Other Disk Details

Disk Formatting

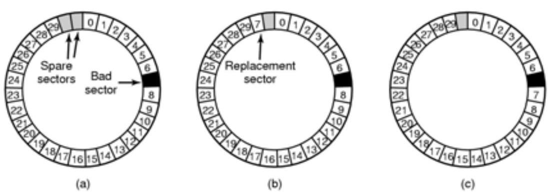
- After manufacturing disk has no information
  - Is stack of platters coated with magnetizable metal oxide
- Before use, each platter receives low-level format
  - Format has series of concentric tracks
  - Each track contains some sectors
  - There is a short gap between sectors

Preamble	Data	ECC

- Preamble allows h/w to recognize start of sector
  - Also contains cylinder and sector numbers
  - Data is usually 512 bytes
  - ECC field used to detect and recover from read errors

Handling Errors

- A disk track with a bad sector
- Solutions:
  - Substitute a spare for the bad sector (sector sparing)
  - Shift all sectors to bypass bad one (sector forwarding)



RAID Motivation

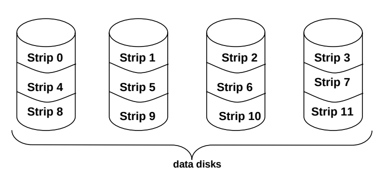
- Disks are improving, but not as fast as CPUs
  - 1970s seek time: 50-100 ms.
  - 2000s seek time: <5 ms.
  - Factor of 20 improvement in 3 decades
- We can use multiple disks for improving performance
  - By <u>striping</u> files across multiple disks (placing parts of each file on a different disk), parallel I/O can improve access time
- Striping reduces reliability
  - 100 disks have 1/100th mean time between failures of one disk
- So, we need striping for performance, but we need something to help with reliability / availability
- To improve reliability, we can add redundant data to the disks, in addition to striping

RAID

- A RAID is a Redundant Array of Inexpensive Disks
  - In industry, "I" is for "Independent"
  - The alternative is SLED, single large expensive disk
- Disks are small and cheap, so it's easy to put lots of disks (10s to 100s) in one box for increased storage, performance, and availability
- The RAID box with a RAID controller looks just like a SLED to the computer
- Data plus some redundant information is striped across the disks in some way
- How that striping is done is key to performance and reliability.

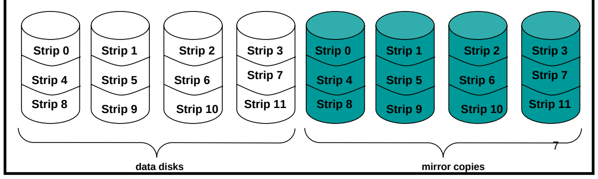
Raid Level 0

- Level 0 is <u>nonredundant</u> disk array
- Files are striped across disks, no redundant info
- High read throughput
- Best write throughput (no redundant info to write)
- Any disk failure results in data loss
  - Reliability worse than SLED



Raid Level 1

- Mirrored Disks
- Data is written to two places
  - On failure, just use surviving disk
- On read, choose fastest to read
  - Write performance is same as single drive, read performance is 2x better
- Expensive



Parity and Hamming Code

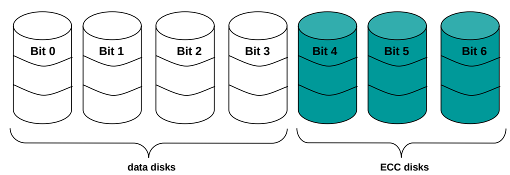
- What do you need to do in order to detect and correct a one-bit error ?
  - Suppose you have a binary number, represented as a collection of bits: <b3, b2, b1, b0>, e.g. 0110
- Detection is easy
- Parity:
  - Count the number of bits that are on, see if it's odd or even
    - EVEN parity is 0 if the number of 1 bits is even
  - Parity(<b3, b2, b1, b0 >) = P0 = b0 ⊗ b1 ⊗ b2 ⊗ b3
  - Parity(<b3, b2, b1, b0, p0>) = 0 if all bits are intact
  - Parity(0110) = 0, Parity(01100) = 0
  - Parity(11100) = 1 => ERROR!
  - Parity can detect a single error, but can't tell you which of the bits got flipped

