ECE590-03
Enterprise Storage Architecture

Fall 2016

Failures in hard disks and SSDs

Tyler Bletsch

Duke University

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

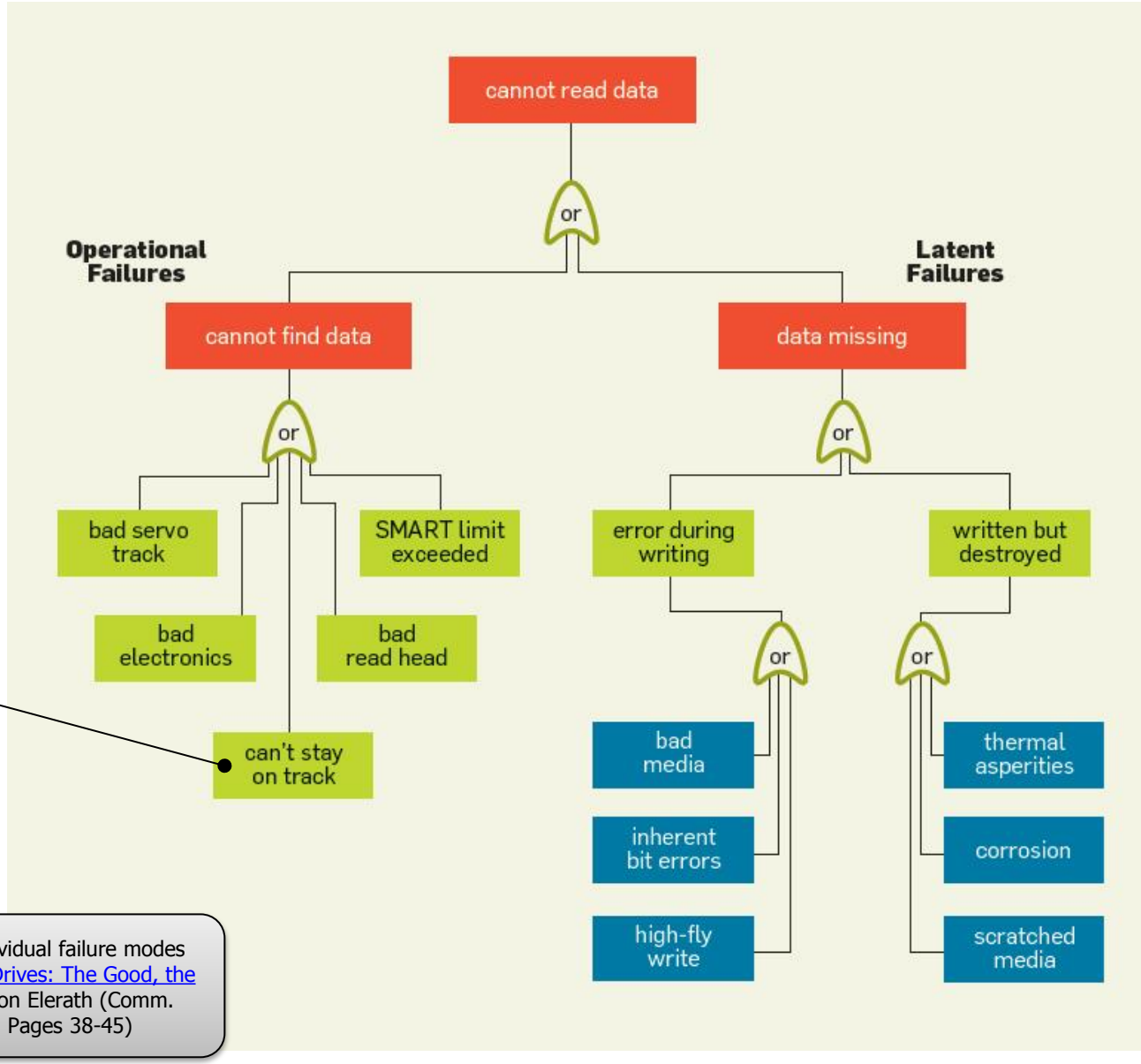
- Hard disks are the weak link
  - A mechanical system in a silicon world!
- SSDs better, but still fallible

