A Study of Soft Error Consequences in Hard Disk Drives

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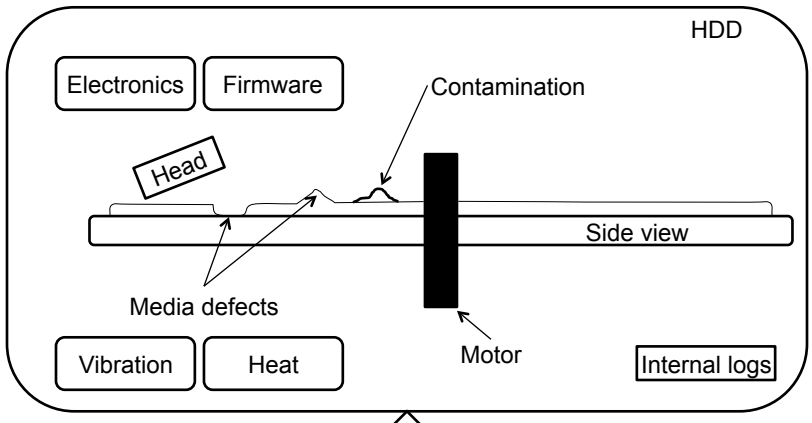
How to predict imminent HDD failure?

- **Scenarios**
  - Home and personal storage
    - Often no redundancy (real-time or backups)
  - Enterprise
    - Redundancy, but performance overhead is critical (e.g., RAID rebuilds)
- **Would be useful to predict imminent HDD failure**
- **Many failure modes (from user perspective)**
  - No response (e.g., electronics, firmware)
  - Hard read error (e.g., media, head, HDI, flyheight, servo) ← Focus of this paper
- **For effective predictor, need**
  - High true positive rate
  - Low false positive rate (to minimize user disturbance and performance overhead)
  - "Adequate" time from alarm to failure
    - Enough time to take action
    - Imminent (e.g., no use to predict failure in 5 years)
- **What are the effective predictors?**
  - This paper studies the use of soft error events to predict future hard errors

HDD failure modes



Catastrophic → No response | Response

OK with redundancy → Error | No error

Concern about performance overhead → Soft error level

Sources of observability:
Host-HDD interface*
Internal logs+
Teardown

*Other published papers
+Our paper

Contribution of the paper

- **Study utilizing internal HDD data**
  - Internal log contains following data
    - Time, Serial, Event ID, ScsiOpCode, Error code, Temperature, LBA, Cylinder, Head, Sector
  - More internal soft errors collected than reported over drive interface
    - Minimum ERP threshold for reporting soft errors
    - At most one error reported per read request
- **Results**
  - Most soft errors do not predict hard errors well
  - For those soft errors that do predict hard errors, the prediction allows sufficient time for action

HGST a Western Digital company Terminology

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Raw sector error → ECC → Retries → Hard error
Failure detection via CRC

- **Raw sector error: One or more bit errors in a sector**
- **ECC: Reed-Solomon correction code**
- **Retries: Proprietary sequence of retry steps**
- **Hard error: Read request that returns with an error status (HDD ECC, retries, and CRC fail)**
- **Soft error: Read request that returns correct data (e.g., CRC passes), but internal HDD retries are needed**
  - Excludes soft errors corrected via ECC and via retries below the reporting threshold (i.e., excludes first two steps to avoid overflowing log)

HGST a Western Digital company Retries

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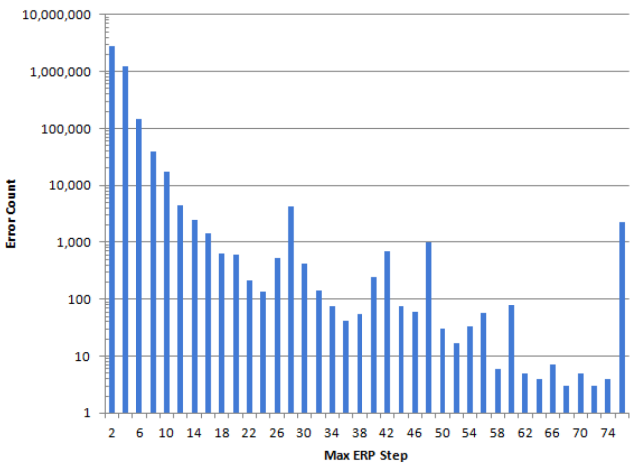

- **ERP = Error Recovery Procedure**
- **ERP is after ECC failure**
- **Sequence of repeated attempts to read, with possible variations**
  - Multiple sequences possible based on results at each step
- **As expected, most errors are corrected in the first few steps**

