Storage

Amir H. Payberah
amir@sics.se

Amirkabir University of Technology
(Tehran Polytechnic)

Motivation

Secondary Storage

- Main memory is usually too small.
- Computer systems must provide secondary storage to back up main memory.

File Systems and Secondary Storage

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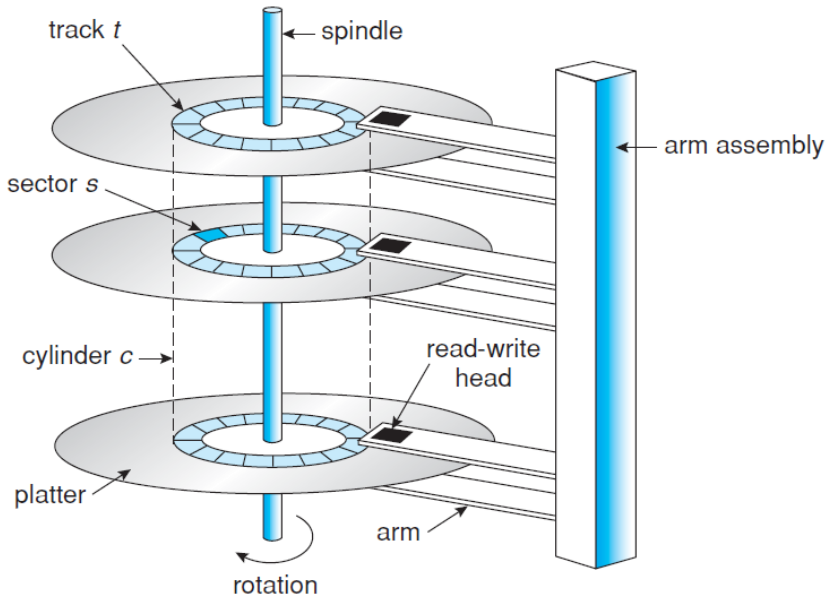
  - The user and programmer interface to the file system.
  - The internal data structures and algorithms used by the OS to implement this interface.

Overview of Mass-Storage Structure

Mass Storage Structure (1/3)

- Magnetic disks: bulk of secondary storage



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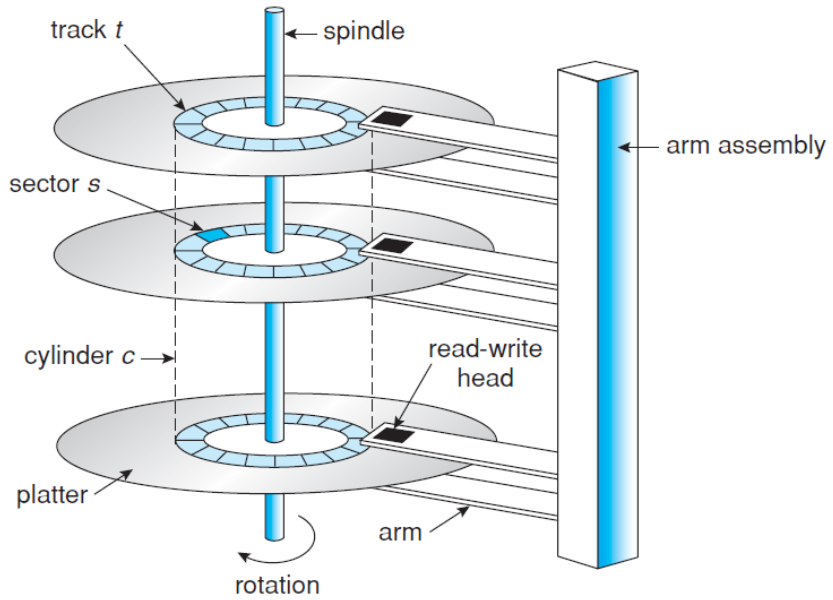

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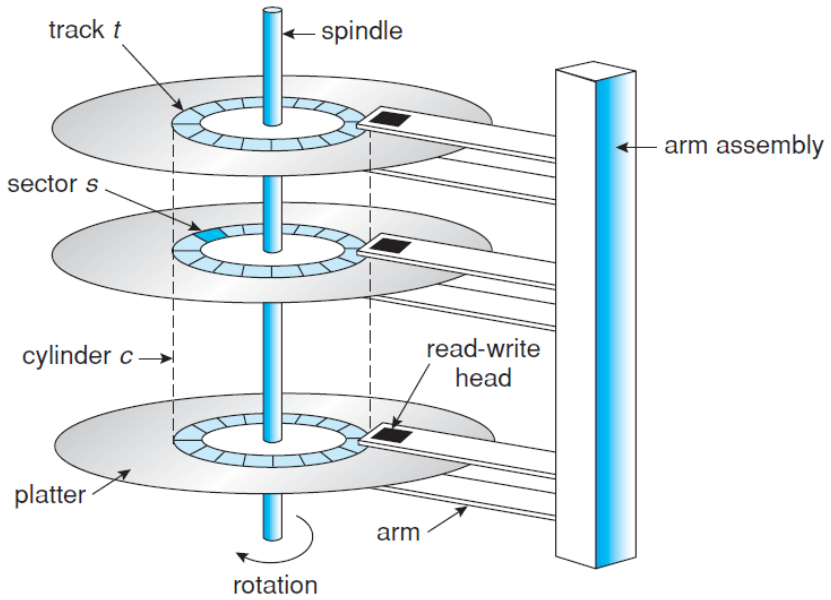