- 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

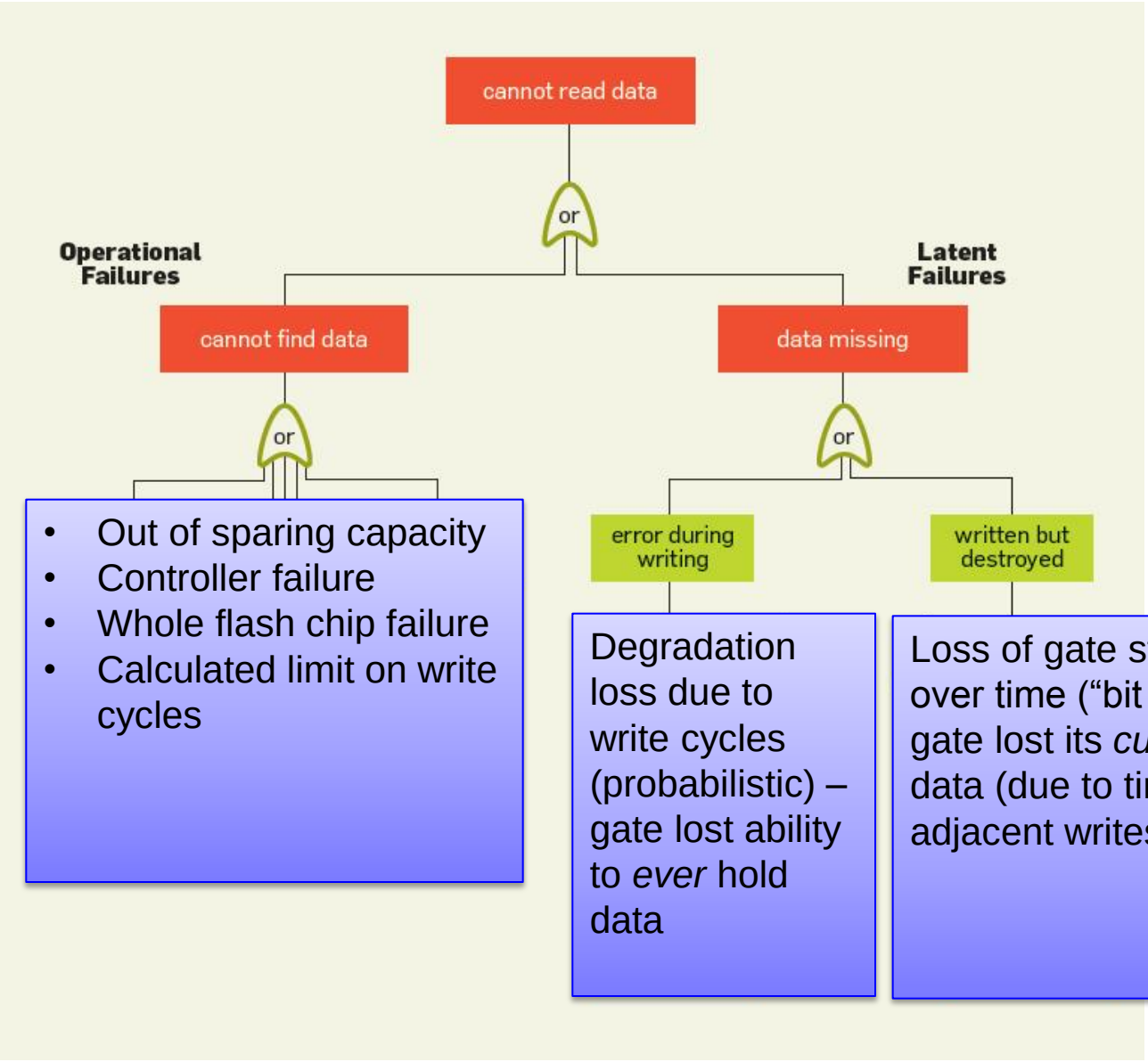
- Failure: cannot access the data
- Operational: faults detected when they occur
  - Does not return data
  - Easy to detect
  - Low rates of occurrence
- Latent: undetected fault, only found when it's too late
  - Returned data is corrupt
  - Hard to detect
  - Relatively high rates of occurrence

