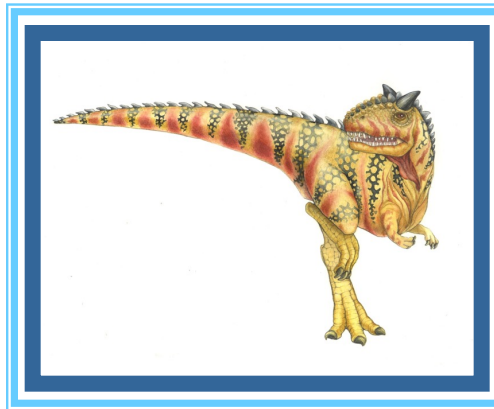
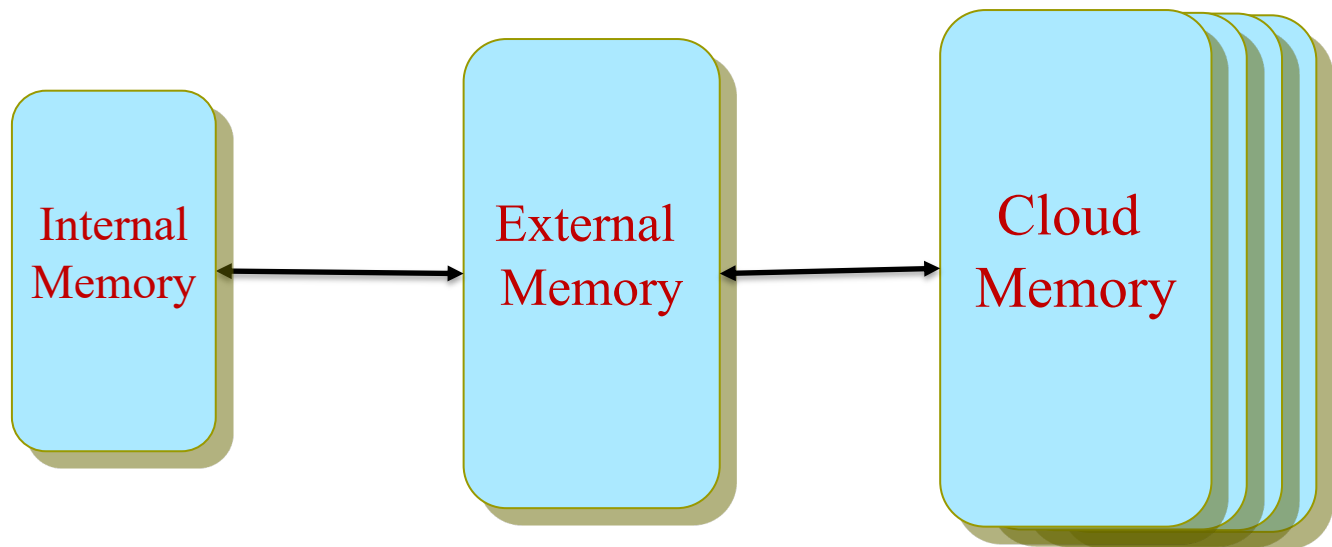


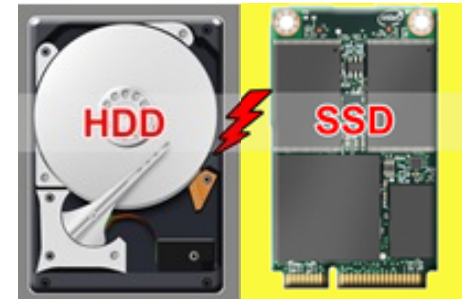
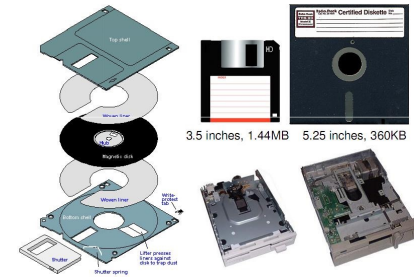
Chapter 11: Mass-Storage Systems





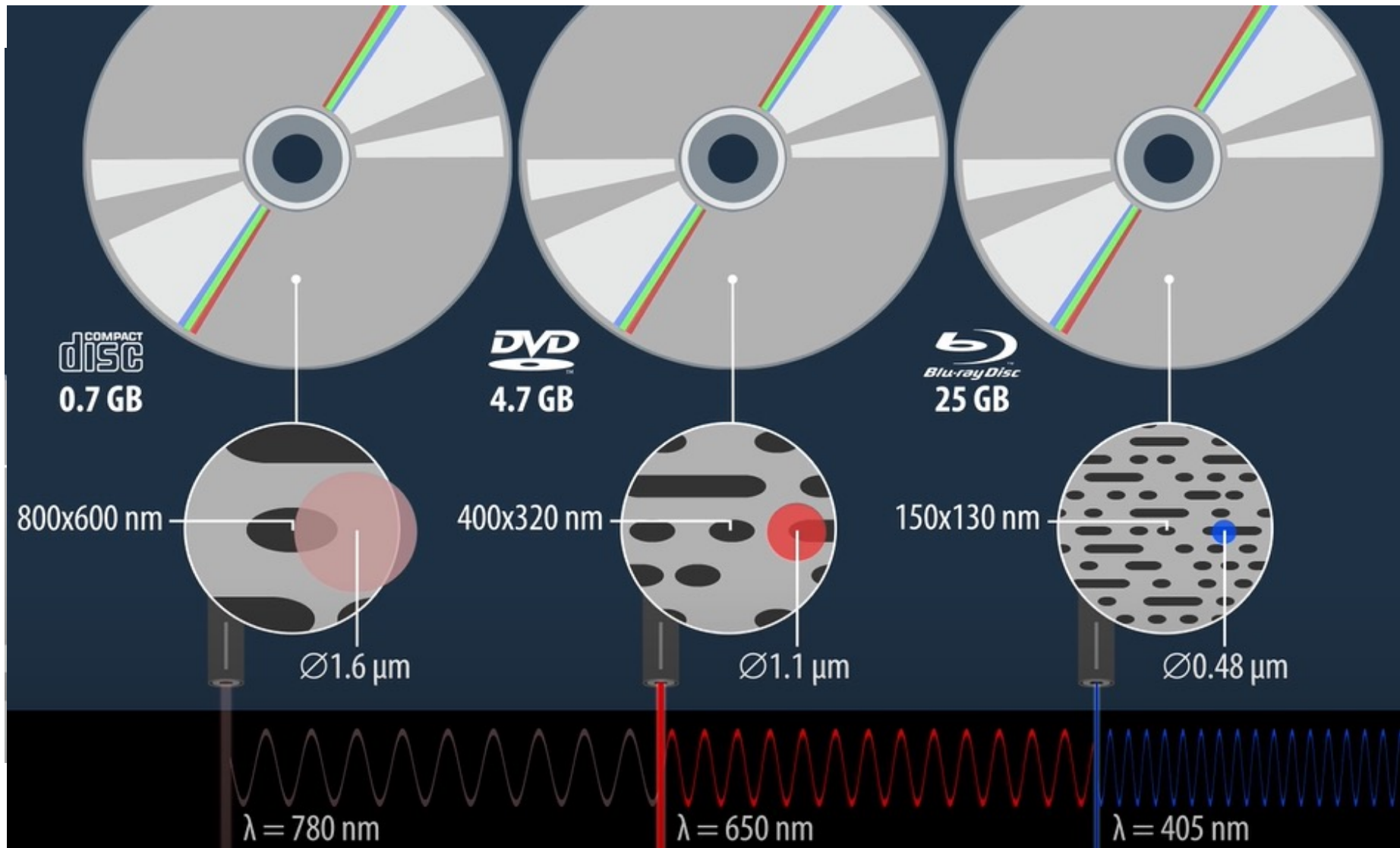
Memory Overview







Overview of Data Storage





Overview of Data Storage

➤ Hard disk drive (HDD)

800

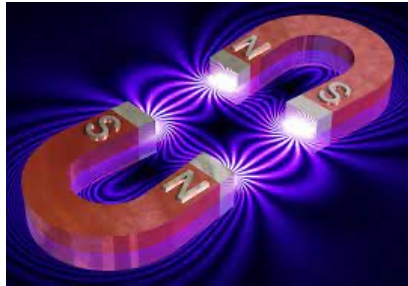


2800

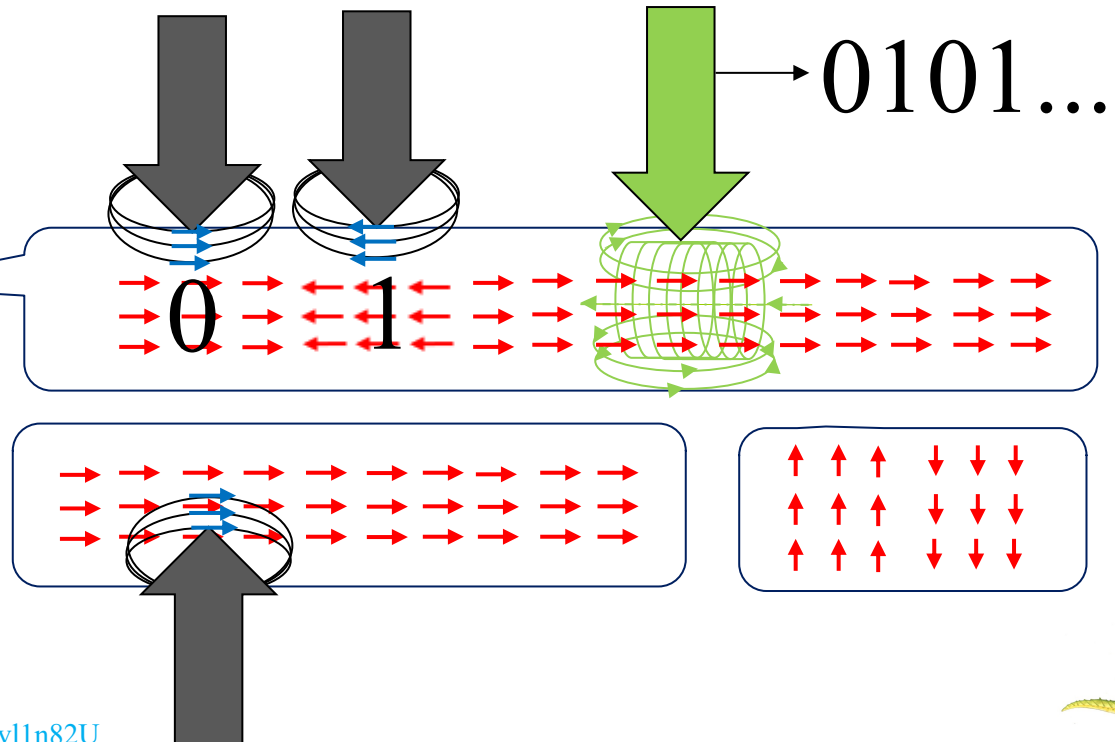
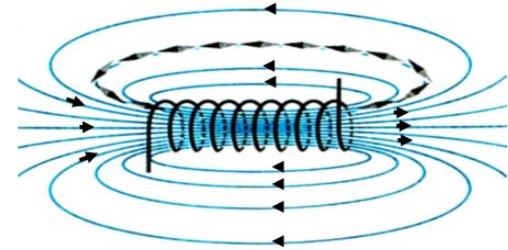
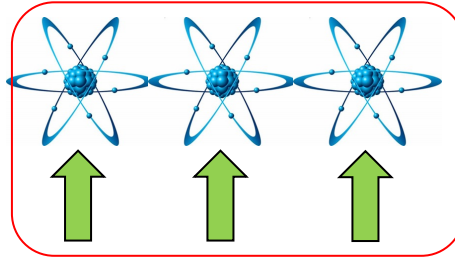




