Hardware

Read Sections 11.2, 11.3, 11.7
of Garcia-Molina et al.

Slides derived from those by Hector Garcia-Molina
Some images by Wikipedia

Outline

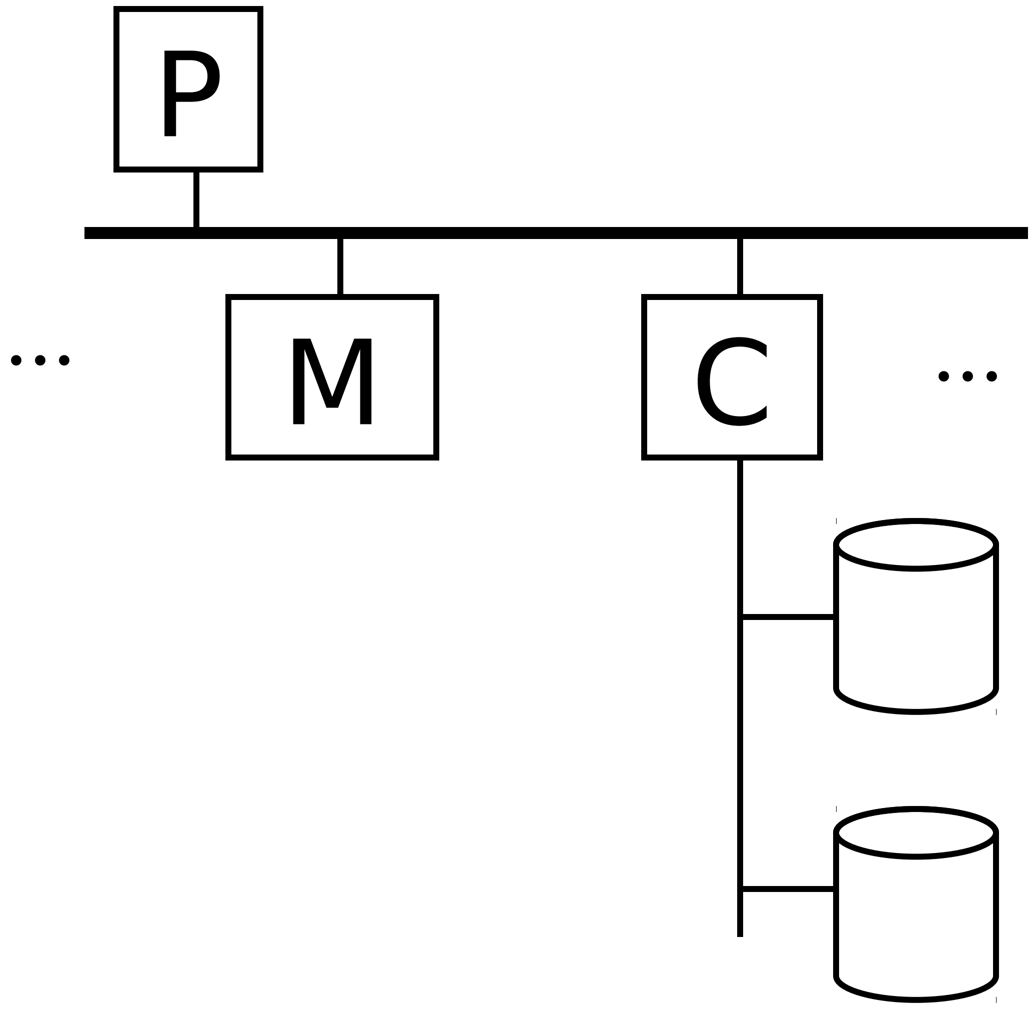
- Hardware: Disks
- Access Times
- Example - Megatron 747
- Reliability
- RAID

Hardware

DBMS

Data Storage

<u>Typical Computer</u>



Secondary Storage

Processor

Fast, slow, reduced instruction set, with cache, pipelined…

Speed: 1000 $\rightarrow$ 10000 MIPS

Memory

Fast, slow, non-volatile, read-only,…

Access time: $10^{-6} \rightarrow 10^{-9}$ sec.

1 μs $\rightarrow$ 1 ns

Secondary storage

Hard Disks

Tertiary storage

Optical disks:

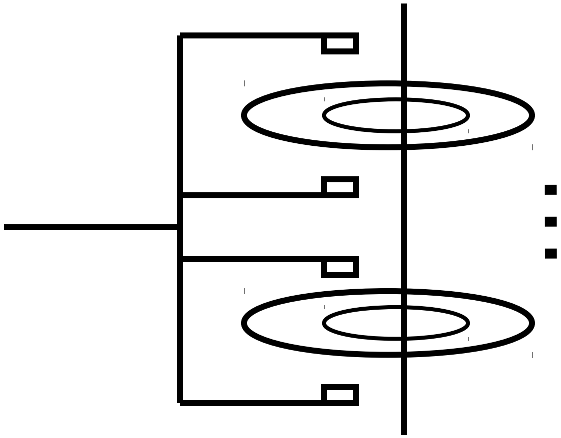
- CD-ROM
- DVD-ROM…

Tape

- Cartridges

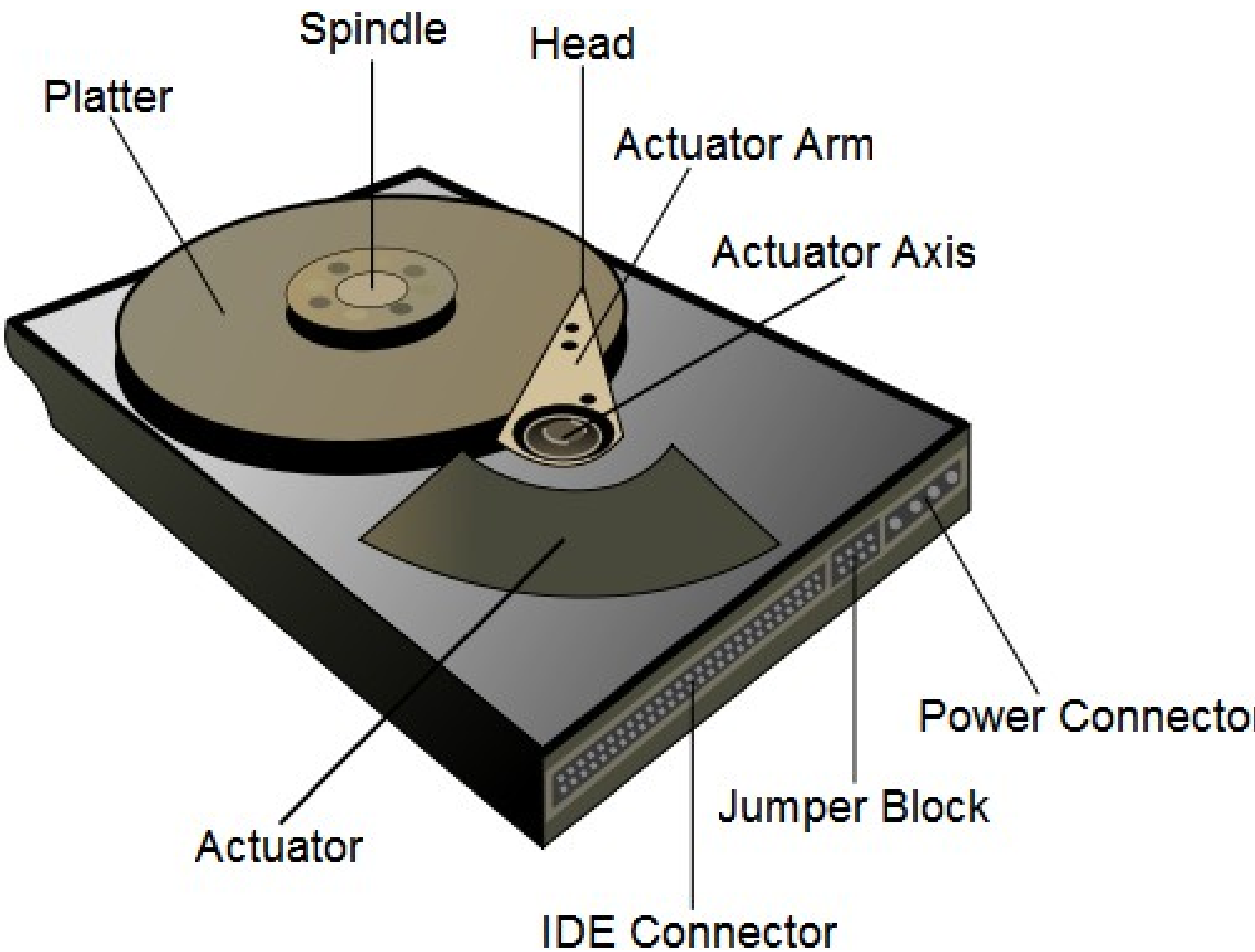
Robots

<u>Focus on</u>: "Typical Disk"

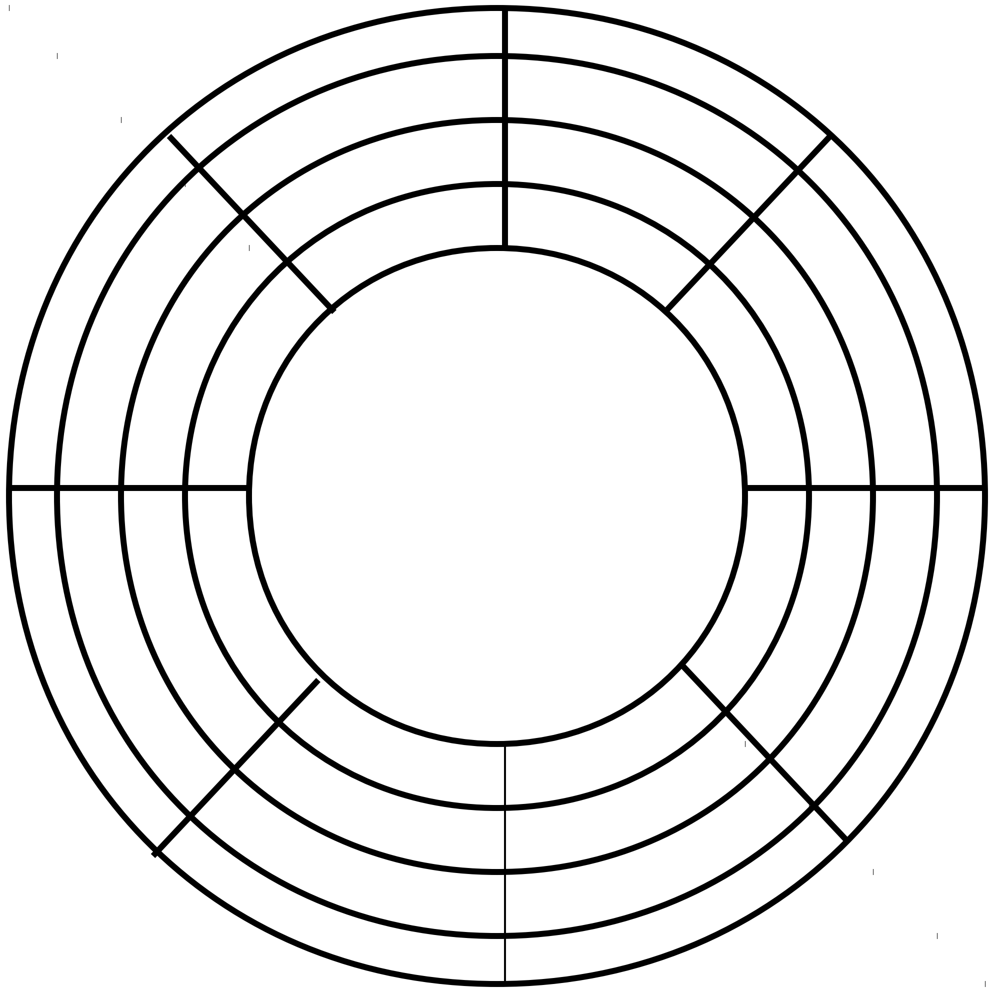


Terms: Platter, Surface, Head, Actuator
Cylinder, Track
Sector (physical),
Block (logical), Gap