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



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

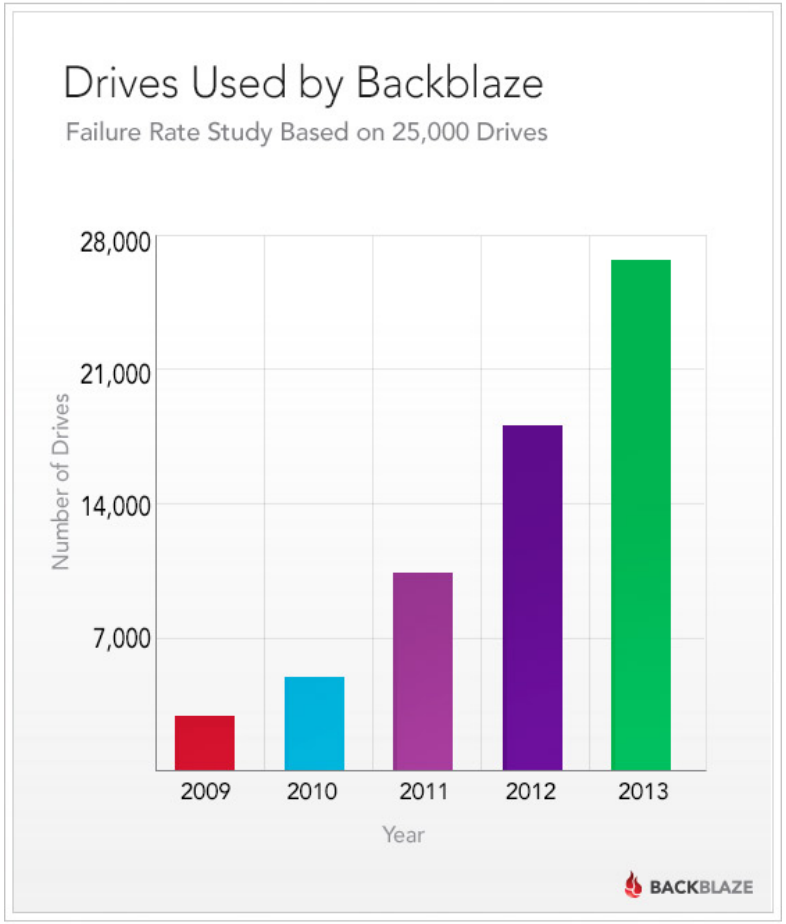
Specifications	8TB	6TB	5TB	4TB	3TB	2TB	1TB
Model number[1]	WD80EFZX	WD60EFRX	WD50EFRX	WD40EFRX	WD30EFRX	WD20EFRX	WD10EFRX
Interface	SATA 6 Gb/s	SATA 6 Gb/s	SATA 6 Gb/s	SATA 6 Gb/s	SATA 6 Gb/s	SATA 6 Gb/s	SATA 6 Gb/s
Formatted capacity[2]	8TB	6TB	5TB	4TB	3TB	2TB	1TB
Form factor	3.5-inch	3.5-inch	3.5-inch	3.5-inch	3.5-inch	3.5-inch	3.5-inch
Advanced Format (AF)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Native command queuing	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RoHS compliant[3]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Performance							
Data transfer rate (max) Interface speed Internal transfer rate	 6 Gb/s 178 MB/s	 6 Gb/s 175 MB/s	 6 Gb/s 170 MB/s	 6 Gb/s 150 MB/s	 6 Gb/s 147 MB/s	 6 Gb/s 147 MB/s	 6 Gb/s 150 MB/s
Cache (MB)	128	64	64	64	64	64	64
Performance Class	5400 RPM Class	5400 RPM Class	5400 RPM Class	5400 RPM Class	5400 RPM Class	5400 RPM Class	5400 RPM Class
Reliability/Data Integrity							
Load/unload cycles[4]	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Non-recoverable read errors per bits read	<1 in 10^{14}	<1 in 10^{14}	<1 in 10^{14}	<1 in 10^{14}	<1 in 10^{14}	<1 in 10^{14}	<1 in 10^{14}
MTBF (hours)[5]	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Limited warranty (years)[6]	3	3	3	3	3	3	3