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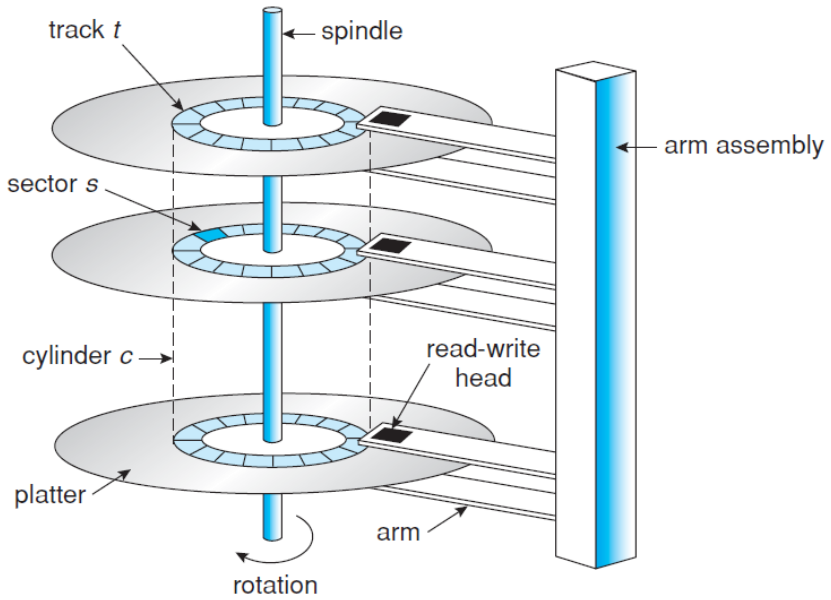

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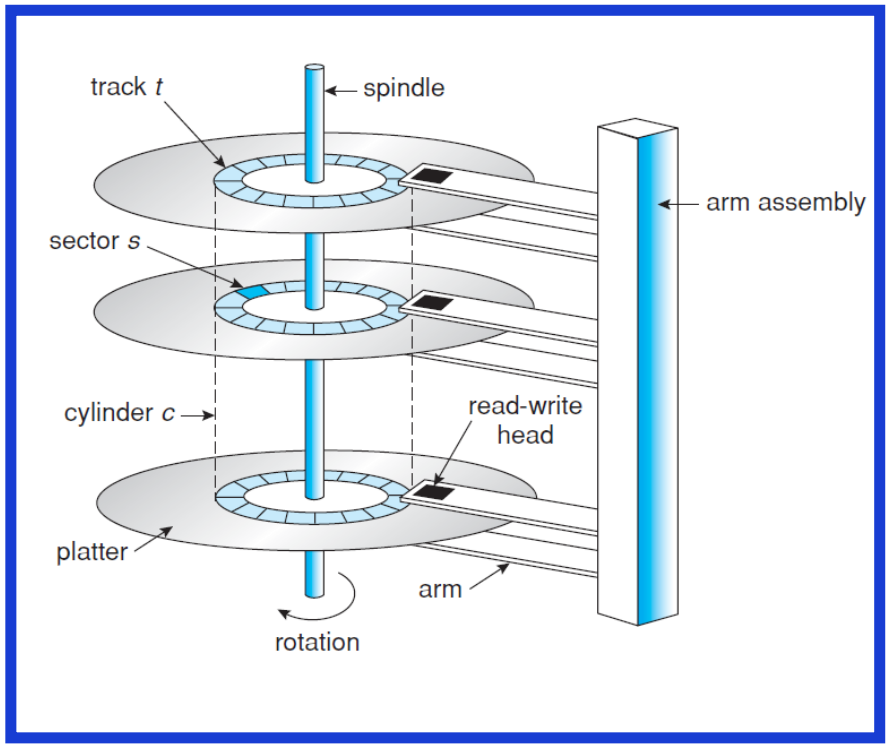

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- Head crash results from disk head making contact with the disk surface.

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- Host controller in computer uses bus to talk to disk controller built into drive or storage array.

Hard Disks

- Platters range from 0.85" to 14" (historically).
- Commonly 3.5", 2.5", and 1.8".
- Range from 30GB to 3TB per drive.

The First Commercial Disk Drive

- IBM, 1956
- 350 disk storage system
- 5M
- Access time $\leq$ 1 second

Solid-State Disks (SSDs)

- Non-volatile memory used like a hard drive.
- More expensive per MB.
- Maybe have shorter life span.
- Less capacity, but much faster.
- No moving parts, so no seek time or rotational latency.

Magnetic Tape

- Early secondary-storage medium.
- Relatively permanent and holds large quantities of data.
- Access time slow.
- Random access $\sim$ 1000 times slower than disk.
- Mainly used for backup, storage of infrequently-used data.
- Once data under head, transfer rates comparable to disk.

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- Low-level formatting creates logical blocks on physical media.

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  - Mapping proceeds in order through that track, then the rest of the tracks in that cylinder, and then through the rest of the cylinders from outermost to innermost.
- Logical to physical address should be easy.
  - Except for bad sectors.
  - Non-constant num. of sectors per track via constant angular velocity.

Disk Attachment

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- Host-attached storage
- Network-attached storage (NAS)
- Storage-area network (SAN)

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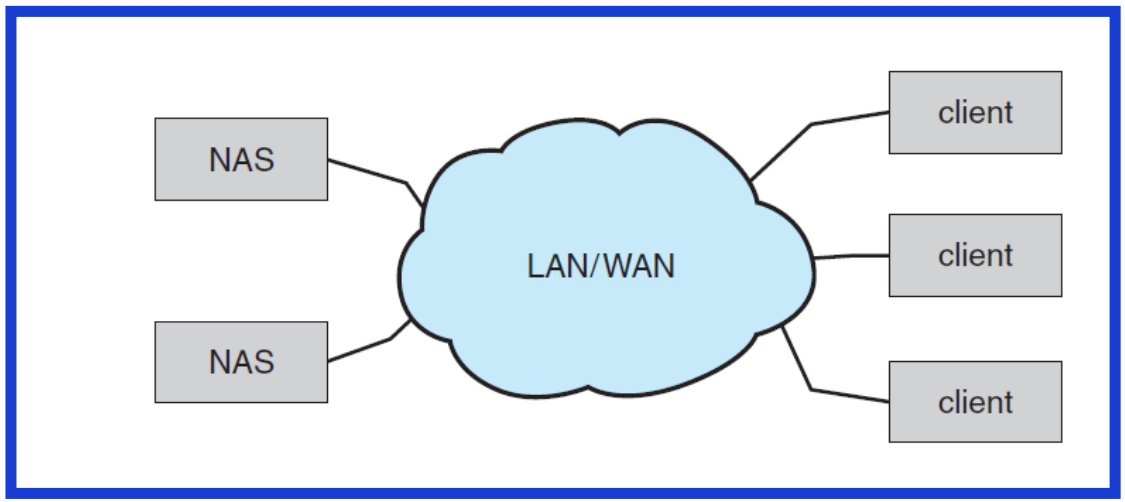
- SCSI is a bus, up to 16 devices on one cable.
- Fiber Channel (FC) is high-speed serial architecture.

