CSE 421/521 - Operating Systems
Spring 2018

LECTURE - XXI

MASS STORAGE & IO - II

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Storage System Reliability

- What can happen if disk loses power or machine software crashes?
  - Some operations in progress may complete
  - Some operations in progress may be lost
  - Overwrite of a block may only partially complete
- File system wants durability (as a minimum!)
  - Data previously stored can be retrieved (maybe after some recovery step), regardless of failure

1. Caching Issues

- For performance, all must be cached!
  This is OK for reads but what about writes?

- Options for writing data:
  Write-through: write change immediately to disk
  Problem: slow! Have to wait for write to complete before you go on

  Write-back: delay writing modified data back to disk (for example, until replaced)
  Problem: can lose data on a crash!

2. Multiple Update Issues

- If multiple updates needed to perform some operations, crash can occur between them!
  - Moving a file between directories:
    * Delete file from old directory
    * Add file to new directory
  - Create new file
    * Allocate space on disk for header, data
    * Write new header to disk
    * Add the new file to directory

What if there is a crash in the middle? Even with write-through it can still have problems

Storage Reliability Problem

- Single logical file operation can involve updates to multiple physical disk blocks
  - inode, indirect block, data block, bitmap, …
  - With remapping, single update to physical disk block can require multiple (even lower level) updates
- At a physical level, operations complete one at a time
  - Want concurrent operations for performance
- How do we guarantee consistency regardless of when crash occurs?

Transaction Concept

- Transaction is a group of operations
  - Atomic: operations appear to happen as a group, or not at all (at logical level)
    - At physical level, only single disk/flash write is atomic
  - Durable: operations that complete stay completed
    - Future failures do not corrupt previously stored data
  - Isolation: other transactions do not see results of earlier transactions until they are committed
  - Consistency: sequential memory model

Transaction Implementation

- Key idea: fix problem of how you make multiple updates to disk, by turning multiple updates into a single disk write!
- Example: money transfer from account x to account y:

  Begin transaction

  x = x - a

  y = y + a

  Commit

- Keep "redo" log on disk of all changes in transaction.
  - A log is like a journal, never erased, record of everything you've done
  - Once both changes are on log, transaction is committed.
  - Then can "write behind" changes to disk --- if crash after commit, replay log to make sure updates get to disk

RAID Concept

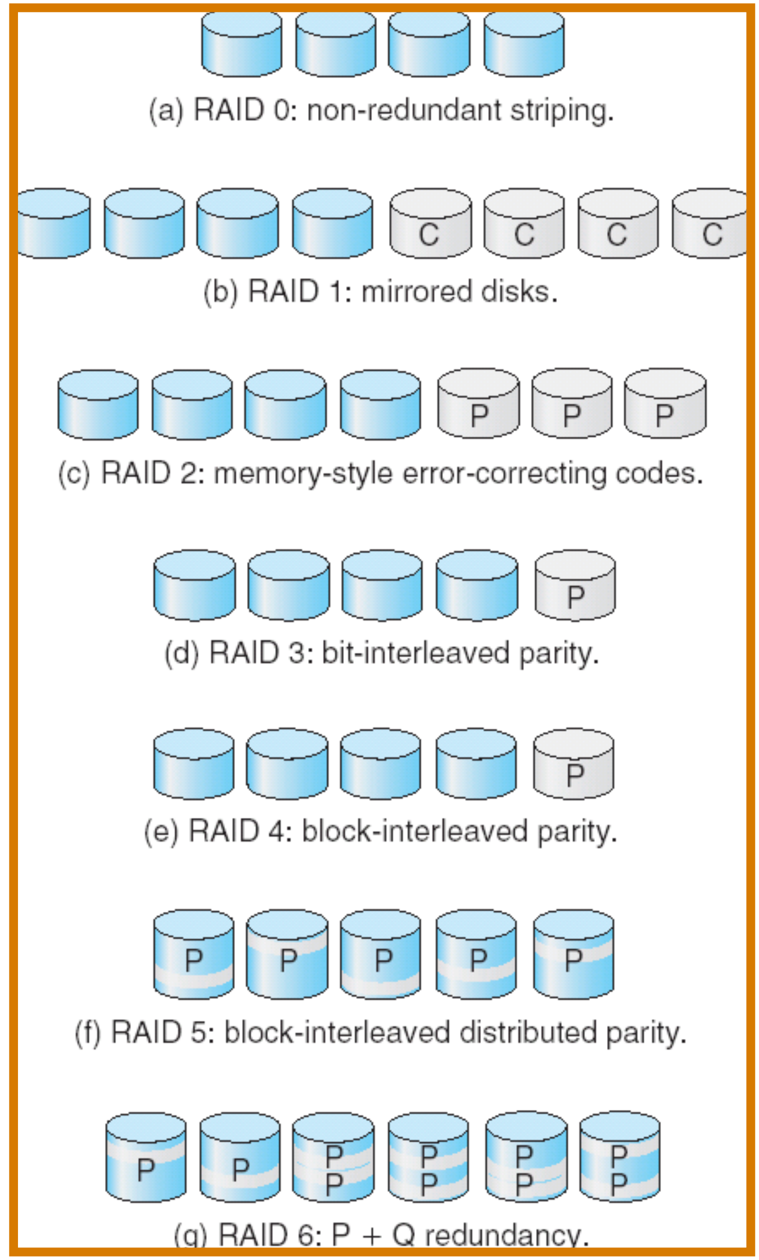
- As disks get cheaper, adding multiple disks to the same system provides increased storage space, as well as increased reliability and performance.

