Chap. 11) Mass-Storage Structure

경희대학교 컴퓨터공학과

조 진 성

Mass-Storage

HDD (Hard Disk Drive)

SSD (Solid State Disk)

RAM disk

Magnetic tape

Disk Attachment

Disks may be attached one of two ways:

1. **Host attached** via an I/O port

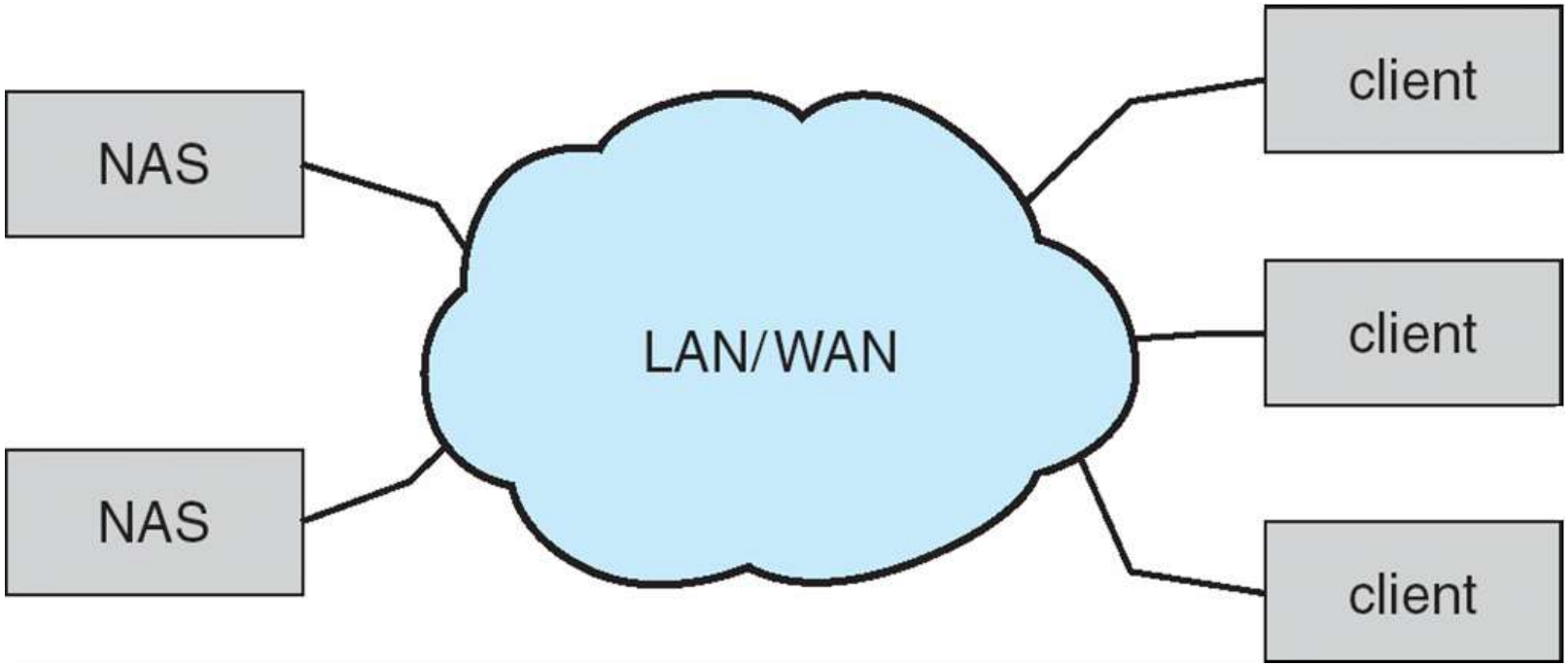
2. **Network attached** via a network connection

Network-Attached Storage (NAS)

Accessed via IP networks

NFS, CIFS, etc.

File-level access



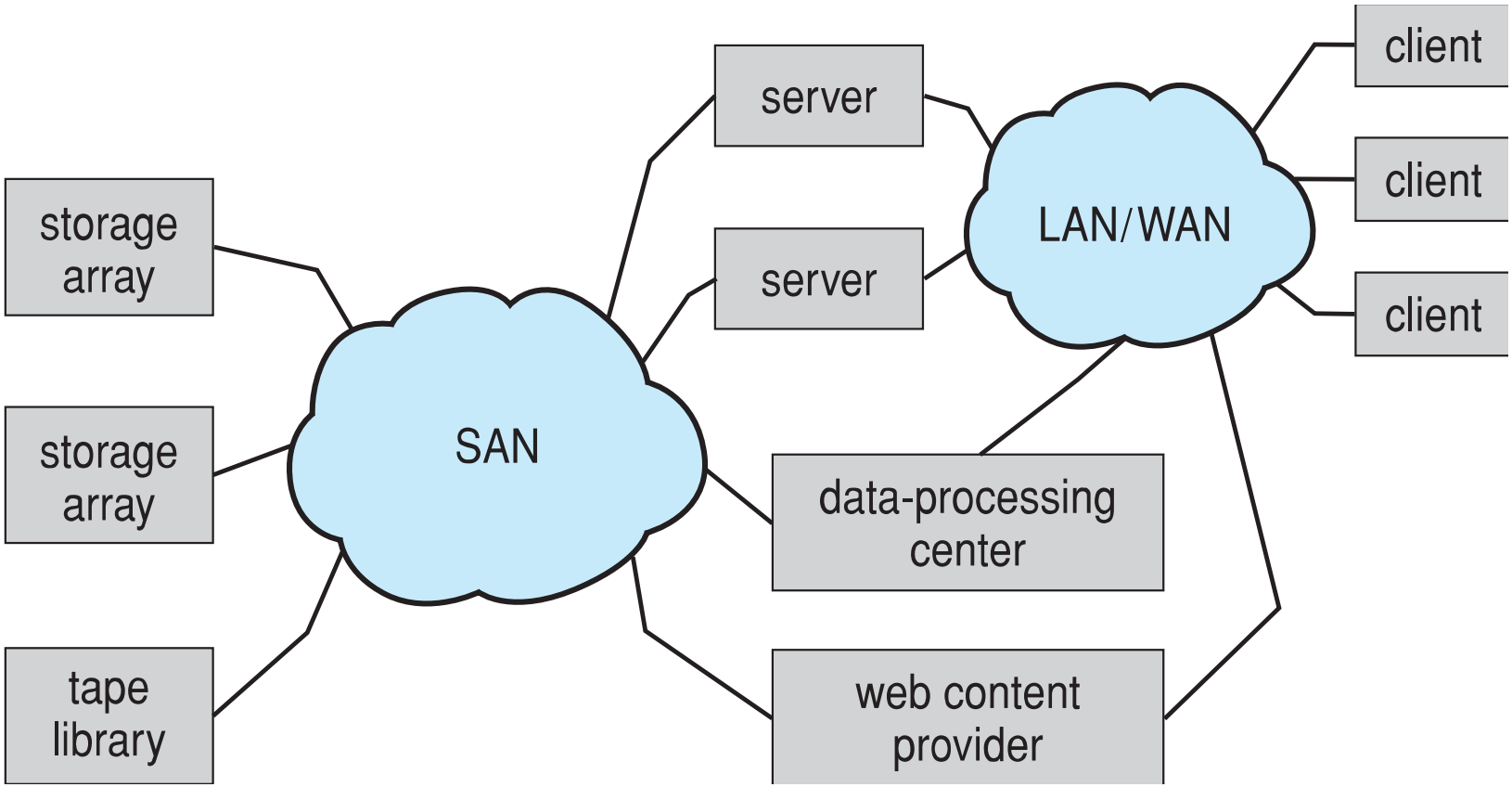
Storage-Area Network (SAN)