Disk Architecture



Top View



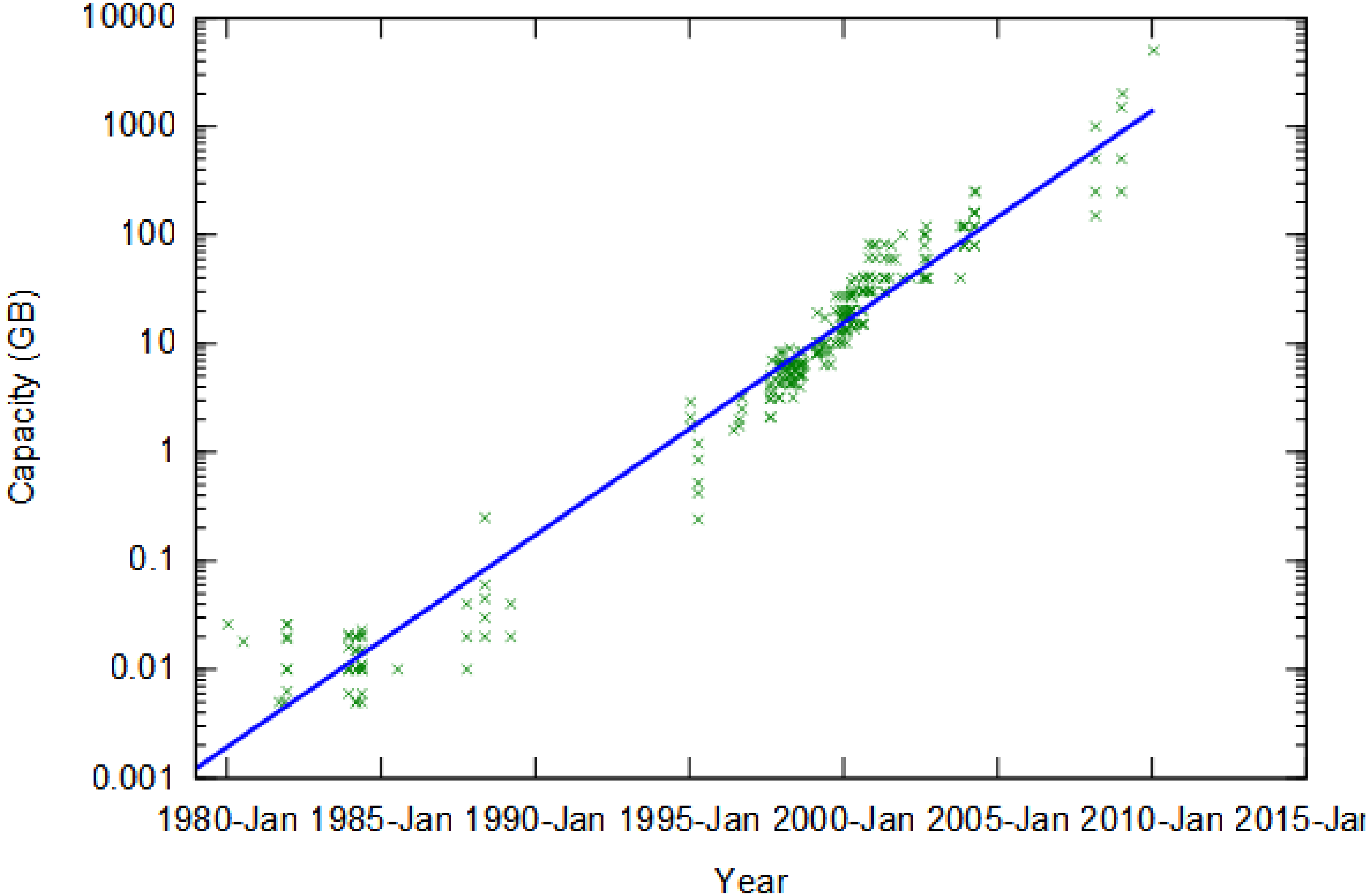
“Typical” Numbers

Diameter: 1 inch $\rightarrow$ 15 inches
(1 inch=2.54 cm:
2.5 cm $\rightarrow$ 38.1 cm)
Cylinders: 10000 $\rightarrow$ 50000
Surfaces: 2 -> 30
(Tracks/cyl)
Sector Size: 512B $\rightarrow$ 50KB
Capacity: 72 GB $\rightarrow$ 2TB

Diameter

- Form factors:
  - 8 inches
  - 5.25 inches
  - 3,5 inches
  - 2,5 inches
  - 1,8 inches
  - 1 inch

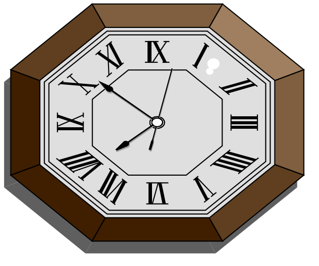
Capacity



10000
1000
100
10
1
0.1
0.01
0.001
Capacity (GB)
1980-Jan 1985-Jan 1990-Jan 1995-Jan 2000-Jan 2005-Jan 2010-Jan 2015-Jan
Year