- RAID: Redundant Array of Inexpensive Disks
  - multiple disk drives provides reliability via redundancy.

- RAID is arranged into seven standard levels.
  - (RAID 0 -- 6)

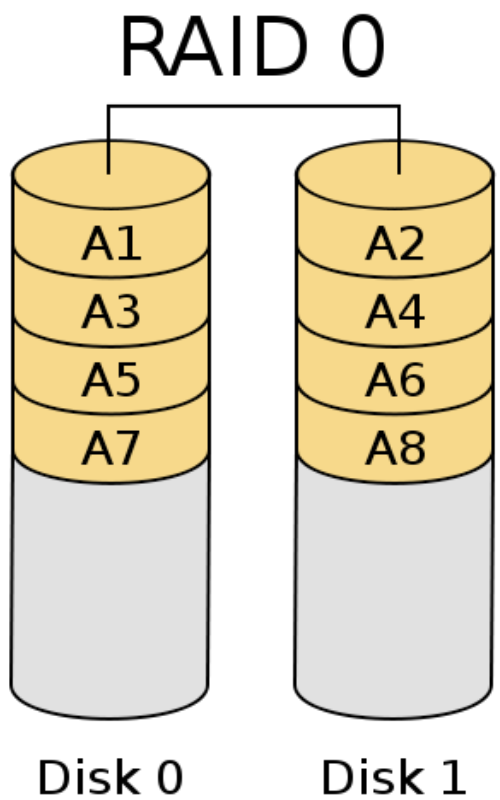
RAID (cont)

- RAID schemes improve performance and improve the reliability of the storage system by storing redundant data.
  - Data Striping: splitting each bit (or block) of a file across multiple disks.
  - Mirroring (shadowing): duplicate each disk
    - Simplest but most expensive approach
  - Block interleaved parity uses much less redundancy.



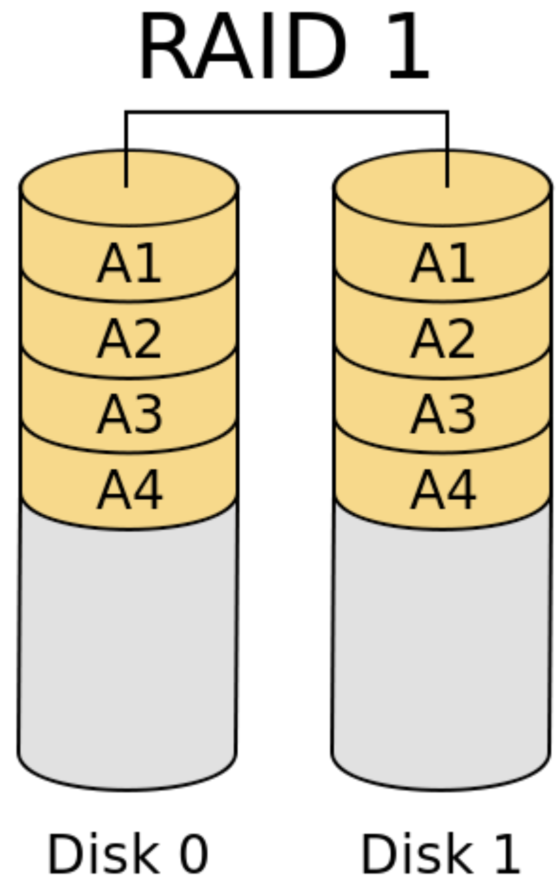
RAID Level 0

- Data is divided into blocks and is spread in a fixed order among all the disks in the array
- also known as disk striping
- + improves read and write performance via parallel access
- - does not provide any fault tolerance