Accessed via private network dedicated for storages

Use storage protocols such as SCSI or Fibre channel

Block-level access

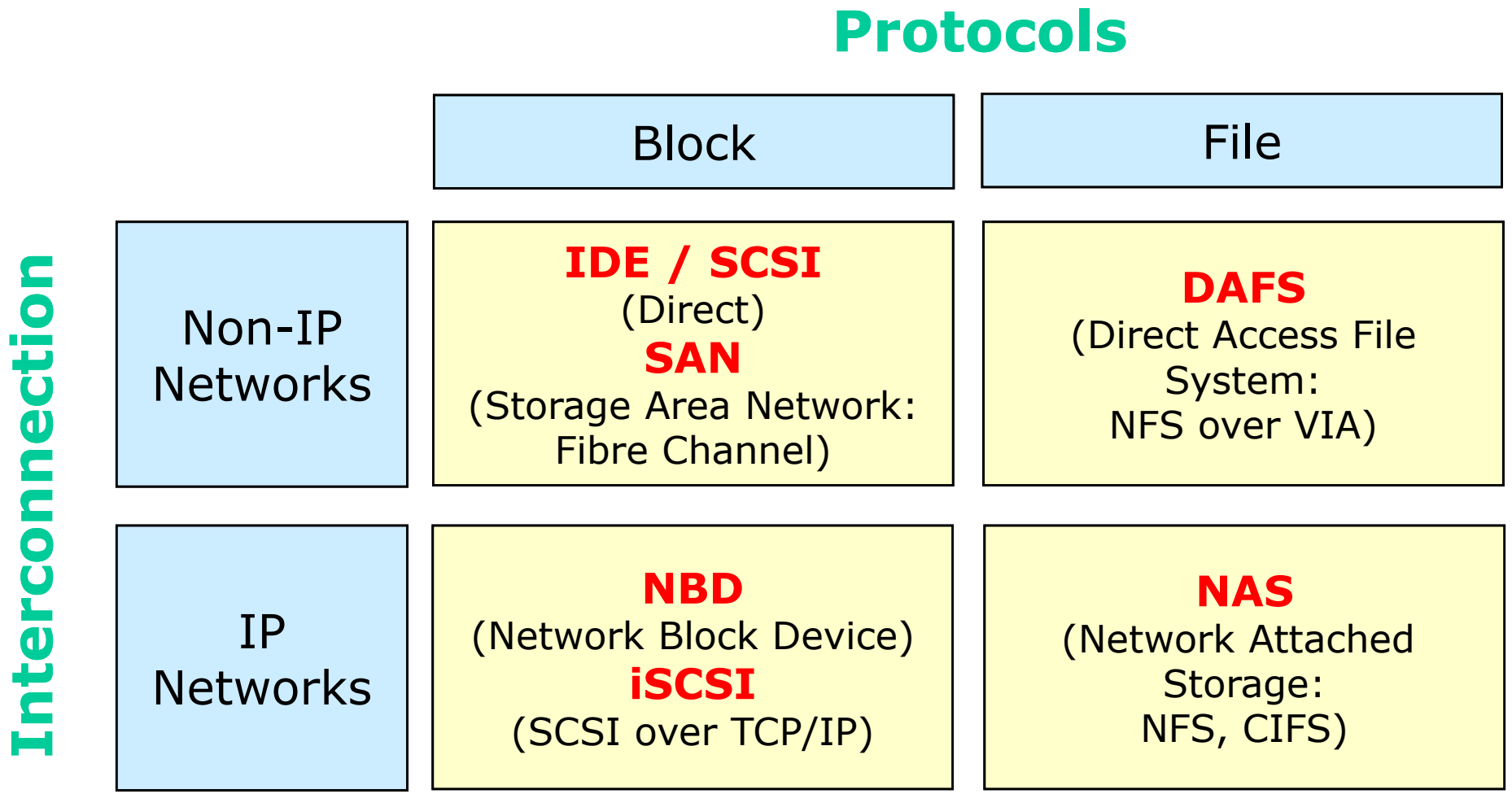
File systems for SAN is another story (e.g. GFS)



Storage-Area Network (SAN)

