Storage

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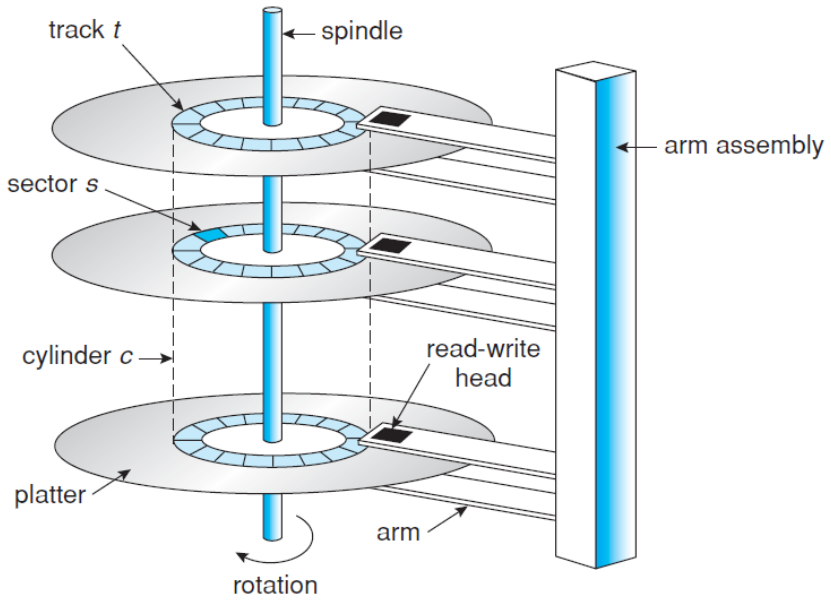
  - The user and programmer interface to the file system.
  - The internal data structures and algorithms used by the OS to implement this interface.

Overview of Mass-Storage Structure

Mass Storage Structure (1/3)

- Magnetic disks: bulk of secondary storage



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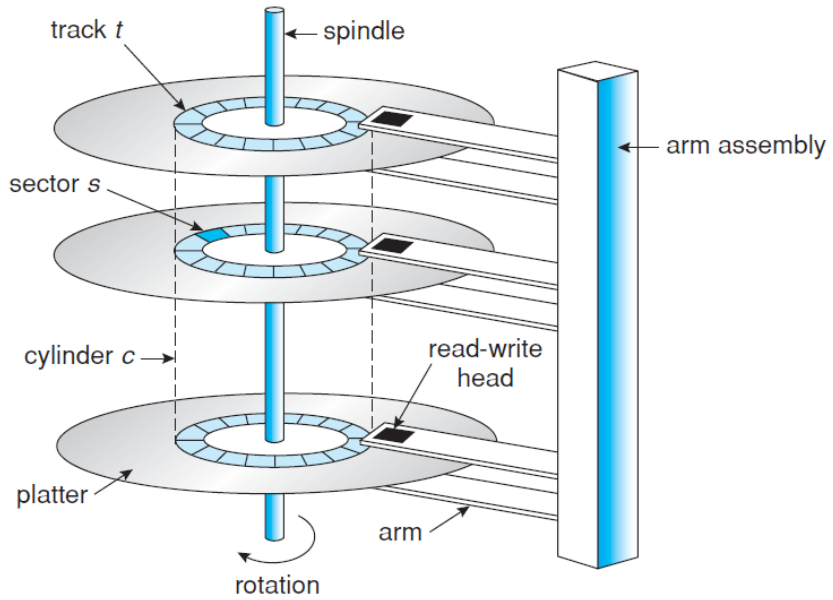

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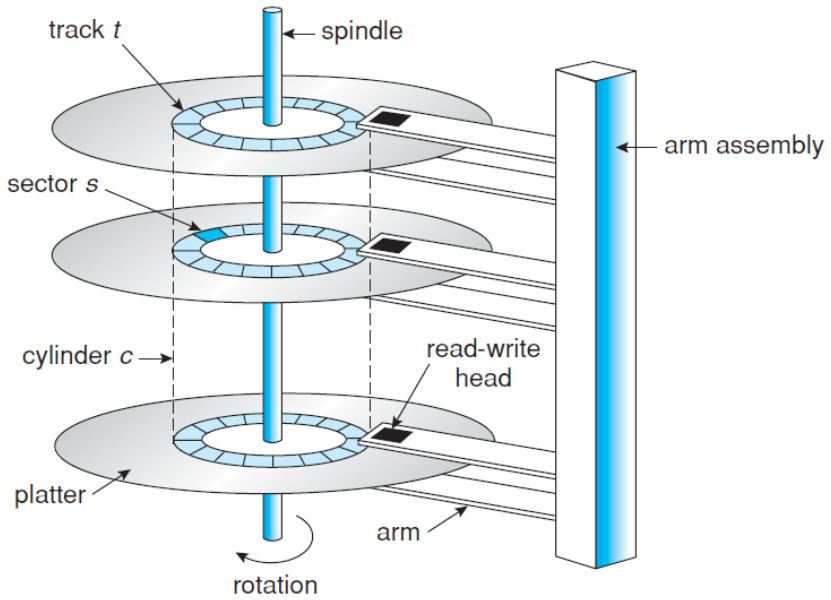

