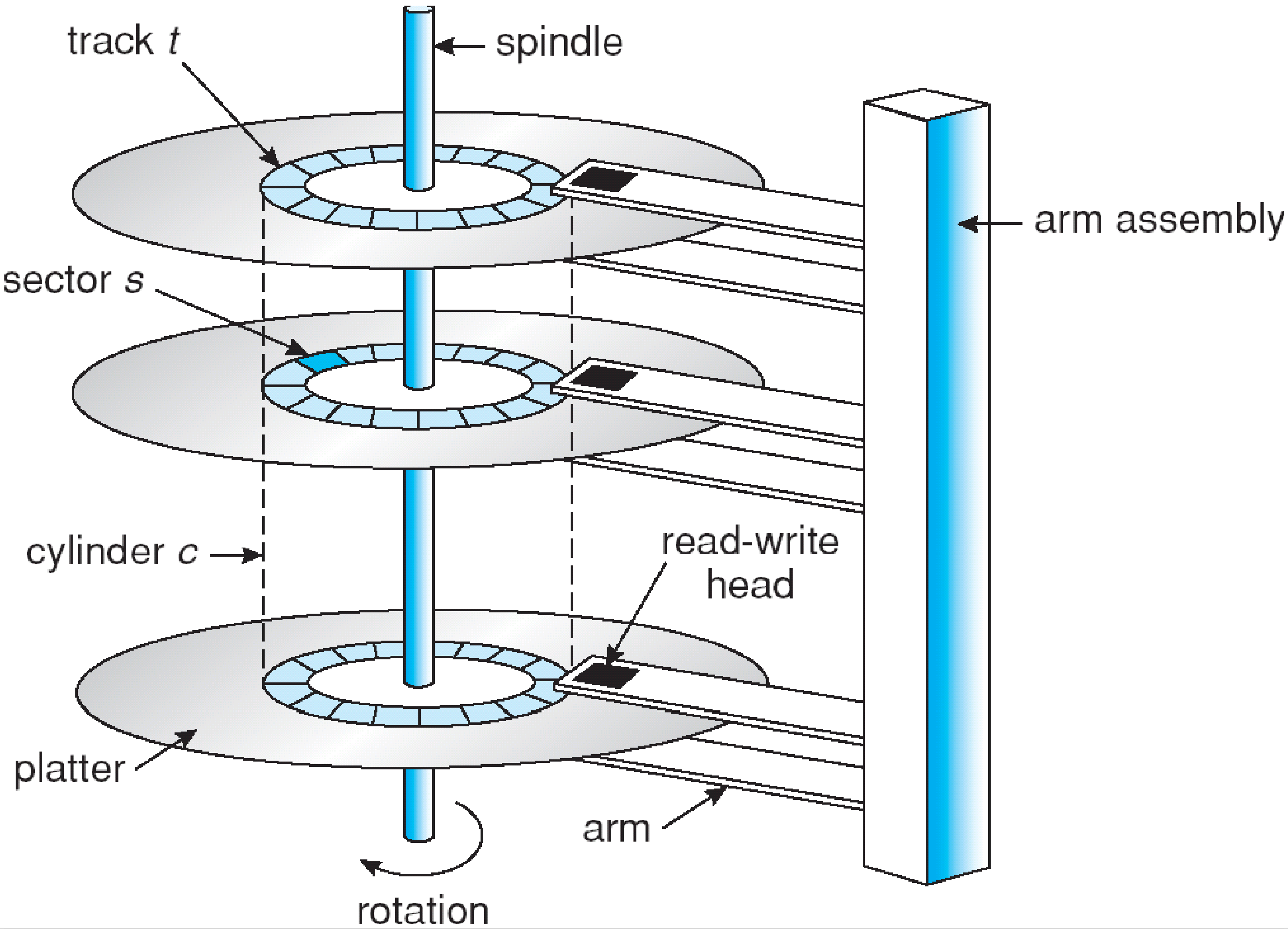
Chapter 5.12: Secondary-Storage Structure

- Overview of Mass Storage Structure
- Disk Structure
- Disk Scheduling
- Disk Management
- RAID Structure
- Tertiary Storage Devices

Overview of Mass Storage Structure

- Magnetic disks provide bulk of secondary storage of modern computers
  - Drives rotate at 60 to 250 times per second
  - **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
- Drive attached to computer via **I/O bus**
  - Busses vary, including **ATA (IDE), SATA, Fibre Channel, SCSI**
  - **Host controller** in computer uses bus to talk to **disk controller** built into drive or storage array

Moving-head Disk Mechanism



Overview of Mass Storage Structure (Cont.)

- Magnetic tape
  - Was early secondary-storage medium
  - Relatively permanent and holds large quantities of data
  - Access time slow
  - Random access ~1000 times slower than disk
  - Mainly used for backup, storage of infrequently-used data, transfer medium between systems
  - Kept in spool and wound or rewound past read-write head
  - Once data under head, transfer rates comparable to disk
  - 20-800GB typical storage
  - Common technologies are 4mm, 8mm, 19mm, LTO-4 and SDLT

Disk Structure

- Disk drives are addressed as large 1-dimensional arrays of *logical blocks*, where the logical block is the smallest unit of transfer.

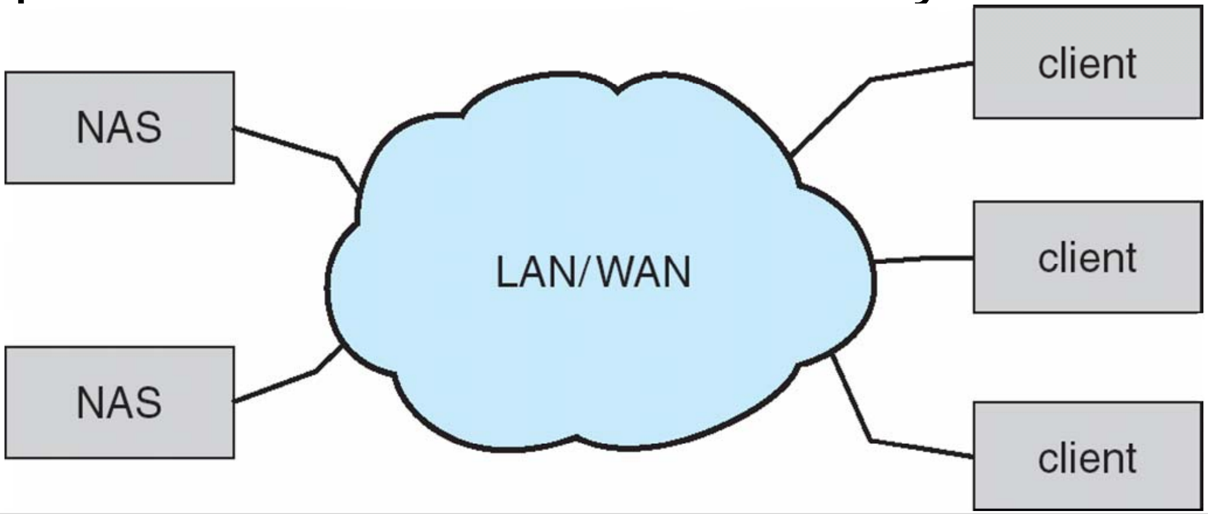
- The 1-dimensional array of logical blocks is mapped into the sectors of the disk sequentially.
  - Sector 0 is the first sector of the first track on the outermost cylinder.
  - Mapping proceeds in order through that track, then the rest of the tracks in that cylinder, and then through the rest of the cylinders from outermost to innermost.