Overview of Data Storage



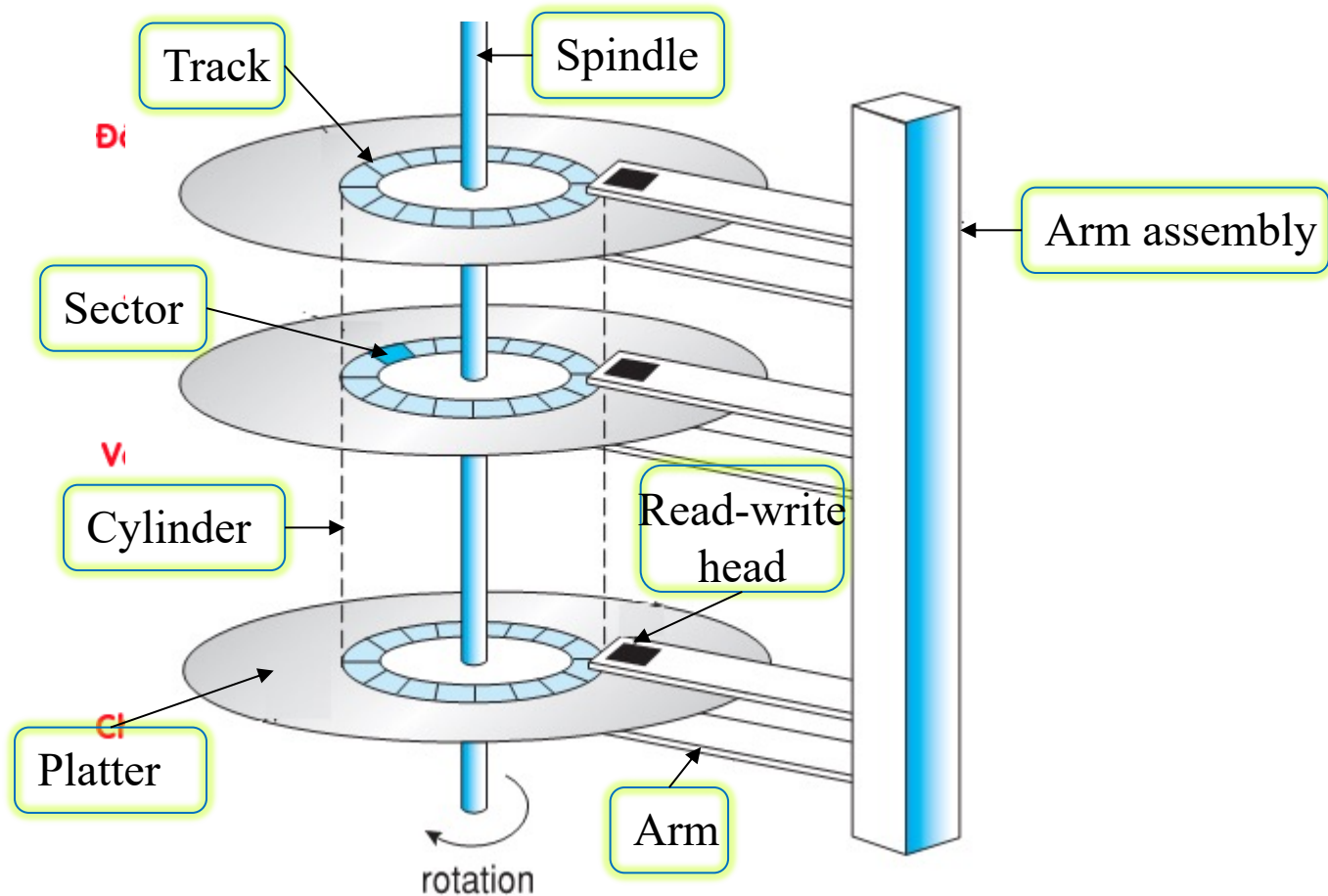
Đô Men Từ





Overview of Mass Storage Structure

- Bulk of secondary storage for modern computers is **hard disk drives (HDDs)** devices.





Overview of Mass Storage Structure

- **Drives rotate** at 60 to 250 times per second, specified in terms of rotations per minute (**RPM**) Common drives spin at 5,400, 7,200, 10,000, and 15,000 RPM
- **Transfer rate** is rate at which data flow between drive and computer
- **Positioning time** (**random-access time**) is time to move disk arm to desired cylinder (**seek time**) and time for desired sector to rotate under the disk head (**rotational latency**)
- **Head crash** results from disk head making contact with the disk surface -- That's bad
- Disks can be removable





HDD Scheduling

- The operating system is responsible for using hardware efficiently — for the disk drives, this means 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





Disk Scheduling (Cont.)

- There are many sources of disk I/O request
 - OS
 - System processes
 - Users processes
- I/O request includes input or output mode, disk address, memory address, number of sectors to transfer
- OS maintains queue of requests, per disk or device
- Idle disk can immediately work on I/O request, busy disk means work must queue
 - Optimization algorithms only make sense when a queue exists
- In the past, operating system responsible for queue management, disk drive head scheduling
 - Now, built into the storage devices, controllers
 - Just provide LBAs, handle sorting of requests
 - ▶ Some of the algorithms they use described next





Disk Scheduling (Cont.)

- Note that drive controllers have small buffers and can manage a queue of I/O requests (of varying “depth”)
- Several algorithms exist to schedule the servicing of disk I/O requests
- The analysis is true for one or many platters
- We illustrate scheduling algorithms with a request queue (0-199)