Parity and Hamming Code

- Detection and correction require more work
- Hamming codes can detect double bit errors and detect & correct single bit errors
- 7/4 Hamming Code
  - h0 = b0 ⊗ b1 ⊗ b3
  - h1 = b0 ⊗ b2 ⊗ b3
  - h2 = b1 ⊗ b2 ⊗ b3
  - H0(<1101>) = 0
  - H1(<1101>) = 1
  - H2(<1101>) = 0
  - Hamming(<1101>) = <b3, b2, b1, h2, b0, h1, h0> = <1100110>
  - If a bit is flipped, e.g. <1110110>
  - Hamming(<1111>) = <h2, h1, h0> = <111> compared to <010>, <101> are in error. Error occurred in bit 5.

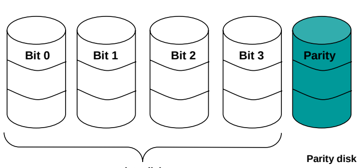
Raid Level 2

- Bit-level striping with Hamming (ECC) codes for error correction
- All 7 disk arms are synchronized and move in unison
- Complicated controller
- Single access at a time
- Tolerates only one error, but with no performance degradation



Raid Level 3

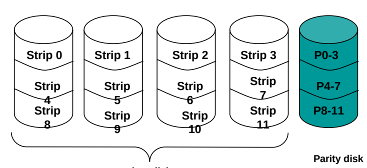
- Use a parity disk
  - Each bit on the parity disk is a parity function of the corresponding bits on all the other disks
- A read accesses all the data disks
- A write accesses all data disks <u>plus</u> the parity disk
- On disk failure, read remaining disks plus parity disk to compute the missing data



Single parity disk can be used to detect and <u>correct</u> errors

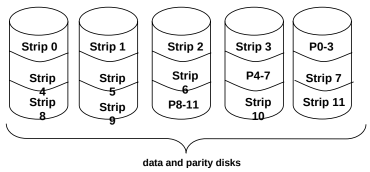
Raid Level 4

- Combines Level 0 and 3 – block-level parity with stripes
- A read accesses all the data disks
- A write accesses all data disks <u>plus</u> the parity disk
- Heavy load on the parity disk



Raid Level 5

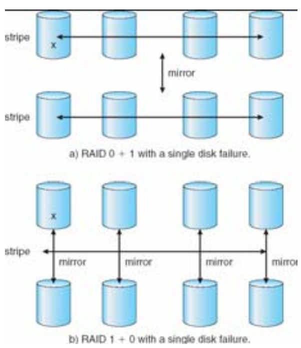
- Block Interleaved Distributed Parity
- Like parity scheme, but distribute the parity info over all disks (as well as data over all disks)
- Better read performance, large write performance
  - Reads can outperform SLEDs and RAID-0



Raid Level 6

- Level 5 with an extra parity bit
- Can tolerate two failures
  - What are the odds of having two concurrent failures ?
- May outperform Level-5 on reads, slower on writes

RAID 0+1 and 1+0



Stable Storage

- Handling disk write errors:
  - Write lays down bad data
  - Crash during a write corrupts original data
- What we want to achieve? Stable Storage
  - When a write is issued, the disk either correctly writes data, or it does nothing, leaving existing data intact
- Model:
  - An incorrect disk write can be detected by looking at the ECC
  - It is very rare that same sector goes bad on multiple disks
  - CPU is fail-stop

Approach

- Use 2 identical disks
  - corresponding blocks on both drives are the same
- 3 operations:
  - Stable write: retry on 1st until successful, then try 2nd disk
  - Stable read: read from 1st. If ECC error, then try 2nd
  - Crash recovery: scan corresponding blocks on both disks
    - If one block is bad, replace with good one
    - If both are good, replace block in 2nd with the one in 1st