1,000,000 hours = 114 years

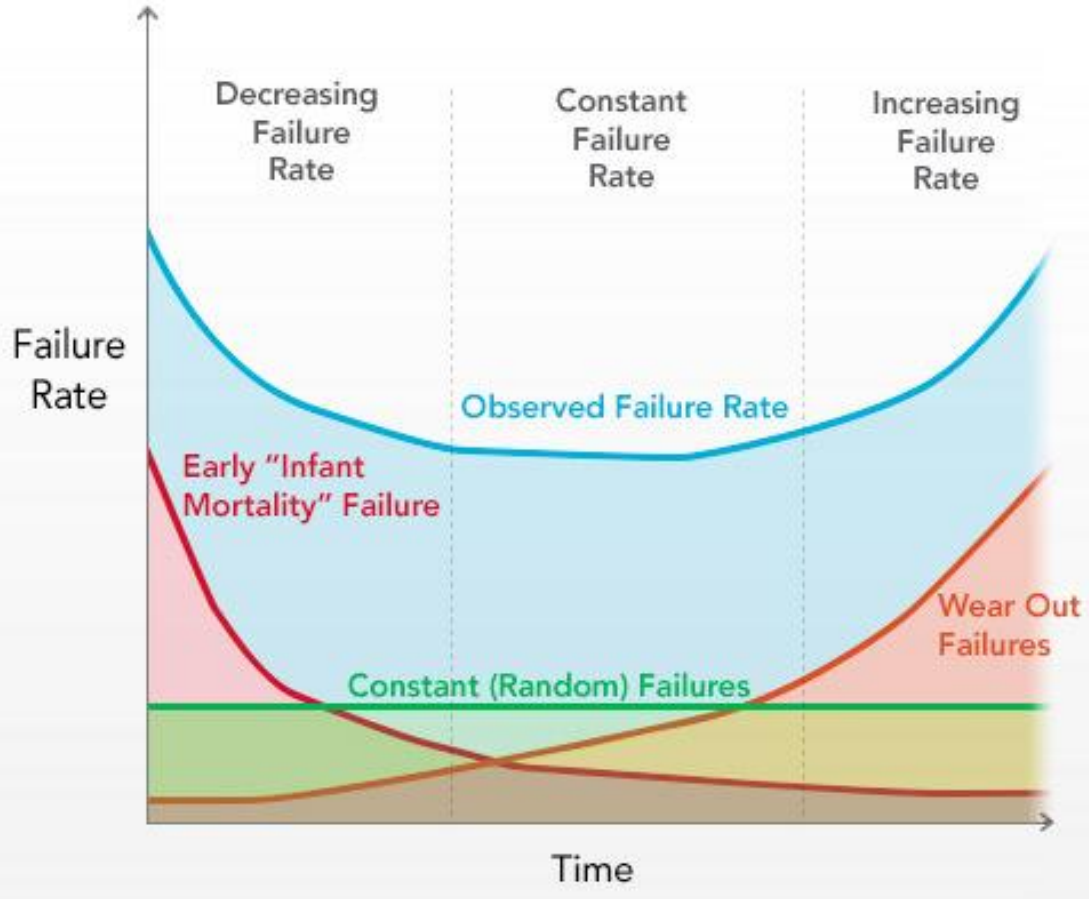
"Our drives fail after around century of continuous use."
-- A Huge Liar