98, 183, 37, 122, 14, 124, 65, 67

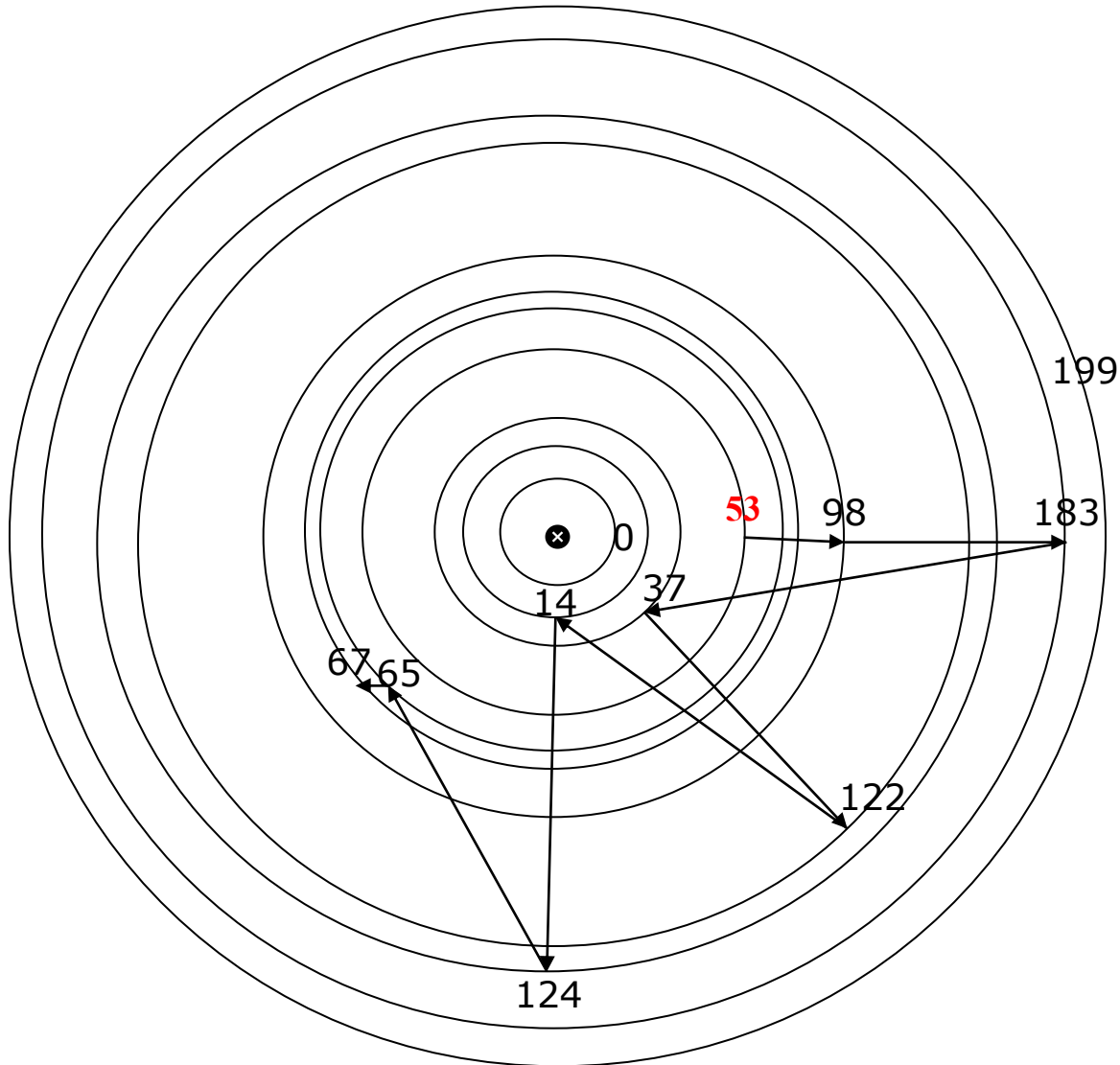
Head pointer 53





FCFS

queue = 98, 183, 37, 122, 14, 124, 65, 67: Head pointer 53

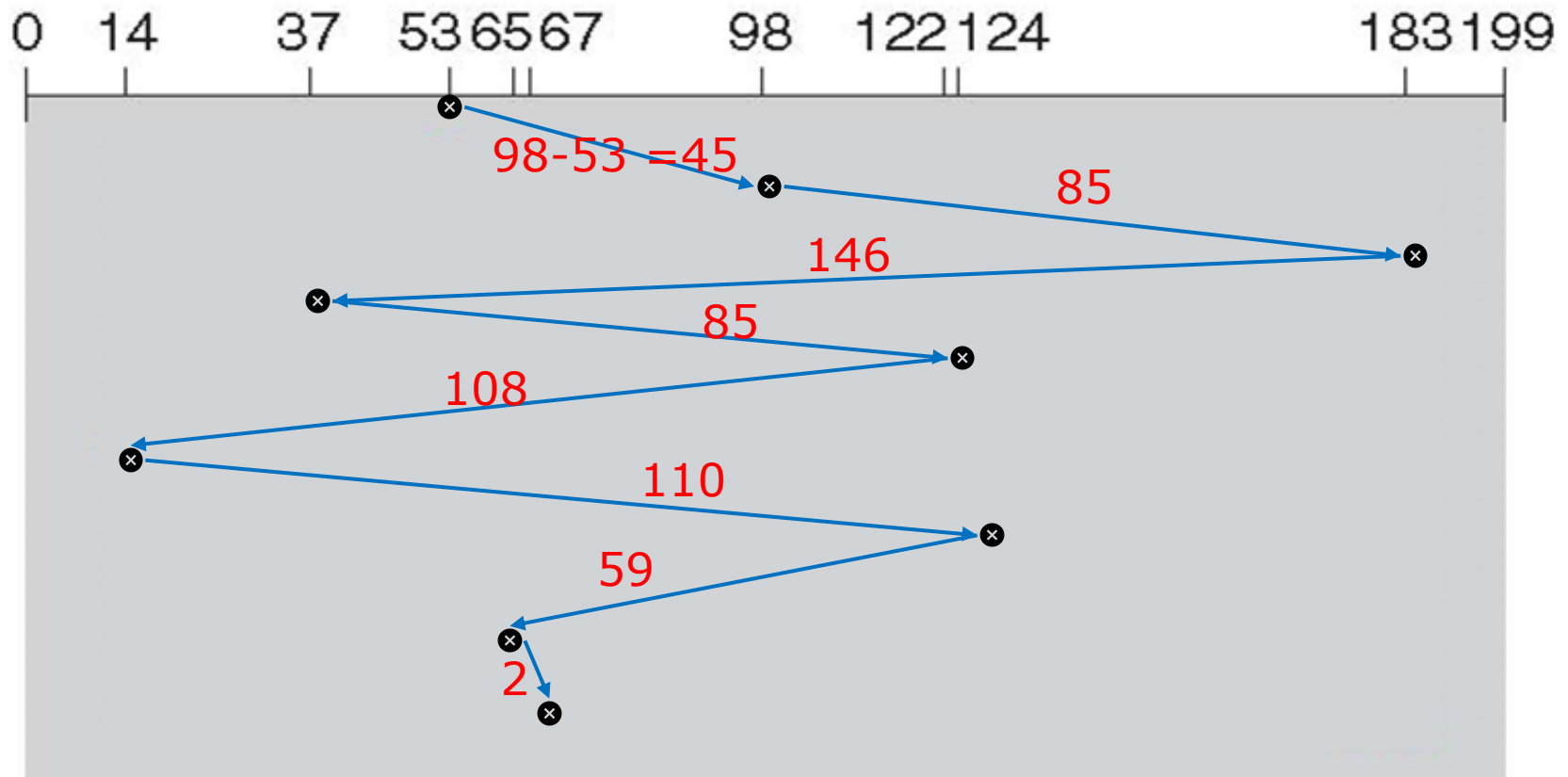




FCFS (Cont.)

queue = 98, 183, 37, 122, 14, 124, 65, 67

head starts at 53



Total head movement of 640 cylinders





Shortest Seek Time First (SSTF)

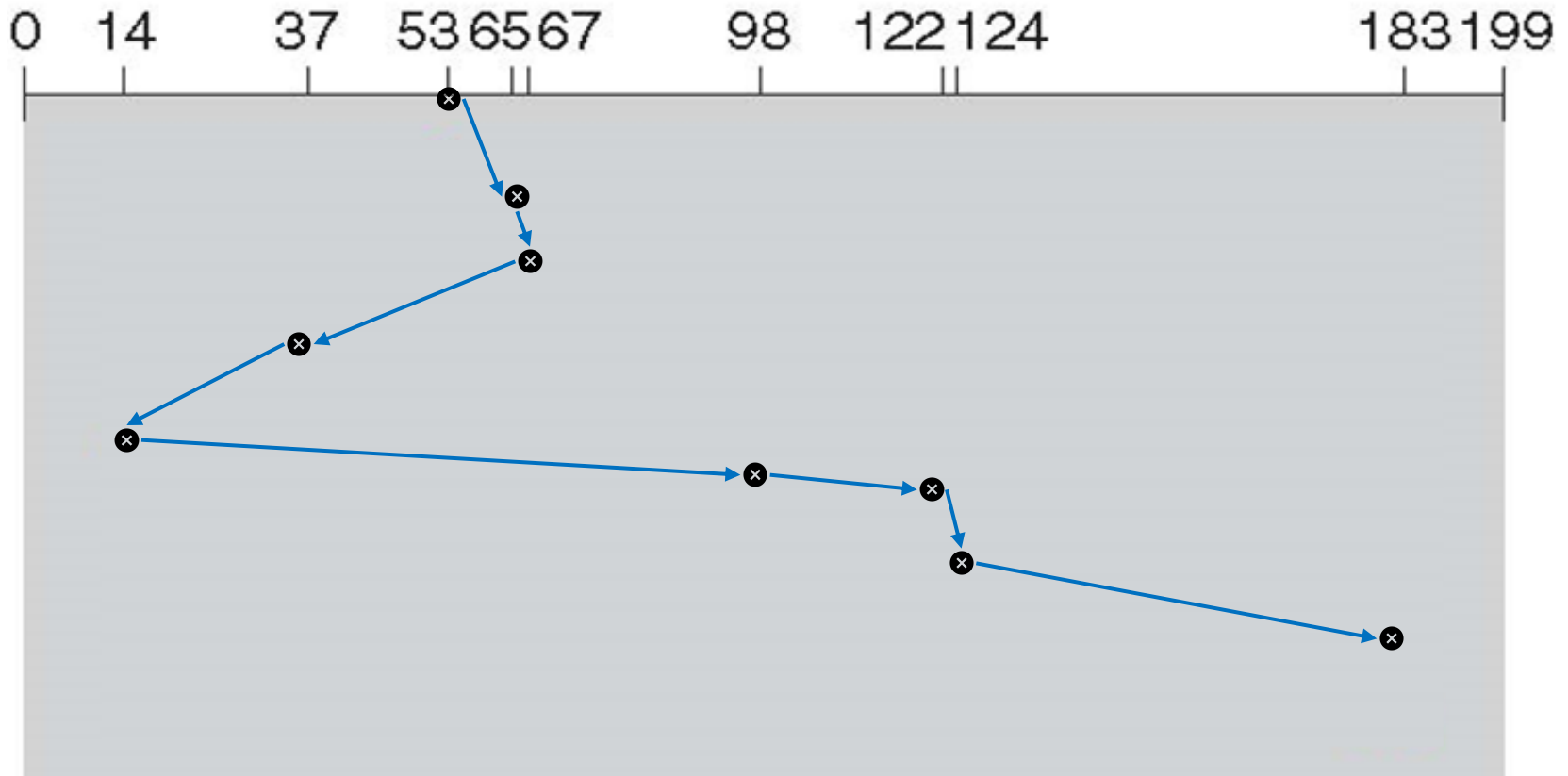
- Shortest Seek Time First selects the request with the minimum seek time from the current head position
- SSTF scheduling is a form of SJF scheduling; may cause starvation of some requests





SSTF (Cont.)

queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53



Total head movement of cylinders = ?