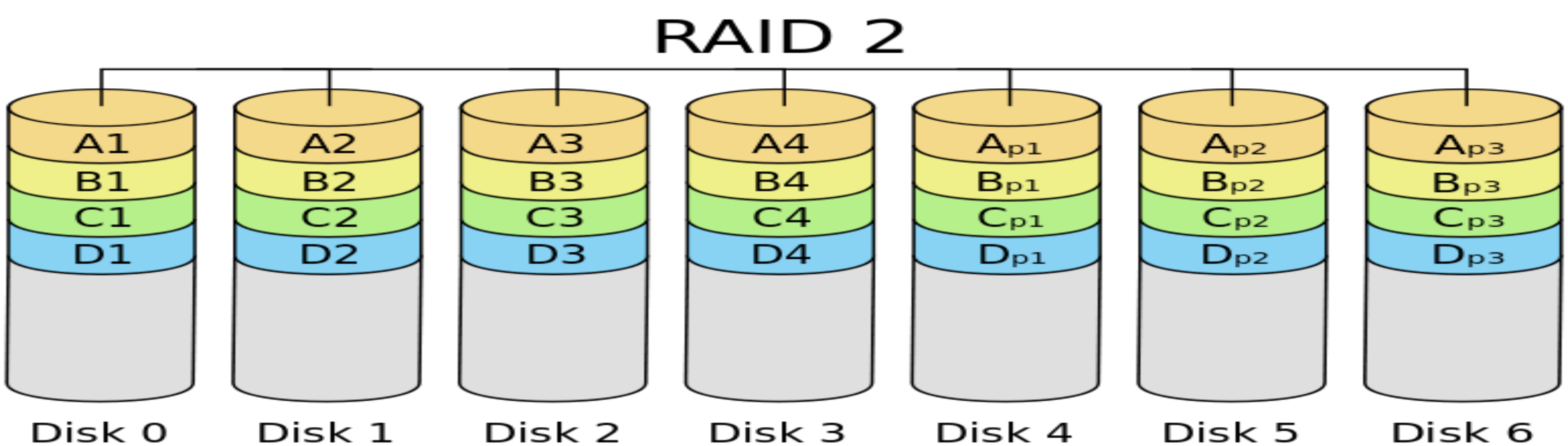
RAID Level 1

- All data written to the primary disk is written to the mirror disk
- provides a redundant, identical copy of all data
- also known as disk mirroring
- + provides fault tolerance
- + also generally improves read performance (but may degrade write performance)
- - doubles the storage requirement



RAID Level 2

- uses memory-style error correcting code (ECC) that employs disk-striping strategy that breaks a file into bits and spreads it across multiple disks
- Used Hamming Code (7,4) method requires three extra disks for four data disks



Hamming Code

- Linear error correcting code (named after its inventor - Richard Hamming)
- Hamming (7,4) -> 4 data bits, 3 parity bits
  - Can find and correct 1-bit errors
  - Can find but not correct 2-bit errors
- Hamming bits table:
  - $p1 = d1 \oplus d2 \oplus d4$
  - $p2 = d1 \oplus d3 \oplus d4$
  - $p3 = d2 \oplus d3 \oplus d4$

Bit position		1	2	3	4	5	6	7	
Encoded data bits		p1	p2	d1	p3	d2	d3	d4	
Parity bit coverage	p1	X		X		X		X	…
	p2		X	X			X	X	
	p3				X	X	X	X	

Example

Byte 1011 0001

Two data blocks, 1011 and 0001.

Expand the first block to 7 bits: _ _ 1 _ 0 1 1.

Bit 1 is 0, because b3+b5+b7 is even.

Bit 2 is 1, b3+b6+b7 is odd.

bit 4 is 0, because b5+b6+b7 is even.

Our 7 bit block is: 0 1 1 0 0 1 1

Repeat for right block giving 1 1 0 1 0 0 1

Examples

$$
\begin{array}{ccc}
\underline{\text{Data bits}} & & \underline{\text{Data + parity bits}} \\
(0\ 0\ 0\ 0) & \longrightarrow & (0\ 0\ 0\ 0\ 0\ 0\ 0) \\
(0\ 0\ 0\ 1) & \longrightarrow & (1\ 1\ 0\ 1\ 0\ 0\ 1) \\
(0\ 0\ 1\ 0) & \longrightarrow & (0\ 1\ 0\ 1\ 0\ 1\ 0) \\
(0\ 0\ 1\ 1) & \longrightarrow & (1\ 0\ 0\ 0\ 0\ 1\ 1) \\
(0\ 1\ 0\ 0) & \longrightarrow & (1\ 0\ 0\ 1\ 1\ 0\ 0) \\
(0\ 1\ 0\ 1) & \longrightarrow & (0\ 1\ 0\ 0\ 1\ 0\ 1) \\
(0\ 1\ 1\ 0) & \longrightarrow & (1\ 1\ 0\ 0\ 1\ 1\ 0) \\
(0\ 1\ 1\ 1) & \longrightarrow & (0\ 0\ 0\ 0\ 1\ 1\ 1) \\
 & \vdots &
\end{array}
$$