Storage array

Storage Architecture

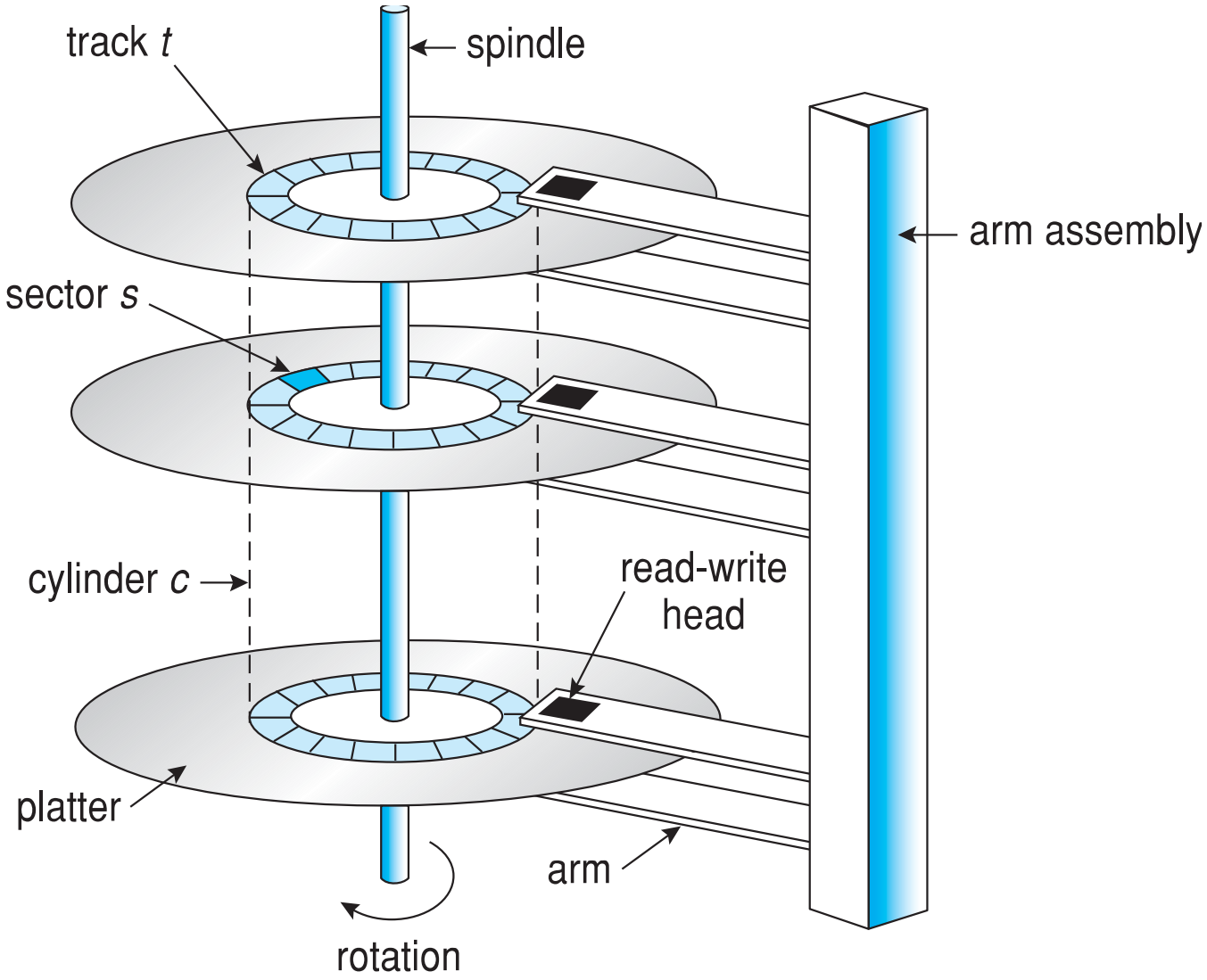


HDD

Disks and the OS

- ✓ Disks are messy physical devices:
  - Errors, bad blocks, missed seeks, etc.
- ✓ The job of the OS is to hide this mess from higher-level software
  - Low-level device drivers (initiate a disk read, etc)
  - Higher-level abstractions (files, databases, etc.)
- ✓ The OS may provide different levels of disk access to different clients
  - Physical disk block (surface, cylinder, sector)
  - Disk logical block (disk block #)
  - Logical file (filename, block or record or byte #)

HDD Structure



HDD

Interacting with disks

- ✓ Specifying disk requests requires a lot of info:
  - Cylinder #, surface #, track #, sector #, transfer size, etc.
- ✓ Older disks required the OS to specify all of this
  - The OS needs to know all disk parameters
- ✓ Modern disks are more complicated
  - Not all sectors are the same size, sectors are remapped, etc.
- ✓ Current disks provide a higher-level interface (e.g. SCSI)
  - The disks exports its data as a logical array of blocks [0..N]
  - Disk maps logical blocks to cylinder/surface/track/sector
  - Only need to specify the logical block # to read/write
  - As a result, physical parameters are hidden from OS