Disk Attachment

- Host-attached storage accessed through I/O ports talking to I/O busses
- SCSI itself is a bus, up to 16 devices on one cable, **SCSI initiator** requests operation and **SCSI targets** perform tasks
  - Each target can have up to 8 **logical units** (disks attached to device controller
- FC is high-speed serial architecture
  - Can be switched fabric with 24-bit address space – the basis of **storage area networks** (**SAN**s) in which many hosts attach to many storage units
  - Can be **arbitrated loop** (**FC-AL**) of 126 devices

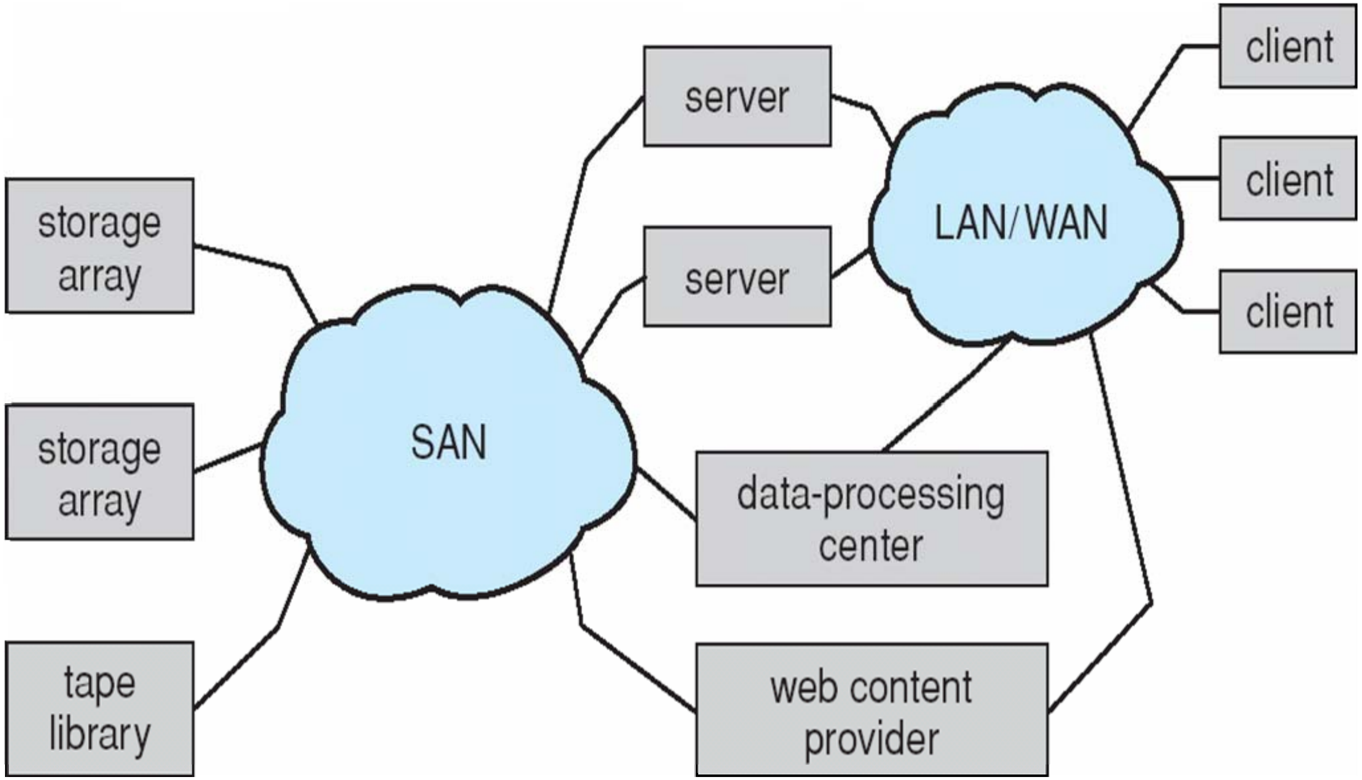
Network-Attached Storage

- Network-attached storage (**NAS**) is storage made available over a network rather than over a local connection (such as a bus)
- NFS and CIFS are common protocols
- Implemented via remote procedure calls (RPCs) between host and storage
- New iSCSI protocol uses IP network to carry the SCSI protocol



Storage Area Network

- Common in large storage environments (and becoming more common)
- Multiple hosts attached to multiple storage arrays - flexible



Disk Scheduling

- The operating system is responsible for using hardware efficiently — for the disk drives, this means having a fast access time and disk bandwidth.
- Access time has two major components
  - *Seek time* is the time for the disk are to move the heads to the cylinder containing the desired sector.
  - *Rotational delay* is the additional time waiting for the disk to rotate the desired sector to the disk head.
- Minimize seek time
- Seek time ≈ 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.)

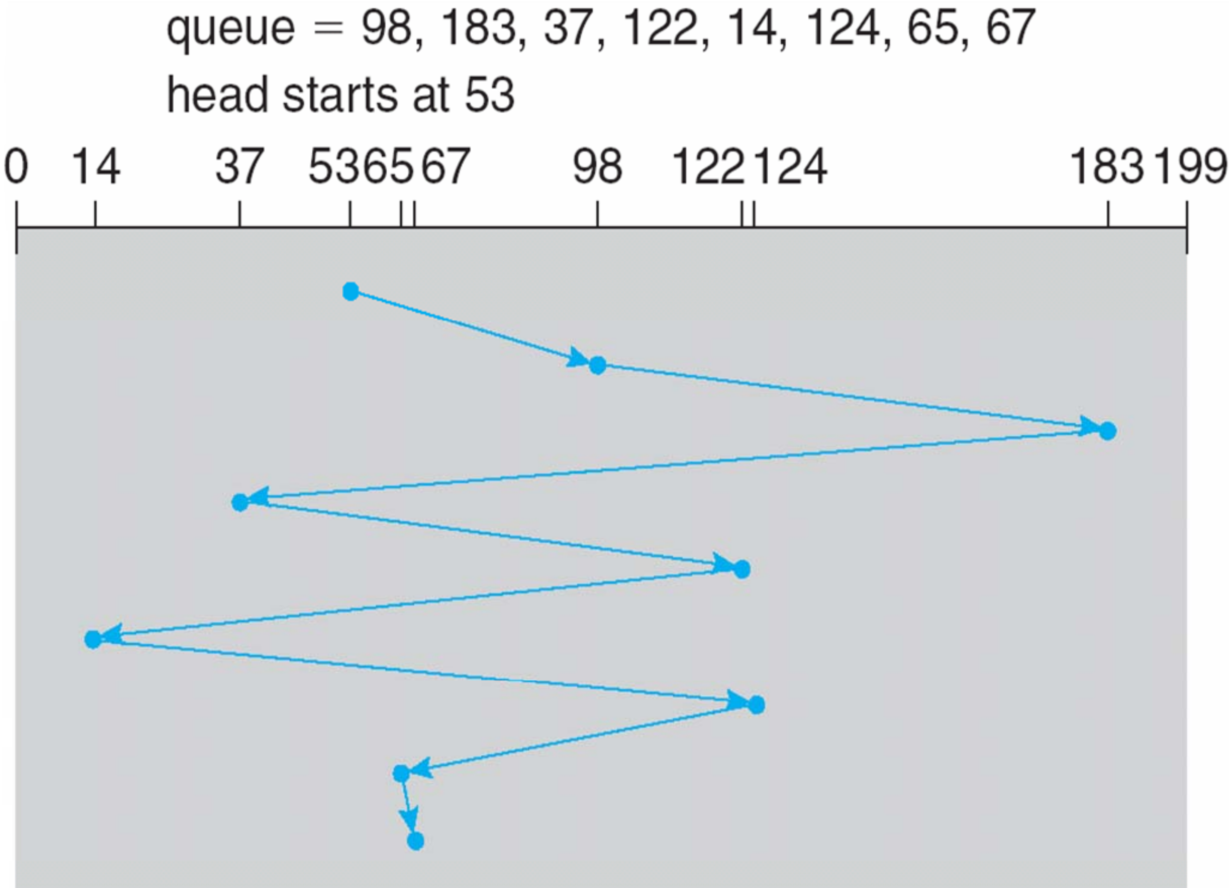
- Several algorithms exist to schedule the servicing of disk I/O requests.
- We illustrate them with a request queue (0-199).