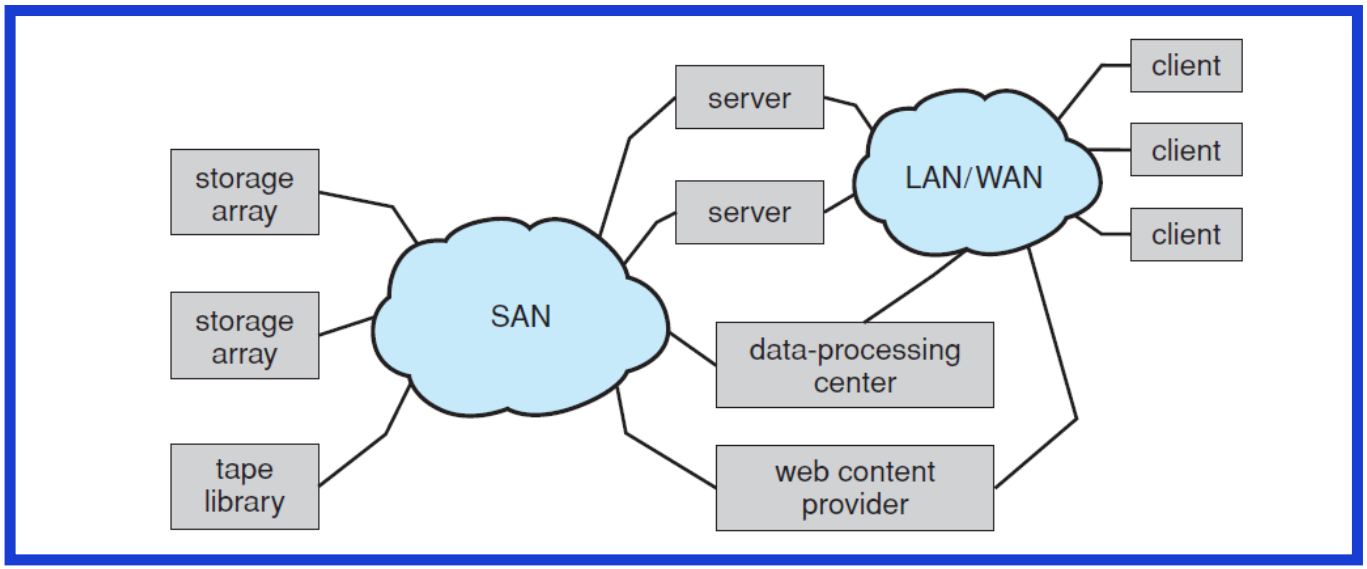
Network-Attached Storage

- Network-attached storage (NAS) is storage made available over a network rather than over a local connection.
- Remotely attaching to file systems.
- NFS and CIFS are common protocols.
- Implemented via remote procedure calls (RPCs) between host and storage over typically TCP or UDP on IP network.



Storage-Area Network

- Storage-area network (SAN) is common in large storage environments.
- Multiple hosts attached to multiple storage arrays.
- Storage arrays and Hosts are connected to one or more Fibre Channel switches.



Disk Scheduling

Disk Scheduling (1/2)

- Having a fast access time and disk bandwidth.
- Minimize seek time.
- Seek time $\approx$ seek distance
- Disk bandwidth is the total number of bytes transferred, divided by the total time between the first request for service and the completion of the last transfer.

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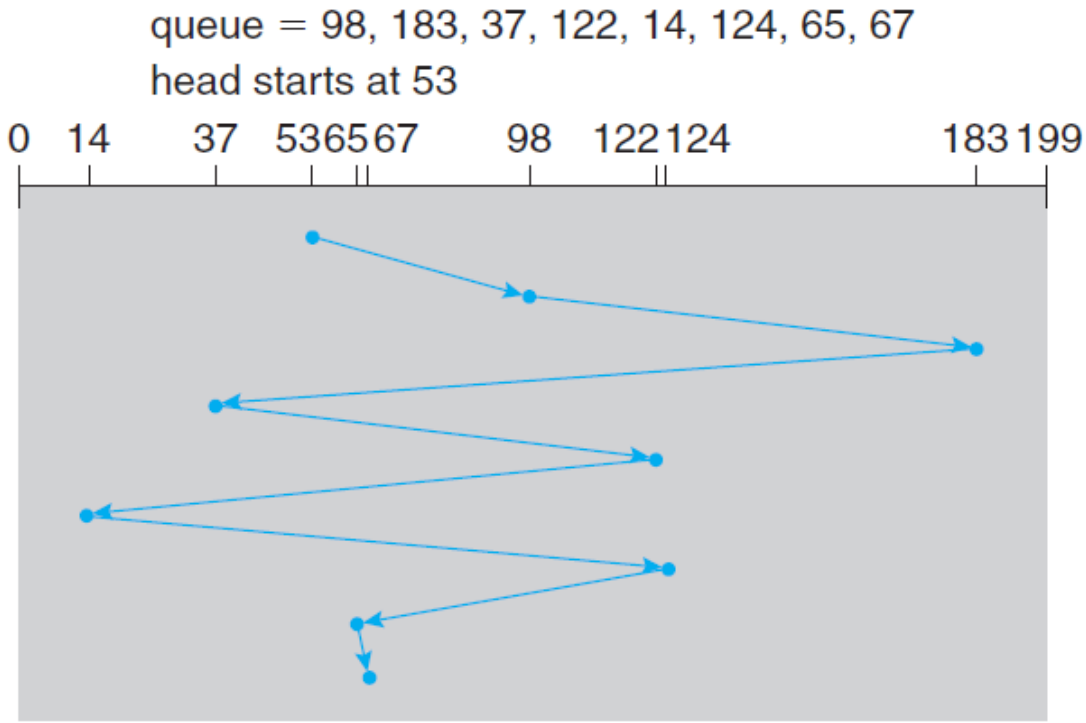
- Note that drive controllers have small buffers and can manage a queue of I/O requests.