Disk Access Time

I want block X

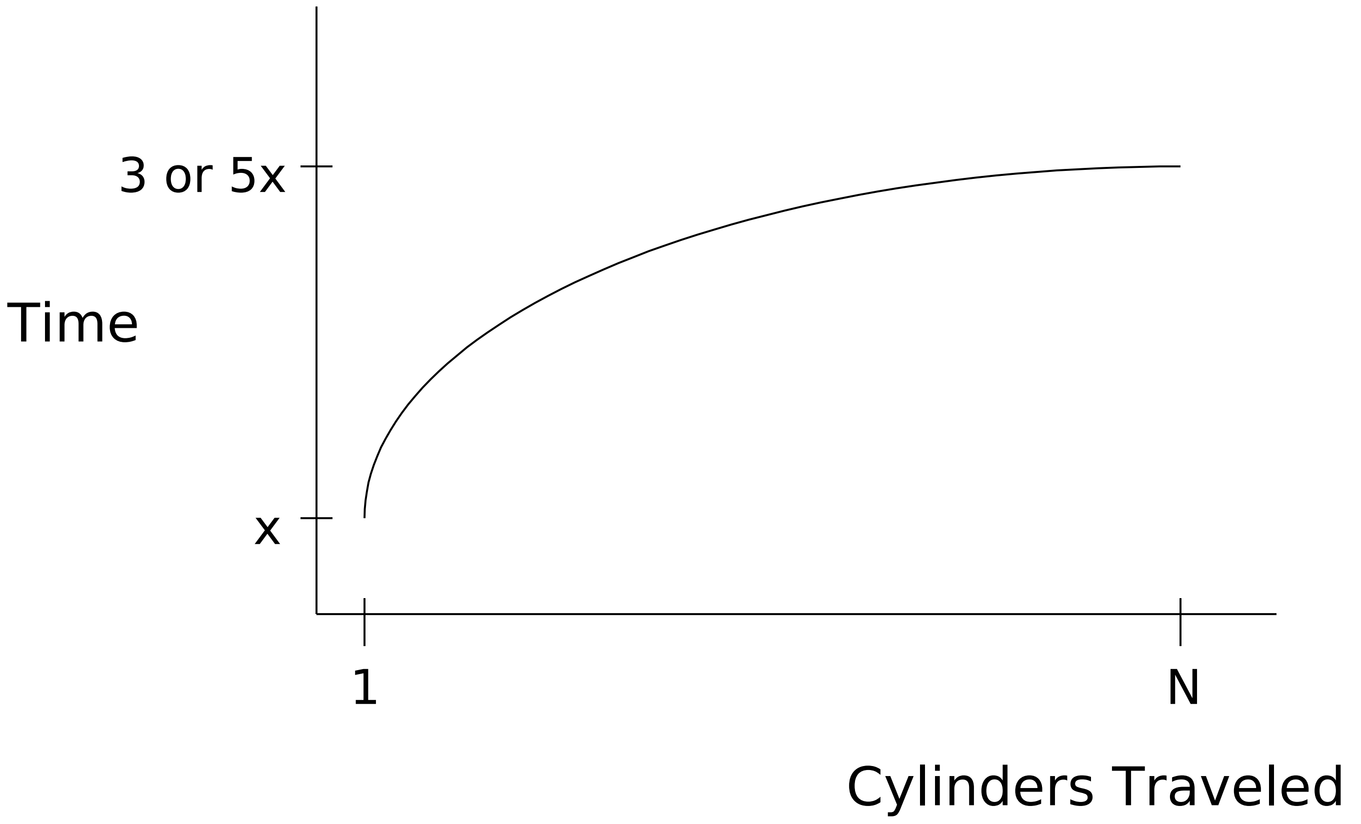


block x in memory

?

Time = Seek Time +
Rotational Delay +
Transfer Time +
Other

Seek Time

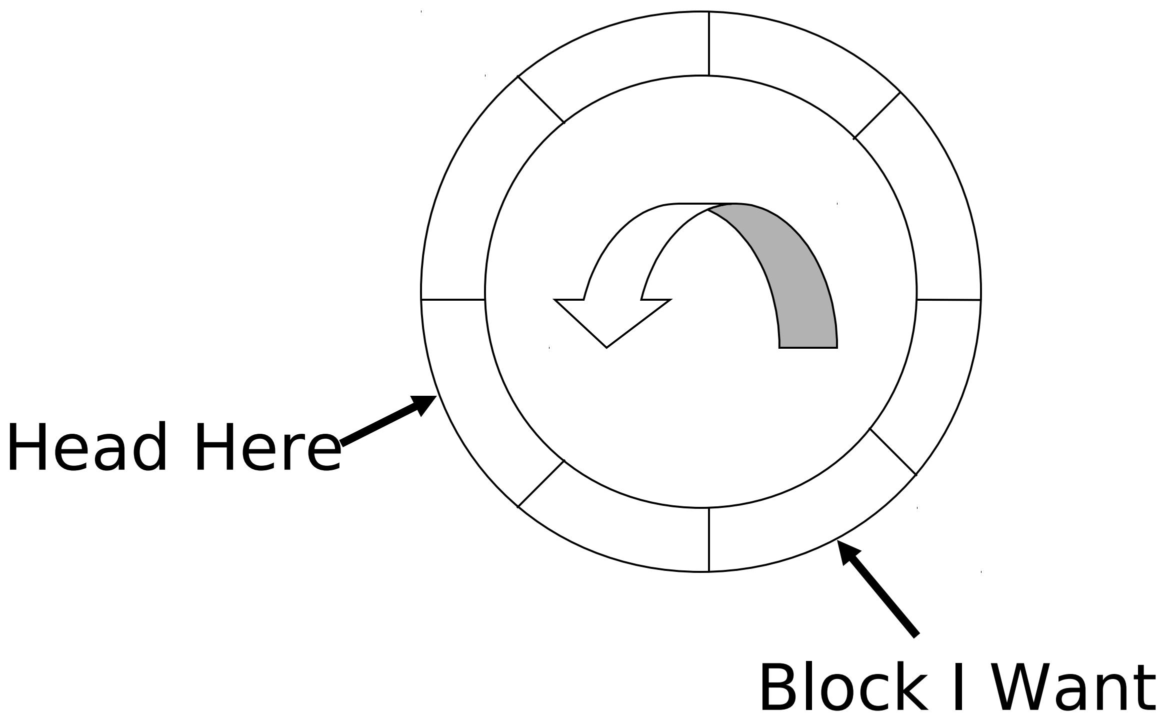


Average Random Seek Time

$$S = \frac{\sum_{i=1}^{N} \sum_{\substack{j=1 \\ j \neq i}}^{N} \text{SEEKTIME}(i \rightarrow j)}{N(N-1)}$$