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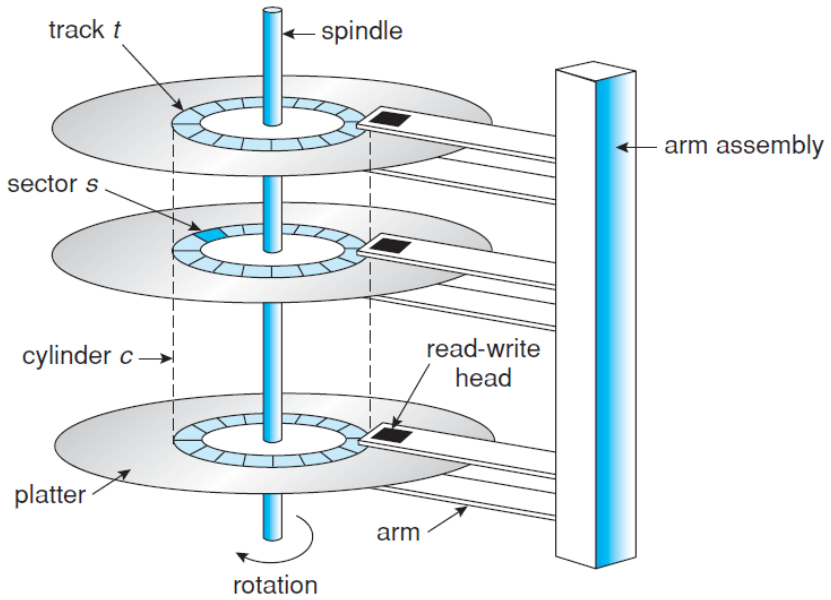

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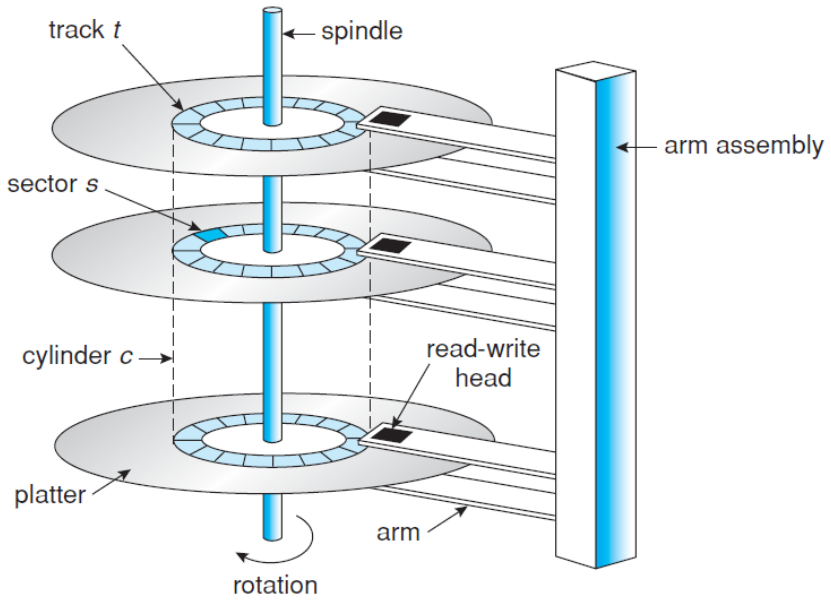

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- Head crash results from disk head making contact with the disk surface.

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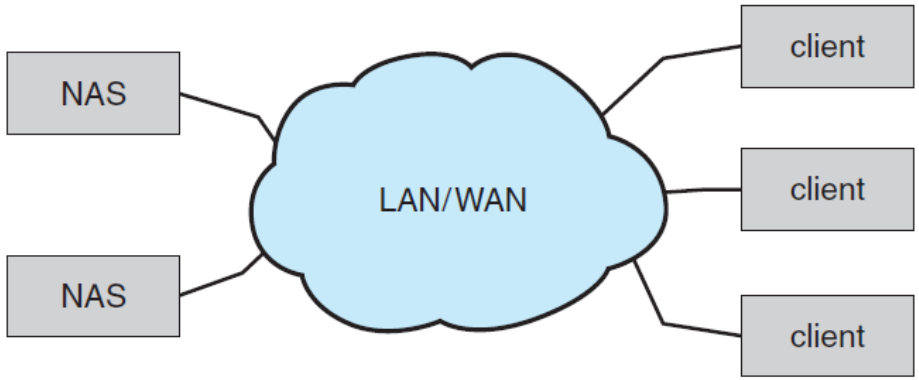
- SCSI is a bus, up to 16 devices on one cable.
- Fiber Channel (FC) is high-speed serial architecture.