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

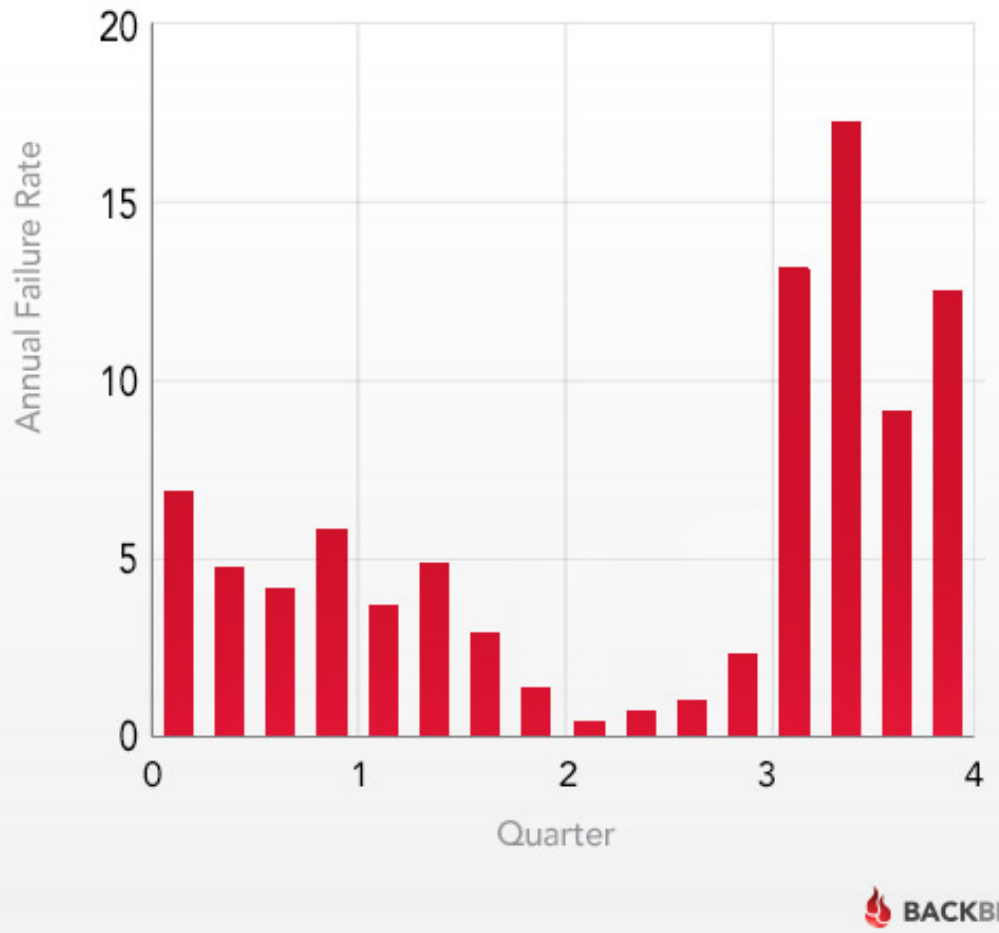


General Predicted Failure Rates



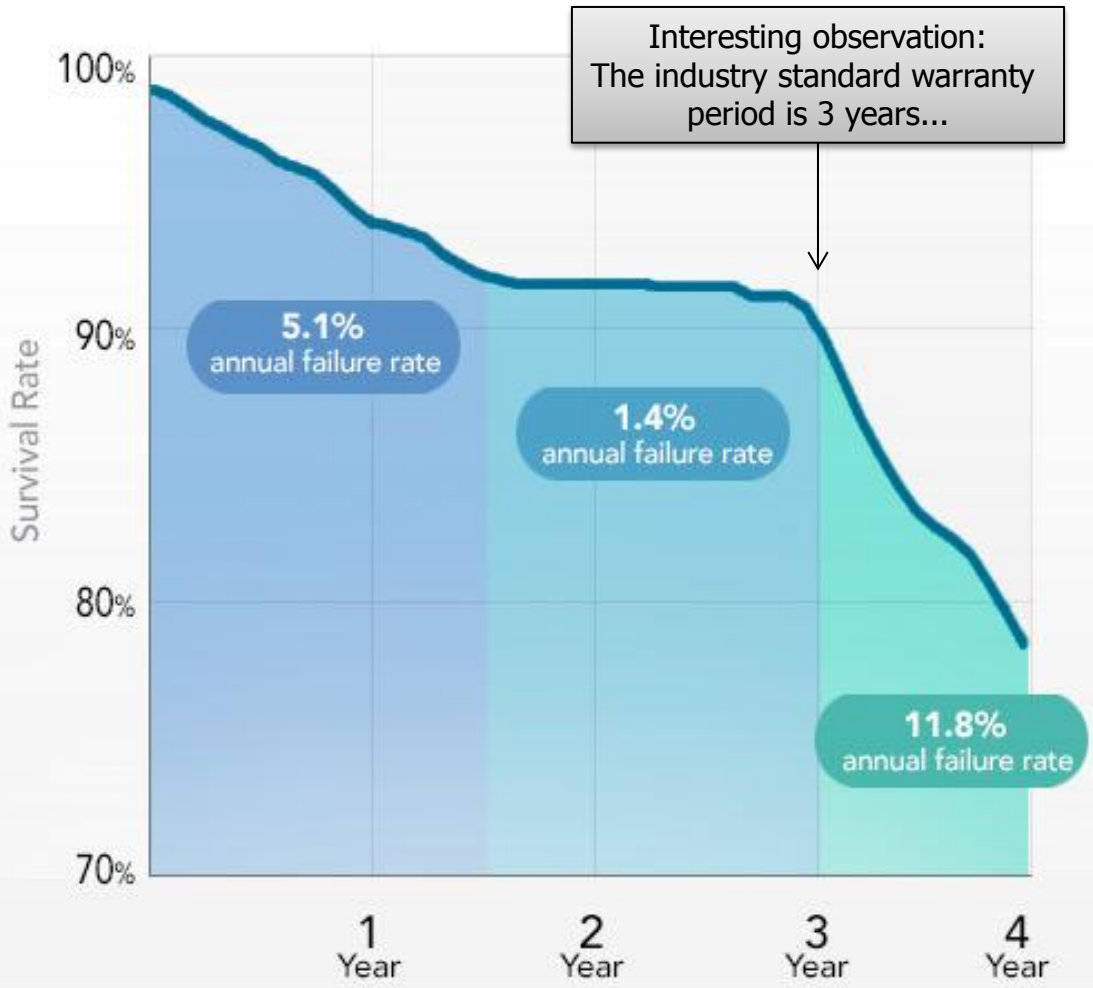
BACKBLAZE

Annual Failure Rate Each Quarter