SCAN

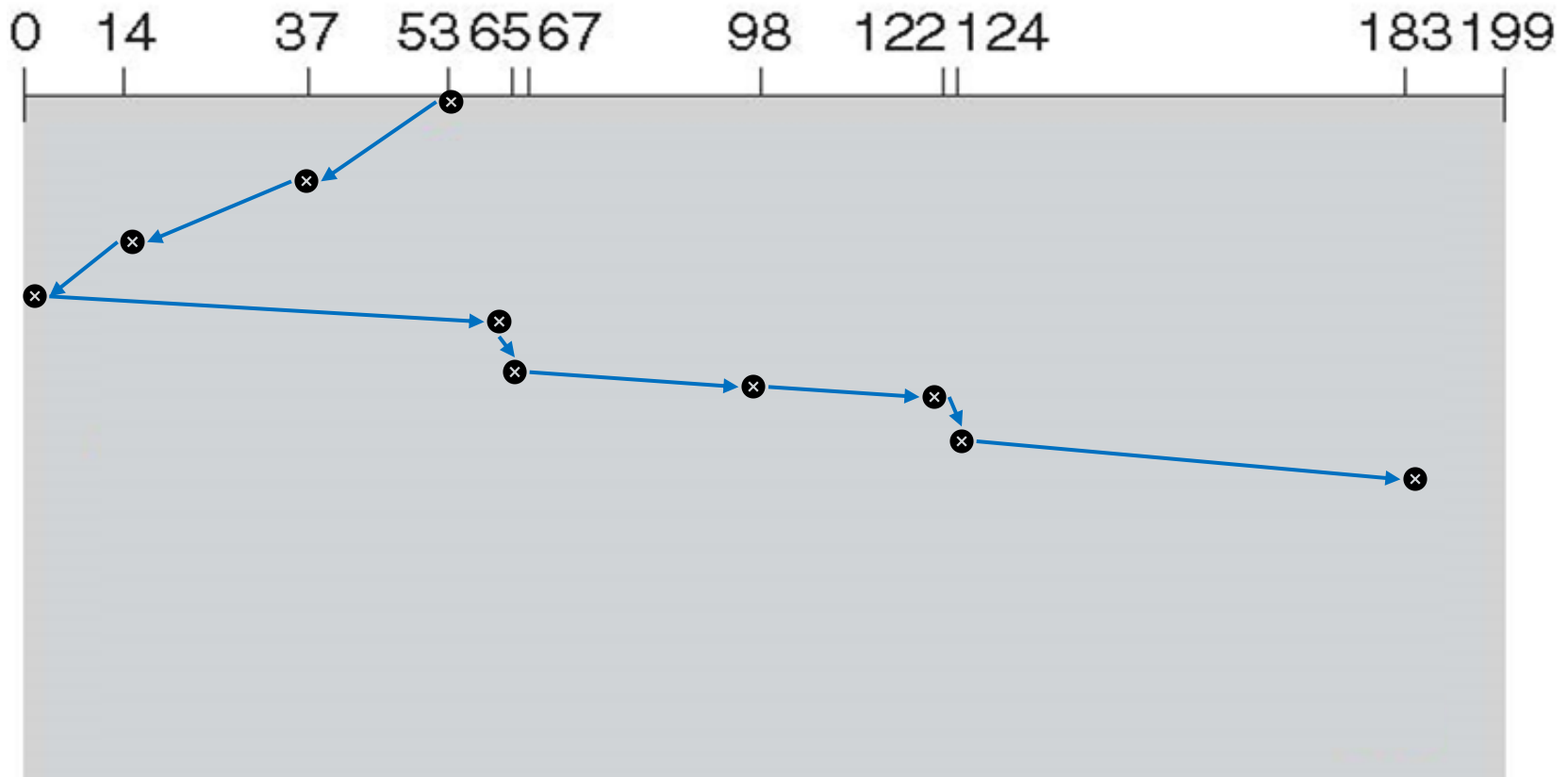
- The disk arm starts at one end of the disk, and moves toward the other end, servicing requests until it gets to the other end of the disk, where the head movement is reversed and servicing continues.
- **SCAN algorithm** Sometimes called the **elevator algorithm**
- But note that if requests are uniformly dense, largest density at other end of disk and those wait the longest





SCAN (Cont.)

queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53



Total head movement of cylinders = ?





C-SCAN

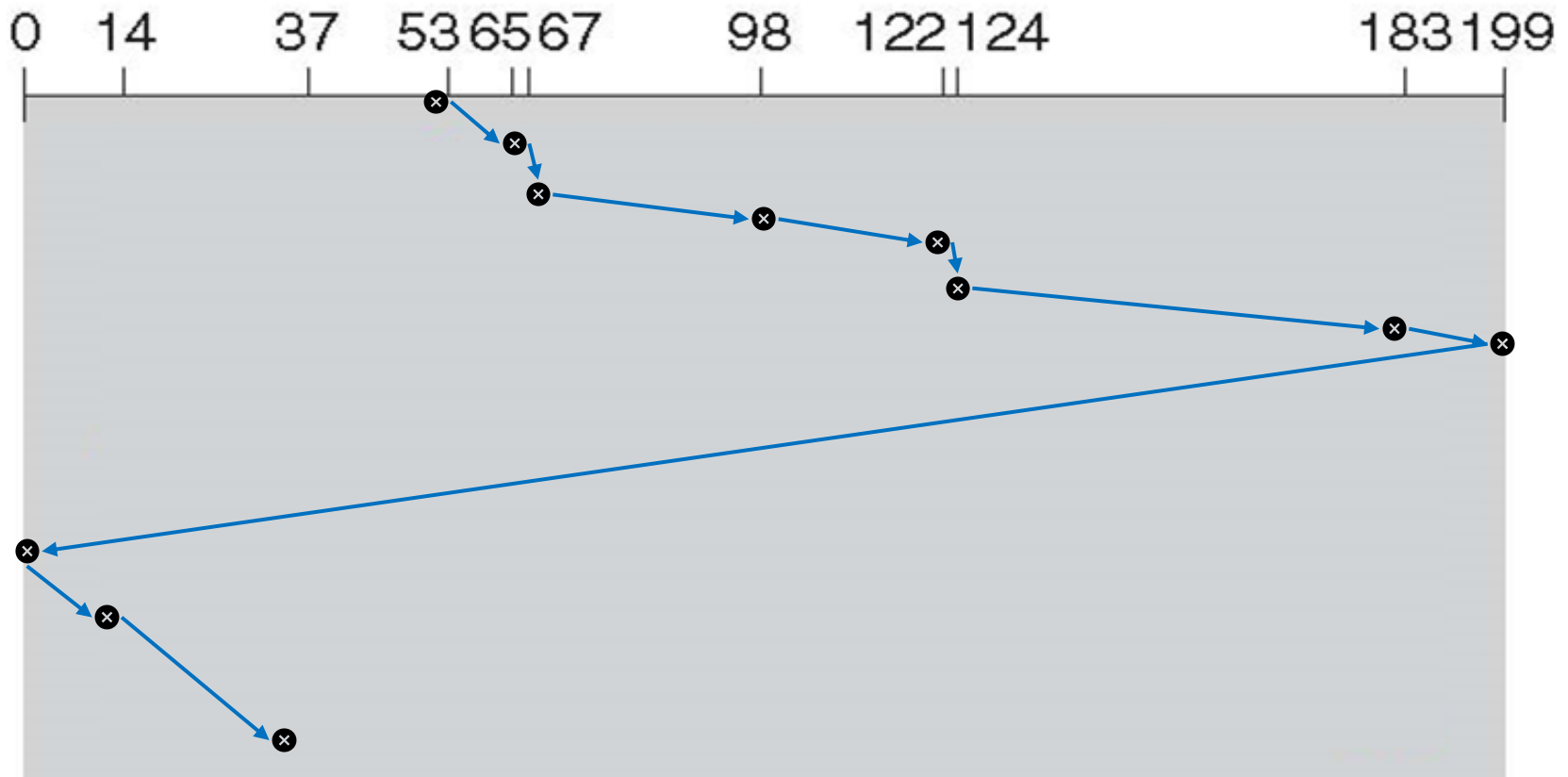
- Provides a more uniform wait time than SCAN
- The head moves from one end of the disk to the other, servicing requests as it goes
 - When it reaches the other end, however, it immediately returns to the beginning of the disk, without servicing any requests on the return trip
- Treats the cylinders as a circular list that wraps around from the last cylinder to the first one
- Total number of cylinders?





C-SCAN (Cont.)

queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53



Total head movement of cylinders = ?





LOOK and C-LOOK

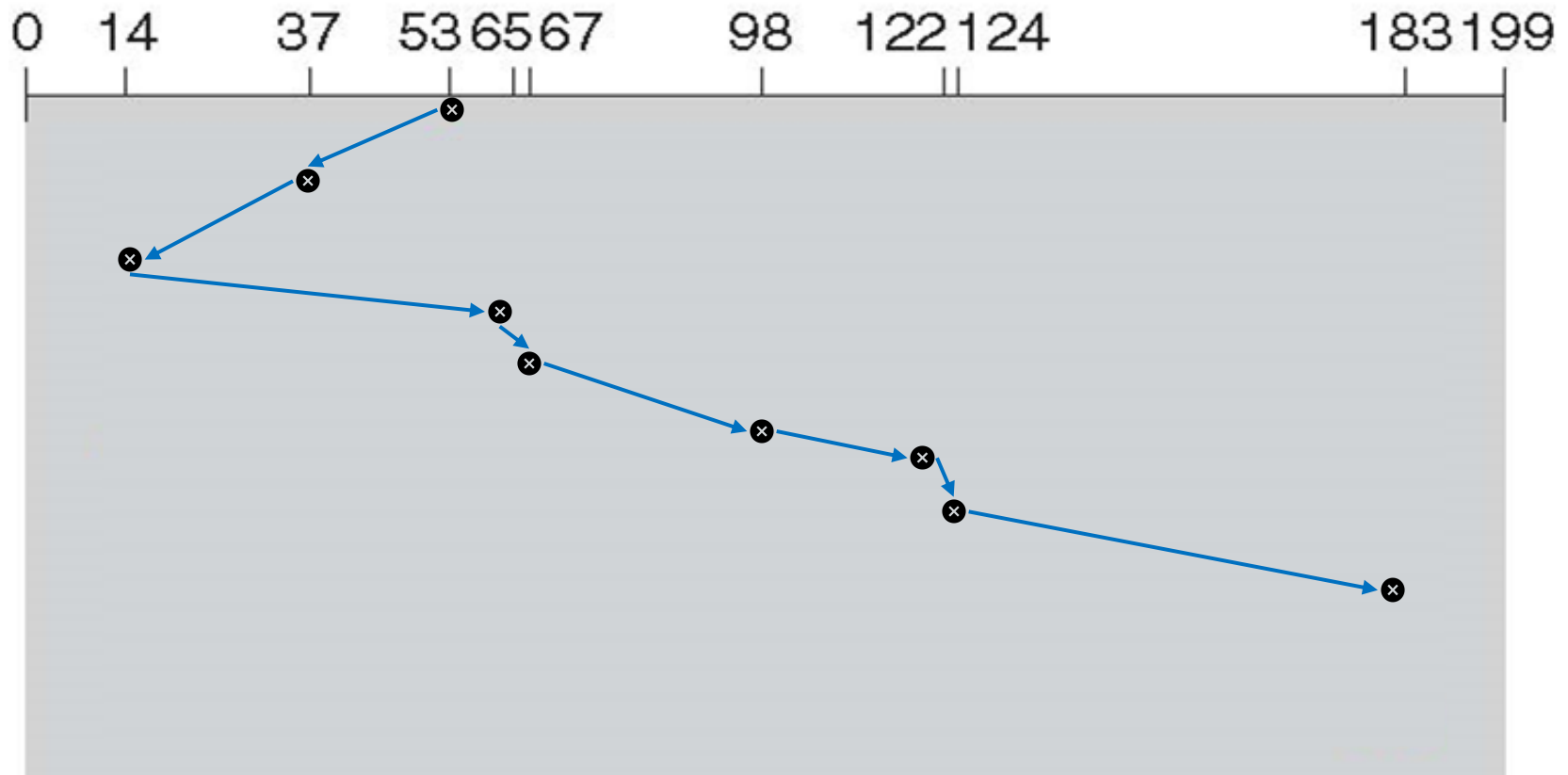
- LOOK a version of SCAN, C-LOOK a version of C-SCAN
- Arm only goes as far as the last request in each direction, then reverses direction immediately, without first going all the way to the end of the disk
- Total number of cylinders?