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

Head pointer 53

FCFS

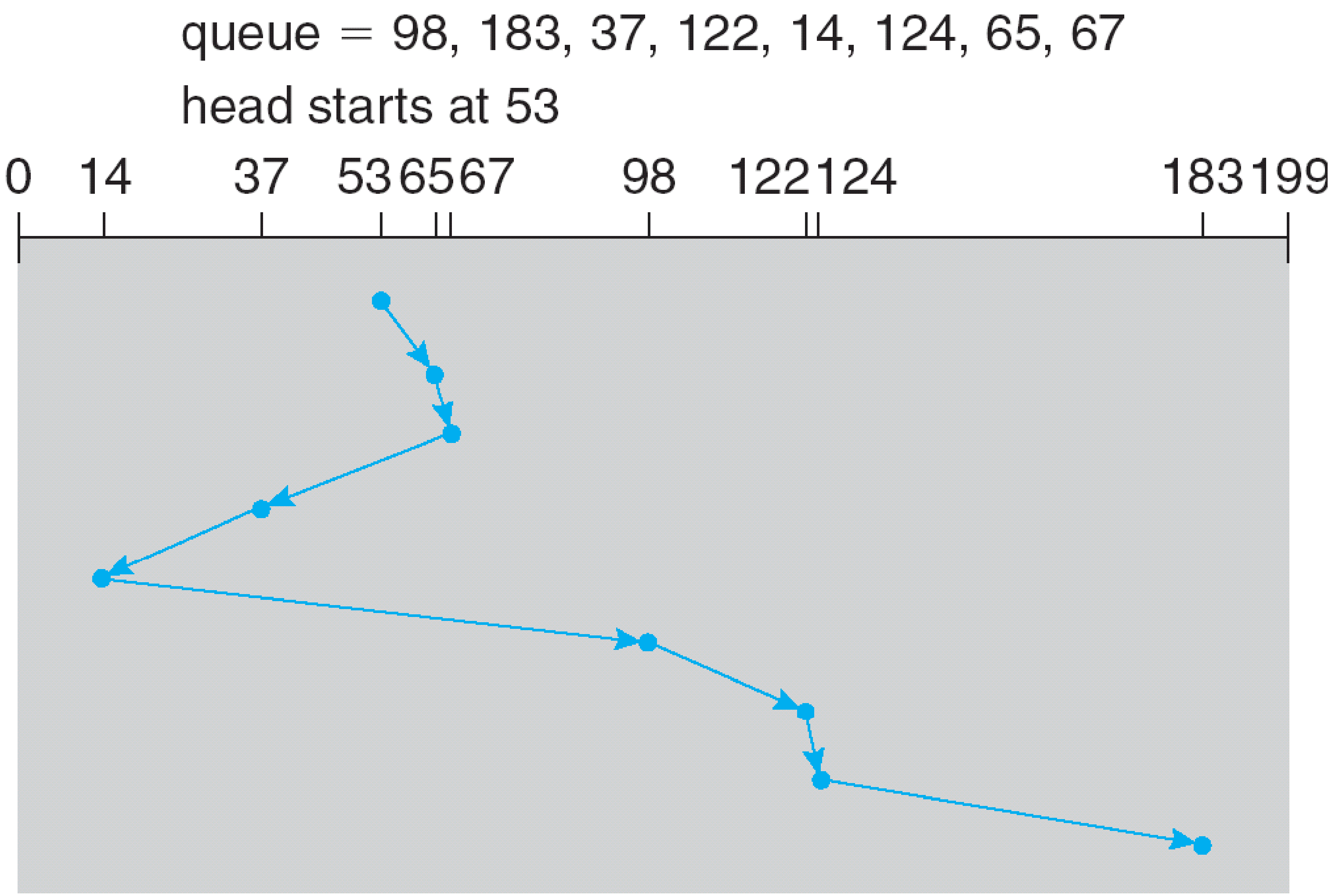
Illustration shows total head movement of 640 cylinders.



SSTF

- 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.
- Illustration shows total head movement of 236 cylinders.

SSTF (Cont.)

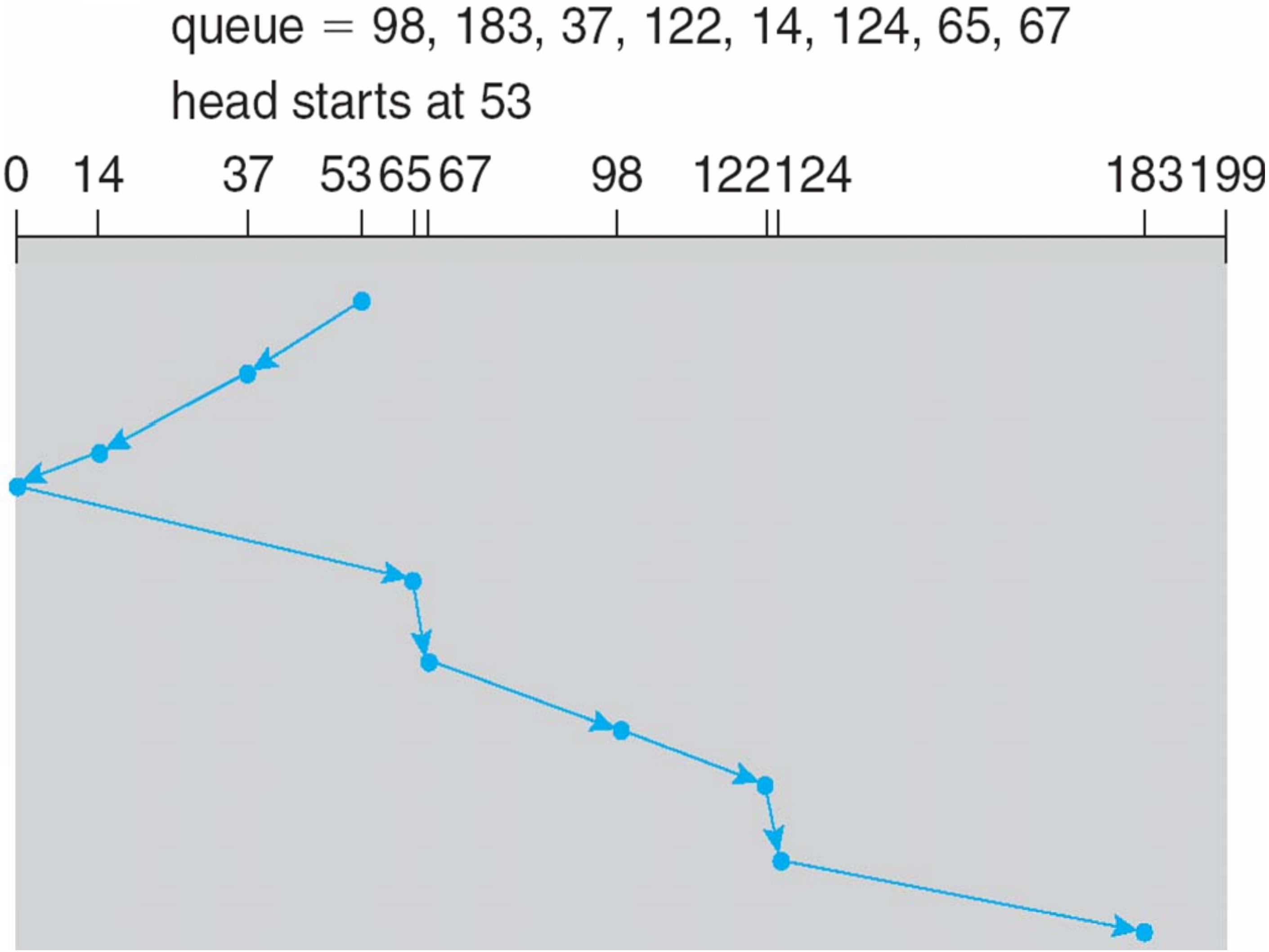


queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53
0 14 37 53 65 67 98 122 124 183 199

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.
- Sometimes called the *elevator algorithm*.
- Illustration shows total head movement of 208 cylinders.