HGST a Western Digital company — Drive population

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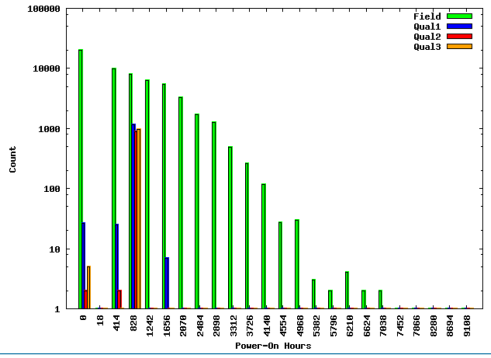
- **Drive population**
  - Field drives: Over 57,154 drives from a large storage system vendor deployed at customer sites.
  - Qualification drives: 3,077 drives from qualification tests.
  - Drives are 3.5” and 2.5” SAS/FC drives from about 2008.
- **Power-on hours indicate the number of hours that the drive has been powered on since leaving the factory. Resolution is in fractions of a second.**



HGST a Western Digital company — Results (All populations)

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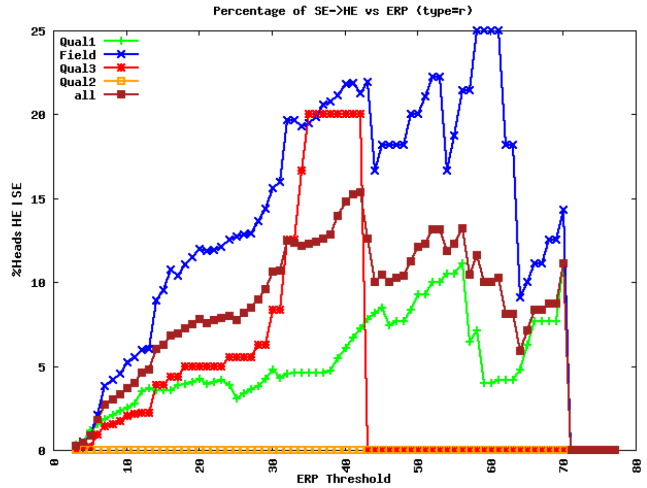
ERP Step Cutoff	Total Heads	#Heads with HE	#Heads with SE	#Heads HE preceded by SE (% of all HE)	%Heads HE | SE
3	387,840	157	18,932	61 (38.9%)	0.32%
4	387,840	157	11,142	58 (36.9%)	0.52%
5	387,840	157	5,711	57 (36.3%)	1.00%
6	387,840	157	2,496	53 (33.8%)	2.12%
7	387,840	157	1,634	52 (33.1%)	3.18%
8	387,840	157	1,426	50 (31.8%)	3.51%
9	387,840	157	1,276	49 (31.2%)	3.84%
10	387,840	157	1,133	49 (31.2%)	4.33%
11	387,840	157	1,050	49 (31.2%)	4.67%
12	387,840	157	910	48 (30.6%)	5.28%

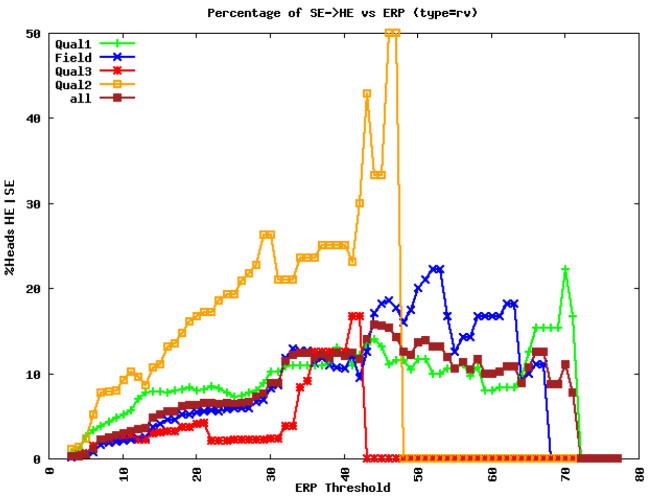
- **Reported by heads, since head disk interaction (HDI) is most common source of hard/soft errors**
- **157 heads (0.04%) experience at least one hard error**
- **For highlighted row above**
  - 2496 heads reported at least one soft error.
  - 53 of the 157 heads with hard errors had at least one soft error at the cutoff step or above precede the hard error → About 1/3 of hard errors were preceded by a soft error!
  - 2.12% of the soft errors were on heads that eventually experienced hard errors
    - Precision, i.e., the percentage of all alarms that are actual failures

SE→HE prediction precision for reads



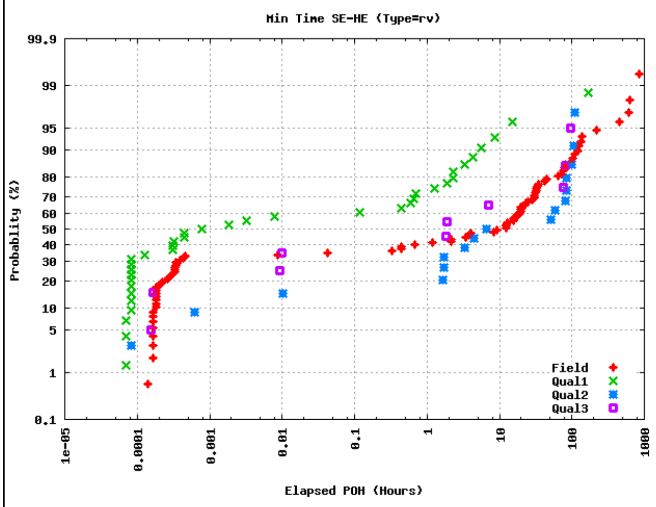
- SE→HE prediction indicates the true positive rate
- Shown for all four populations and aggregate
- Sometimes decreases with higher thresholds because some heads with HE are eliminated
- Precision (i.e., the percentage of all alarms that are actual failures) is low