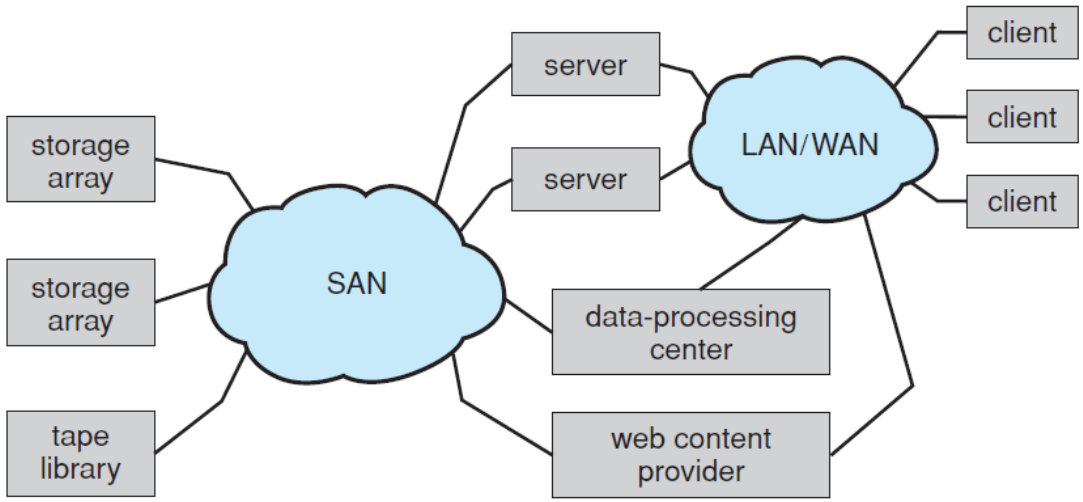
Network-Attached Storage

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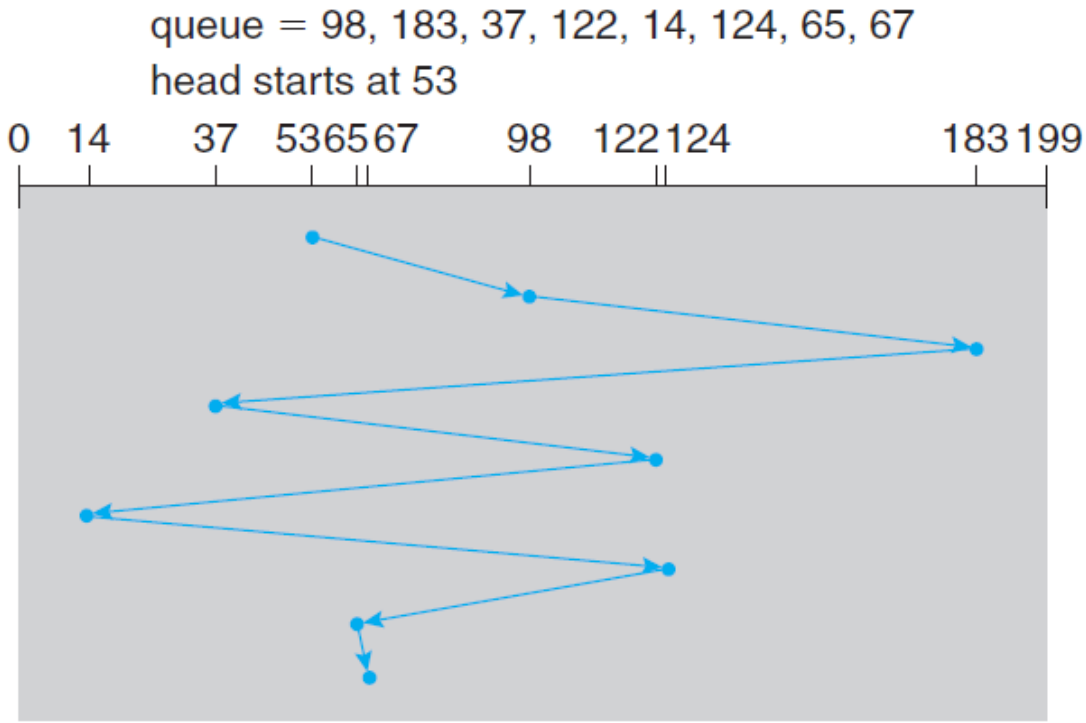
- Note that drive controllers have small buffers and can manage a queue of I/O requests.