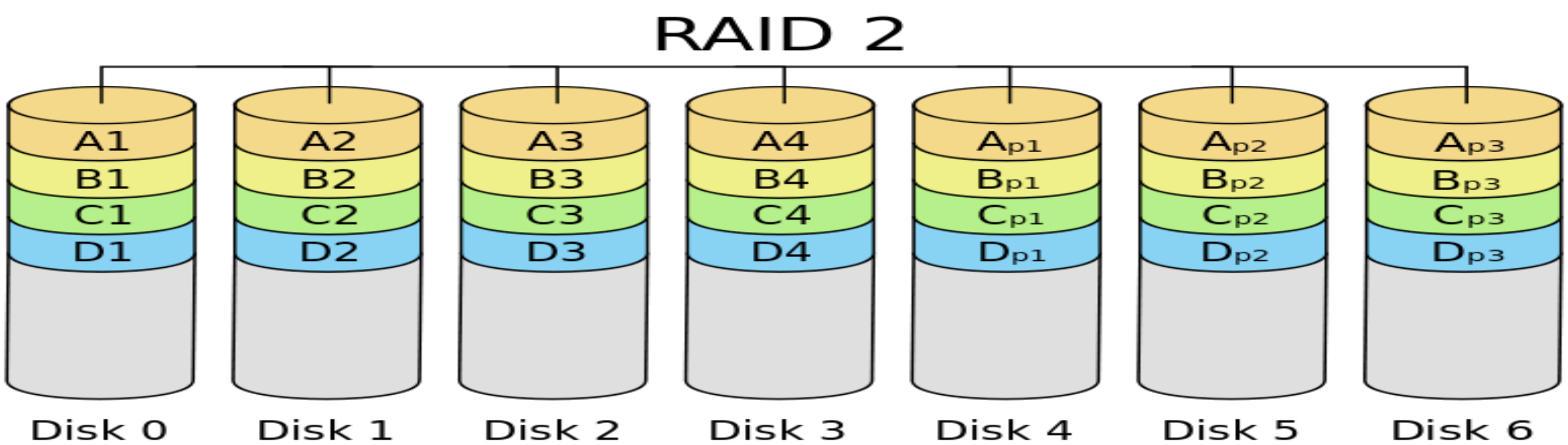
How to detect errors

- Check the parity bits, if they do not match, they will reveal the corrupted data bit:
  - p1 & p2 —> d1
  - p1 & p3 —> d2
  - p2 & p3 —> d3
  - p1 & p2 & p3 —> d4

Bit position		1	2	3	4	5	6	7	
Encoded data bits		p1	p2	d1	p3	d2	d3	d4	
Parity bit coverage	p1	X		X		X		X	...
	p2		X	X			X	X	
	p3				X	X	X	X	

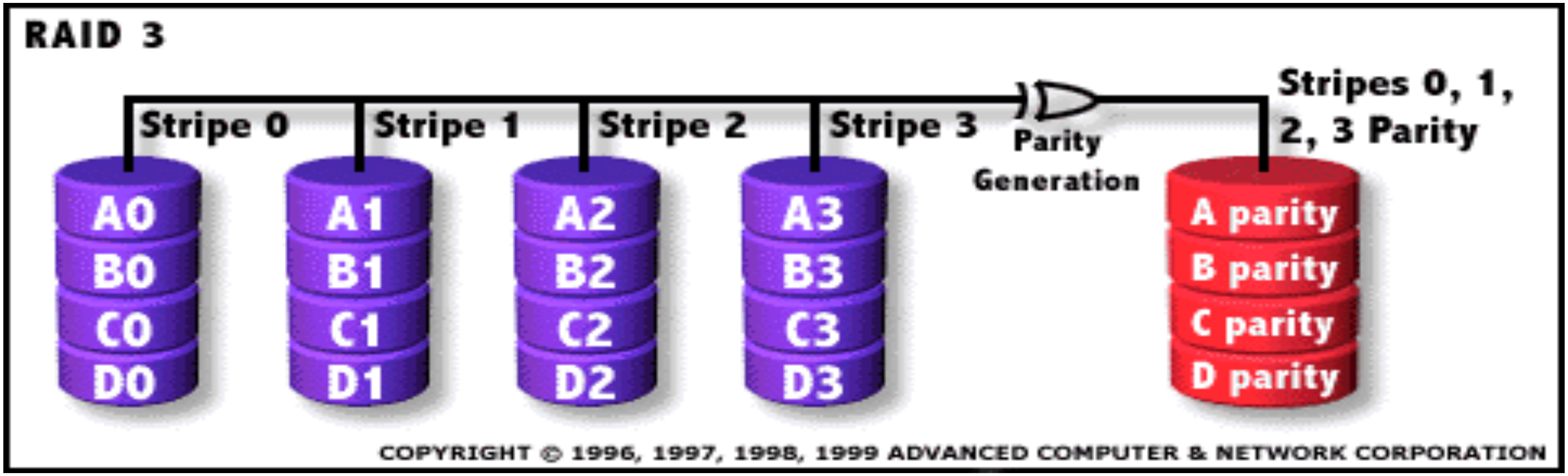
RAID Level 2 - wrap up

- + It provides fault tolerance
- - Commercially one of the most inefficient solutions
- - Overhead of Hamming code calculation slows down data access rates
- - Almost doubles the storage requirement



RAID Level 3

- it uses byte-level striping
- \+ requires only one disk for parity for 4 data disks
- \- suffers from a write bottleneck, because all parity data is written to a single drive
- \- RAID 2 & 3 cannot serve multiple requests simultaneously



Parity Block Calculation (using XOR)

- Parity block: Block1 xor block2 xor block3 ...