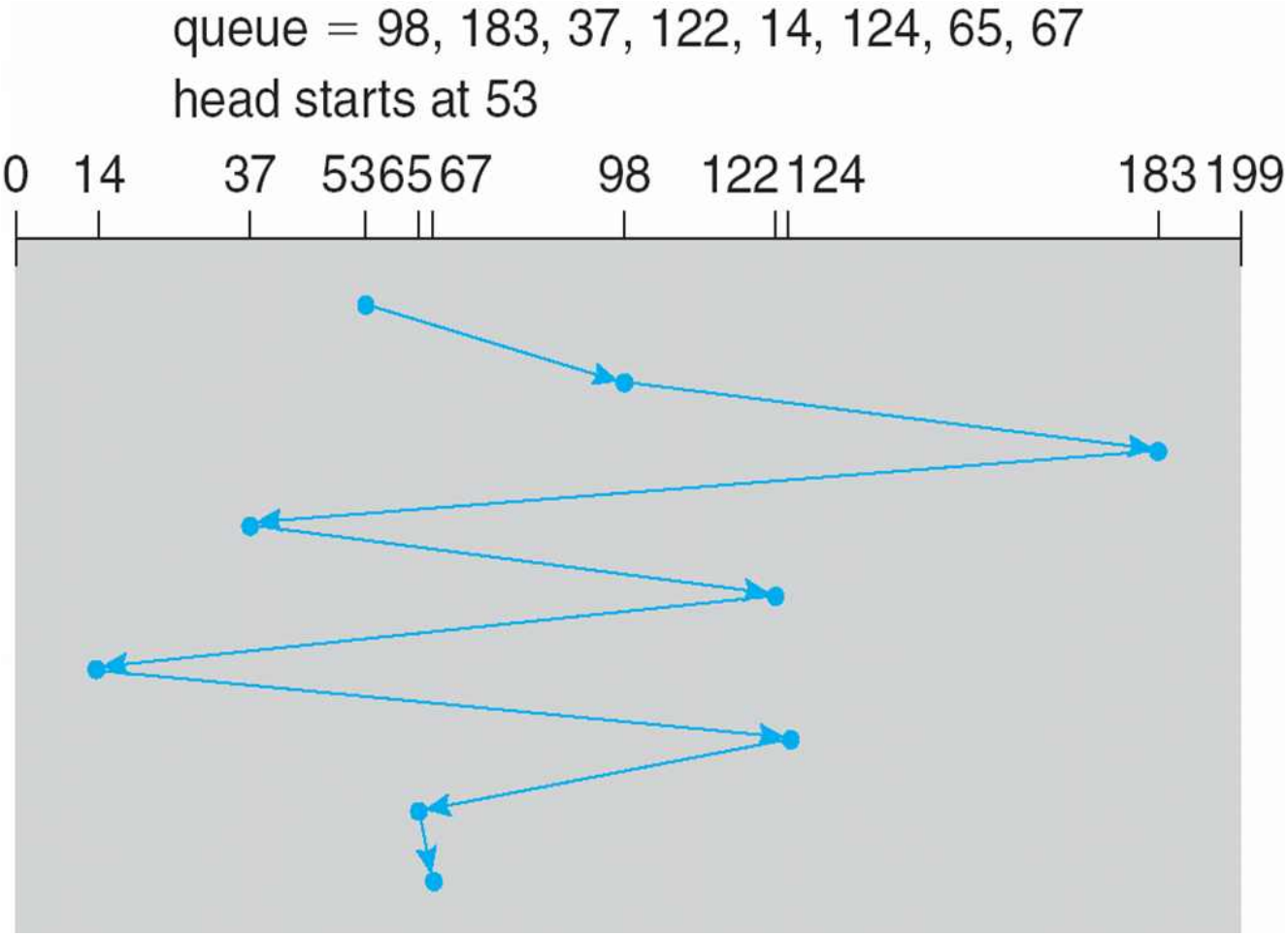
HDD

Disk performance

- ✓ Performance depends on a number of steps
  - Seek: moving the disk arm to the correct cylinder
    → depends on how fast disk arm can move (increasing very slowly)
  - Rotation: waiting for the sector to rotate under head
    → depends on rotation rate of disk (increasing, but slowly)
  - Transfer: transferring data from surface into disk controller, sending it back to the host
    → depends on density of bytes on disk (increasing, and very quickly)
- ✓ Disk scheduling:
  - Because seeks are so expensive, the OS tries to schedule disk requests that are queued waiting for the disk
  - Minimize seek time
  - Seek time ≈ seek distance

FCFS

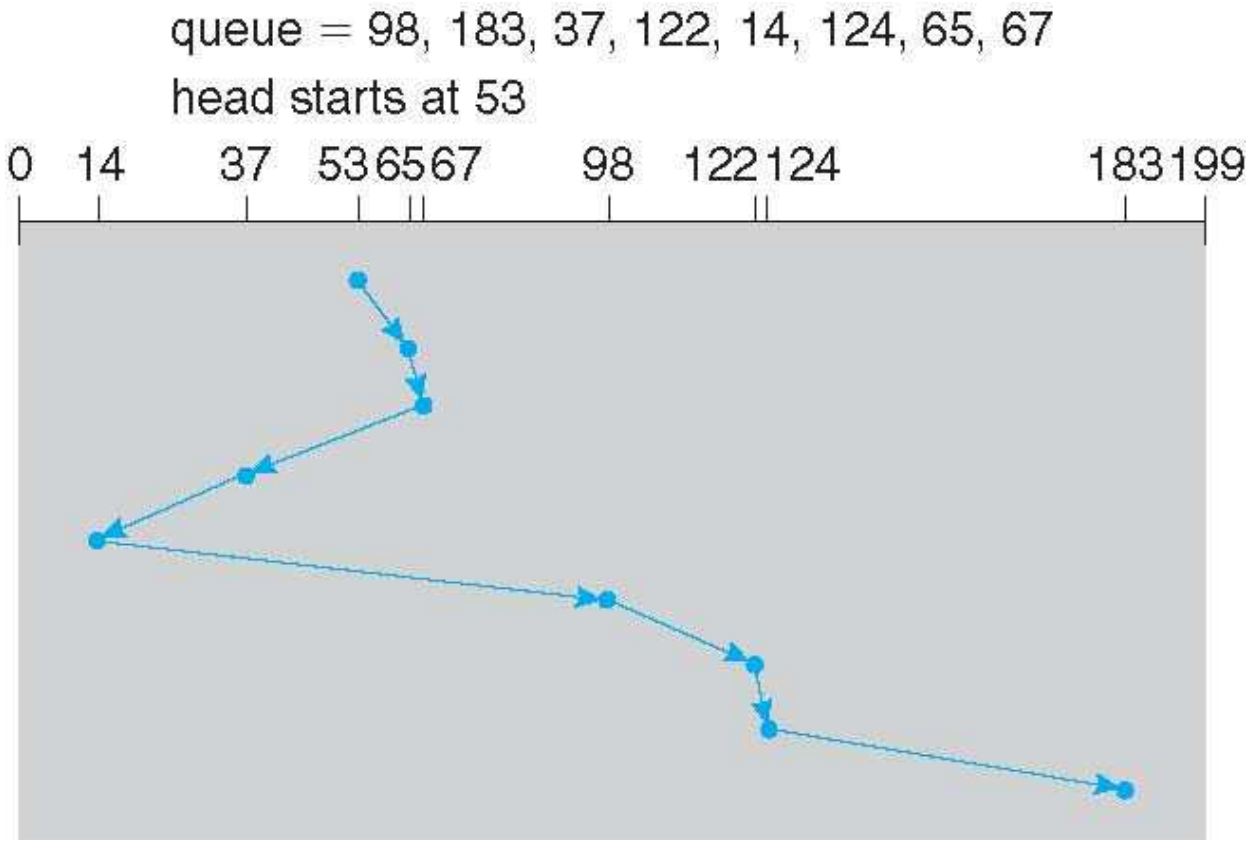
Illustration shows total head movement of 640 cylinders