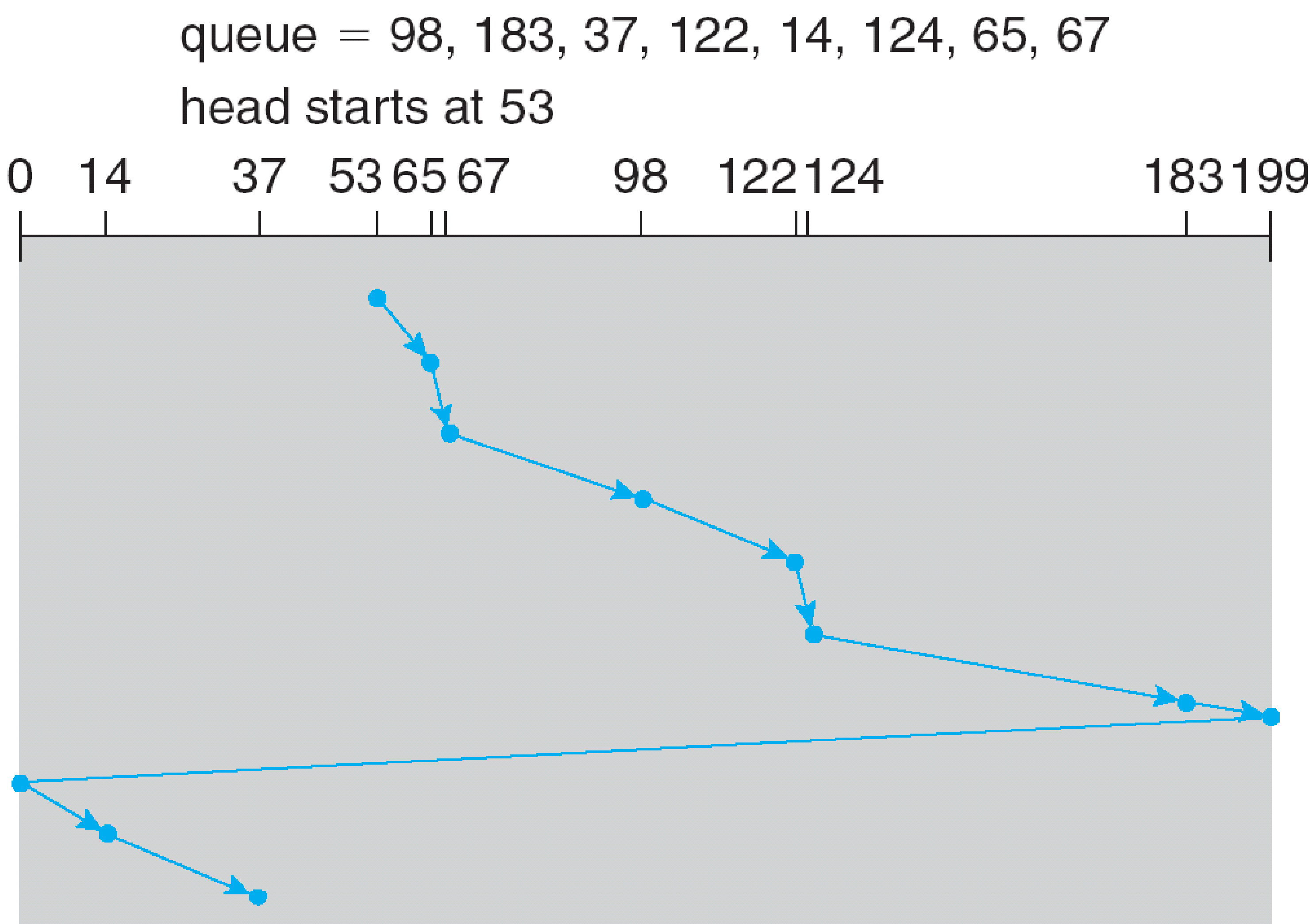
SCAN (Cont.)


queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53
0
14
37
53
65
67
98
122
124
183
199

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.

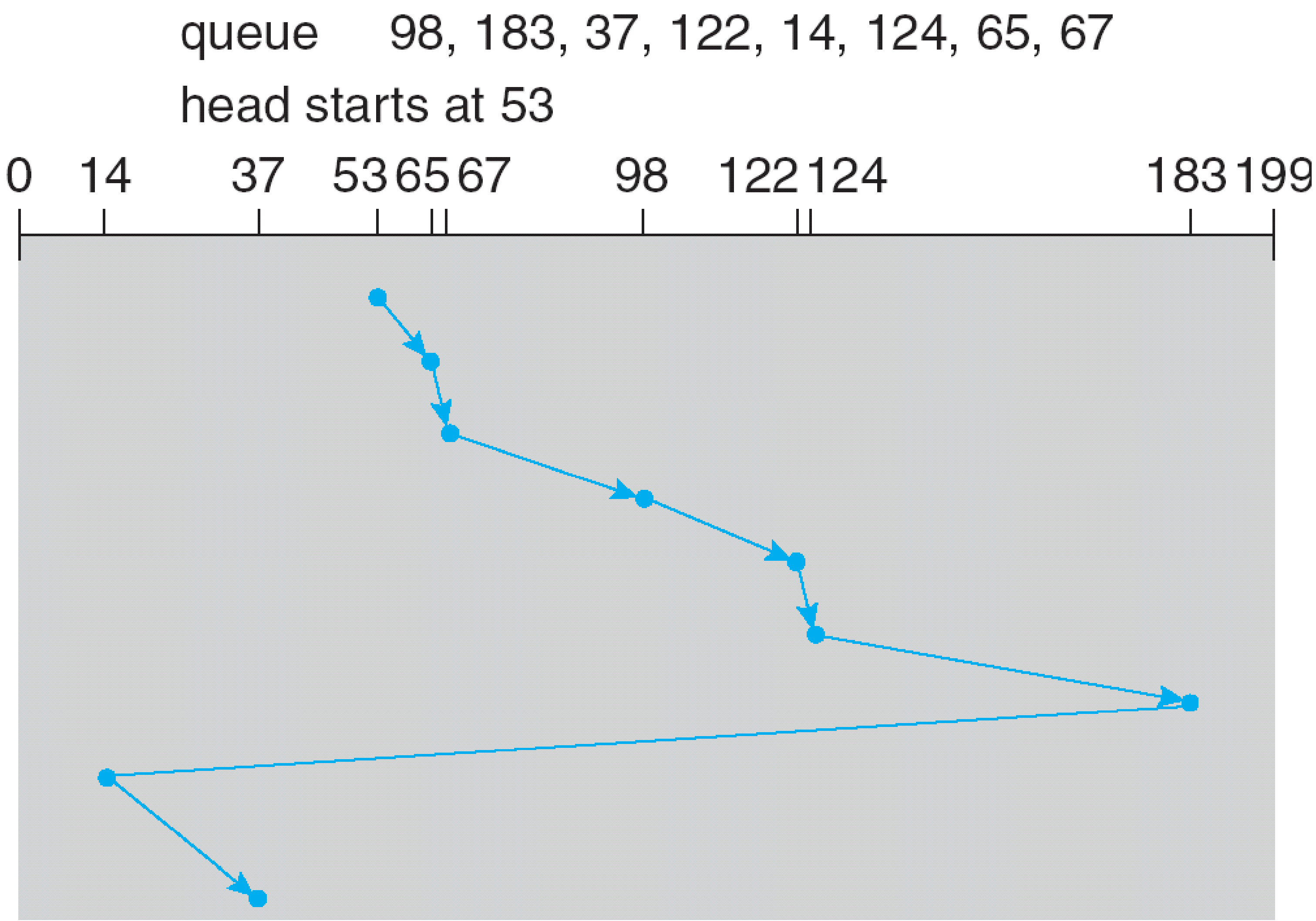
C-SCAN (Cont.)


queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53
0
14
37
53
65
67
98
122
124
183
199

C-LOOK

- 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.