Disk Scheduling Algorithms

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

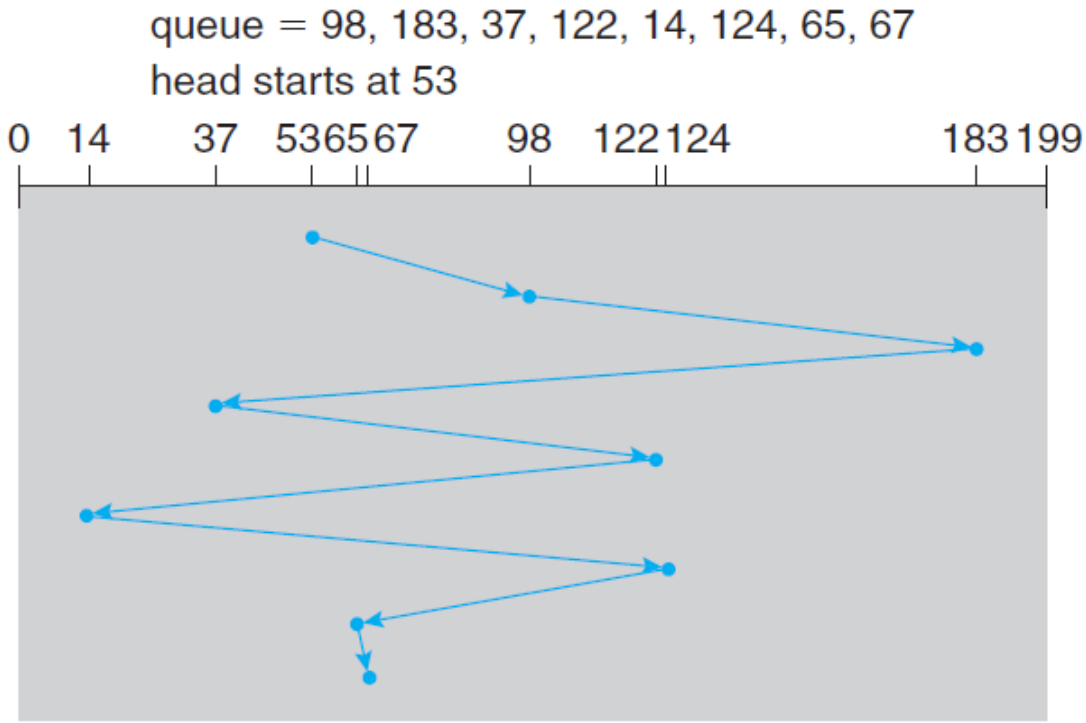
FCFS

- 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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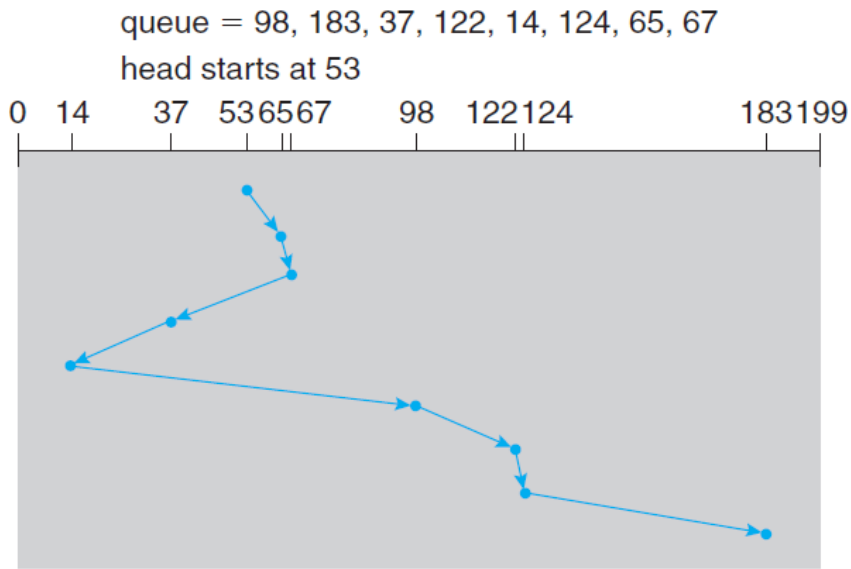

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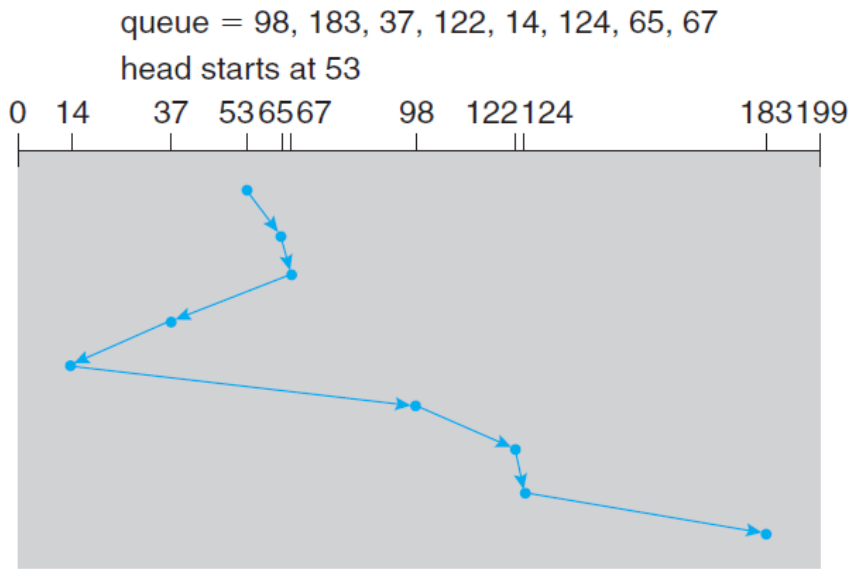
- Total head movement: 236 cylinders.