SSTF

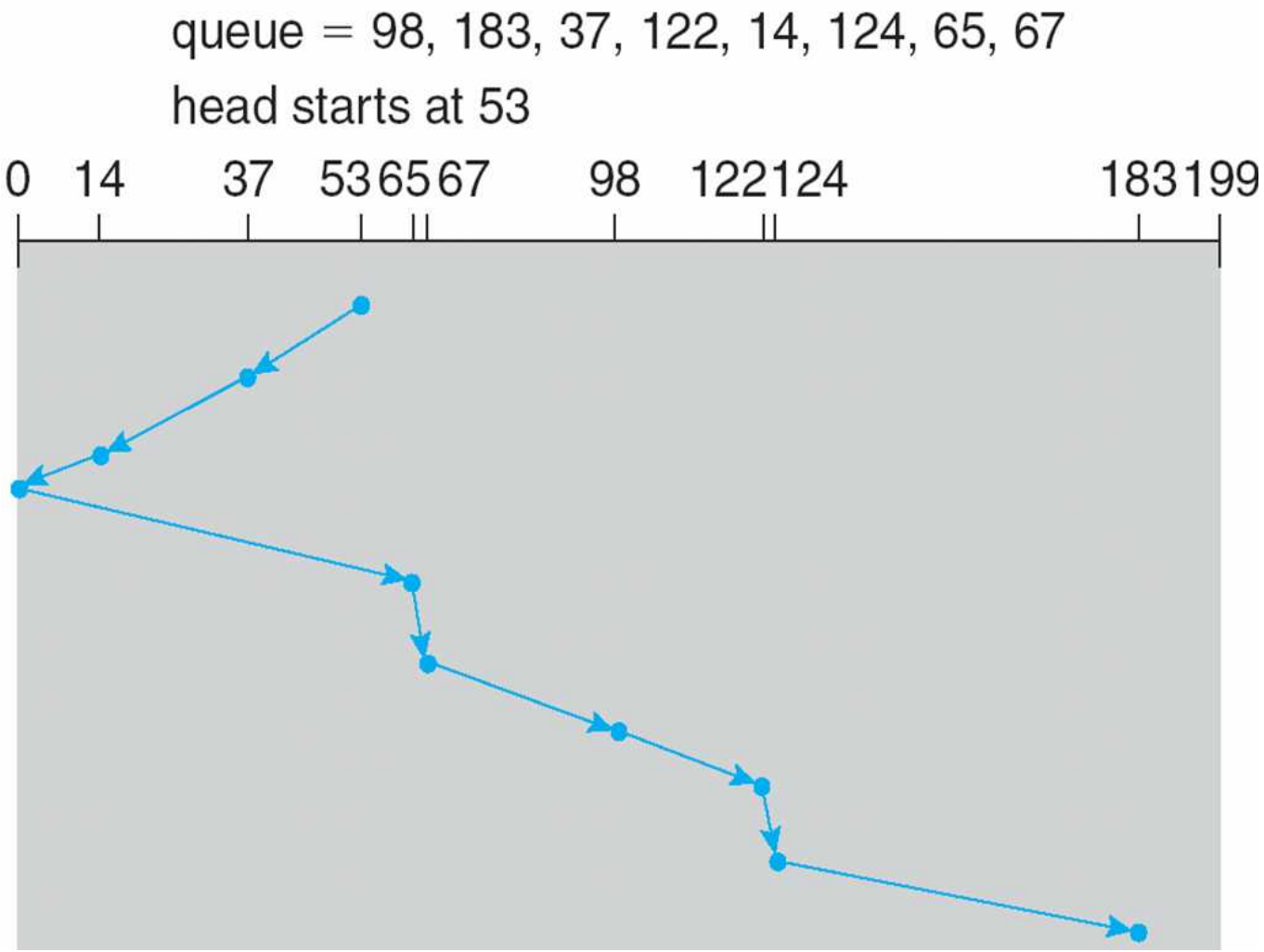
Shortest Seek Time First

- ✓ selects the request with the minimum seek time from the current head position
- ✓ a form of SJF scheduling
- ✓ may cause starvation of some requests