LOOK(Cont.)

queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53



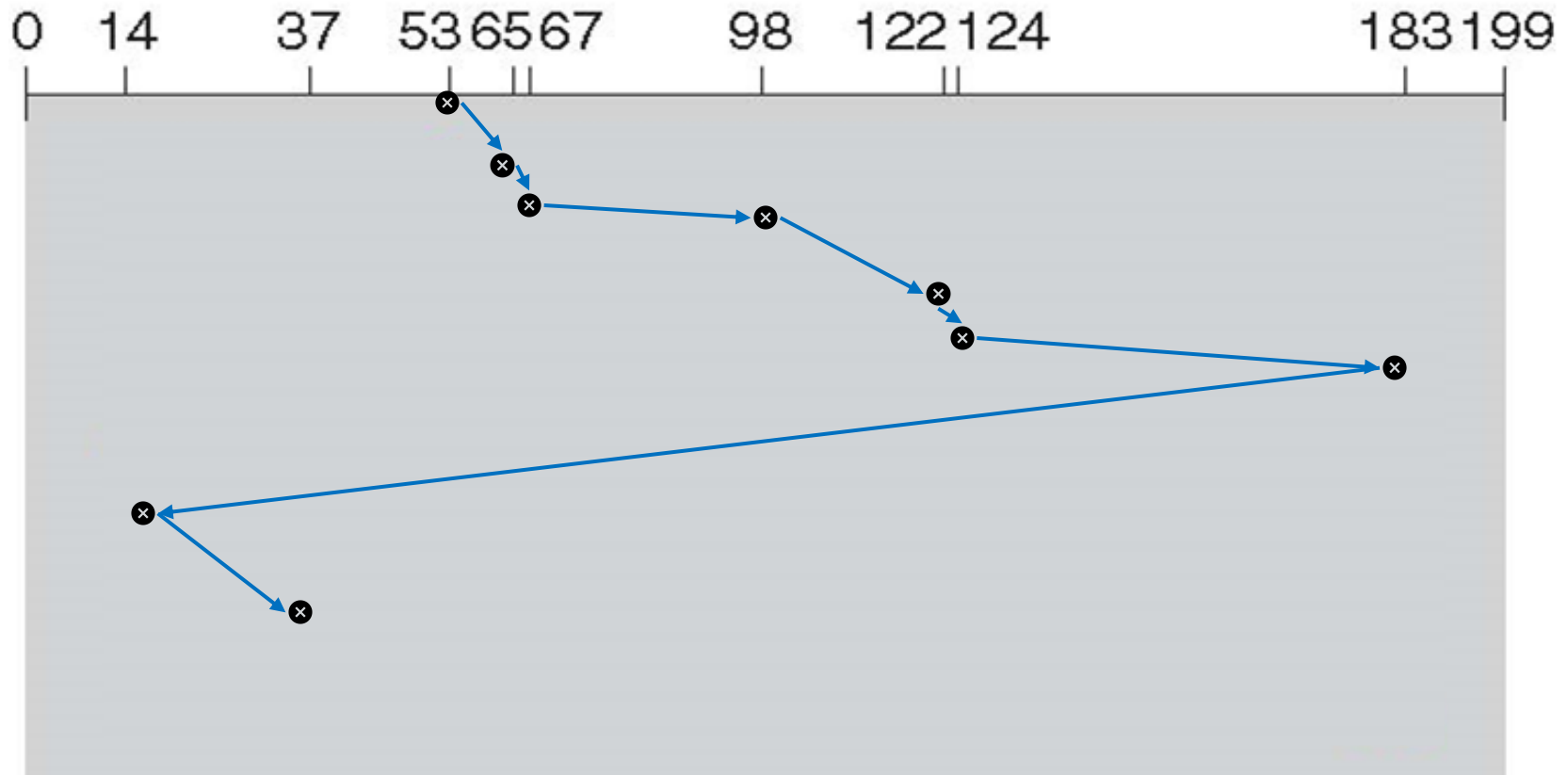
Total head movement of cylinders = ?





C - LOOK(Cont.)

queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53



Total head movement of cylinders = ?





Selecting a Disk-Scheduling Algorithm

- SSTF is common and has a natural appeal
- SCAN and C-SCAN perform better for systems that place a heavy load on the disk
 - Less starvation, but still possible
- To avoid starvation Linux implements **deadline** scheduler
 - Maintains separate read and write queues, gives read priority
 - ▶ Because processes more likely to block on read than write
 - Implements four queues: 2 x read and 2 x write
 - ▶ 1 read and 1 write queue sorted in LBA order, essentially implementing C-SCAN
 - ▶ 1 read and 1 write queue sorted in FCFS order
 - ▶ All I/O requests sent in batch sorted in that queue's order
 - ▶ After each batch, checks if any requests in FCFS older than configured age (default 500ms)
 - If so, LBA queue containing that request is selected for next batch of I/O
- In RHEL 7 also **NOOP** and **completely fair queueing** scheduler (**CFQ**) also available, defaults vary by storage device





Error Detection and Correction

- Fundamental aspect of many parts of computing (memory, networking, storage)
- **Error detection** determines if there a problem has occurred (for example a bit flipping)
 - If detected, can halt the operation
 - Detection frequently done via parity bit
- Parity one form of **checksum** – uses modular arithmetic to compute, store, compare values of fixed-length words
 - Another error-detection method common in networking is **cyclic redundancy check (CRC)** which uses hash function to detect multiple-bit errors
- **Error-correction code (ECC)** not only detects, but can correct some errors
 - Soft errors correctable, hard errors detected but not corrected





Storage Device Management

- **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, plus data, plus error correction code (**ECC**)
 - Usually 512 bytes of data but can be selectable
- To use a disk to hold files, the operating system still needs to record its own data structures on the disk
 - **Partition** the disk into one or more groups of cylinders, each treated as a logical disk
 - **Logical formatting** or “making a file system”
 - To increase efficiency most file systems group blocks into **clusters**
 - ▶ Disk I/O done in blocks
 - ▶ File I/O done in clusters





Storage Device Management (cont.)

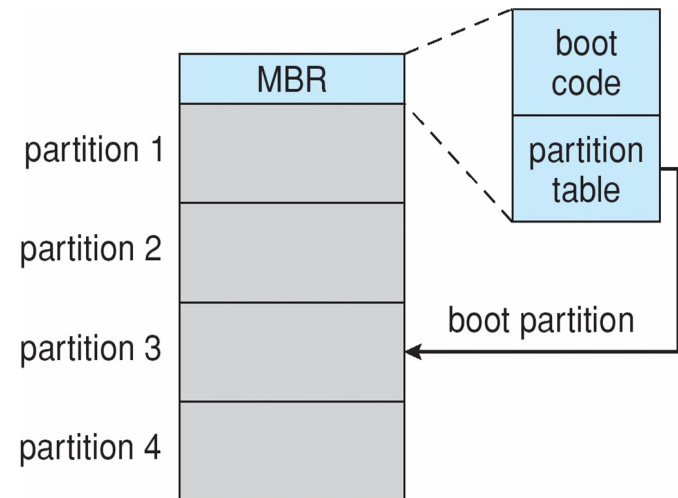
- **Root partition** contains the OS, other partitions can hold other Oses, other file systems, or be raw
 - **Mounted** at boot time
 - Other partitions can mount automatically or manually
- At mount time, file system consistency checked
 - Is all metadata correct?
 - ▶ If not, fix it, try again
 - ▶ If yes, add to mount table, allow access
- Boot block can point to boot volume or boot loader set of blocks that contain enough code to know how to load the kernel from the file system
 - Or a boot management program for multi-os booting





Device Storage Management (Cont.)

- Raw disk access for apps that want to do their own block management, keep OS out of the way (databases for example)
- Boot block initializes system
 - The bootstrap is stored in ROM, firmware
 - **Bootstrap loader** program stored in boot blocks of boot partition
- Methods such as **sector sparing** used to handle bad blocks



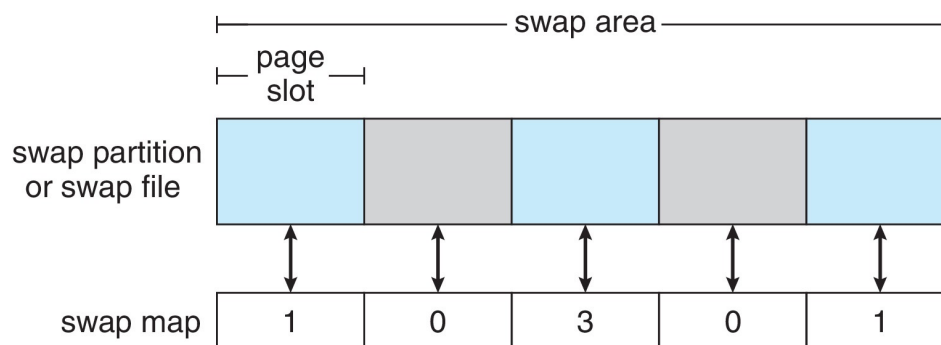
Booting from secondary storage in Windows





Swap-Space Management

- Used for moving entire processes (swapping), or pages (paging), from DRAM to secondary storage when DRAM not large enough for all processes
- Operating system provides **swap space management**
 - Secondary storage slower than DRAM, so important to optimize performance
 - Usually multiple swap spaces possible – decreasing I/O load on any given device
 - Best to have dedicated devices
 - Can be in raw partition or a file within a file system (for convenience of adding)
 - Data structures for swapping on Linux systems:





Storage Attachment

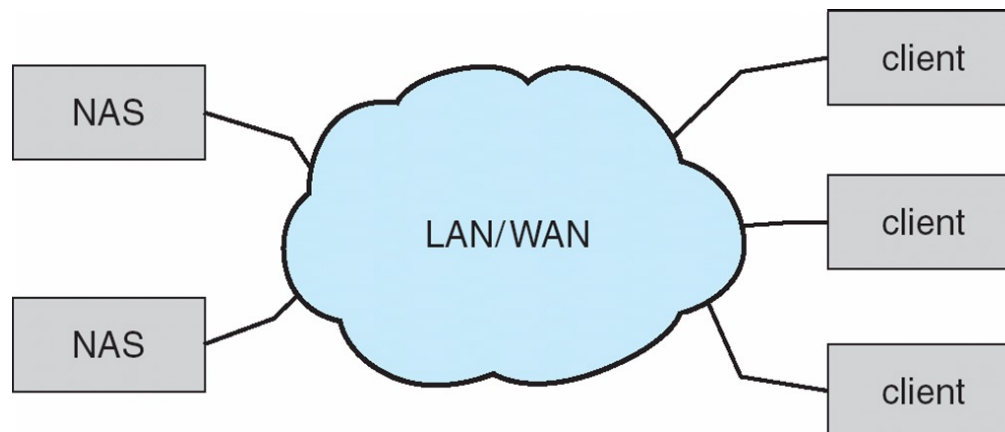
- Computers access storage in three ways
 - host-attached
 - network-attached
 - cloud
- Host attached access through local I/O ports, using one of several technologies
 - To attach many devices, use storage busses such as USB, firewire, thunderbolt
 - High-end systems use **fibre channel (FC)**
 - ▶ High-speed serial architecture using fibre or copper cables
 - ▶ Multiple hosts and storage devices can connect to the FC fabric





Network-Attached Storage

- Network-attached storage (**NAS**) is storage made available over a network rather than over a local connection (such as a bus)
 - 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
- **iSCSI** protocol uses IP network to carry the SCSI protocol
 - Remotely attaching to devices (blocks)





Cloud Storage

- Similar to NAS, provides access to storage across a network
 - Unlike NAS, accessed over the Internet or a WAN to remote data center
- NAS presented as just another file system, while cloud storage is API based, with programs using the APIs to provide access
 - Examples include Dropbox, Amazon S3, Microsoft OneDrive, Apple iCloud
 - Use APIs because of latency and failure scenarios (NAS protocols wouldn't work well)





Storage Array

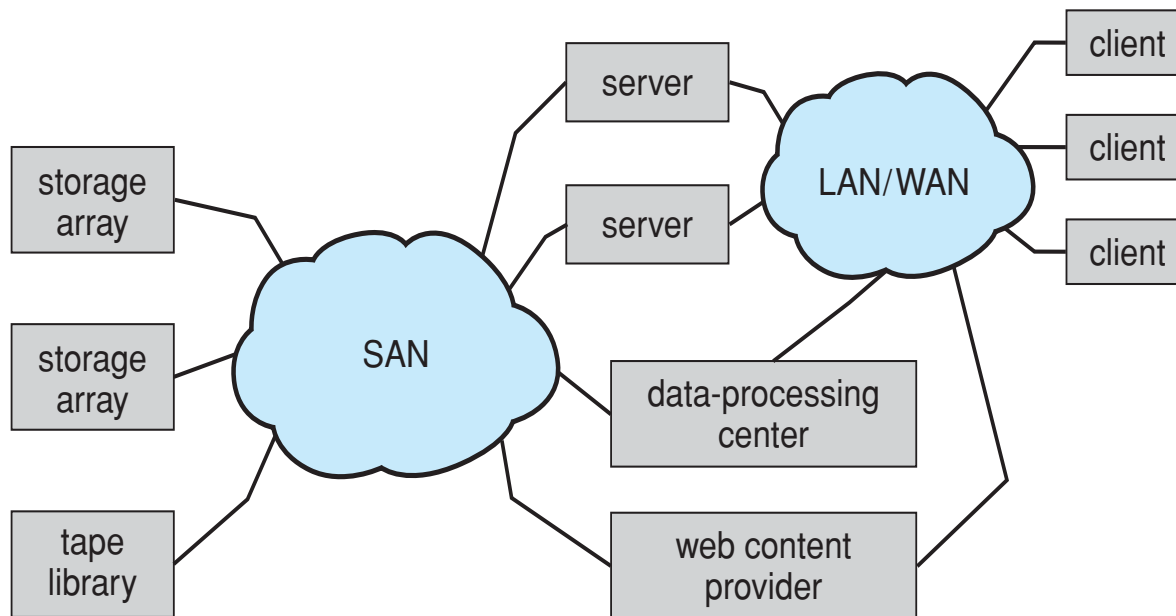
- Can just attach disks, or arrays of disks
- Avoids the NAS drawback of using network bandwidth
- Storage Array has controller(s), provides features to attached host(s)
 - Ports to connect hosts to array
 - Memory, controlling software (sometimes NVRAM, etc)
 - A few to thousands of disks
 - RAID, hot spares, hot swap (discussed later)
 - Shared storage -> more efficiency
 - Features found in some file systems
 - ▶ Snapshots, clones, thin provisioning, replication, deduplication, etc





Storage Area Network

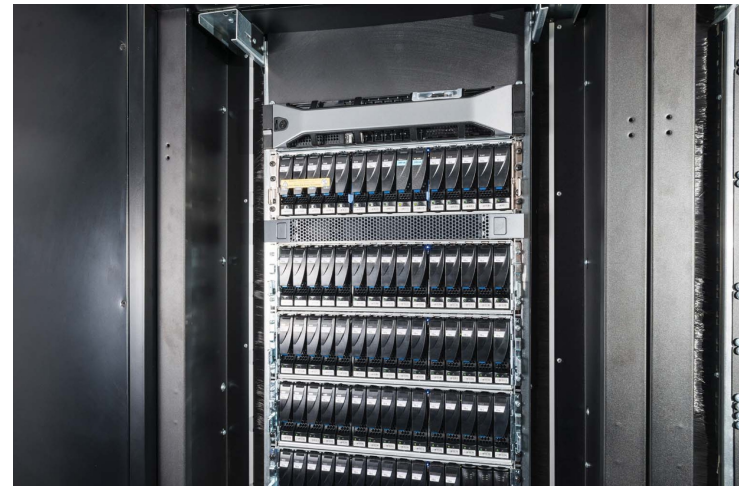
- Common in large storage environments
- Multiple hosts attached to multiple storage arrays – flexible





Storage Area Network (Cont.)

- SAN is one or more storage arrays
 - Connected to one or more Fibre Channel switches or **InfiniBand (IB)** network
- Hosts also attach to the switches
- Storage made available via **LUN Masking** from specific arrays to specific servers
- Easy to add or remove storage, add new host and allocate it storage
- Why have separate storage networks and communications networks?
 - Consider iSCSI, FCOE



A Storage Array





RAID Structure

- **RAID – redundant array of inexpensive disks (Redundant Array of Independent Disks)**
 - multiple disk drives provides reliability via **redundancy**
- Increases the **mean time to failure**
- **Mean time to repair** – exposure time when another failure could cause data loss
- **Mean time to data loss** based on above factors
- If mirrored disks fail independently, consider disk with 1300,000 **mean time to failure** and 10 hour mean time to repair
 - Mean time to data loss is $100,000^2 / (2 * 10) = 500 * 10^6$ hours, or 57,000 years!
- Frequently combined with **NVRAM** to improve write performance
- Several improvements in disk-use techniques involve the use of multiple disks working cooperatively





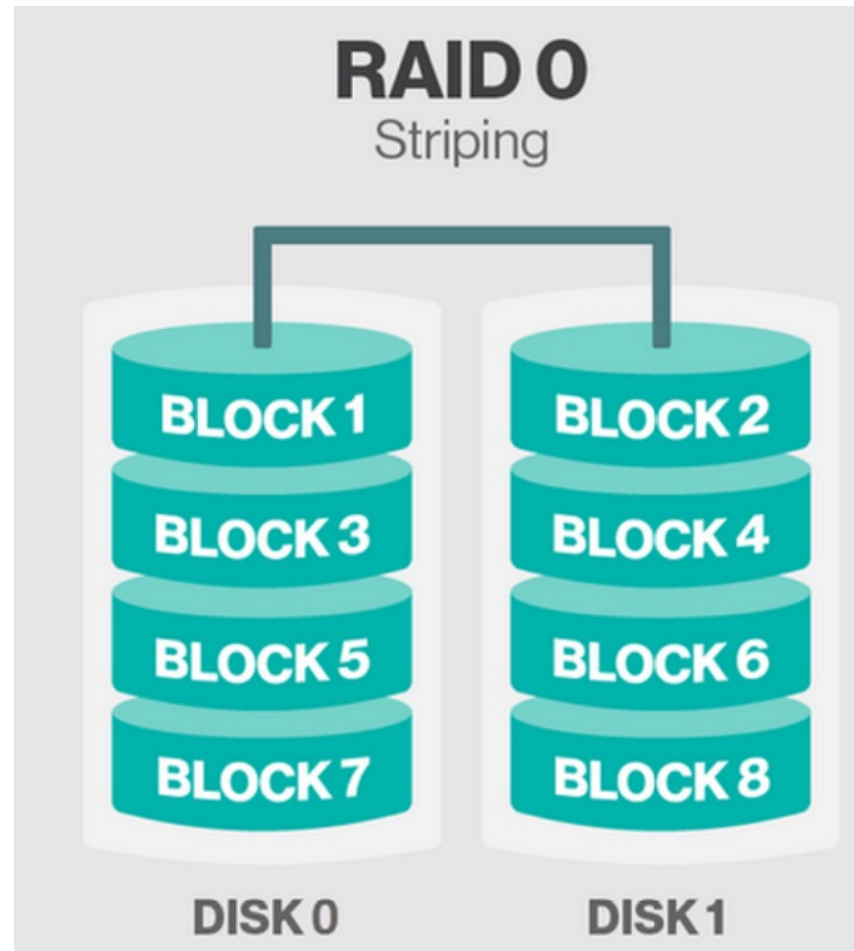
RAID (Cont.)