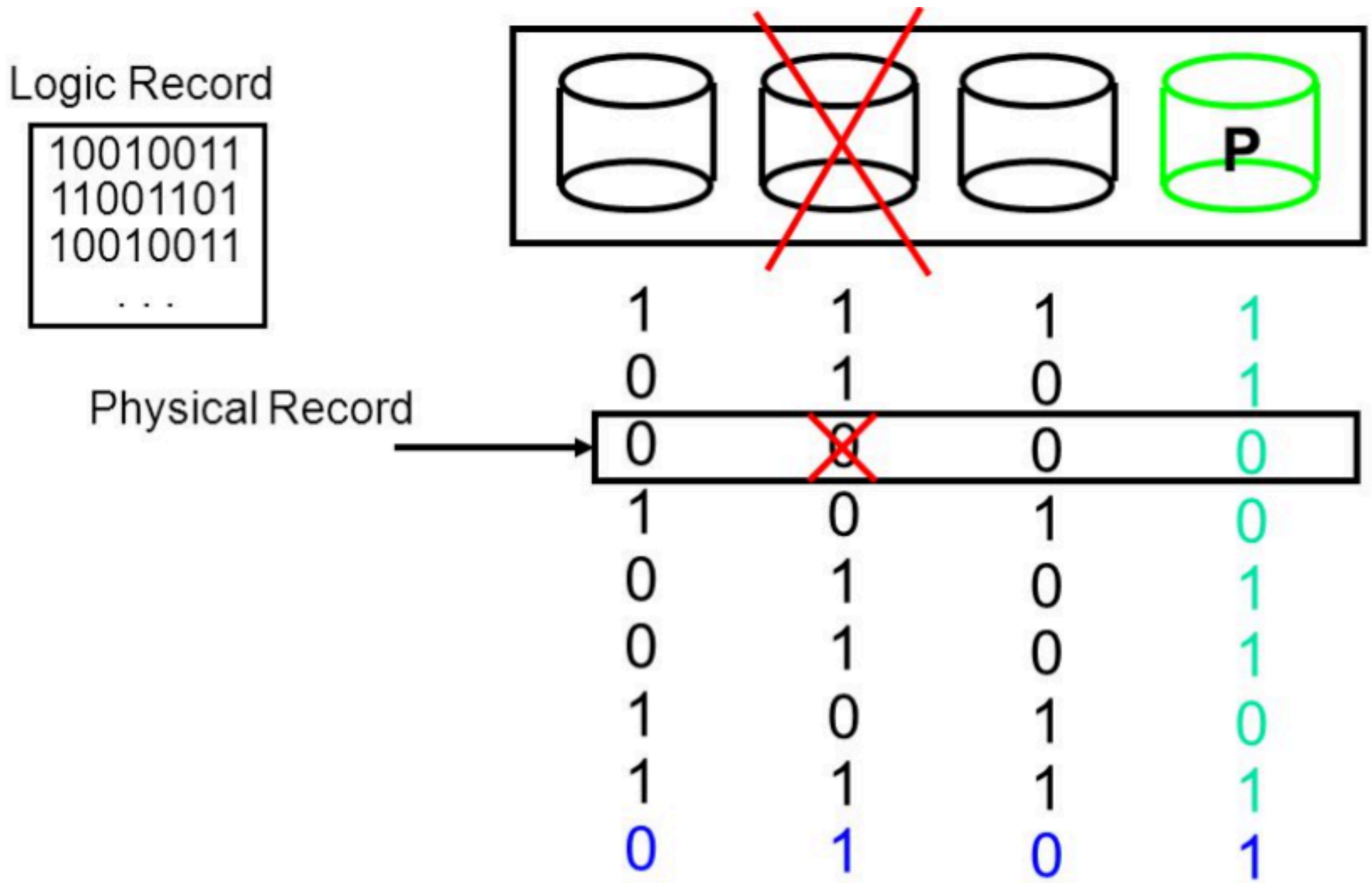
10001101	block1
01101100	block2
11000110	block3