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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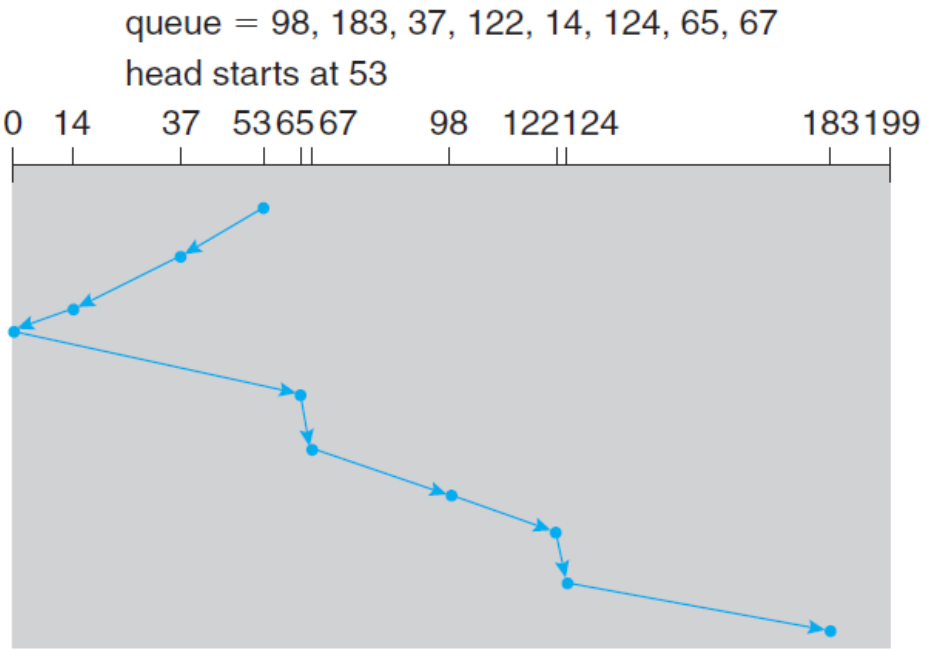

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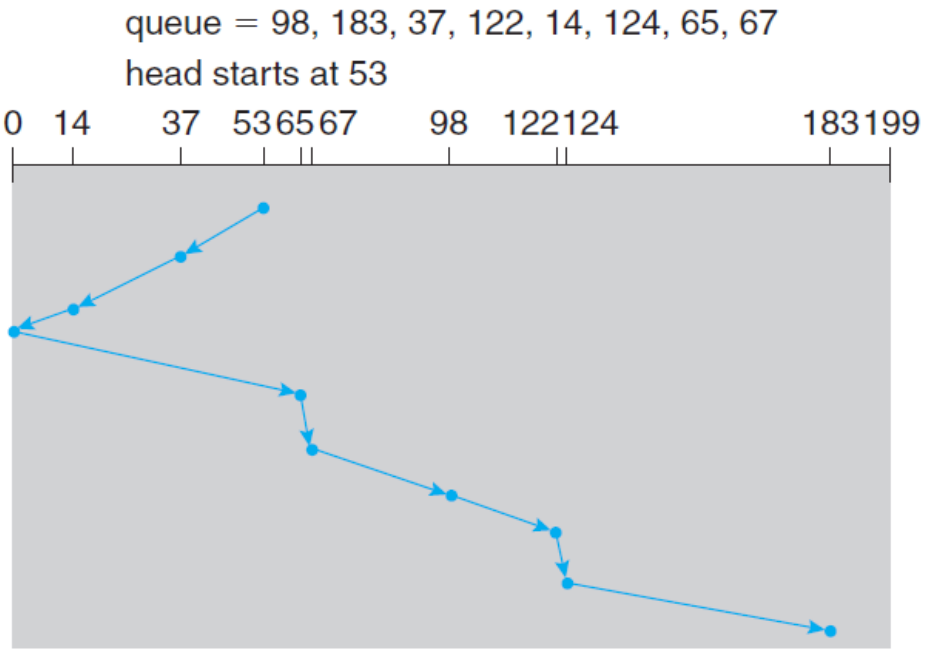
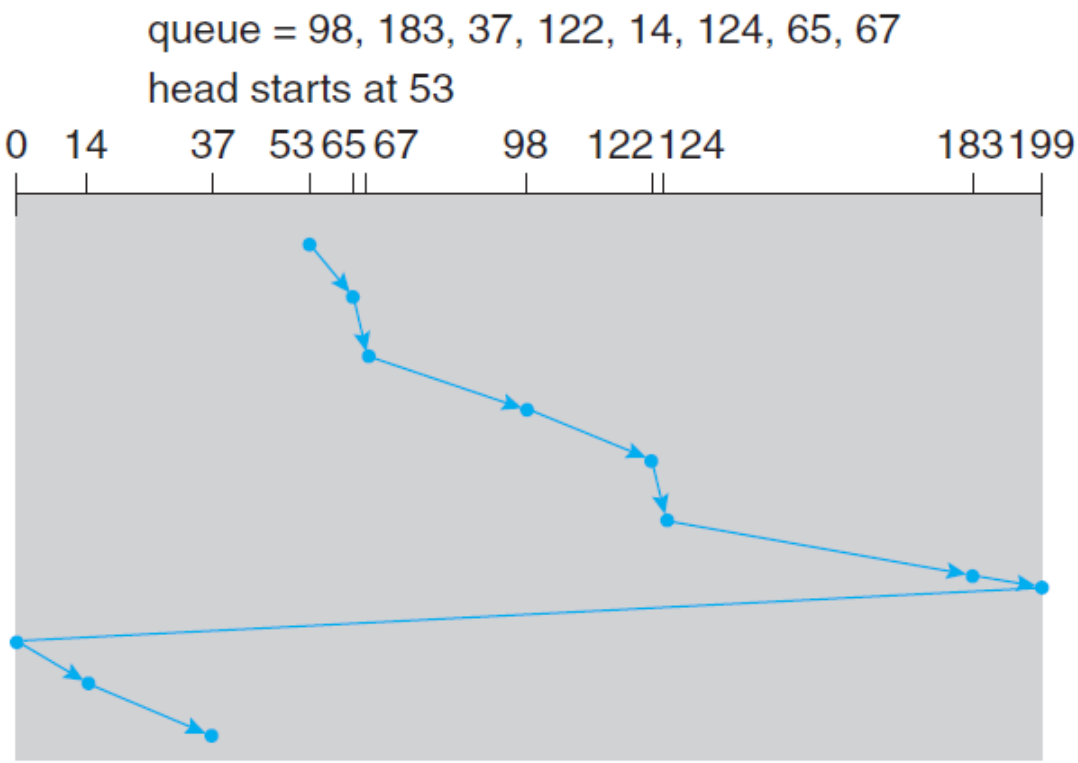