- Disk **striping** uses a group of disks as one storage unit
- RAID is arranged into six different levels
- RAID schemes improve performance and improve the reliability of the storage system by storing redundant data
 - **Mirroring** or **shadowing** (**RAID 1**) keeps duplicate of each disk
 - Striped mirrors (**RAID 1+0**) or mirrored stripes (**RAID 0+1**) provides high performance and high reliability
 - **Block interleaved parity** (**RAID 4, 5, 6**) uses much less redundancy
- RAID within a storage array can still fail if the array fails, so automatic **replication** of the data between arrays is common
- Frequently, a small number of **hot-spare** disks are left unallocated, automatically replacing a failed disk and having data rebuilt onto them



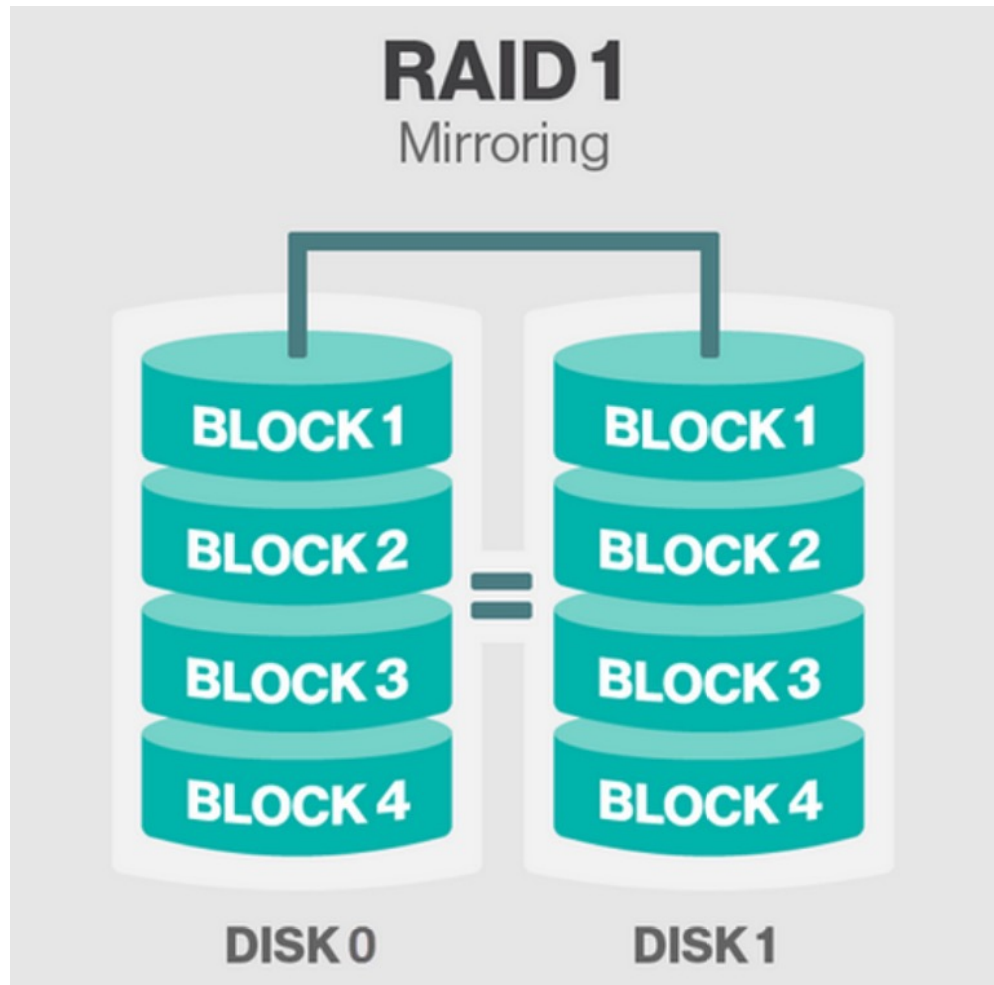


RAID (Cont.)



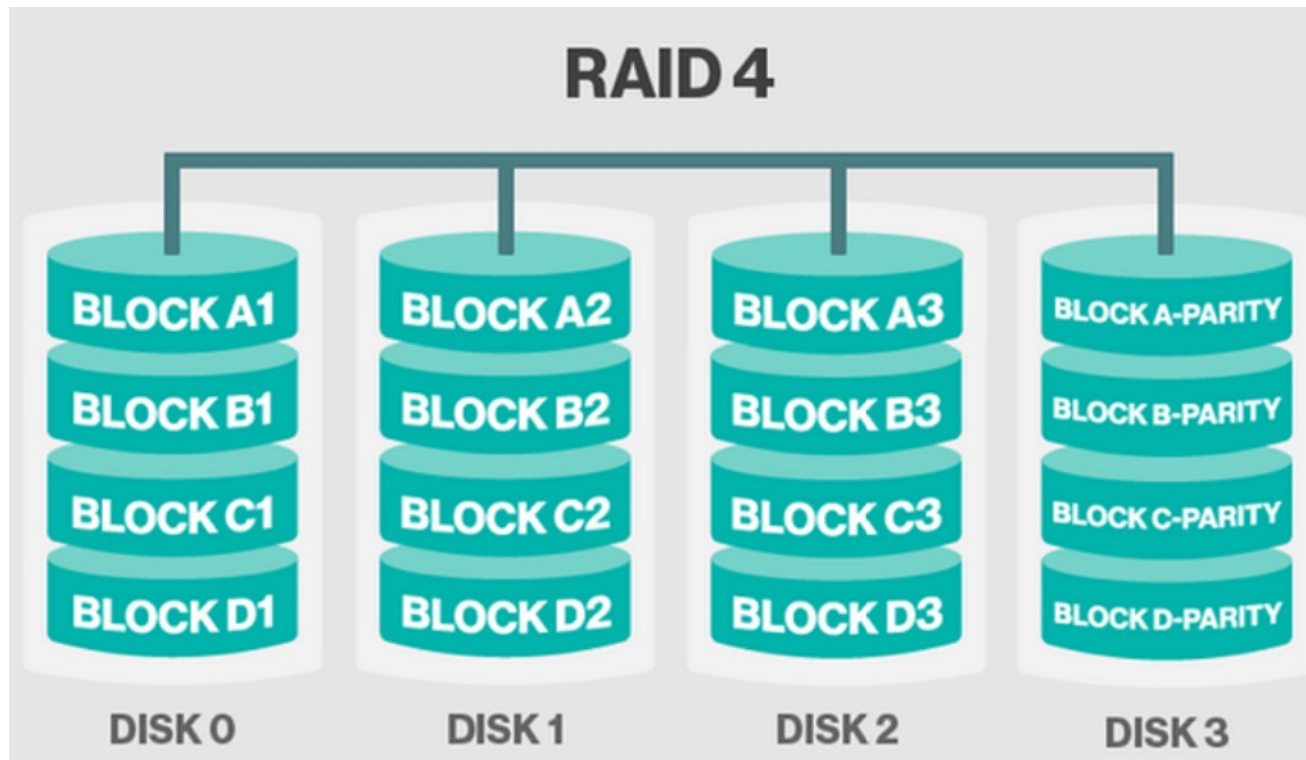


RAID (Cont.)



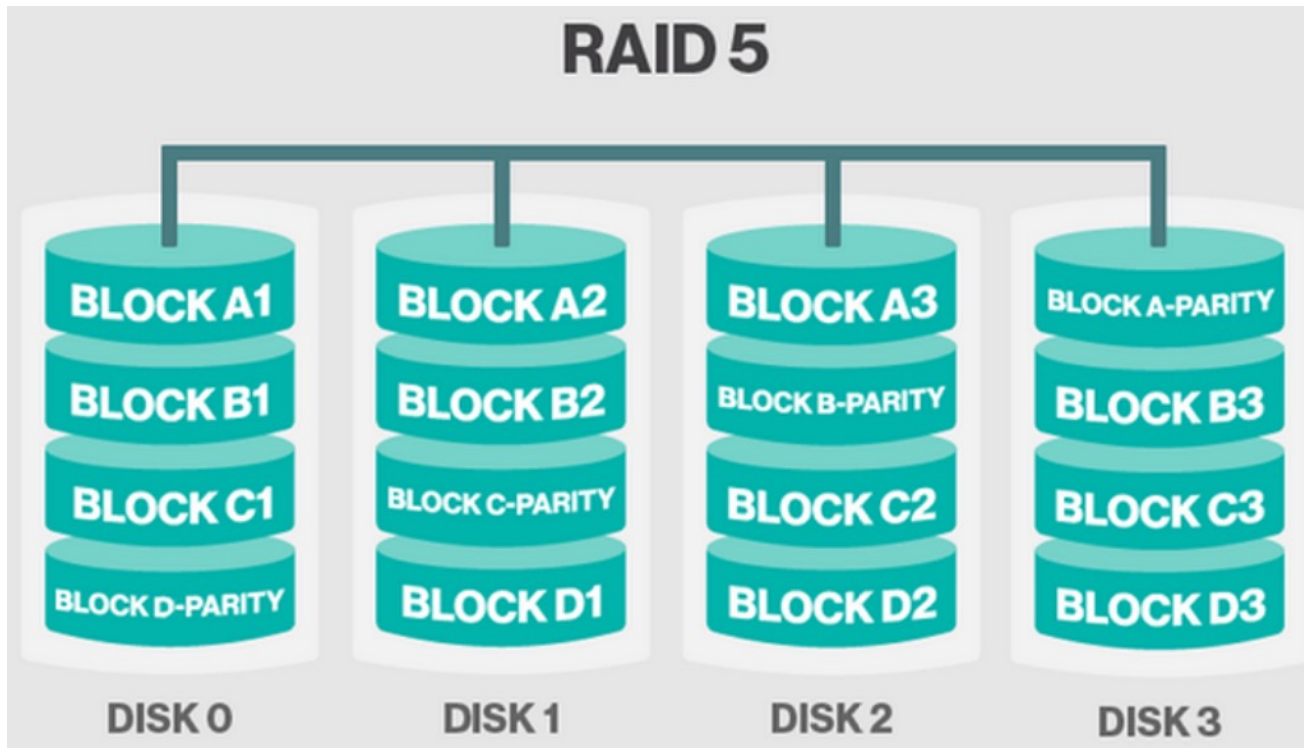


RAID (Cont.)