"Typical" S: 3 ms $\rightarrow$ 10 ms

Rotational Delay



Average Rotational Delay

R = 1/2 revolution

“typical” R = 4.17 ms (7200 RPM)
R=3 ms (10000 RPM)
R=2 ms (15000 RPM)

Transfer Rate: t

- “typical” t: 60 MB/second
- transfer time: $\frac{\text{block size}}{t}$

Other Delays

- CPU time to issue I/O
- Contention for controller
- Contention for bus, memory

“Typical” Value: 0

- So far: Random Block Access
- What about: Reading “Next” block?

Time to get = Block Size + Negligible

block t

- skip gap

Cost for <u>Writing</u> similar to <u>Reading</u>

..... unless we want to verify!

need to add (full) rotation + $\frac{\text{Block size}}{t}$

- To Modify a Block?

To Modify Block:

(a) Read Block

(b) Modify in Memory

(c) Write Block

[(d) Verify?]

Block Address:

- Physical Device
- Cylinder (Track) #
- Surface #
- Sector

Complication: Bad Blocks

- Messy to handle
- May map via software to integer sequence

1
2
.
.
m

Map → Actual Block Addresse

An Example

Megatron 747 Disk

ter

- 8 platters, 16 surfaces
- $2^{14}=16,384$ tracks per surface (16,384 cylinders)
- $2^{7}=128$ sectors per track
- $2^{12}=4096$ bytes per sector

- Capacity
  - Disk$=2^{4}*2^{14}*2^{7}*2^{12}=2^{37}=$128GB
  - Single track$=2^{7}*2^{12}=$512KB

Megatron 747 Disk

- Rotation speed: 7200 RPM
- Average seek time: 8.5 ms

Layout

- Radius: 1.75 inches
- The tracks occupy the outer inch
- The inner 0.75 inch is unoccupied
- Track density in the radial direction: 16,384 tracks per inch
- 10% overhead between blocks

Density of bits

- Outermost track
  - Length=3.5π≈11 inches
  - One track = 512KB = 4Mbits
  - 90% of 11 inches holds 4Mbits
  - Density=420,000 bits per inch
- Innermost track
  - 90% of 4.71 inches holds 4Mbits
  - Density≈1Mbit per inch

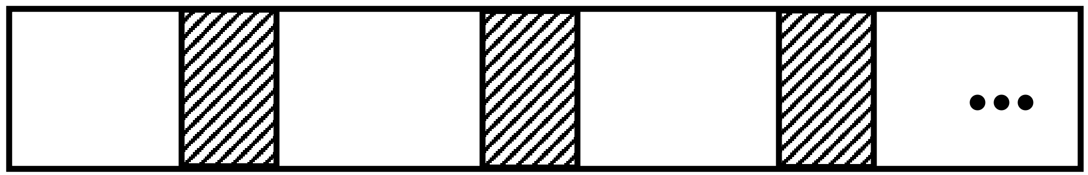
Density of bits

- To avoid such a high difference of density, the disk stores more sectors on the outer track than on the inner tracks
  - 96 sectors per track in the inner third
  - 128 in the middle third
  - 160 in the outer third
- The density varies from 742,000 bits per inch to 530,000 bits per inch

7200 RPM → 120 revolutions / sec

→ 1 rev. = 8.33 msec.

One track:



Time over useful data:(8.33)(0.9)=7.5 ms.

Time over gaps: (8.33)(0.1) = 0.833 ms.

Transfer time 1 sector = 7.5/128=0.059 ms.

Trans. time 1 sector+gap=8.33/128=0.065ms

Burst Bandwith

4 KB in 0.059 ms.

BB = 4/0.059 = 68 KB/ms.

or

BB =68 KB/ms x 1000 ms/1sec x 1MB/1024KB

= 68,000/1024 = 66.4 MB/sec

Sustained bandwith (over track)

512 KB in 8.33 ms.

SB = 512/8.33 = 61.5 KB/ms

or

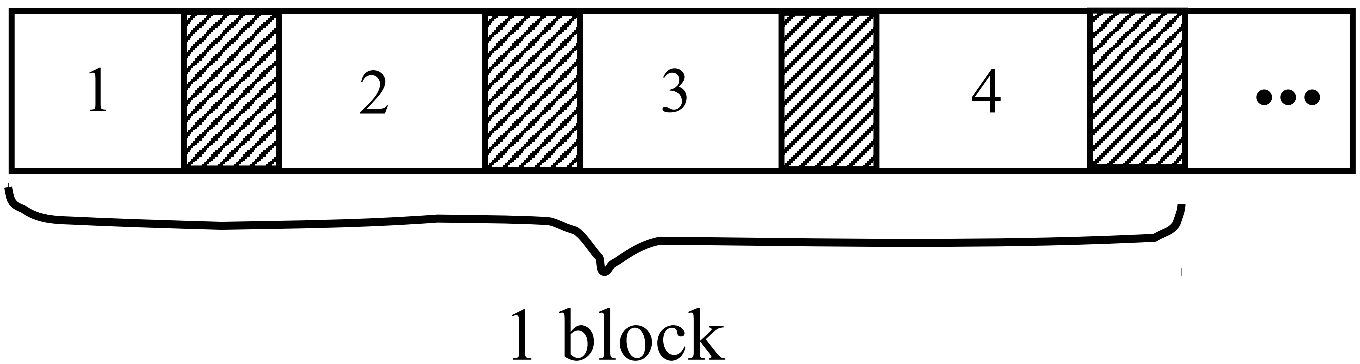
SB = 61.5 x 1000/1024 = 60 MB/sec.