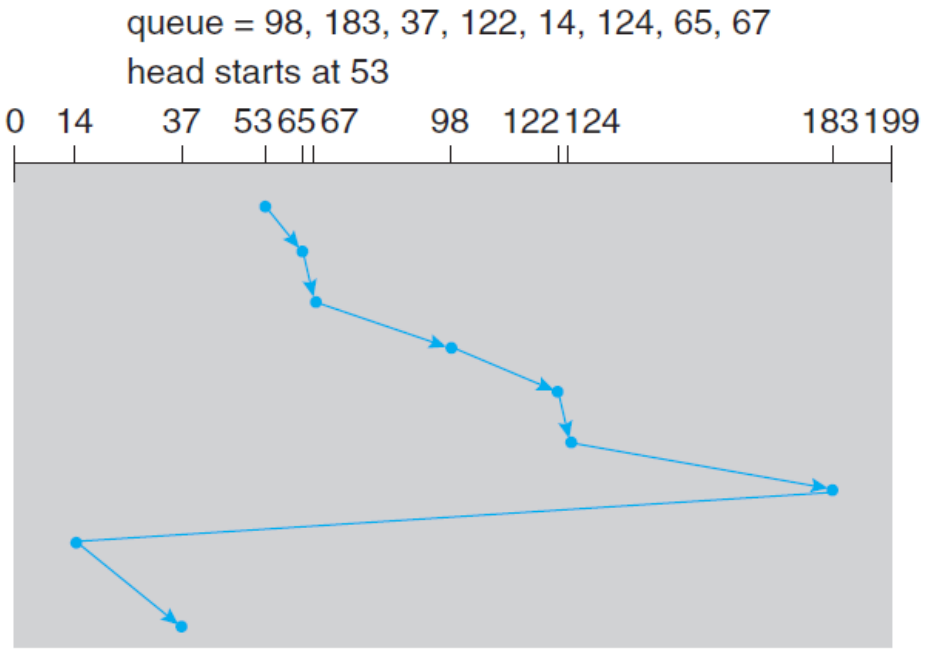
C-SCAN

- 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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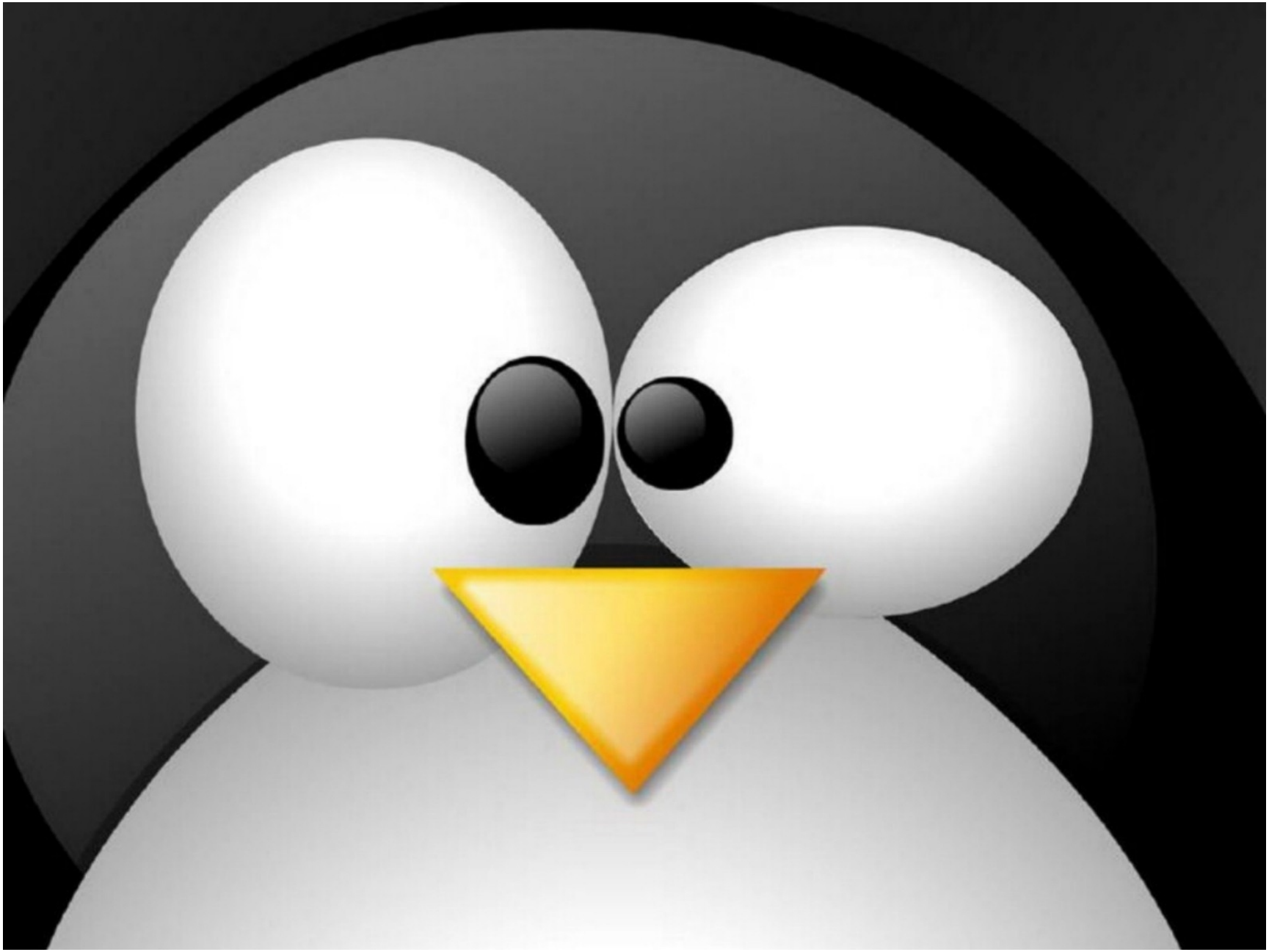

Swap-Space On Linux (1/2)

- 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