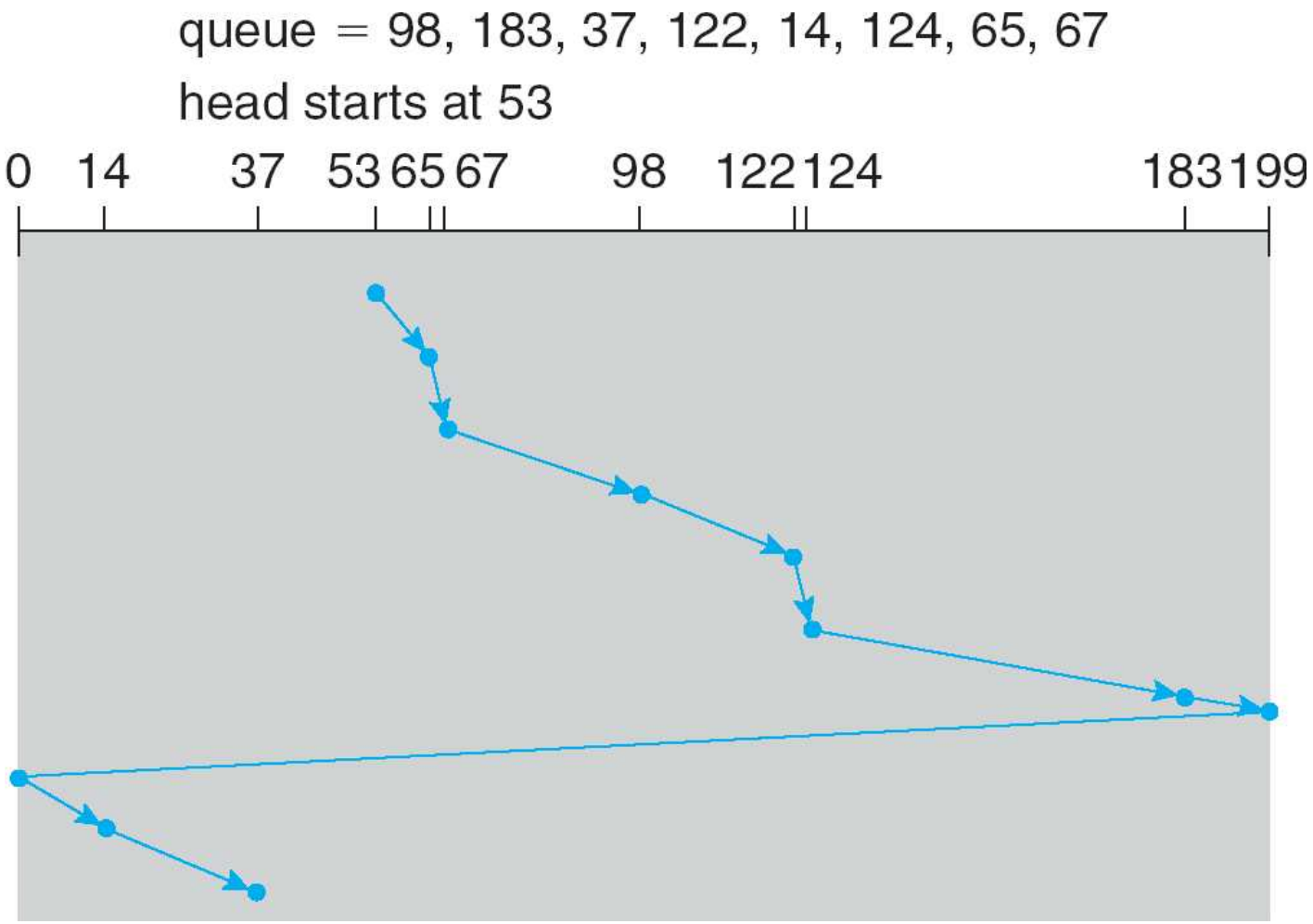
SCAN

elevator algorithm



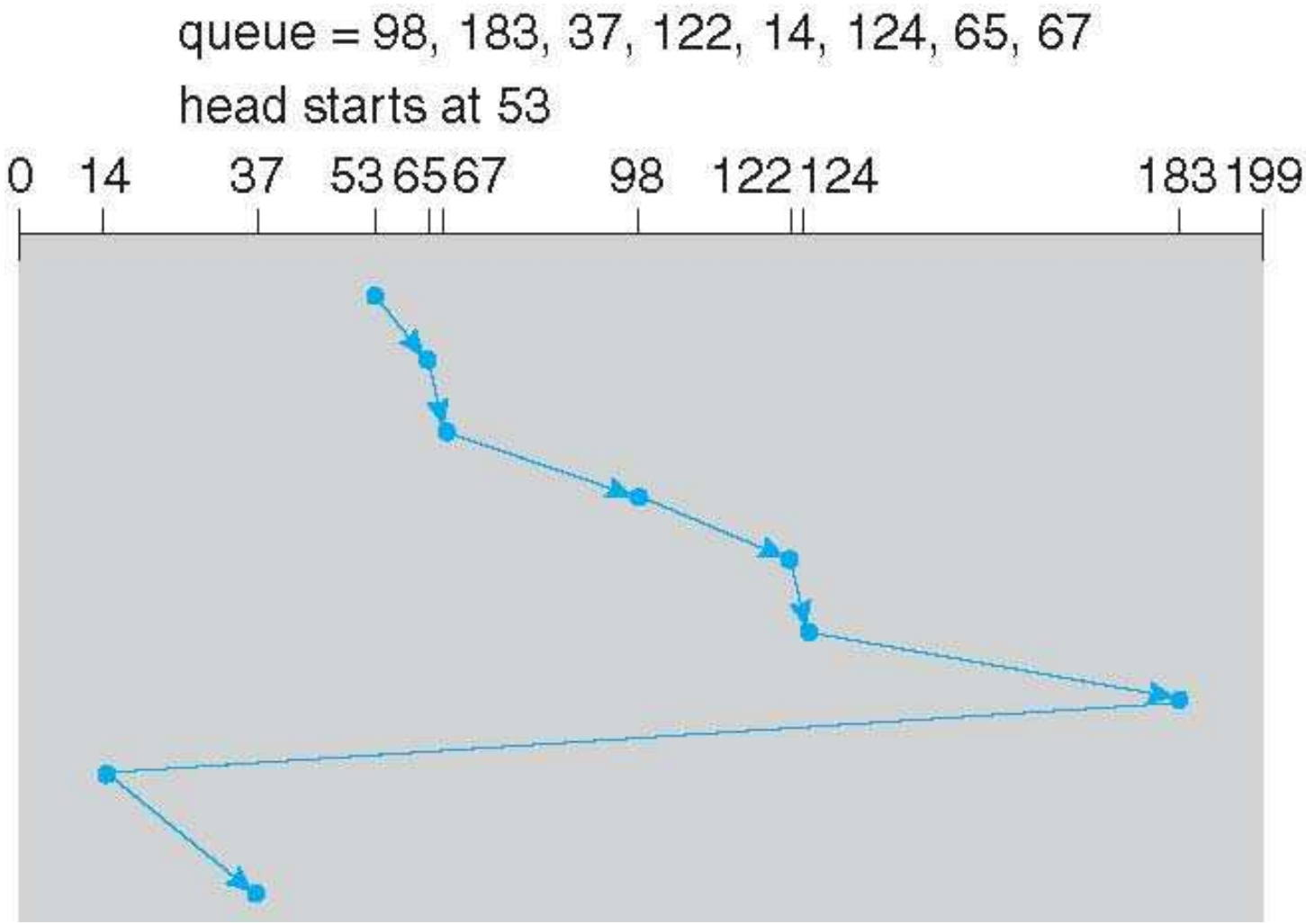
C-SCAN

Provides a more uniform wait time than SCAN



C-LOOK

LOOK a version of SCAN, C-LOOK a version of C-SCAN



Selecting a Disk-Scheduling Algorithm

Performance depends on the number and types of requests

- ✓ SSTF is common and has a natural appeal
- ✓ SCAN and C-SCAN perform better for systems that place a heavy load on the disk