T_1 = Time to read one random block

T_1 = seek + rotational delay + TT

= 8.5 + (8.33/2) + 0.059 = 12.72 ms.

Suppose OS deals with 16 KB blocks



T_4 = 8.5 + (8.33/2) + 0.059*1 + (0.065) * 3 = 12.92 ms

[Compare to T_1 = 12.72 ms]

T_T = Time to read a full track

(start at any block)

$T_T = 8.5 + (0.065/2) + 8.33^{*} = 16.86$ ms

to get to first block

* Actually, a bit less; do not have to read last gap.

Block Size Selection?

- Big Block $\rightarrow$ Amortize I/O Cost

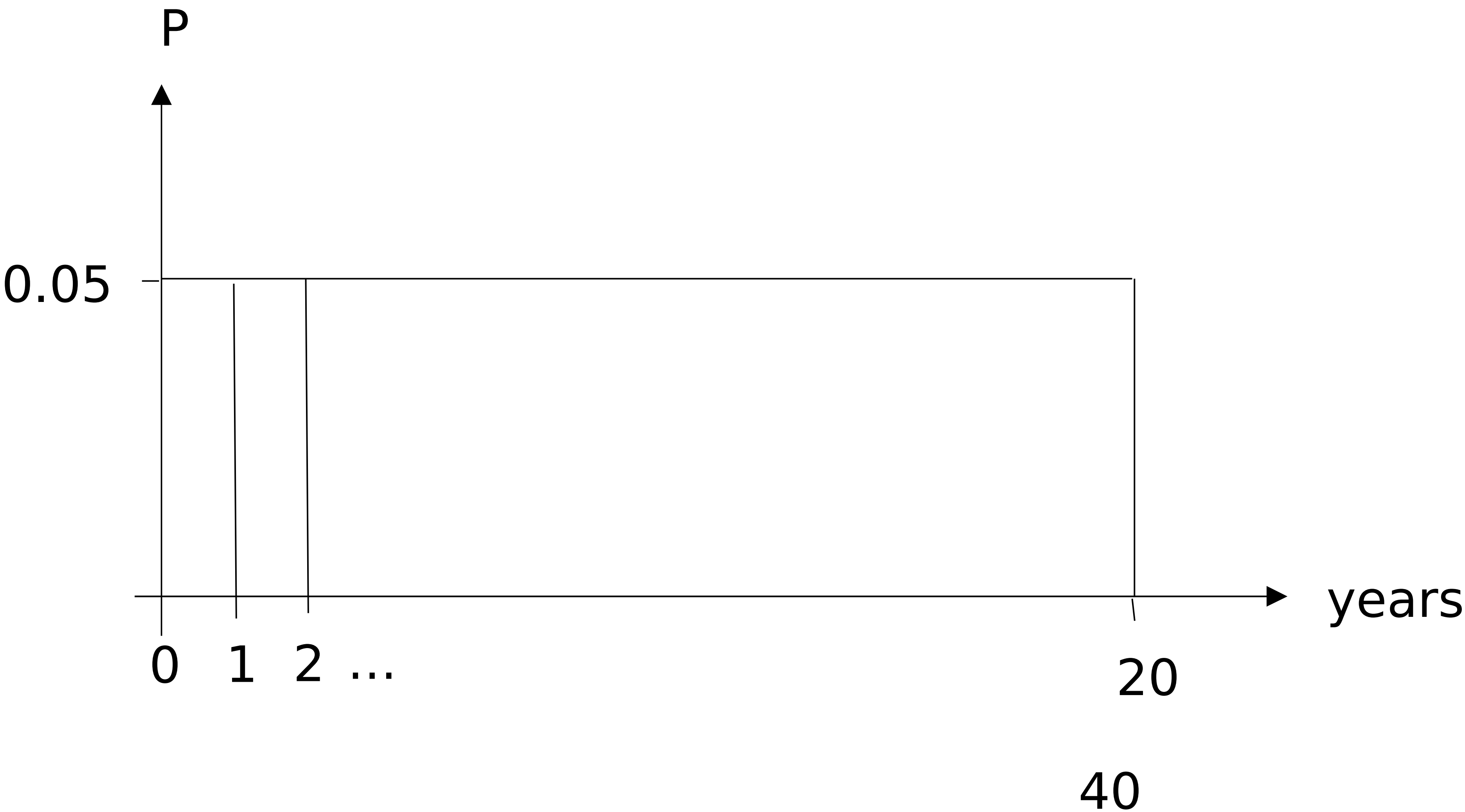
Unfortunately...

- Big Block $\Rightarrow$ Read in more useless stuff!
  and takes longer to read

Reliability

- Measured by the Mean Time to Failure (MTTF):
  - Length of time by which 50% of a population of disks will have failed catastrophically (head crash, no longer readable)
  - For modern disks, the MTTF is 10 years
  - This means that, on average, after 10 years it will crash
  - We can assume that every year 5% of the disks fail (uniform distribution assumption)
    - Probability that a disk fails in one year P_F=5%=1/20

Probability of Failure



MTTF

- Expected value of the failure year:
- MTTF=E(year)=
  =0.05*1+....+0.05*20=
  =0.05*20*(20+1)/2=21/2 $\approx$ 10

Disk Arrays

- Redundant Arrays of Inexpensive Disks (RAID)
- Two aims: increase speed and reliability

RAID 0

- Uses “block level striping”
  - Blocks that are consecutive for the OS are distributed evenly across different disks

RAID 0

A1	A2	consecutive blocks: A1-A8
A3	A4	
A5	A6	
A7	A8	

RAID 0

- Improves reading and writing speed
  - With two disks, two blocks can be read at the same time
  - A request for block "A1" would be serviced by disk 1. A simultaneous request for block A3 would have to wait, but a request for A2 could be serviced concurrently
- Reduces reliability: if one disk fails, the data is lost.