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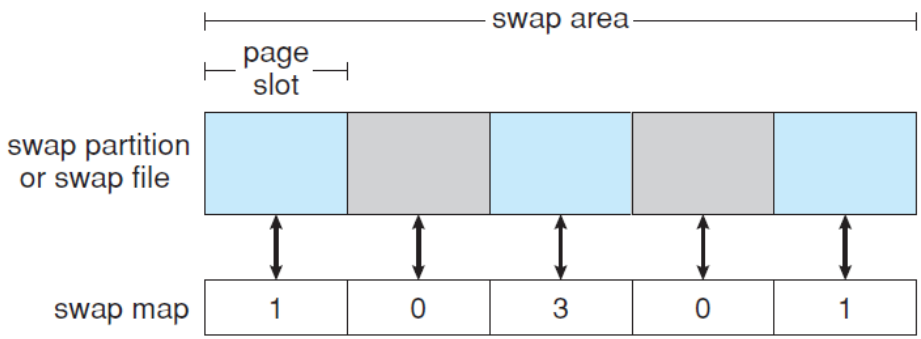
- Each swap area consists of a series of 4KB page slots, which are used to hold swapped pages.



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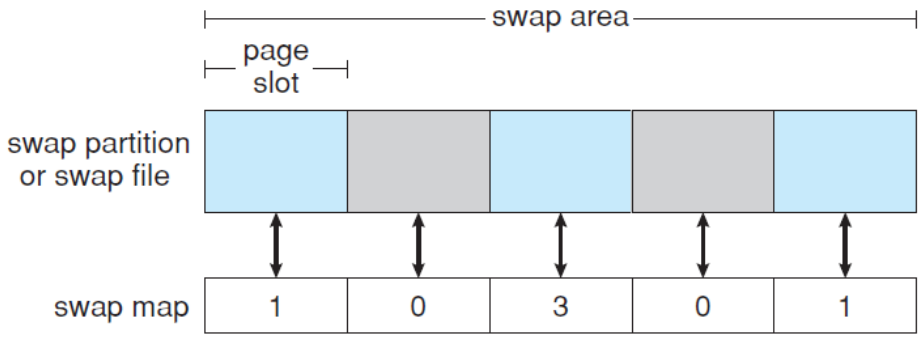