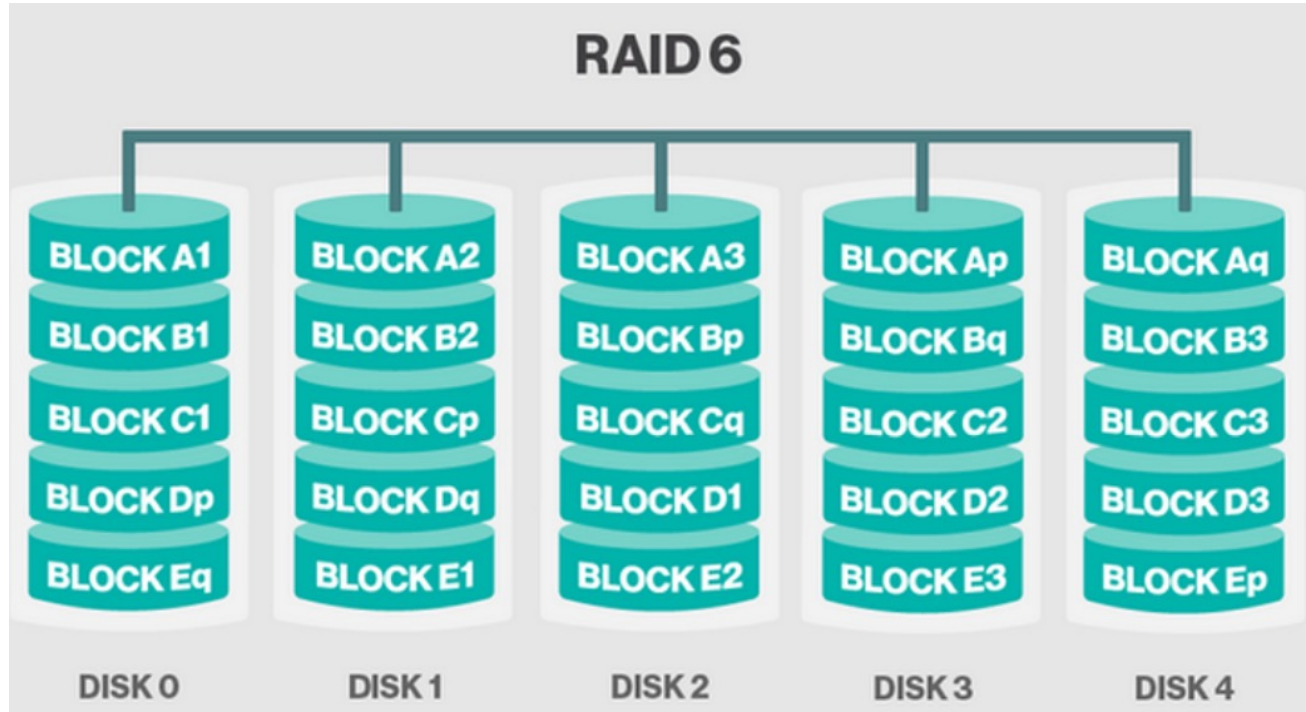


RAID (Cont.)





RAID (Cont.)





RAID Levels



(a) RAID 0: non-redundant striping.



(b) RAID 1: mirrored disks.



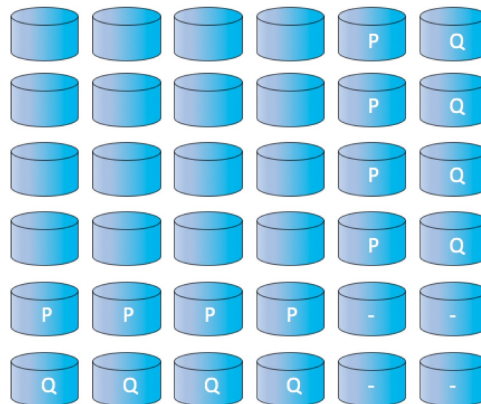
(c) RAID 4: block-interleaved parity.



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



(e) RAID 6: P + Q redundancy.

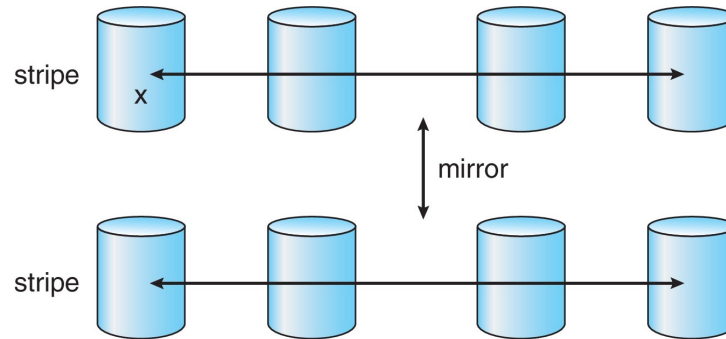


(f) Multidimensional RAID 6.

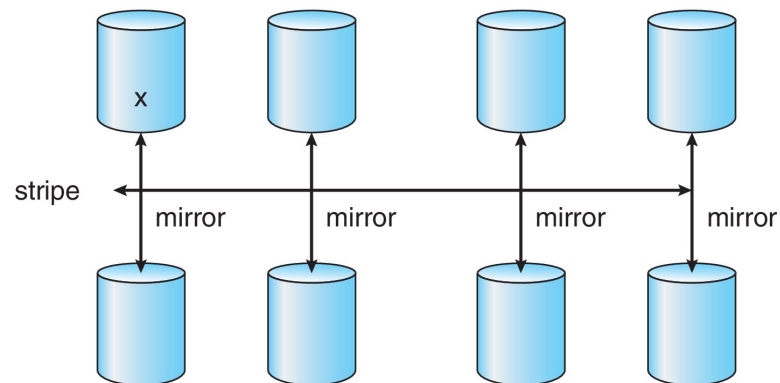




RAID (0 + 1) and (1 + 0)



a) RAID 0 + 1 with a single disk failure.



b) RAID 1 + 0 with a single disk failure.





Other Features

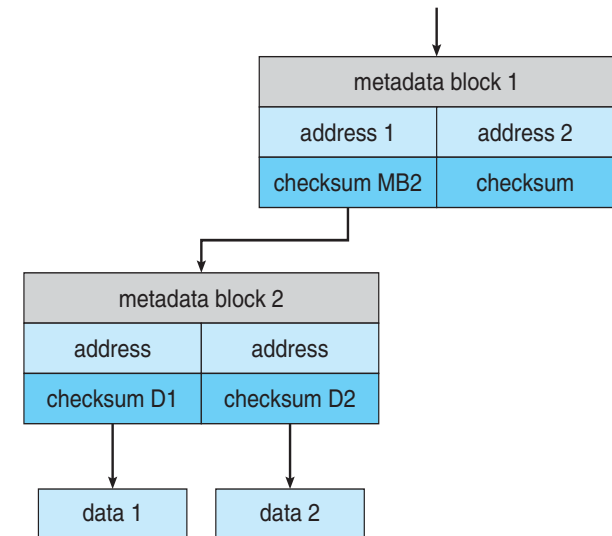
- Regardless of where RAID implemented, other useful features can be added
- **Snapshot** is a view of file system before a set of changes take place (i.e. at a point in time)
 - More in Ch 12
- Replication is automatic duplication of writes between separate sites
 - For redundancy and disaster recovery
 - Can be synchronous or asynchronous
- Hot spare disk is unused, automatically used by RAID production if a disk fails to replace the failed disk and rebuild the RAID set if possible
 - Decreases mean time to repair





Extensions

- RAID alone does not prevent or detect data corruption or other errors, just disk failures
- Solaris ZFS adds **checksums** of all data and metadata
- Checksums kept with pointer to object, to detect if object is the right one and whether it changed
- Can detect and correct data and metadata corruption
- ZFS also removes volumes, partitions
 - Disks allocated in **pools**
 - Filesystems with a pool share that pool, use and release space like `malloc()` and `free()` memory allocate / release calls

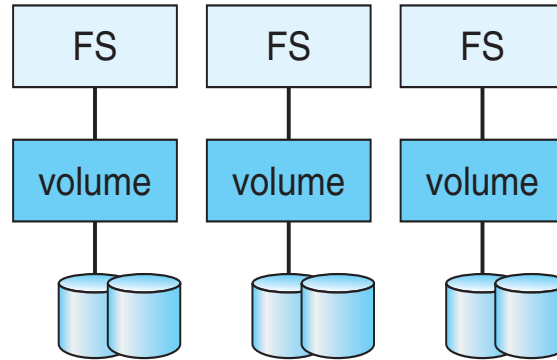


ZFS checksums all metadata and data

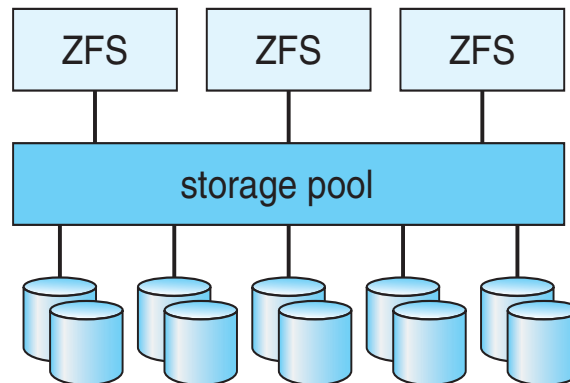




Traditional and Pooled Storage



(a) Traditional volumes and file systems.



(b) ZFS and pooled storage.



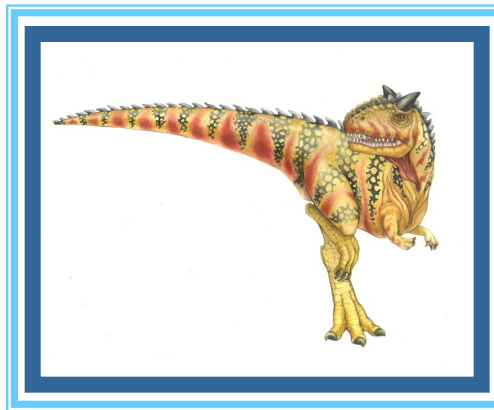


Object Storage

- General-purpose computing, file systems not sufficient for very large scale
- Another approach – start with a storage pool and place objects in it
 - Object just a container of data
 - No way to navigate the pool to find objects (no directory structures, few services)
 - Computer-oriented, not user-oriented
- Typical sequence
 - Create an object within the pool, receive an object ID
 - Access object via that ID
 - Delete object via that ID
- Object storage management software like **Hadoop file system (HDFS)** and **Ceph** determine where to store objects, manages protection
 - Typically by storing N copies, across N systems, in the object storage cluster
 - **Horizontally scalable**
 - **Content addressable, unstructured**



End of Chapter 11





■ <https://www.youtube.com/watch?v=YM9xlurjfbw>