RAID 0

- P(data loss)=P(disk1 fails or disk2 fails)=

=P(disk1 fails)+P(disk2 fails)-P(disk1 fails and disk2 fails)=

$=P_F+P_F-P_F*P_F=2P_F-P_F^2=$

=2*0.05-0.0025=0.0975

RAID 0

- Number of years=1/0.0975 $\approx$10
- MTTF =E(year)=
  $\approx$ 0.0975*10*(10+1)/2 $\approx$ 11/2 $\approx$5.5

RAID 1

- Creates an exact copy (or **mirror**) of a set of data on two or more disks.
- Typically, a RAID 1 array contains two disks
- Improved
  - Reading speed: two blocks can be read at the same time
  - Reliability: if one disk crashes, we can use the other
- Writing speed remains the same

RAID 1

RAID 1

A1	A1
A2	A2
A3	A3
A4	A4

RAID 1 Reliability

- Two disks with MTTF of 10 years
- What is the MTTF resulting in data loss?
- Data loss happens when one disk fails and the other fails as well while we are replacing the first.
- Supposing it takes 3 hours to replace the first disk. This is 1/2920 of a year
- P(fails rep)=1/2920=3.42E-04

RAID 1 Reliability

- The probability that the second disk fails while replacing the first is

  P(fails1 and fails2 rep)=

  =5E-2*5E-2*3.42E-04=8.55E-07
- P(data loss)=P(fails1 and fails2 rep or fails2 and fails1 rep)=

RAID 1 Reliability

= P(fails1 and fails2 rep) + P(fails2 and fails1 rep)-P(fails2 and fails1 rep and fails1 and fails2 rep)=

≈2*8.55E-07

=1.71E-06

RAID 1 Reliability

- Number of years=1/1.71E-06 ≈ 584795
- MTTF=E(years)= =1.71E-06*584795*584796/2= =584796/2=292398

RAID 4

- Uses block-level striping with a dedicated parity disk.

RAID 4

A1 A2 A3 Ap	Consecutive blocks
B1 B2 B3 Bp	A1-A3,B1-B3,
C1 C2 C3 Cp	C1-C3, D1-D3
D1 D2 D3 Dp	

Parity block

- Bit i of the block in position j on the parity disk is the parity bit of the bits in position i in the blocks in position j in the other disks
- Eg., blocks of one byte, blocks A1-A3

  Disk1 11110000

  Disk2 10101010

  Disk3 00111000

  Disk4 01100010 (parity disk)

RAID 4

- Improves reading time: multiple blocks can be read at the same time
- Improves reliability: if one disk fails, we can reconstruct its content (assuming the others are correct)

RAID 4

- Problem:
  - When writing a block, we need to read and write the parity disk's block
  - This creates a bottleneck

RAID 5

- Uses block-level striping with parity data distributed across all member disks.

RAID 5

A1	A2	A3	Ap
B1	B2	Bp	B3
C1	Cp	C2	C3
Dp	D1	D2	D3

RAID 5

- Reading and reliability as RAID 4
- Writing improved because the parity blocks are not all on one disk

RAID 6

- Uses block-level striping with dual parity data distributed across all member disks.

RAID 6

A1	A2	A3	Ap	Aq
B1	B2	Bp	Bq	B3
C1	Cp	Cq	C2	C3
Dp	Dq	D1	D2	D3

RAID 6

- p and q blocks are computed with two different algorithms, e.g.
  - parity and Reed-Solomon
  - orthogonal dual parity
  - diagonal parity

RAID 6

- It is able to recover from the loss of two disks
- Writing improved because the parity blocks are not all on one disk

Nested RAID Levels

- RAID 0+1:

```
               RAID 1
                 |
        /-----------------\
        |                 |
      RAID 0            RAID 0
  /-----------\     /-----------\
  |     |     |     |     |     |
120GB 120GB 120GB 120GB 120GB 120GB
```

RAID 0+1

- If a disk fails, it can be rebuilt from the corresponding disk in the other RAID 0 batch
- If two disk fails from the same stripe, no recovery

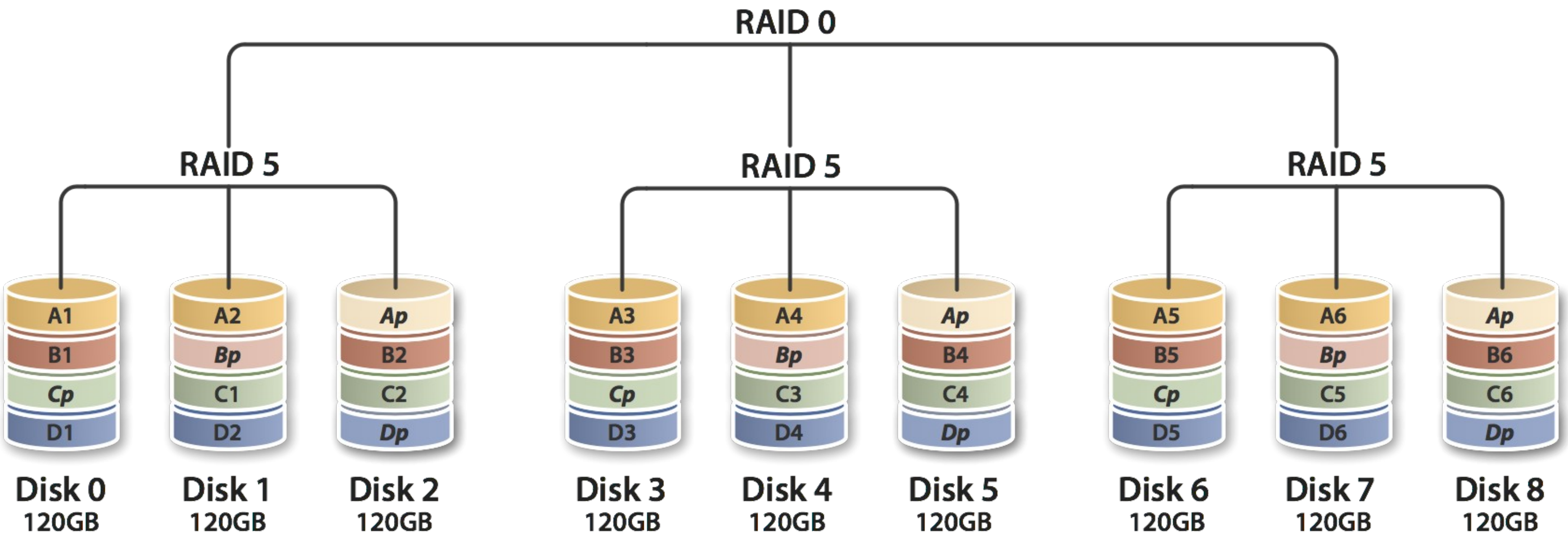
RAID 1+0 o RAID 10

```
                  RAID 0
                    |
     /-----------------------------\
     |              |              |
   RAID 1         RAID 1         RAID 1
  /------\       /------\       /------\
  |      |       |      |       |      |
120GB  120GB   120GB  120GB   120GB  120GB
```