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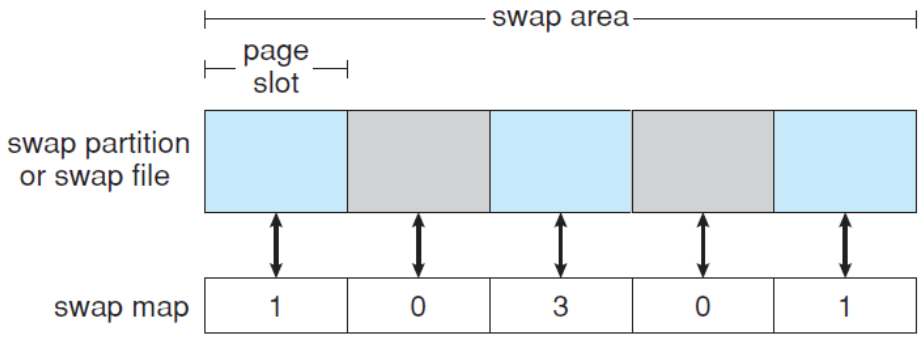
- The value indicates the number of mappings to the swapped page.
  - E.g., a value of 3 indicates that the swapped page is mapped to three different processes.



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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

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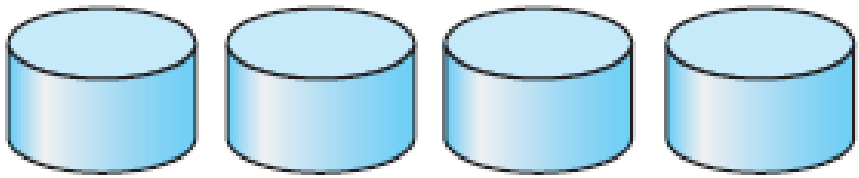
  - It is called bit-level striping.
  - E.g., if we have an array of eight disks, we write bit i of each byte to disk i.
- Block-level striping: blocks of a file are striped across multiple disks.
  - E.g., with n disks, block i of a file goes to disk $(i \bmod n) + 1$.

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

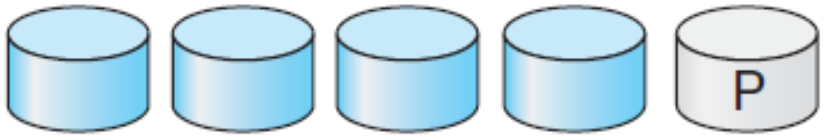
- Disk mirroring

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).

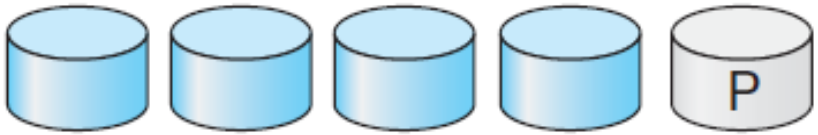
RAID Level 3

- 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

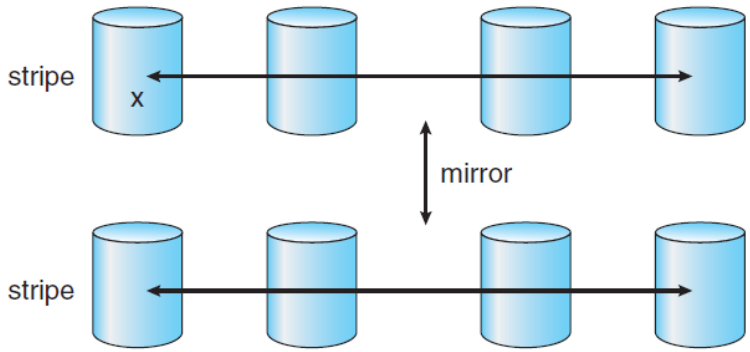
- Spreads data and parity among all N+1 disks, rather than storing data in N disks and parity in one disk.

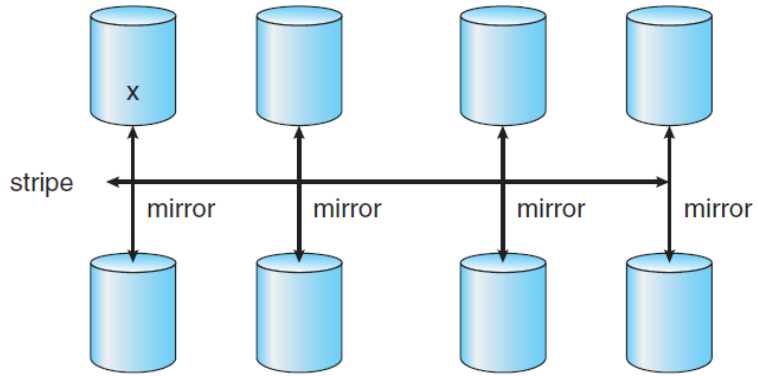
RAID Level 6

- 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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- Partial failure: a failure occurred in the midst of transfer, so only some of the sectors were written with the new data, and the sector being written during the failure may have been corrupted.
- 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

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