Disk Scheduling Algorithms

- First Come First Serve (FCFS)
- Shortest Seek Time First (SSTF)
- SCAN
- C-SCAN
- C-Look

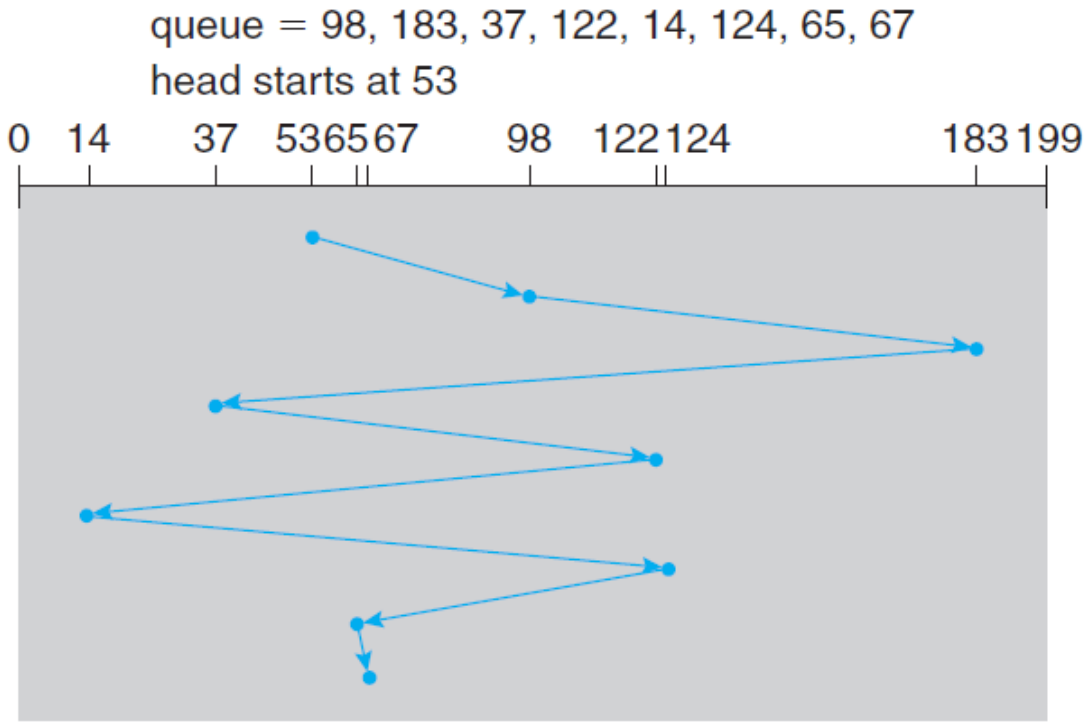
FCFS

- Request queue (0-199): 98, 183, 37, 122, 14, 124, 65, 67
- Head pointer 53



FCFS

- Request queue (0-199): 98, 183, 37, 122, 14, 124, 65, 67
- Head pointer 53
- Total head movement: 640 cylinders



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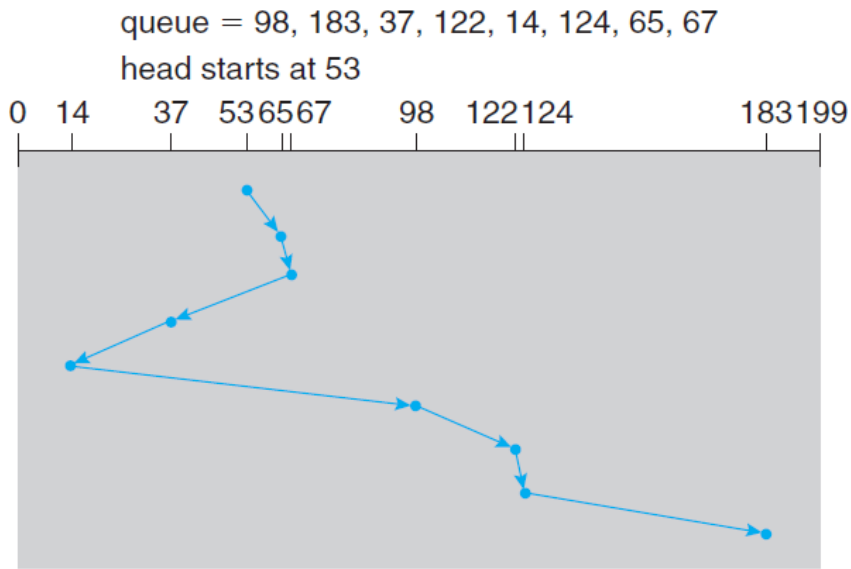

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- Selects the request with the minimum seek time from the current head position.
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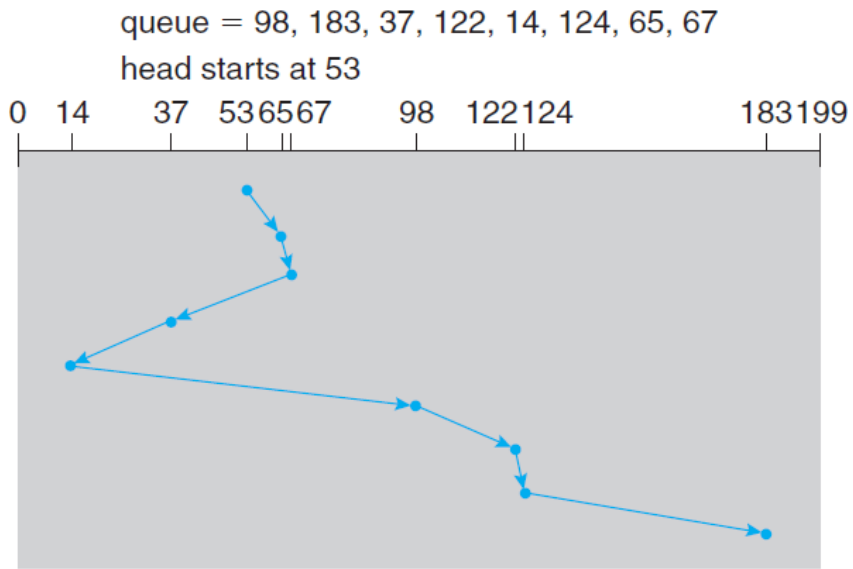
- Total head movement: 236 cylinders.