00100111	parity block

- Can reconstruct any missing block from the others

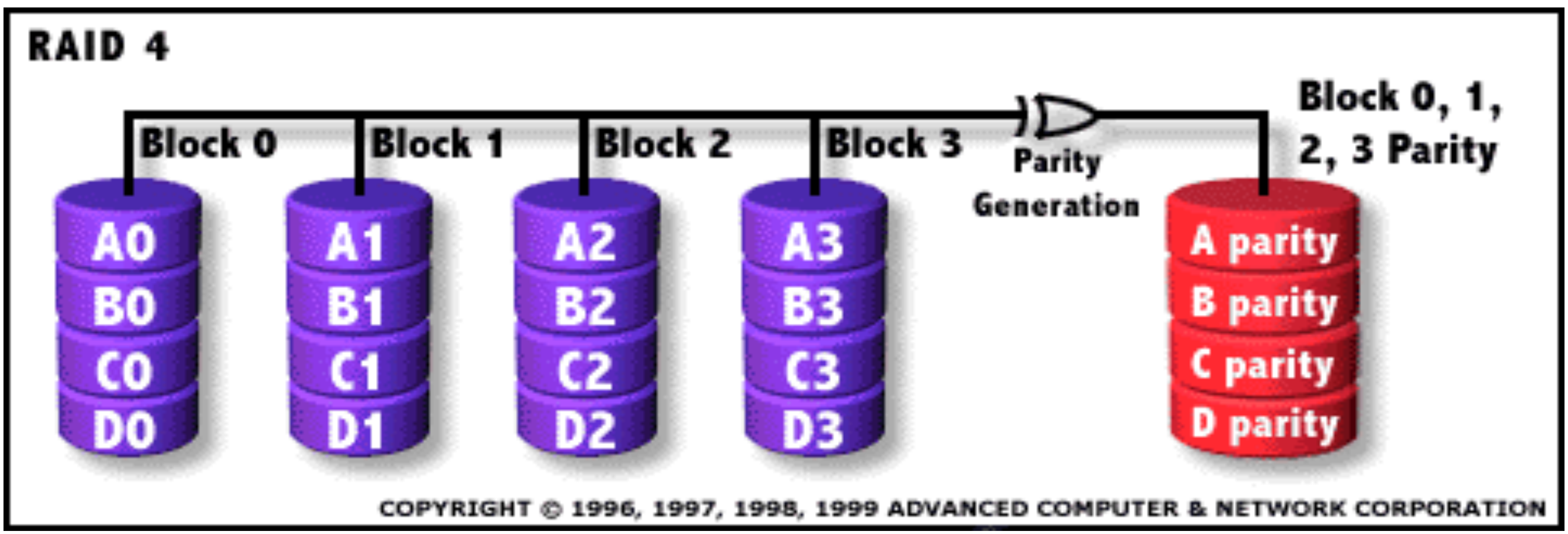
RAID 3 - Example

- ECC is not required, since the controller knows which disk has failed. So parity is enough to recover the failing disk.



RAID Level 4

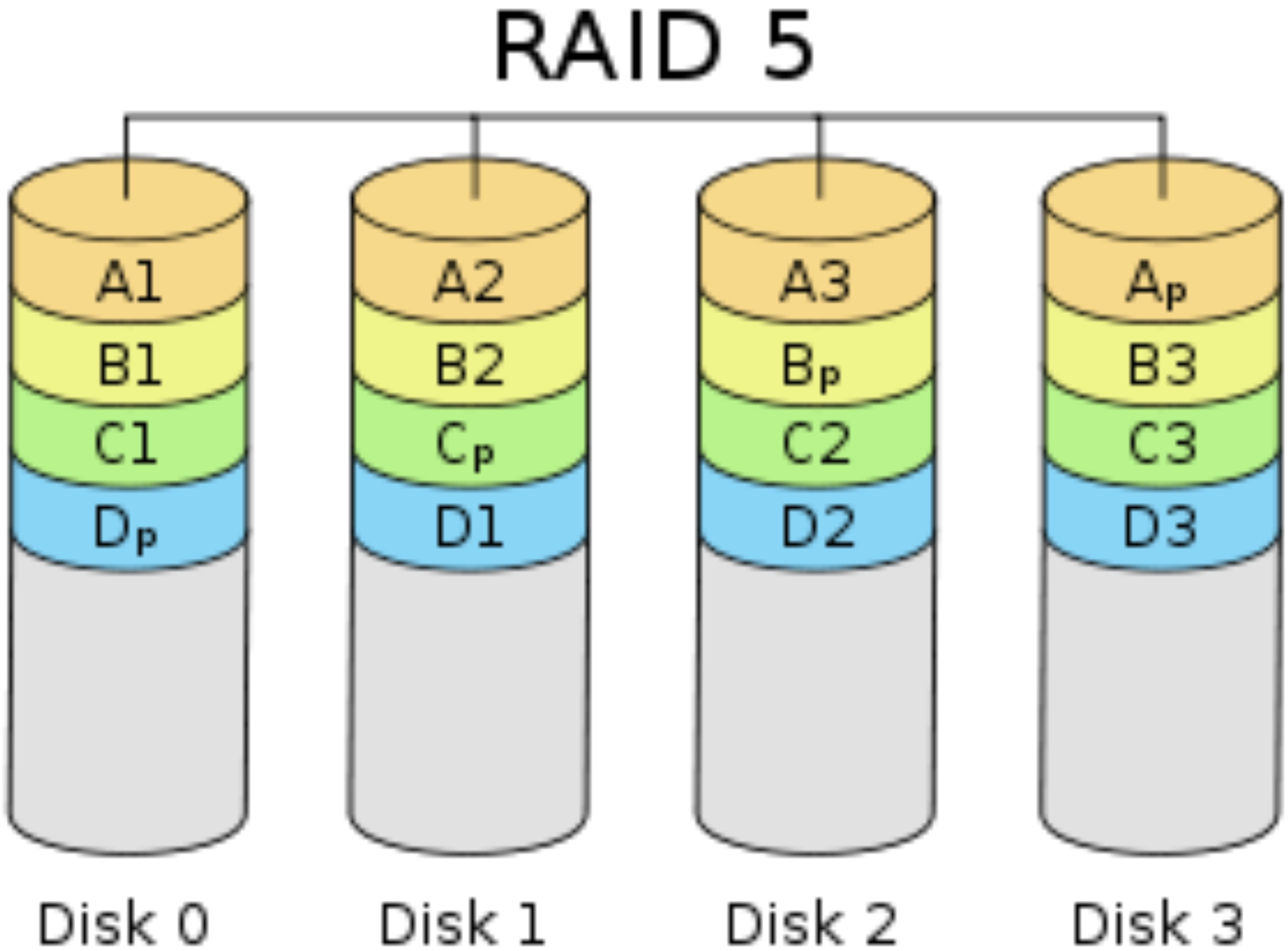
- Similar to RAID level 3, but it employs striped data in much larger blocks or segments
- - RAID level 4 suffers from a write bottleneck (due to parity disk).
- - Not as efficient as RAID level 5, because (as in RAID level 3) all parity data is written to a single drive



