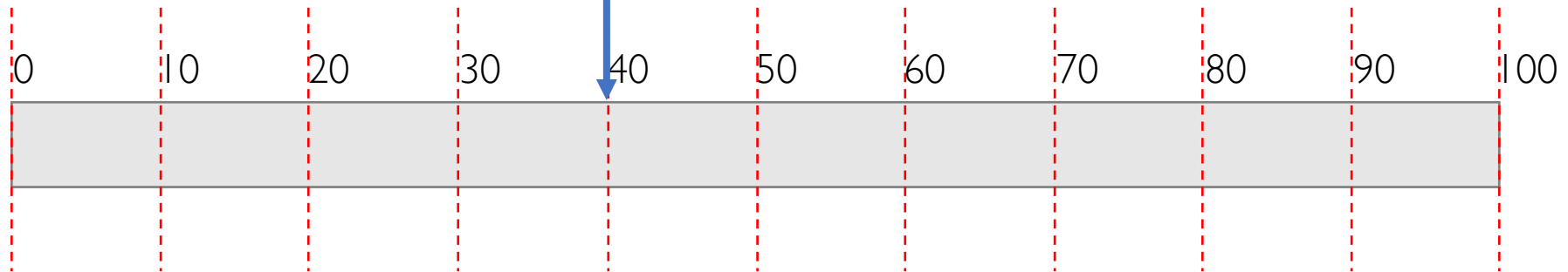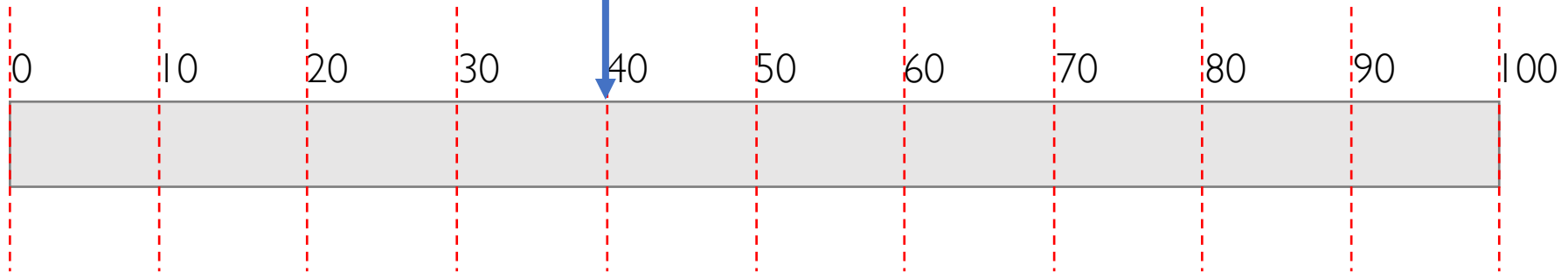
Distance travelled = 165 + |40 − 65| = 190

C-SCAN: Considerations

- C-LOOK: similar optimization to LOOK

  - In the example:

    - no need to go from 18 to 0! Just stop at 18 (first request)

    - no need to restart the head position to the last one (100)! Just reset it to 78

  - Total distance goes from 190 down to 110 (saving 18-0/0-18 and 78-100/100-78 movements)

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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)

Improving Disk Performance: Interleaving

Problem

Contiguous allocation of files on disk blocks only makes sense if the OS can react to one disk request and issue the next one before the disk spins over the next block

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Do not allocate blocks contiguously, but just leave temporarily contiguous blocks few blocks away from each other (e.g., 2 or 3) so as to accommodate rotational speed

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⬇

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Do not allocate blocks contiguously, but just leave temporarily contiguous blocks few blocks away from each other (e.g., 2 or 3) so as to accommodate rotational speed

Filesystem-level optimization

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Read-Ahead
Read blocks from the disk ahead of process requests and store them on the buffer (cache) of the disk controller

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Reduce the number of seeks, as several blocks that are on the same track are read even if not explicitly requested (locality)

Virtual Memory vs. Disk Block Pre-fetching

The order of disk accesses more predictable (more locality) than memory accesses

Improving Disk Performance: Read-Ahead

Read-Ahead

Read blocks from the disk ahead of process requests and store them on the buffer (cache) of the disk controller

Goal

Reduce the number of seeks, as several blocks that are on the same track are read even if not explicitly requested (locality)

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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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MBR