SCAN

- Starts from one end of the disk, and moves toward the other end.
  - Servicing requests until it gets to the other end of the disk.
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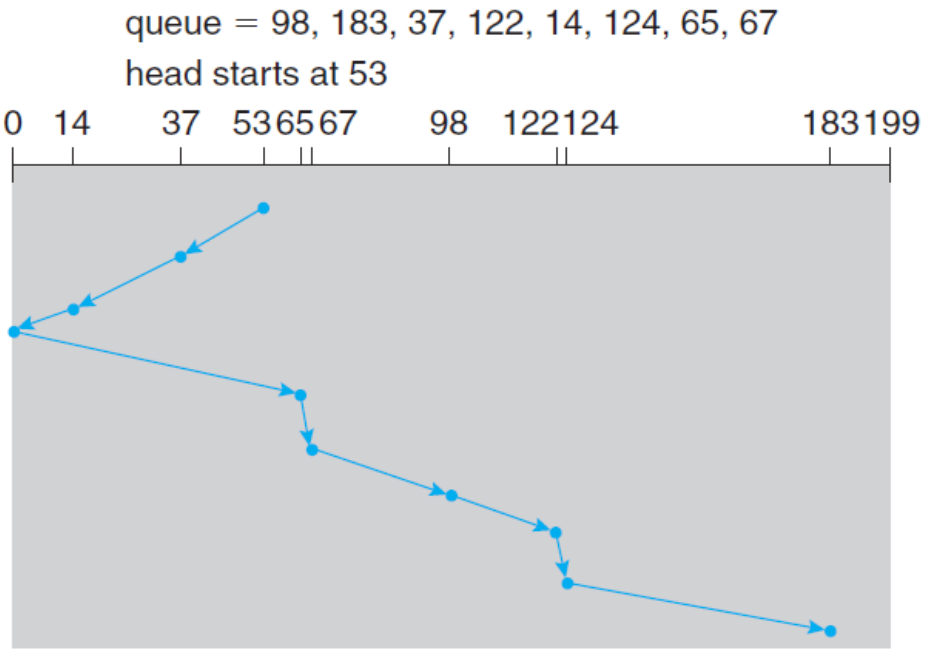

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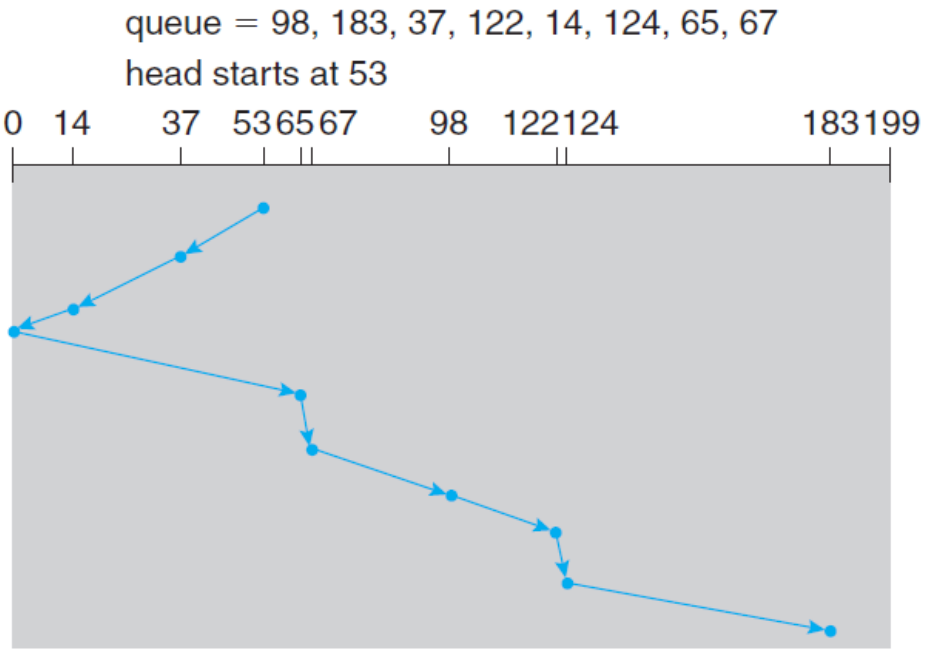
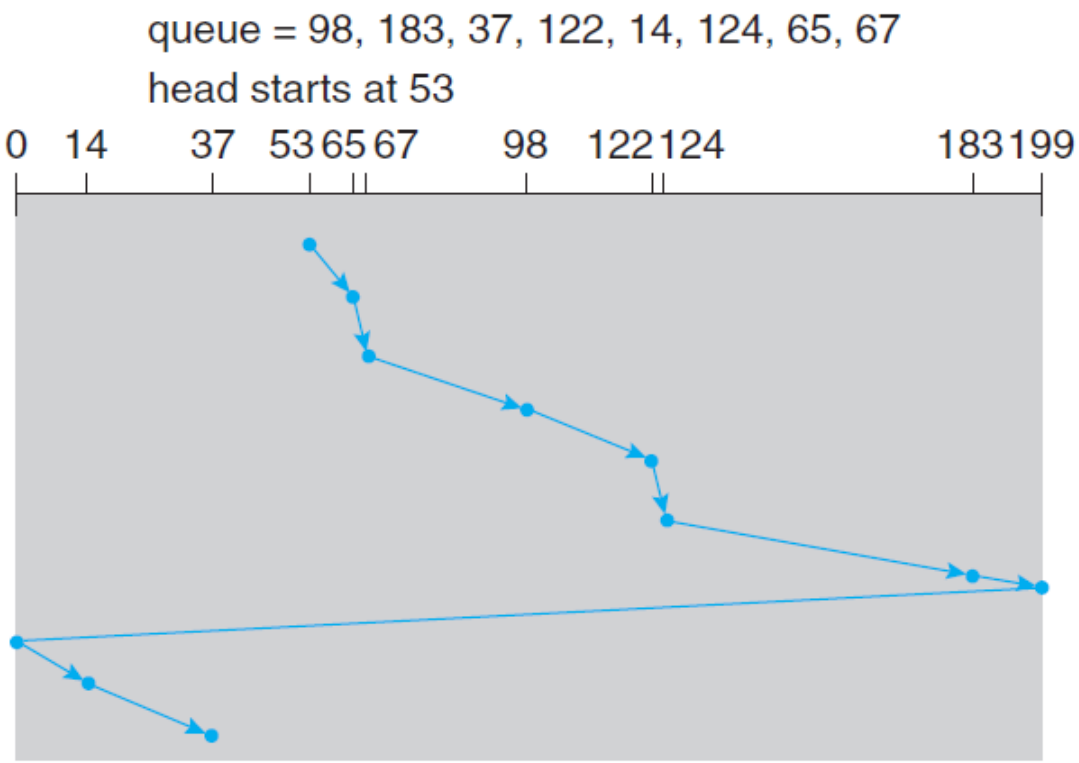