RAID Level 5

- known as striping with parity
- the most popular RAID level, replaced RAID 3 & 4
- similar to level 4 in that it stripes the data in large blocks across all the disks in the array
- It differs in that it writes the parity across all the disks
- The data redundancy is provided by the parity information
- The data and parity information are arranged on the disk array so that the two are always on different disks

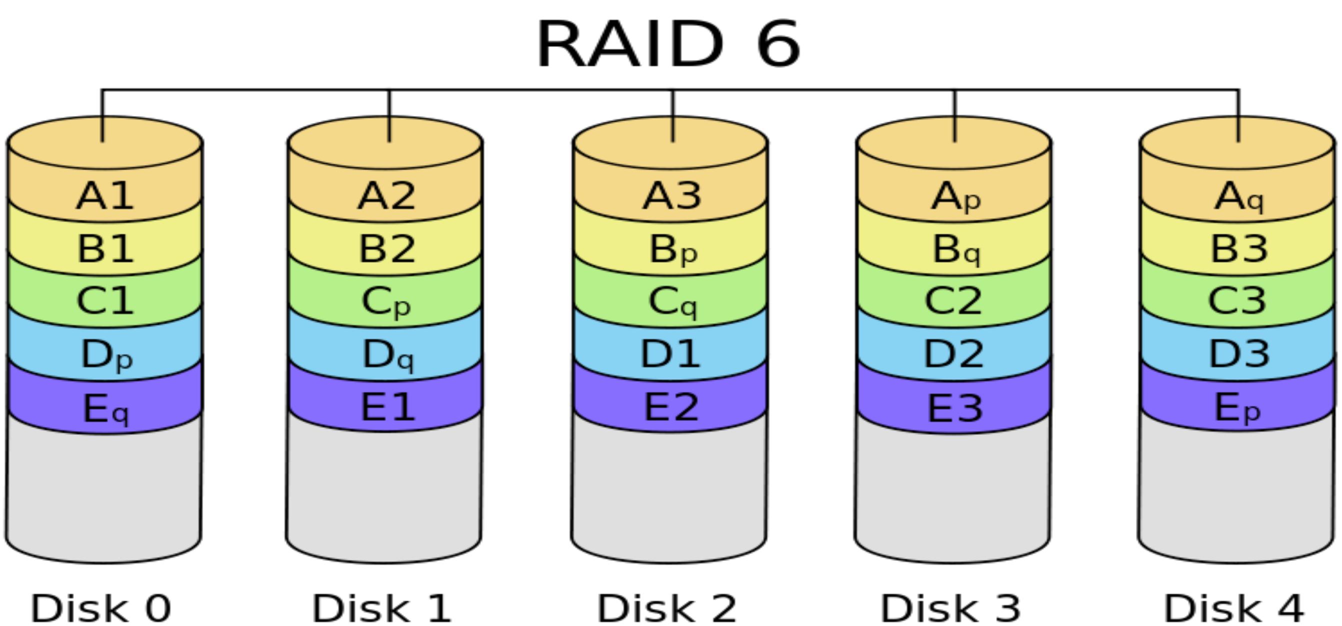
RAID Level 5


RAID 5
A1
A2
A3
Ap
B1
B2
Bp
B3
C1
Cp
C2
C3
Dp
D1
D2
D3
Disk 0
Disk 1
Disk 2
Disk 3

:

RAID Level 6

- stores extra redundant info to recover from multiple disk failures
- would need 2 additional disks for each 4 data disks
  - more reliability versus less data space
- uses Reed-Solomon error correcting code



RAID Level 6 - dual parity

Drive 1	Drive 2	Drive 3	Drive 4	Drive 5
D0	D1	D2	P0	Q0
D3	D4	P1	Q1	D5
D6	P2	Q2	D7	D8
P3	Q3	D9	D10	D11
⋮				⋮

(Dx: Data Block; Px: Parity of data; Qx: Q parity of data)

