Failures in hard disks and SSDs

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Slides include material from Vince Freeh (NCSU), some material adapted from “Hard-Disk Drives: The Good, the Bad, and the Ugly” by Jon Elerath (Comm. ACM, Vol. 52 No. 6, Pages 38-45)
HDD/SSD failures

- Hard disks are the weak link
  - A mechanical system in a silicon world!
- SSDs better, but still fallible

- RAID: Redundant Array of Independent Disks
  - Helps compensate for the device-level problems
  - Increases reliability and performance
  - Will be discussed in depth later
Failure modes

• Failure: cannot access the data
• Operational: faults detected when they occur
  • Does not return data
  • Easy to detect
  • Low rates of occurrence
• Latent: undetected fault, only found when it’s too late
  • Returned data is corrupt
  • Hard to detect
  • Relatively high rates of occurrence
Fault tree for HDD

To learn more about individual failure modes for HDD, see "Hard-Disk Drives: The Good, the Bad, and the Ugly" by Jon Elerath (Comm. ACM, Vol. 52 No. 6, Pages 38-45)
Fault tree for SSD

- Controller failure
- Whole flash chip failure

Operational Failures

Cannot find data

Latent Failures

Data missing

Loss of gate state over time ("bit rot") – gate lost its current data (due to time or adjacent writes)

Degradation loss due to write cycles (probabilistic) – gate lost ability to ever hold data

Error during writing

Written but destroyed
What to do about failure

- Pull disk out
- Throw away
- Restore its data from parity (RAID) or backup
The danger of latent errors

• Operational errors:
  • Detected as soon as they happen
  • When you detect an operational error, the total number of errors is likely one

• Latent errors:
  • Accrue in secret over time!
  • In the darkness, little by little, your data is quietly corrupted
  • When you detect a latent error, the total number of errors is likely many

• In the intensive I/O of reconstructing data lost due to latent errors, more likely to encounter operational error
  • Now you’ve got multiple drive failure, data loss more likely
Minimizing latent errors

- Catch latent errors earlier (so fewer can accrue) with this highly advanced and complex algorithm known as **Disk Scrubbing**:

  Periodically, read everything
## Disk reliability

- **MTBF (Mean Time Between Failure):** a useless lie you can ignore

### Specifications

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<th>8TB</th>
<th>6TB</th>
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<th>4TB</th>
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</table>

### Performance

- **Data transfer rate (max)**
  - Interface speed: 6 Gb/s
  - Internal transfer rate: 178 MB/s
- **Cache (MB)**: 128
- **Performance Class**: 5400 RPM Class
- **Reliability/Data Integrity**
  - Load/unload cycles: 600,000
  - Non-recoverable read errors per bits read:
    - <1 in 10^14
- **MTBF (hours)**: 1,000,000
- **Limited warranty (years)**: 3

### Example Calculation

$1,000,000 \text{ hours} = 114 \text{ years}$

“**Our drives fail after around a century of continuous use.**”

-- A Huge Liar
Data from BackBlaze

- **BackBlaze**: a large scale backup provider
  - Consumes thousands of hard drives, publishes *health data on all of them publically*
  - **Data presented** is a little old – newer data exists (but didn’t come with pretty graphs)
- Other large-scale studies of drive reliability:
  - “Failure Trends in a Large Disk Drive Population” by Pinheiro et al (Google), FAST’07
  - “Disk Failures in the Real World: What Does an MTTF of 1,000,000 Hours Mean to You?” by Schroeder et al (CMU), FAST’07
General Predicted Failure Rates

- Decreasing Failure Rate
- Constant Failure Rate
- Increasing Failure Rate

Failure Rate

- Observed Failure Rate
- Early "Infant Mortality" Failure
- Constant (Random) Failures
- Wear Out Failures

Time
Annual Failure Rate Each Quarter

![Graph showing annual failure rate per quarter. The x-axis represents the quarter, and the y-axis represents the annual failure rate. The highest failure rate is in the third quarter.]
Interesting observation: The industry standard warranty period is 3 years...
80% of Drives Last Four Years

Hard Drive Survival Rates - Chart 2

Survival Rate

80% drives live

Year

1

2

3

4
Annual Failure Rate

- HITACHI
- Seagate
- WD
- Western Digital

Storage Capacity (TB): 2TB, 3TB, 4TB, 1.5TB, 3TB, 4TB, 1TB, 3TB
What about SSDs?

- From recent paper at FAST’16: “Flash Reliability in Production: The Expected and the Unexpected” by Schroeder et al (feat. data from Google)

**KEY CONCLUSIONS**

- Ignore Uncorrectable Bit Error Rate (UBER) specs. A meaningless number.
- **Good news:** Raw Bit Error Rate (RBER) increases slower than expected from wearout and is not correlated with UBER or other failures.
- High-end SLC drives are no more reliable that MLC drives.
- **Bad news:** SSDs fail at a lower rate than disks, but UBER rate is higher (see below for what this means).

**SSD age, not usage, affects reliability.**

- Bad blocks in new SSDs are common, and drives with a large number of bad blocks are much more likely to lose hundreds of other blocks, most likely due to die or chip failure.
- 30-80 percent of SSDs develop at least one bad block and 2-7 percent develop at least one bad chip in the first four years of deployment.

Drive replacements

- Percentage of drives replaced annually due to suspected hardware problems over the first 4 years in the field:

\[ \text{Average annual replacement rates for hard disks} \ (2\% - 20\%) \]

- ~1-2% of drives replaced annually, much lower than hard disks!
- 0.5-1.5% of drives developed bad chips per year
  - Would have been replaced without methods for tolerating chip failure
Errors experienced during a drive’s lifecycle

- Non-transparent errors common:
  - 26-60% of drives with uncorrectable errors
  - 2-6 out of 1,000 drive days experience uncorrectable errors
  - Much worse than for hard disk drives (3.5% experiencing sector errors)
Overall conclusions on drive health

• HDD:
  • Usually just die, sometimes have undetected bit errors.
  • Need to protect against drive data loss!

• SSD:
  • Usually have undetected bit errors, sometimes just die.
  • Need to protect against drive data loss!

• Overall conclusion?
  
  Need to protect against drive data loss!