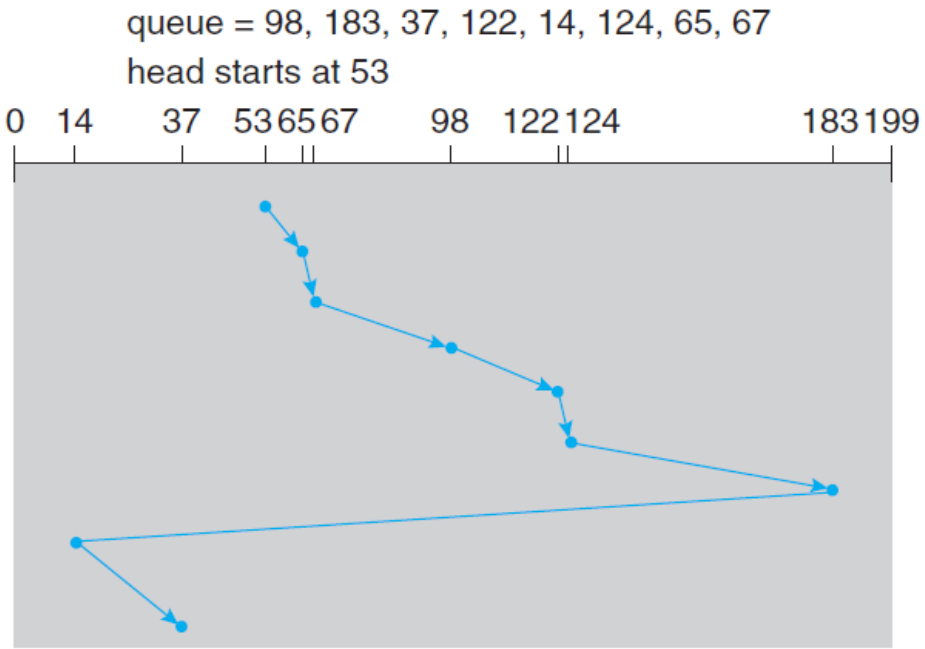
C-SCAN

- Provides a more uniform wait time than SCAN.
- When it reaches the end, it immediately returns to the beginning of the disk without servicing any requests on the return trip.



Look

- LOOK is a version of SCAN, C-LOOK is a version of C-SCAN.
- Arm only goes as far as the last request in each direction, then reverses direction immediately, without first going all the way to the end of the disk.



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- Performance depends on the number and types of requests.

Disk Management

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- Disk formatting
- Boot block
- Bad blocks

Disk Formatting (1/2)

- Low-level formatting, or physical formatting: dividing a disk into sectors that the disk controller can read and write.
- Each sector can hold header information, data, and error correction code (ECC).
- Usually 512 bytes of data but can be selectable.

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- Partition the disk into one or more groups of cylinders, each treated as a logical disk.
- Logical formatting or making a file system.
- Raw disk
  - Use a disk partition as a large sequential array of logical blocks, without any file-system data structures.

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- The full bootstrap program is stored in the boot blocks at a fixed location on the disk.

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  - Whenever the system requests logical block 87, the request is translated into the replacement sector's address by the controller.

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- It is safer to over-estimate than to under-estimate the amount of swap space

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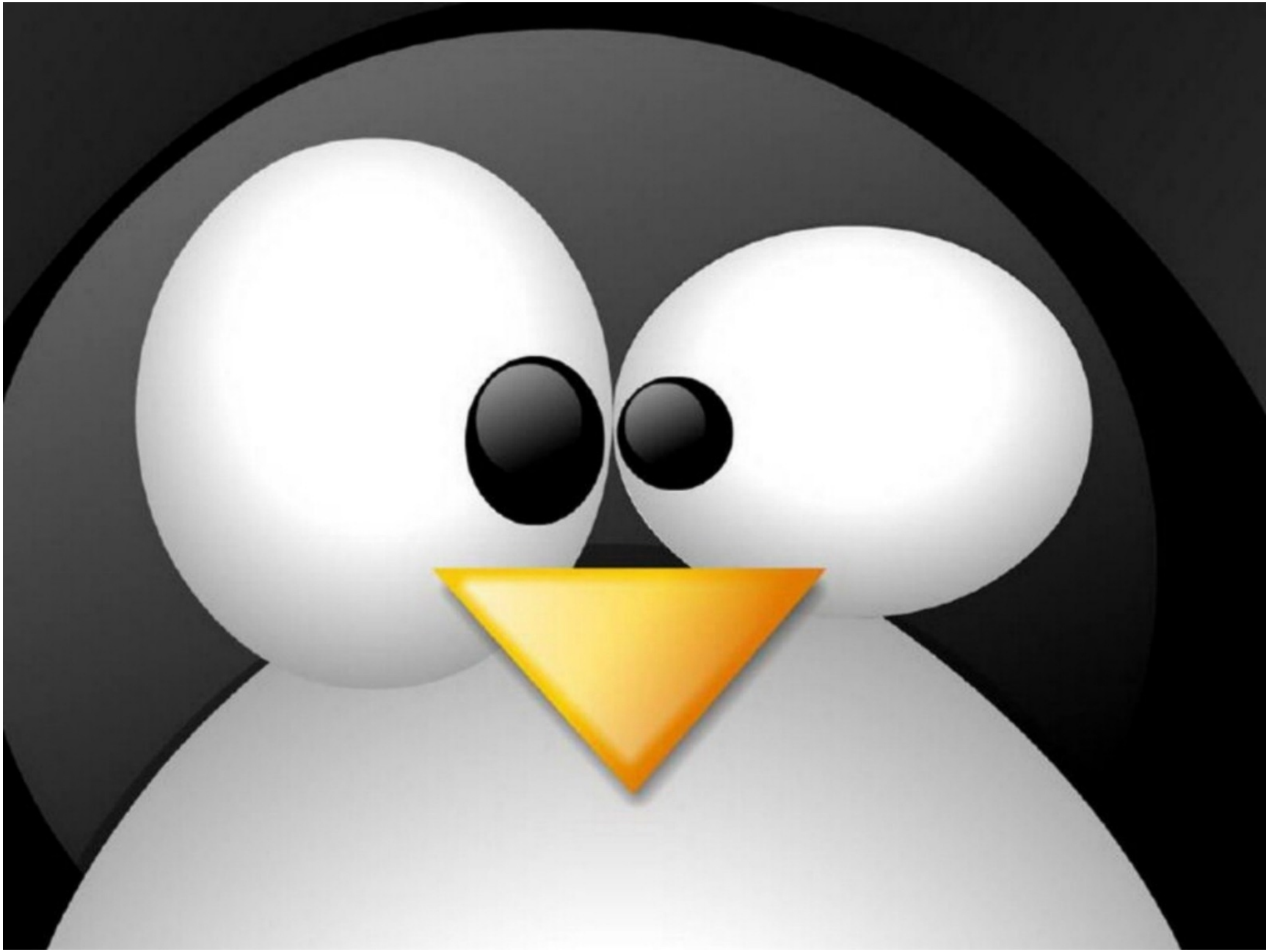