In general, unless there are request queues, disk scheduling does not have much impact

- ✓ Important for servers, less so for PCs

Modern disks often do the disk scheduling themselves

- ✓ Disks know their layout better than OS, can optimize better
- ✓ Ignores, undoes any scheduling done by OS

Disk Controllers

Intelligent controllers

- ✓ Nowadays, most disk controllers are built around a small CPU and have many kilobytes of memory
- ✓ They run a program written by the controller manufacturer to process I/O requests from the CPU and satisfy them
- ✓ Intelligent features:
  - Read-ahead: the current track
  - Caching: frequently-used blocks
  - Request reordering: for seek and/or rotational optimality
  - Request retry on hardware failure
  - Bad block identification
  - Bad block remapping: onto spare blocks and/or tracks

Swap-Space Management

Swap-space

- ✓ Virtual memory uses disk space as an extension of main memory

- ✓ can be carved out of the normal file system (Windows), or,
- ✓ more commonly, it can be in a separate disk partition (Linux)

Swap-space management

- ✓ 4.3BSD allocates swap space when process starts
  - holds *text segment* (the program) and *data segment*
- ✓ Kernel uses *swap maps* to track swap-space use
- ✓ Solaris 2 allocates swap space only when a page is forced out of physical memory, not when the virtual memory page is first created

RAID

Redundant Array of Inexpensive Disks

- ✓ A storage system, not a file system

Motivations

- ✓ Use small cheap disks as a cost-effective alternative to large, expensive disks (I = Inexpensive)
- ✓ Provide higher reliability and higher data-transfer

  (I = Independent)

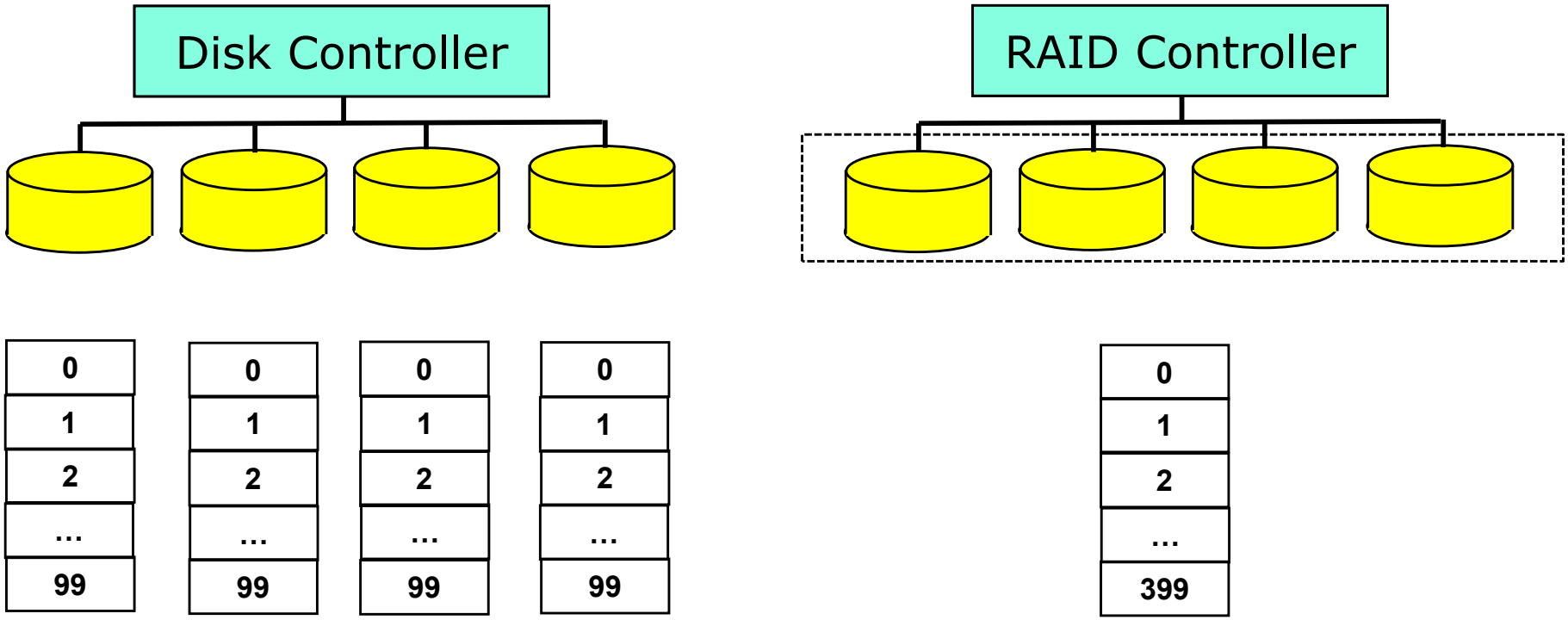
Improving reliability via redundancy

- ✓ Mirroring (shadowing)
- ✓ Parity or error-correcting codes

Improving performance via parallelism

- ✓ Data striping: bit-level vs. block-level

Multiple Disks vs. RAID



RAID Levels

RAID 0

- ✓ Non-redundant striping (no reliability)
- ✓ Data is broken down into blocks and each block is striped across multiple disks
- ✓ I/O performance is greatly improved by spreading the I/O load across many channels and drives
- ✓ Typically used in data rate intensive applications (e.g. video editing)

0	1	2	3
A0	A1	A2	A3
A4	A5	A6	A7
A8	A9	A10	A11
...	...	...	...