C-LOOK (Cont.)


queue 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53
0 14 37 53 65 67 98 122 124 183 199

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.
- Performance depends on the number and types of requests.
- Requests for disk service can be influenced by the file-allocation method.
- The disk-scheduling algorithm should be written as a separate module of the operating system, allowing it to be replaced with a different algorithm if necessary.
- Either SSTF or LOOK is a reasonable choice for the default algorithm.

Disk Management

- *Low-level formatting*, or *physical formatting* — Dividing a disk into sectors that the disk controller can read and write.
- 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.
  - *Logical formatting* or “making a file system”.
- Boot block initializes system.
  - The bootstrap is stored in ROM.
  - *Bootstrap loader* program.
- Methods such as *sector sparing* used to handle bad blocks.

Further Improvements for Disk-I/O

- <u>Analysis:</u>
  data rate of a disk << data rate of CPU or RAM
- <u>Idea</u>:
  - Use multiple disks to parallelize disk-I/O
  - provide a better disk availability
  - Instead of 1 single large expensive disk (SLED) use

$\Rightarrow$ RAID = redundant array of independent disks
(originally: redundant array of *inexpensive* disks)

RAID
(Redundant Array of Inexpensive Disks)

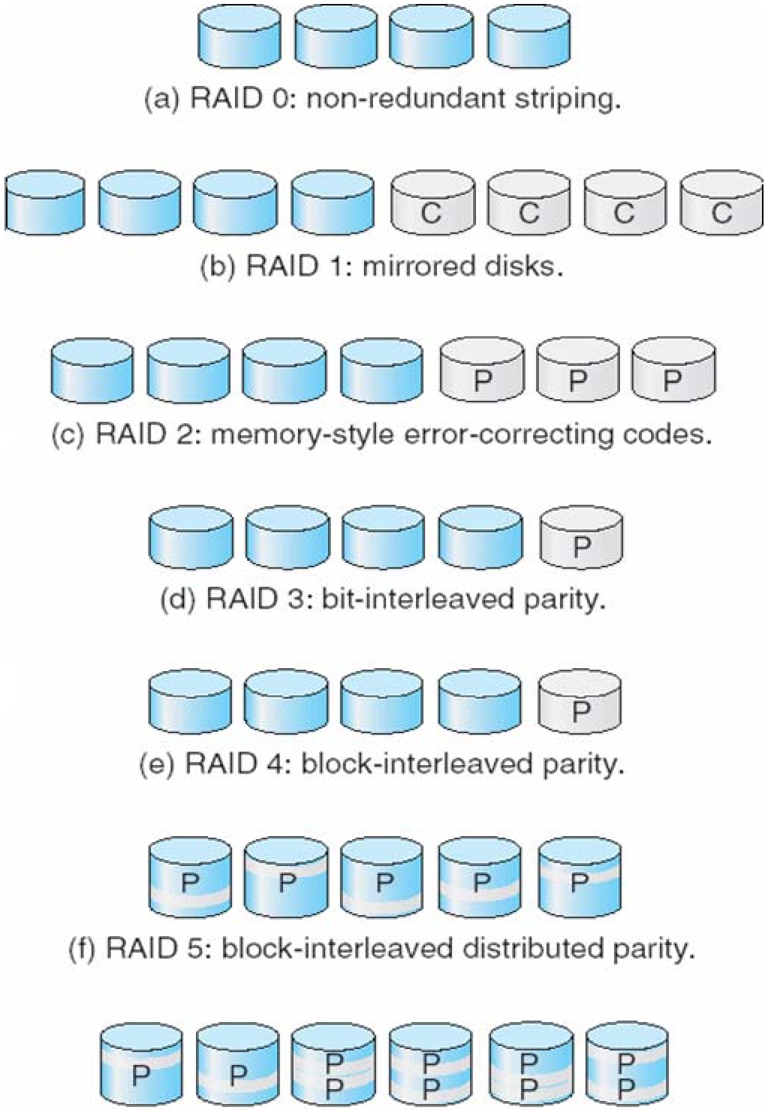
- Multiple disk drives provide high storage volume and performance with improved reliability compared to a single large expensive disk (SLED)

- RAID schemes improve performance and reliability of the storage system by storing redundant data.
  - *Mirroring* or *shadowing* keeps duplicate of each disk.
  - *Block interleaved parity* uses much less redundancy

- Disk striping uses a group of disks as one storage unit.

- RAID is arranged into six different levels.

RAID Levels



(a) RAID 0: non-redundant striping.

(b) RAID 1: mirrored disks.

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

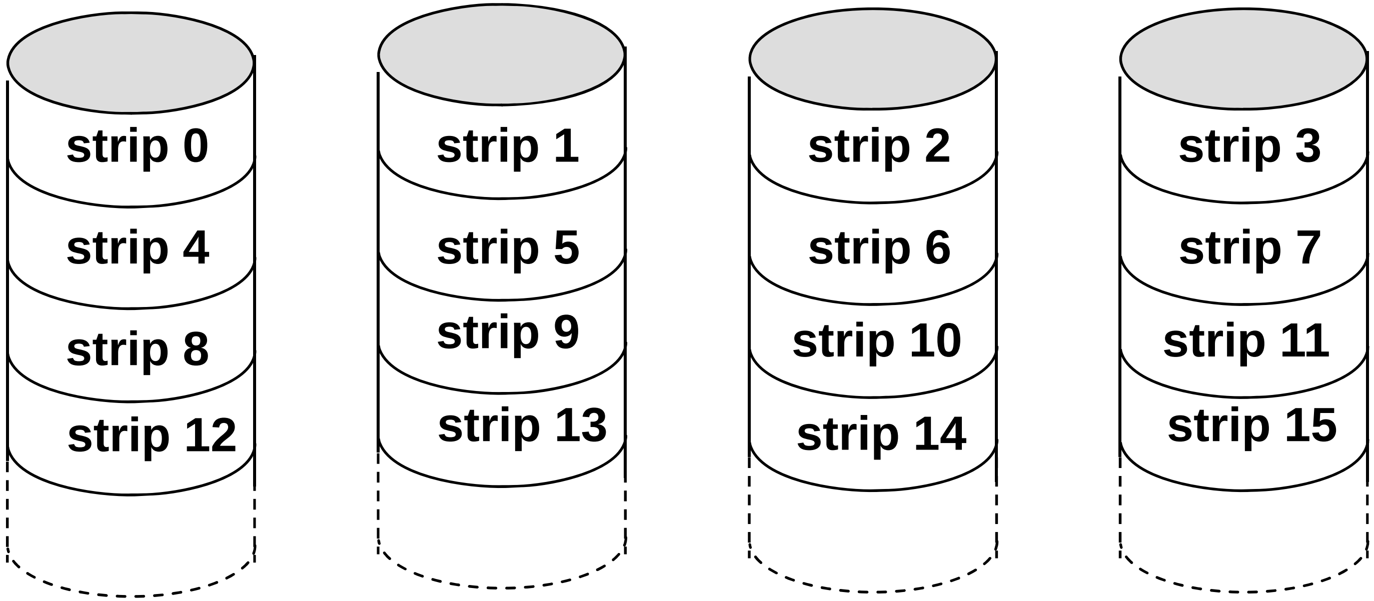
(d) RAID 3: bit-interleaved parity.