RAID 1+0 o RAID 10

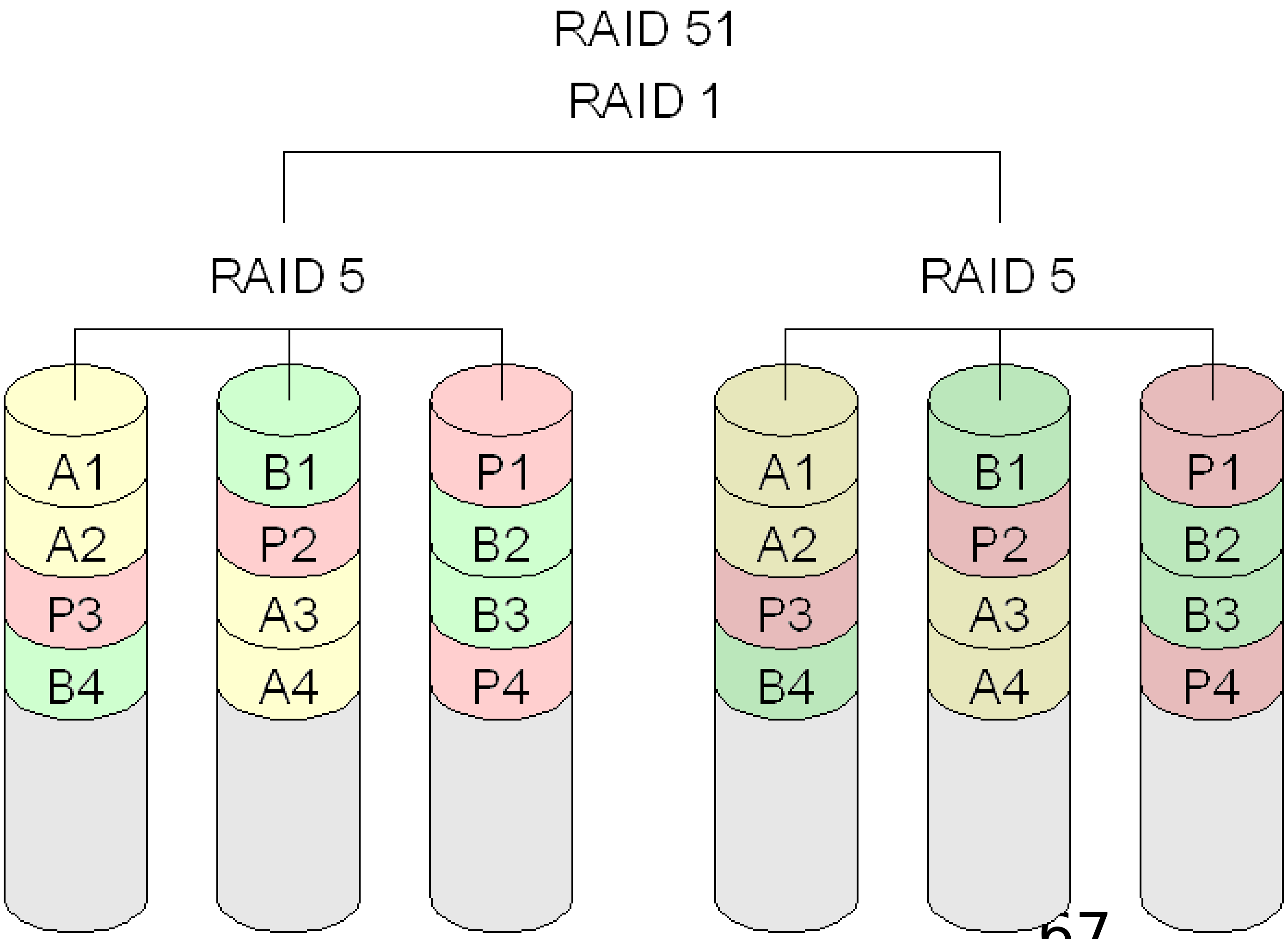
- If a disk fails, it can be rebuilt from the corresponding disk in the other RAID 1 batches
- If two disk fails from the same RAID 1 batch, no recovery

RAID 5+0



RAID 0
RAID 5
RAID 5
RAID 5
A1
B1
Cp
D1
A2
Bp
C1
D2
Ap
B2
C2
Dp
A3
B3
Cp
D3
A4
Bp
C3
D4
Ap
B4
C4
Dp
A5
B5
Cp
D5
A6
Bp
C5
D6
Ap
B6
C6
Dp
Disk 0
120GB
Disk 1
120GB
Disk 2
120GB
Disk 3
120GB
Disk 4
120GB
Disk 5
120GB
Disk 6
120GB
Disk 7
120GB
Disk 8
120GB

RAID 5+1


RAID 51
RAID 1
RAID 5
RAID 5
A1
A2
P3
B4
B1
P2
A3
A4
P1
B2
B3
P4
A1
A2
P3
B4
B1
P2
A3
A4
P1
B2
B3
P4