P0 = D0 XOR D1 XOR D2;
P1 = D3 XOR D4 XOR D5;
P2 = D6 XOR D7 XOR D8;
P3 = D9 XOR D10 XOR D11;
⋮

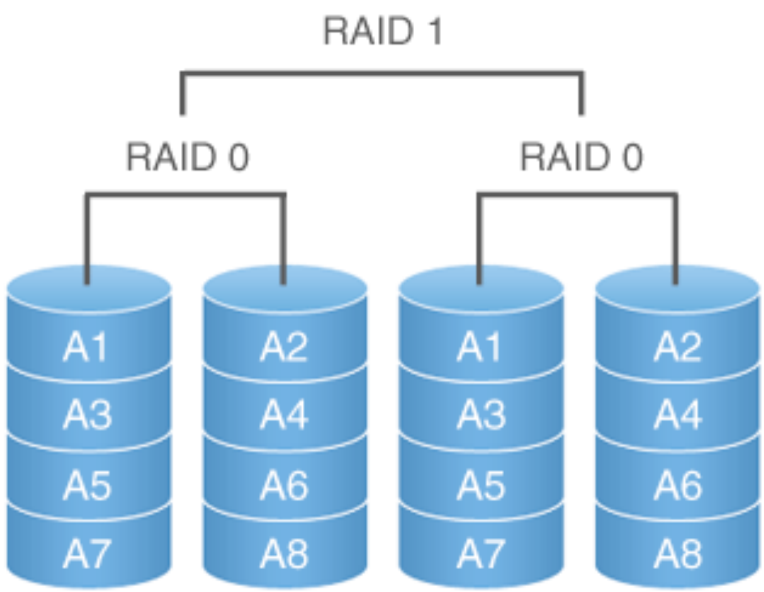
Q0 = GF(D0) XOR GF(D1) XOR GF(D2) ;
Q1 = GF(D3) XOR GF(D4) XOR GF(D5) ;
Q2 = GF(D6) XOR GF(D7) XOR GF(D8) ;
Q3 = GF(D9) XOR GF(D10) XOR GF(D11) ;
⋮

**GF() is Reed-Solomon transformation function;*

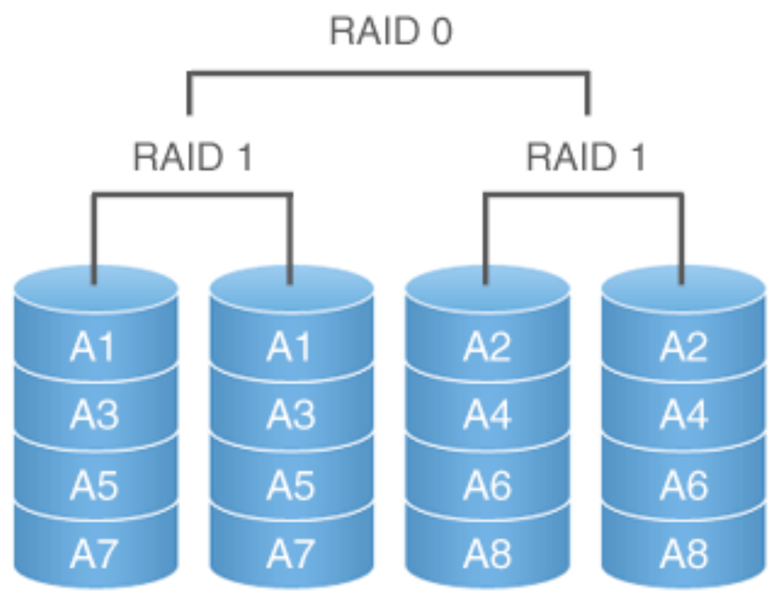
RAID (0+1) and (1+0)

- Combination of RAID 0 & 1
- better performance & reliability, but doubles the disk storage requirement

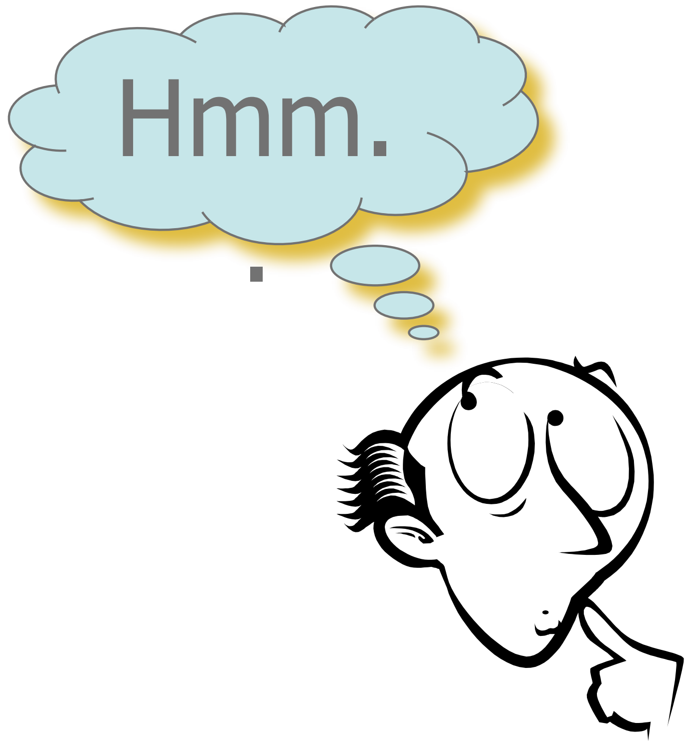
RAID 01 (0+1)



RAID 10 (1+0)



Any Questions?



Acknowledgements

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