(e) RAID 4: block-interleaved parity.

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

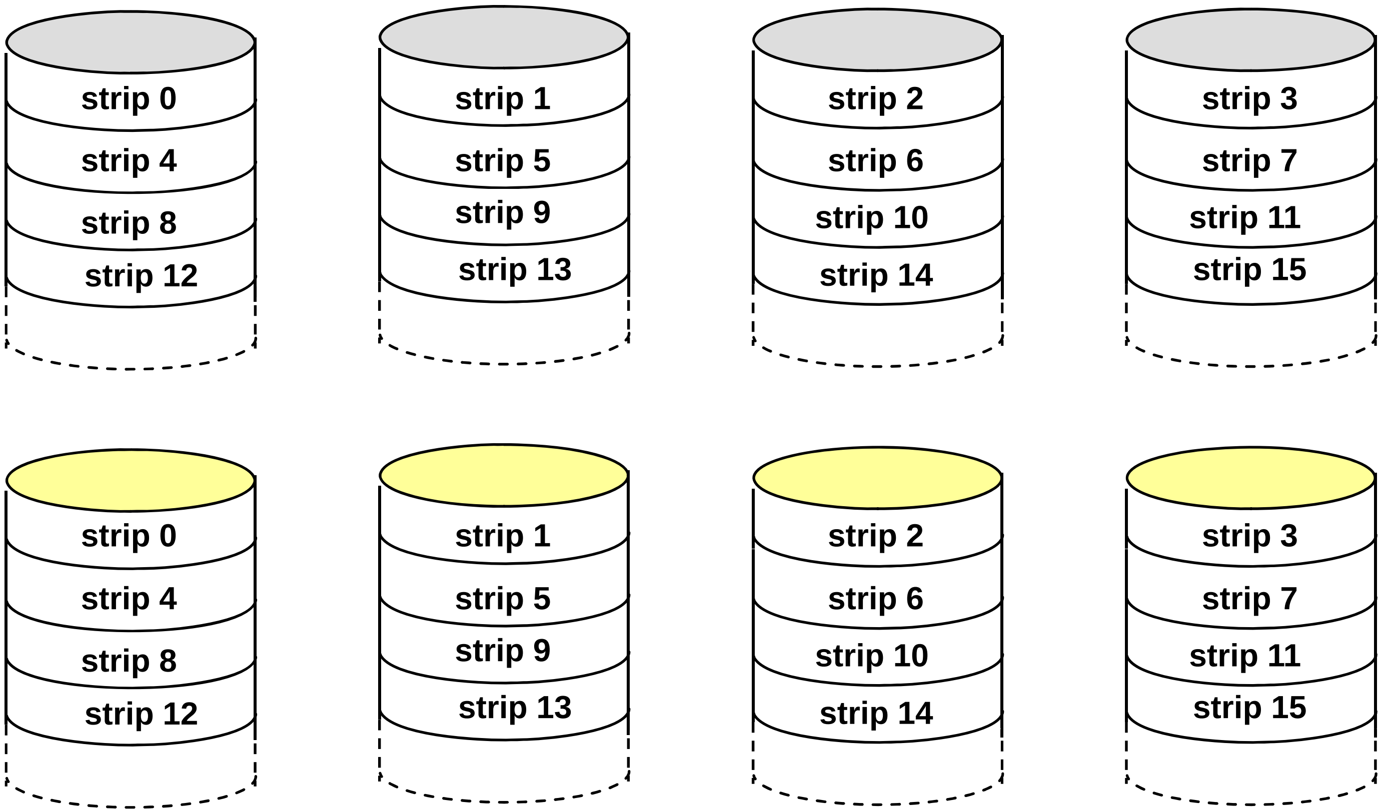
(g) RAID 6: P + Q redundancy.

RAID 0 (without any redundancy)

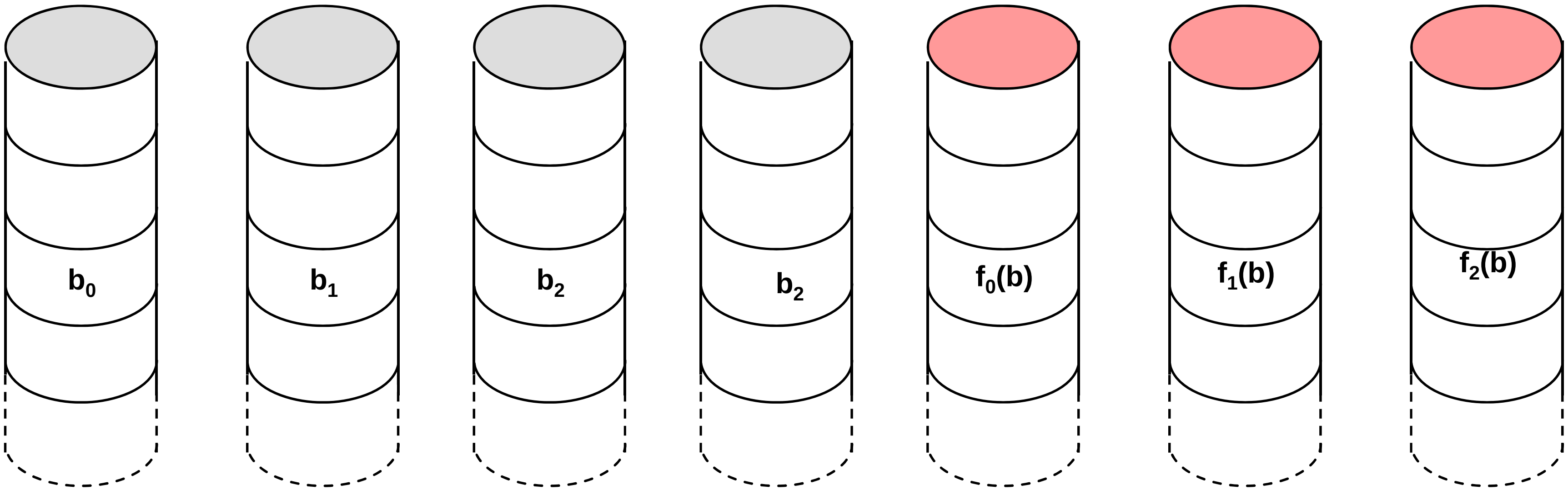


- Decreased availability compared to the SLED
- Increased bandwidth to/from logical disk

RAID 1 (mirrored)