Swap-Space On Linux (1/2)

- Either a swap file on a regular file system or a dedicated swap partition.
- The swap space is used only for anonymous memory.
  - It is more efficient to reread a page from the file system than to write it to swap space and then reread it from there.

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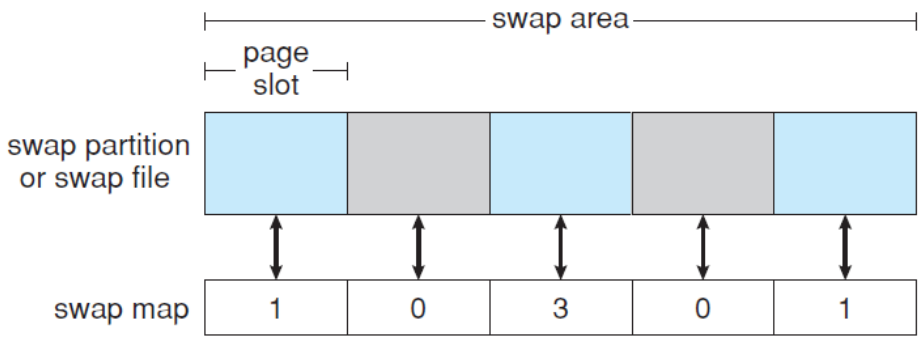

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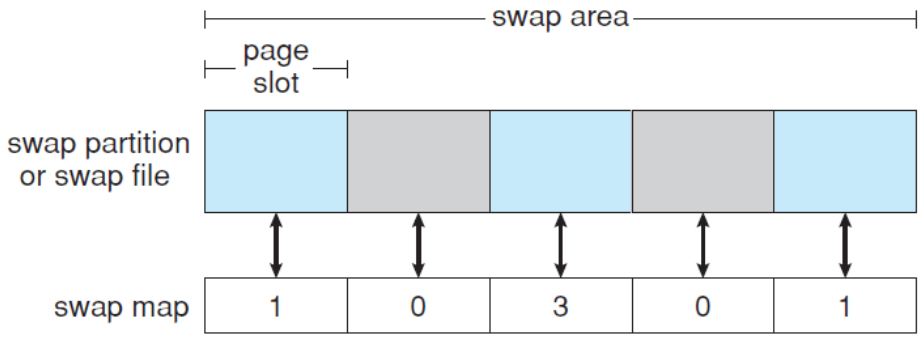

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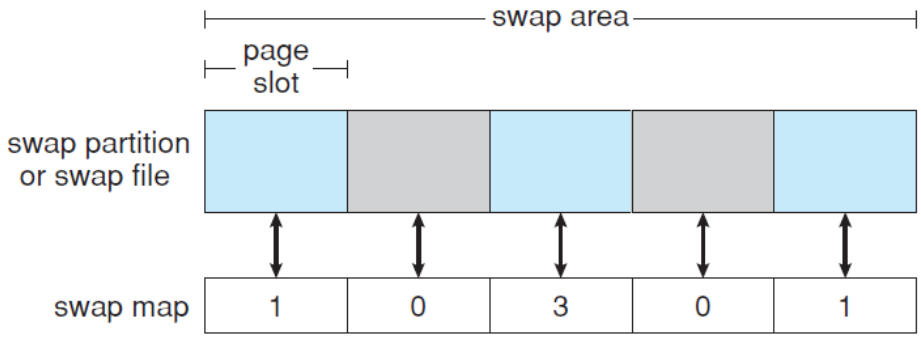
- The value indicates the number of mappings to the swapped page.
  - E.g., a value of 3 indicates that the swapped page is mapped to three different processes.



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  - It is not long at all.

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- If one of the disks in the volume fails, the data can be read from the other.

Mean Time to Failure of A Mirrored Volume

- Depends on two factors:
  - Mean time to failure of the individual disks.
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Mean Time to Failure of A Mirrored Volume

- Depends on two factors:
  - Mean time to failure of the individual disks.
  - Mean time to repair: to replace a failed disk and to restore the data on it.
- Example
  - The mean time to failure of a single disk: 100,000 hours
  - The mean time to repair: 10 hours
  - The mean time to data loss of a mirrored disk system: $100,000^2/(2 \times 10) = 500 \times 10^6$ hours, or 57,000 years!