boot code

partition table

partition 1

partition 2

boot partition

partition 3

partition 4

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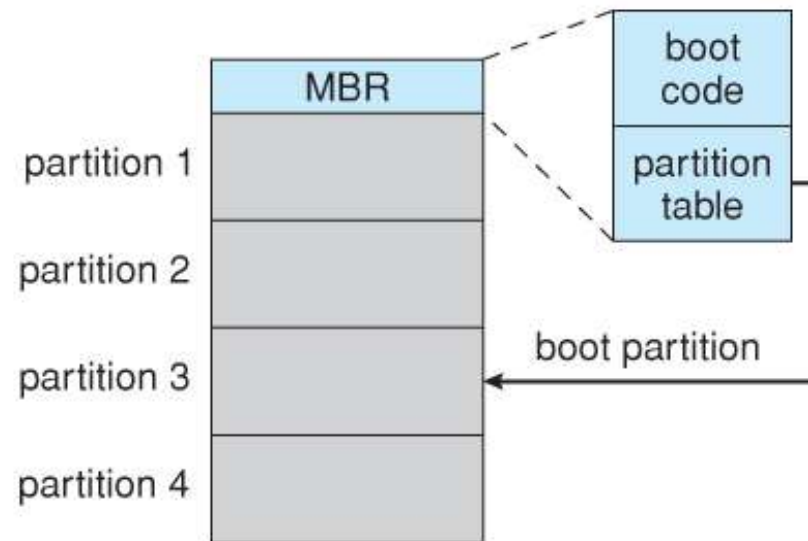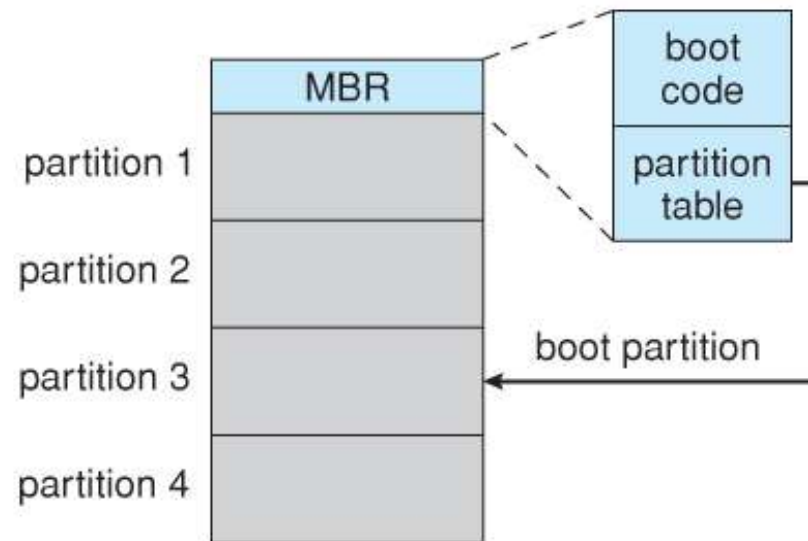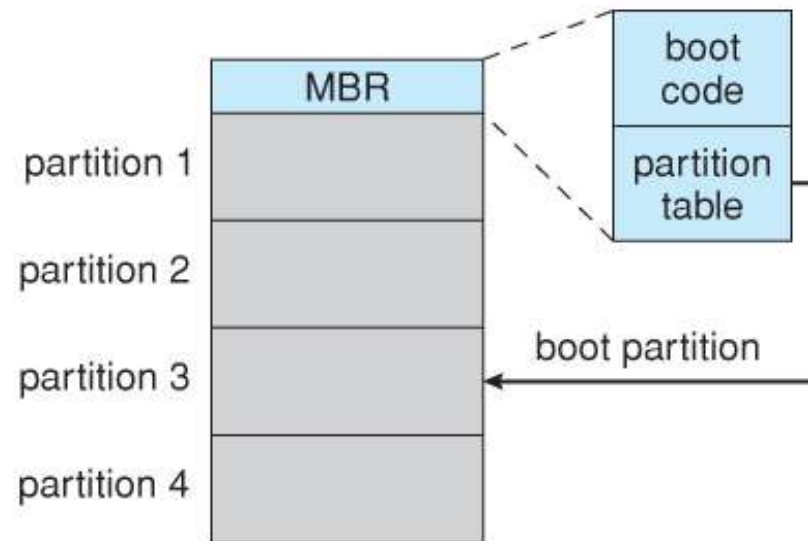
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Once the kernel is found, it is loaded into memory and then control is transferred over to the OS, which initializes all important kernel data structures and system services

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

- SSDs have no moving parts so they are much faster than traditional hard drives

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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 Disk

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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

- RAID → Redundant Array of Inexpensive Disks

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Advanced Topic: RAID Structure

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- <u>Goal:</u> increase reliability or speed up operations, or both

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

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  - E.g., Think about Google or Facebook, just to name a few

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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

Example: Disk Failure

- Suppose we have a system with N disks

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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

- Mirroring → copy the same data onto multiple disks

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$$\boxed{p^N}$$

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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  - RAID Level 1 → mirroring only, no striping
  - …
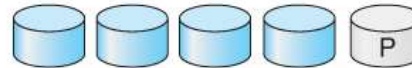 - RAID Level 6 → striping + mirroring + parity bit

RAID Levels
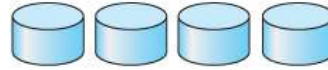
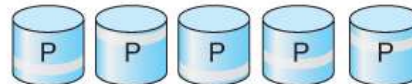(a) RAID 0: non-redundant striping.
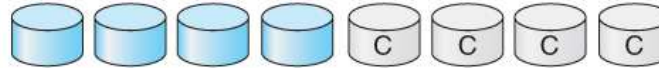
(b) RAID 1: mirrored disks.
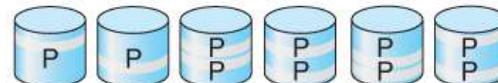
(c) RAID 2: memory-style error-correcting codes.

(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