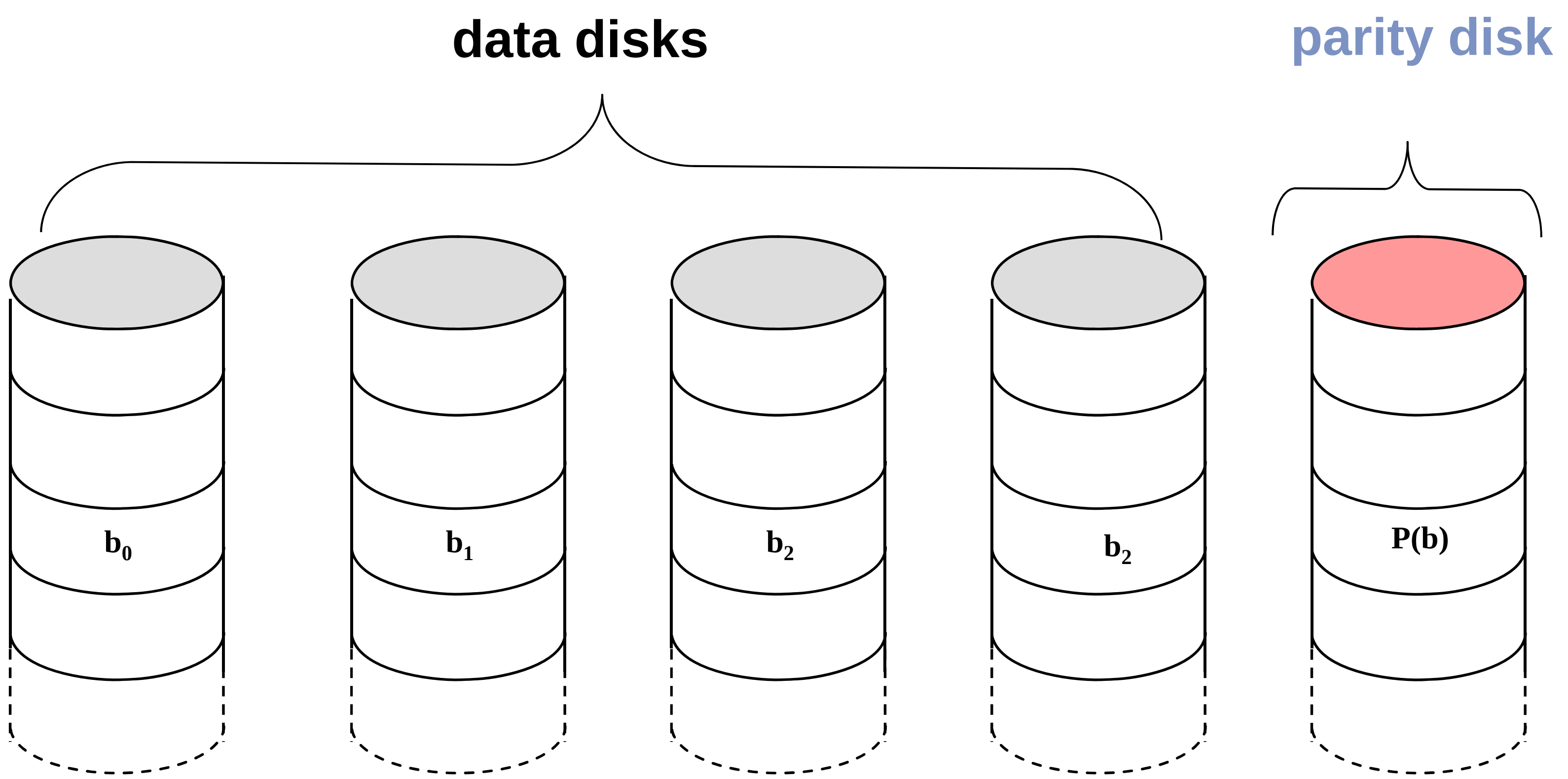


RAID 2 (redundancy through Hamming code)

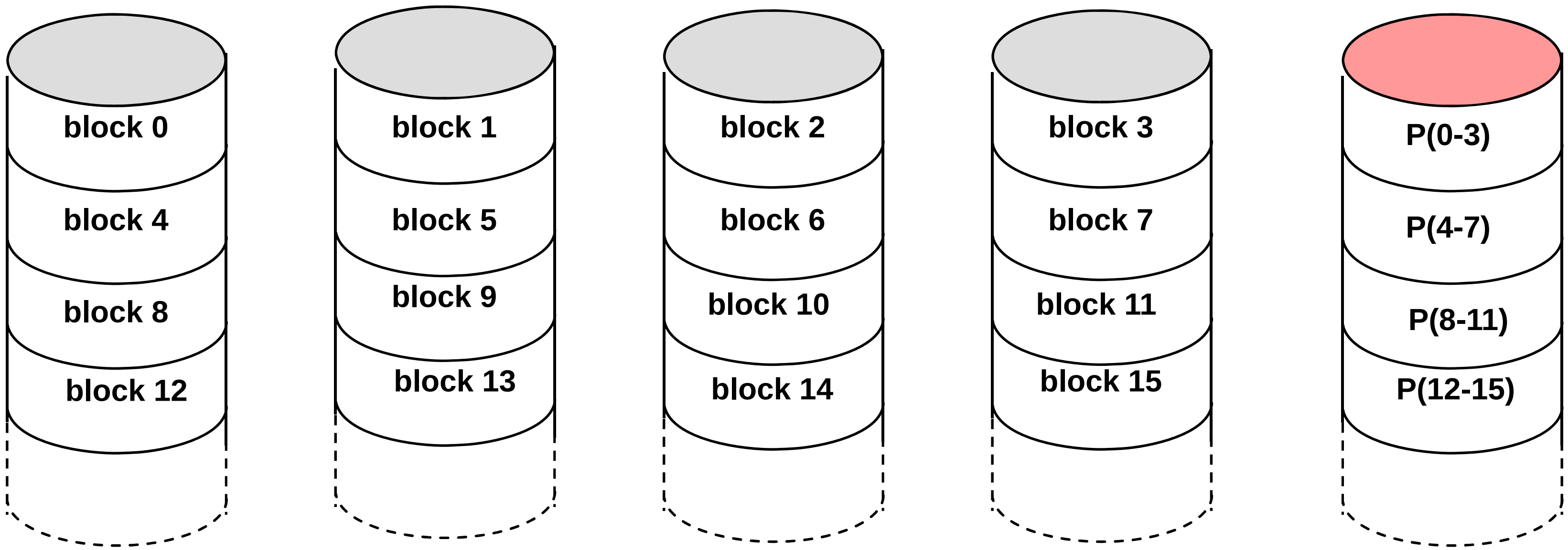


RAID 2 is an overkill and rarely implemented
Hamming code used for f(b), b are very small strips,
still a remarkable disk overhead compared to RAID 0

RAID 3 (bit-interleaved parity)



RAID 4 (block-level parity)



Parity computation: P(0..3) = block0 ⊗ block1 ⊗ block2 ⊗block3

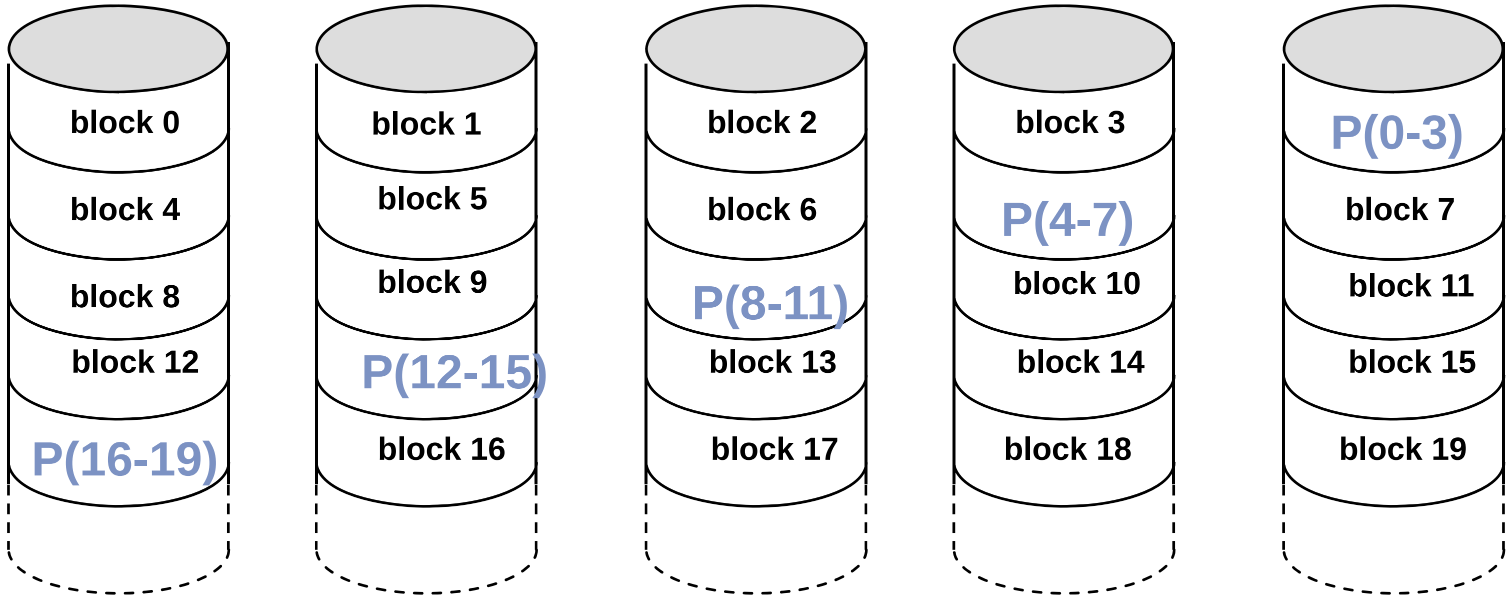
Result:

Small updates require 2 reads (old block + parity) and

2 writes (new block + parity) to update a single disk block

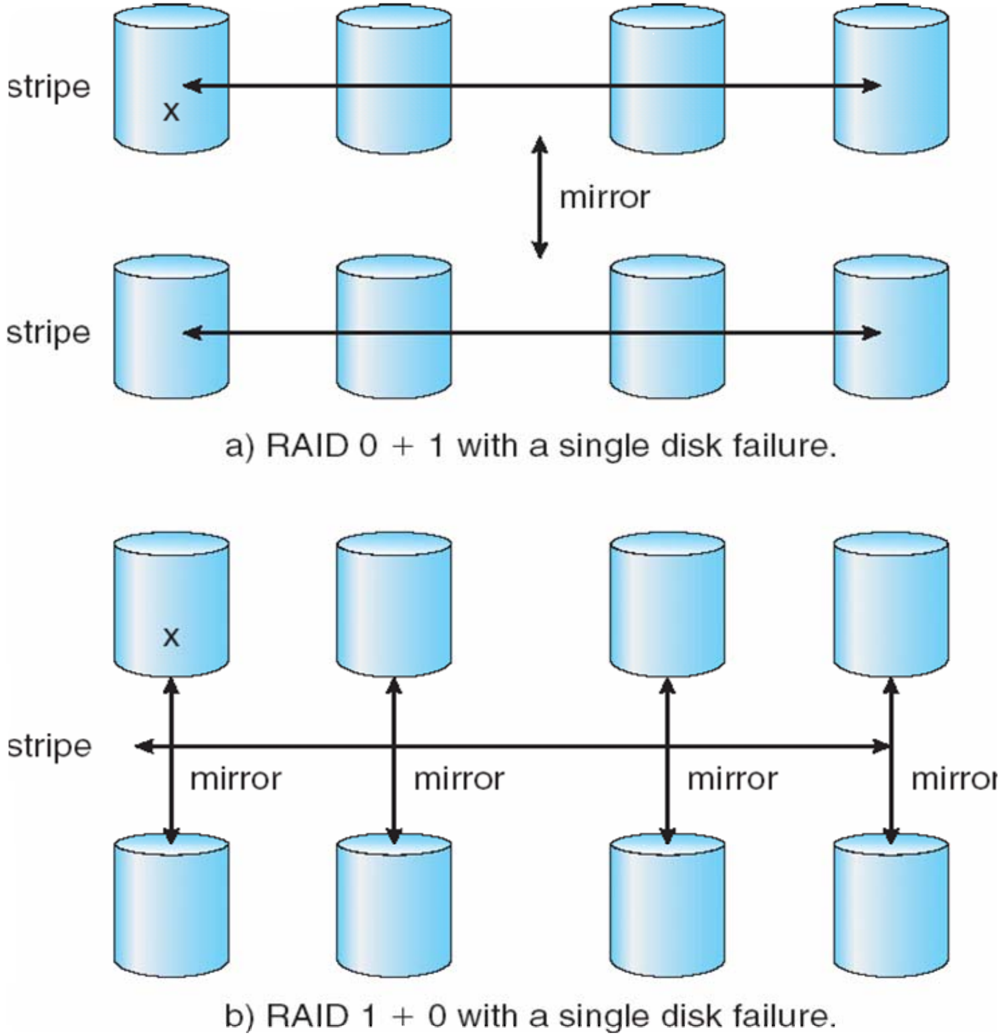
Parity disk may be a bottleneck

RAID 5 (block-level distributed parity)



- Like RAID4, but we distribute parity block on all disks ⇒no longer a “bottleneck disk”
- Update performance still less than on a SLED
- Reconstruction after a failure is a bit tricky

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



Tertiary Storage Devices

- Low cost is the defining characteristic of tertiary storage.
- Generally, tertiary storage is built using *removable media*
- Two aspects of speed in tertiary storage are bandwidth and latency.
- Bandwidth is measured in bytes per second.
  - Sustained bandwidth – average data rate during a large transfer; # of bytes/transfer time.
    Data rate when the data stream is actually flowing.
  - Effective bandwidth – average over the entire I/O time, including **seek** or **locate**, and cartridge switching.
    Drive's overall data rate.
- Common examples of removable media are removable disks, tapes and optical drives (e.g., DVDs)

Removable Disks

- Floppy disk — thin flexible disk coated with magnetic material, enclosed in a protective plastic case.
  - Most floppies hold about 1 MB; similar technology is used for removable disks that hold more than 200 MB.
  - Removable magnetic disks can be nearly as fast as hard disks, but they are at a greater risk of damage from exposure.
- A magneto-optic disk records data on a rigid platter coated with magnetic material.
  - Laser heat is used to amplify a large, weak magnetic field to record a bit.
  - Laser light is also used to read data (Kerr effect).
  - The magneto-optic head flies much farther from the disk surface than a magnetic disk head, and the magnetic material is covered with a protective layer of plastic or glass

Optical Disks (e.g., DVD, CD)

- The data on read-write disks can be modified over and over
  - To write a bit, a laser light heats up phase-change material and brings it to amorphous or crystalline state,
- WORM (“Write Once, Read Many Times”) disks can be written only once.
  - To write a bit, a laser light heats up an organic dye
  - Very durable and reliable.

Tapes

- Compared to a disk, a tape is less expensive and holds more data, but random access is much slower.
- Tape is an economical medium for purposes that do not require fast random access, e.g., backup copies of disk data, holding huge volumes of data.
- Large tape installations typically use robotic tape changers that move tapes between tape drives and storage slots in a tape library.
  - stacker – library that holds a few tapes
  - silo – library that holds thousands of tapes
- A disk-resident file can be *archived* to tape for low cost storage; the computer can *stage* it back into disk storage for active use.

Application Interface

- Most OSs handle removable disks almost exactly like fixed disks — a new cartridge is formatted and an empty file system is generated on the disk.
- Tapes are presented as a raw storage medium, i.e., and application does not not open a file on the tape, it opens the whole tape drive as a raw device.
- Usually the tape drive is reserved for the exclusive use of that application.
- Since the OS does not provide file system services, the application must decide how to use the array of blocks.
- Since every application makes up its own rules for how to organize a tape, a tape full of data can generally only be used by the program that created it.

Tape Drives

- The basic operations for a tape drive differ from those of a disk drive.
- **locate** positions the tape to a specific logical block, not an entire track (corresponds to **seek**).
- The **read position** operation returns the logical block number where the tape head is.
- The **space** operation enables relative motion.
- Tape drives are “append-only” devices; updating a block in the middle of the tape also effectively erases everything beyond that block.
- An EOT mark is placed after a block that is written.

Hierarchical Storage Management (HSM)

- A hierarchical storage system extends the storage hierarchy beyond primary memory and secondary storage to incorporate tertiary storage — usually implemented as a jukebox of tapes or removable disks.
- Usually incorporate tertiary storage by extending the file system.
  - Small and frequently used files remain on disk.
  - Large, old, inactive files are archived to the jukebox.
- HSM is usually found in supercomputing centers and other large installations that have enormous volumes of data.