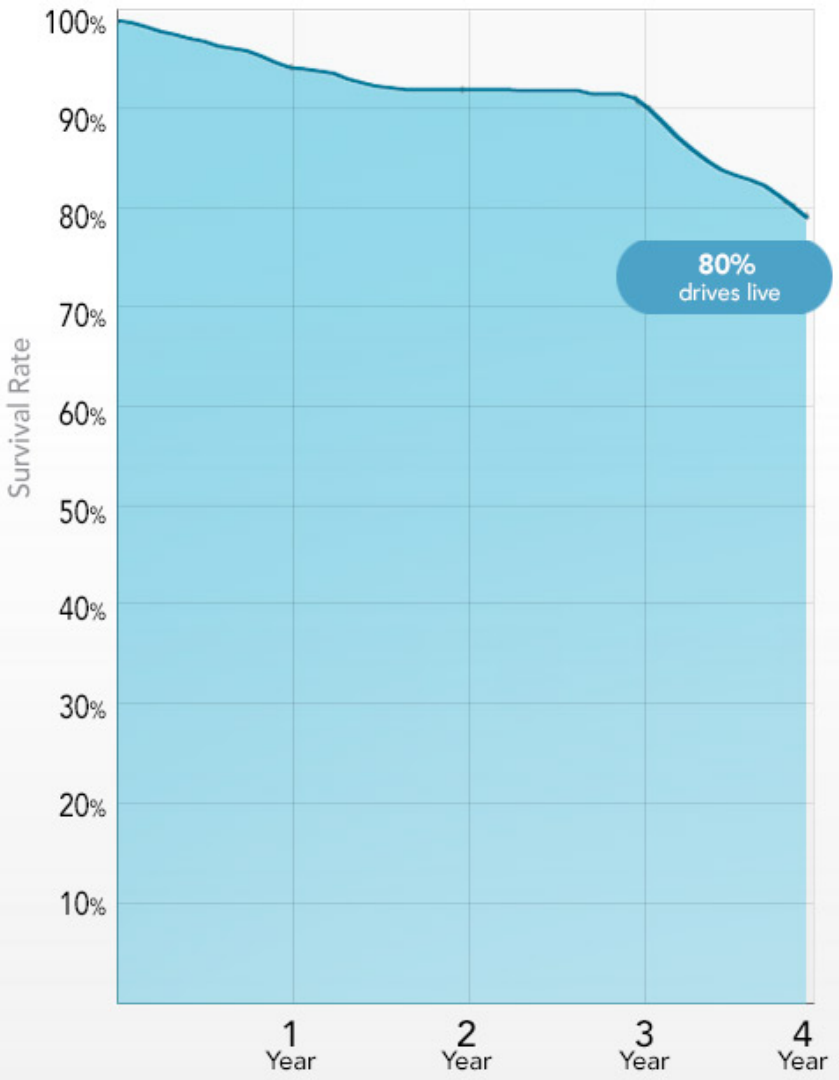
Drives Have 3 Distinct Failure Rates

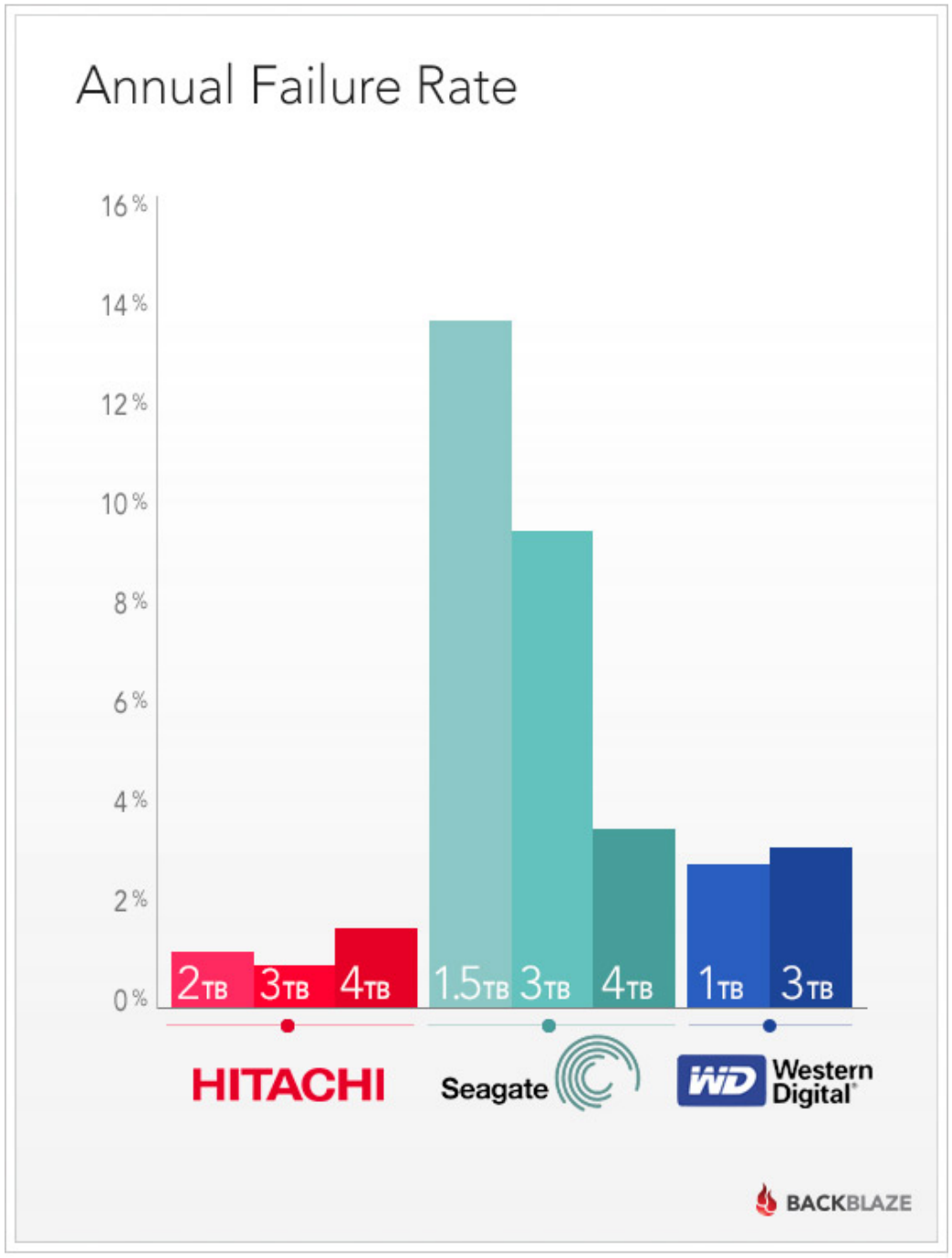
Hard Drive Survival Rates - Chart 1



80% of Drives Last Four Years

Hard Drive Survival Rates - Chart 2