RAID Levels

RAID 1

- ✓ Mirrored disks
- ✓ Twice the write transaction rate of single disks, same read transaction rate as single disks
- ✓ Expensive, highest disk overhead
- ✓ No rebuild is necessary in case of a disk failure

0	1	2	3	4	5	6	7
A0	B0	C0	D0	A0	B0	C0	D0
A1	B1	C1	D1	A1	B1	C1	D1
A2	B2	C2	D2	A2	B2	C2	D2
...	...	...	...	...	...	...	...

RAID Levels

RAID 2

- ✓ Memory-style error-correcting codes (ECC)
- ✓ Each data word has its Hamming Code ECC word recorded on the ECC disks
- ✓ On read, the ECC code verifies correct data or corrects single bit errors
- ✓ ECC is embedded in almost all modern disk drives (e.g. SCSI)

0	1	2	3	4	5	6
A0	A0	A0	A0	Px	Py	Pz
A1	A1	A1	A1	Px	Py	Pz
A2	A2	A2	A2	Px	Py	Pz
A3	A3	A3	A3	Px	Py	Pz
...	...	...	...	...	...	...

RAID Levels

RAID 3

- ✓ Bit-interleaved parity
- ✓ Stripe parity is generated on writes, recorded on the parity disk and checked on reads
- ✓ Less storage overhead than RAID 2
- ✓ Requires hardware support for efficient use

0	1	2	3	4
A0	A0	A0	A0	P
A1	A1	A1	A1	P
A2	A2	A2	A2	P
A3	A3	A3	A3	P
...	...	...	...	...

RAID Levels

RAID 4

- ✓ Block-interleaved parity
- ✓ Parity for same rank blocks is generated on writes, recorded on the parity disk and checked on reads
- ✓ Very good read performance (same as RAID 0)
- ✓ Writes, however, require parity data be updated each time
- ✓ No advantages over RAID 5 and does not support multiple simultaneous write operations

0	1	2	3	4
A0	A1	A2	A3	P
A4	A5	A6	A7	P
A8	A9	A10	A11	P
...	...	...	...	...

RAID Levels

RAID 5

- ✓ Block-interleaved distributed parity
- ✓ Parity for blocks in the same rank is generated on writes, recorded in a distributed location
- ✓ Can speed up small writes in multiprocessing systems, since the parity disk does not become a bottleneck

0	1	2	3	4
A0	A1	A2	A3	P
A4	A5	A6	P	A7
A8	A9	P	A10	A11
A12	P	A13	A14	A15
...	...	...	...	...

RAID Levels

RAID 6

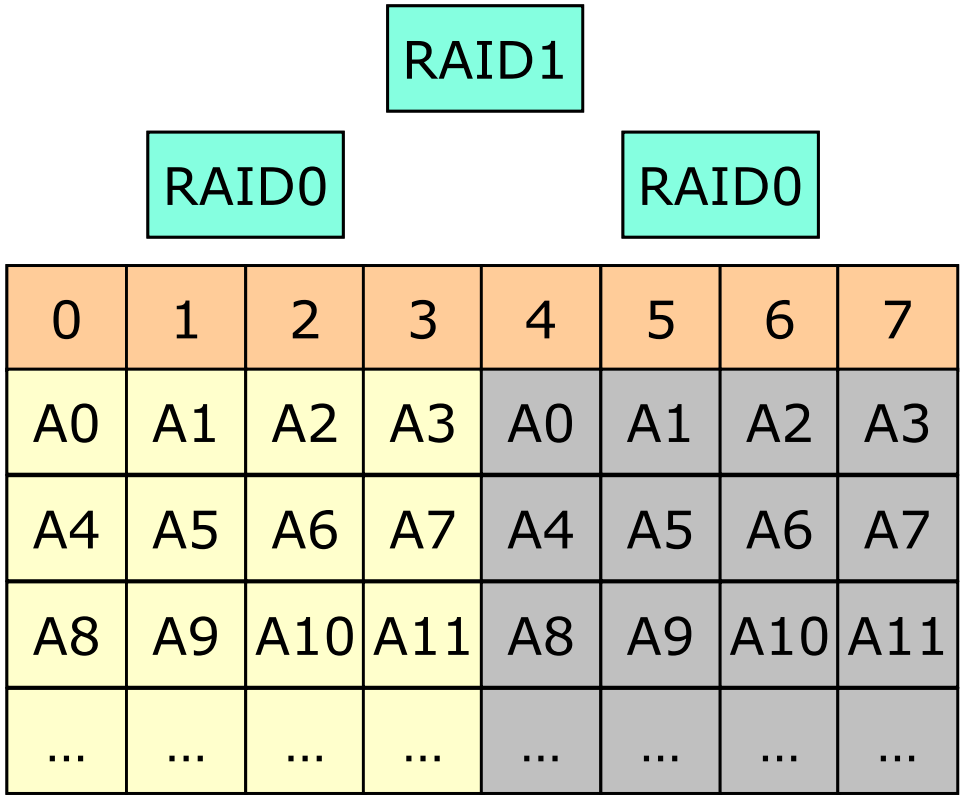
- ✓ P+Q redundancy scheme
- ✓ RAID 5 + extra redundancy information to guard against multiple disk failure
- ✓ Use error-correcting codes instead of parity

0	1	2	3	4	5
A0	A1	A2	A3	Px	Py
A4	A5	A6	Px	Py	A7
A8	A9	Px	Py	A10	A11
A12	Px	Py	A13	A14	A15
...	...	...	...	...	...

RAID Levels

RAID 0+1

- ✓ A set of disks are striped, and then the stripe is mirrored to another, equivalent stripe
- ✓ RAID 0 provides performance, while RAID 1 provides the reliability
- ✓ A single drive failure will cause the whole array to become, in essence, a RAID 0 array



RAID Levels

RAID 10 (or RAID 1+0)

- ✓ Disks are mirrored in pairs, and then the resulting mirror pairs are striped
- ✓ Reliable better than RAID 0+1
  - RAID 0+1 is fault tolerant as long as the second through n-th disk is on the same stripe
  - RAID 1+0 is fault tolerant as long as no two disks are part of the same mirror