Improvement in Performance via Parallelism

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Improvement in Performance via Parallelism

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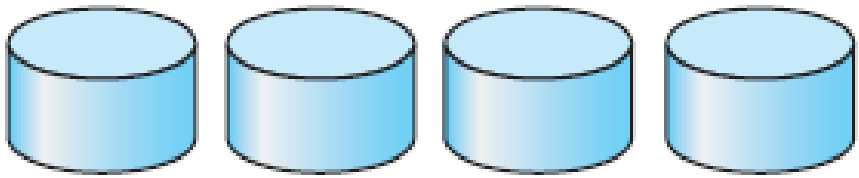
  - It is called bit-level striping.
  - E.g., if we have an array of eight disks, we write bit i of each byte to disk i.
- Block-level striping: blocks of a file are striped across multiple disks.
  - E.g., with n disks, block i of a file goes to disk $(i \bmod n) + 1$.

RAID Levels

- RAID is arranged into six different levels.
- RAID schemes improve performance and improve the reliability of the storage system by storing redundant data.

RAID Level 0

- Disk arrays with striping at the level of blocks but without any redundancy.



RAID Level 1

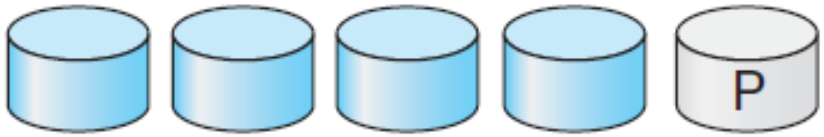
- Disk mirroring

RAID Level 2

- Error-correcting code (ECC)
- Each byte is associated with a parity bit
- It indicates whether the number of bits in the byte set to 1 is even (parity = 0) or odd (parity = 1).

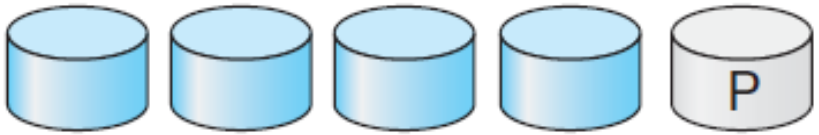
RAID Level 3

- A single parity bit can be used for error detection and correction.
- If one of the sectors is damaged, we know exactly which sector it is
- We can figure out whether any bit in the sector is a 1 or a 0 by computing the parity of the corresponding bits from sectors in the other disks.



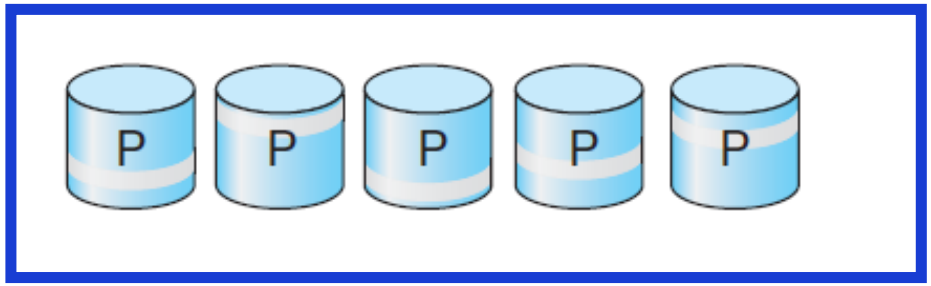
RAID Level 4

- Block-level striping, as in RAID 0.
- Keeps a parity block on a separate disk for corresponding blocks from N other disks.



RAID Level 5

- Spreads data and parity among all N+1 disks, rather than storing data in N disks and parity in one disk.

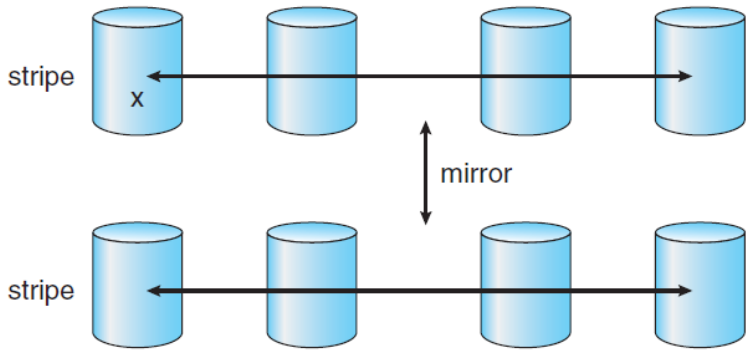


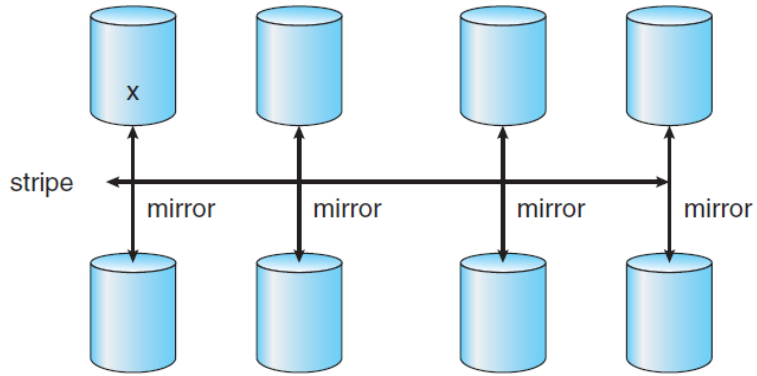
RAID Level 6

- Like RAID level 5 but stores extra redundant information to guard against multiple disk failures.

RAID Level 0 + 1 and 1 + 0

- 0 + 1: RAID 0 provides the performance, while RAID 1 provides the reliability.
- 1 + 0: disks are mirrored in pairs and then the resulting mirrored pairs are striped.





Stable-Storage Implementation

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- Write-ahead log (WAL) scheme requires stable storage.
- In a system using WAL, all modifications are written to a log before they are applied.

Stable-Storage Implementation (2/4)

- To implement stable storage:
- Replicate information on more than one nonvolatile storage media with independent failure modes.
- Update information in a controlled manner to ensure that we can recover the stable data after any failure during data transfer or recovery.

Stable-Storage Implementation (3/4)

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- Total failure: the failure occurred before the disk write started, so the previous data values on the disk remain intact.

Stable-Storage Implementation (4/4)

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- If failure occurs during block write, recovery procedure restores block to consistent state.
- System maintains two physical blocks per logical block and does the following:
  1. Write to 1st physical
  2. When successful, write to 2nd physical
  3. Declare complete only after then second write completes successfully

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- RAID: RAID0-RAID6

Questions?

Acknowledgements

Some slides were derived from Avi Silberschatz slides.