Annual Failure Rate
16 %
14 %
12 %
10 %
8 %
6 %
4 %
2 %
0 %
2TB
3TB
4TB
1.5TB
3TB
4TB
1TB
3TB
HITACHI
Seagate
WD
Western Digital
BACKBLAZE

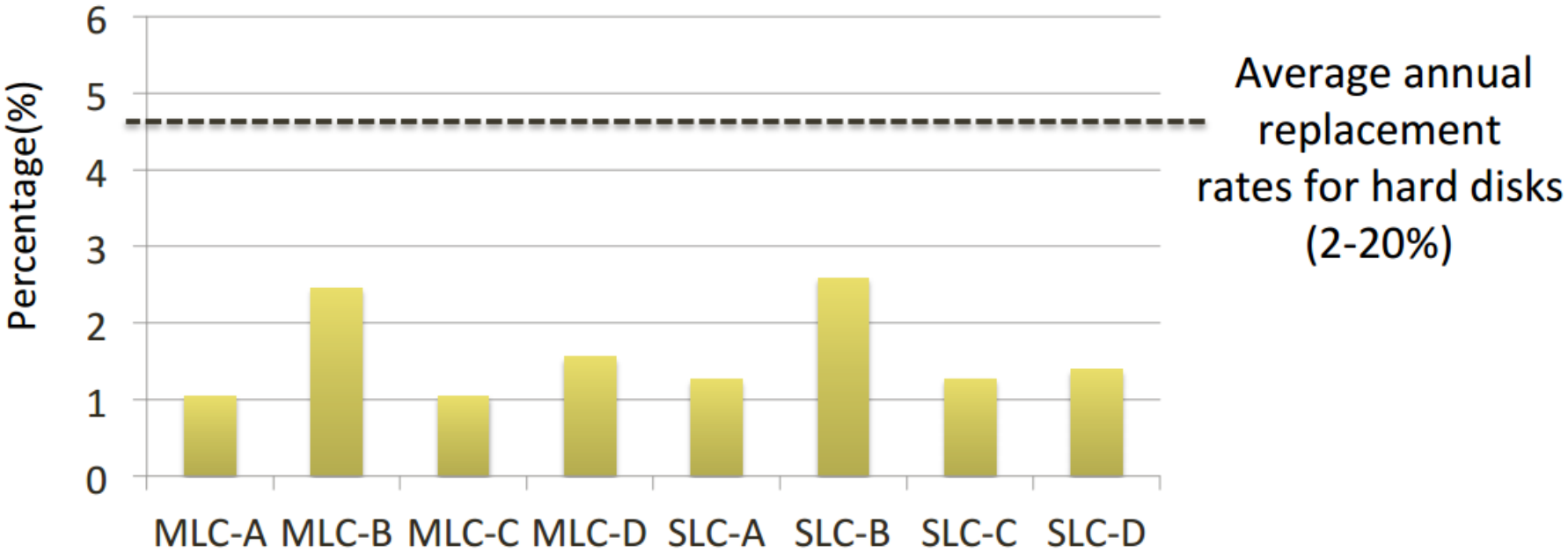
What about SSDs?

- 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.

Key conclusions summary from http://www.zdnet.com/article/ssd-reliability-in-the-real-world-googles-experience/

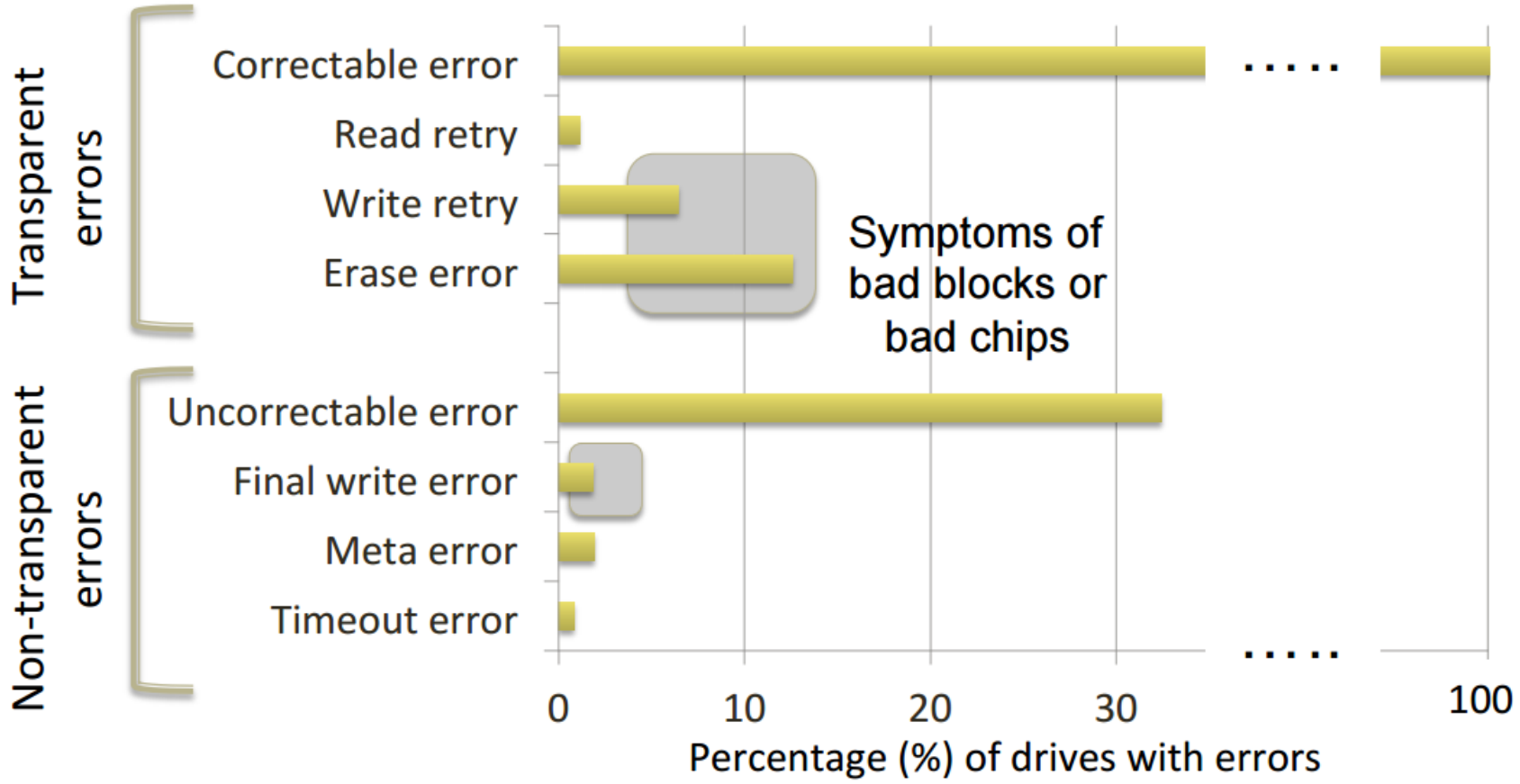
Drive replacements

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



- **~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:

  Need to protect against drive data loss!

- SSD:

  Need to protect against drive data loss!

- Overall conclusion?

  Need to protect against drive data loss!