SE→HE prediction precision for reads/verifies



- Same as before, but considering all read and verify commands
- Not obviously better

Advance warning time

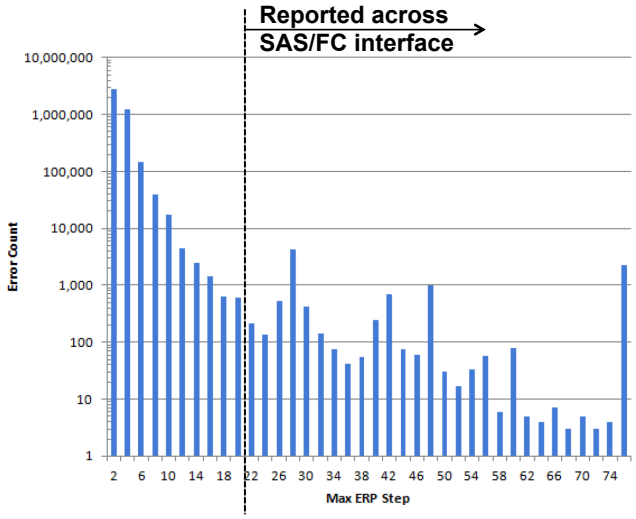


- **For all SE→HE, the time between the last SE and the HE**
- **CDF with normal distribution projection on y-axis**
- **Distributions tend to be bimodal**
  - About 1/3 of all HE occur less than 1 second after a soft error
  - Many HE occur more than 1 hour after a soft error (30-80%)

Related work

- **E. Pinheiro, W.-D. Weber, and L. A. Barroso, "Failure trends in a large disk drive population," in *Proceedings of the 5th USENIX conference on File and Storage Technologies*. Berkeley, CA, USA: USENIX Association, 2007, pp. 17-28.**
- **B. Schroeder and G. A. Gibson, "Disk failures in the real world: what does an mttf of 1,000,000 hours mean to you?" in *Proceedings of the 5th USENIX conference on File and Storage Technologies*. Berkeley, CA, USA: USENIX Association, 2007, pp. 1-16.**
- **L. N. Bairavasundaram, G. R. Goodson, S. Pasupathy, and J. Schindler, "An analysis of latent sector errors in disk drives," in *Proceedings of the 2007 ACM SIGMETRICS International Conference on Measurement and Modeling of Computer Systems*. New York, NY, USA: ACM, 2007, pp. 289–300.**
- **J. F. Murray, G. F. Hughes, and K. Kreutz-Delgado, "Machine learning methods for predicting failures in hard drives: A multiple-instance application," J. Mach. Learn. Res., vol. 6, pp. 783–816, December 2005.**

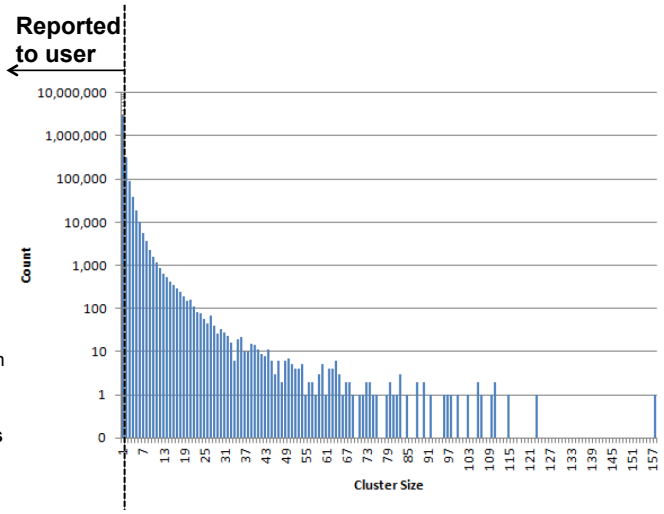
Host has limited soft error info (retry step)



- Most soft errors are not communicated to host (to limit performance impact)
  - For this population, only 0.25% of errors (hard and soft) are reported to the host!
- Retry step at which soft errors are corrected is not communicated to host

Host has limited soft error info (masked errors)

- **HDD informs host if a soft error was associated with the request, but not how many blocks had soft errors.**
- **Quite a few of the requests with soft errors have multiple blocks that require retries.**
- **Host requests with soft errors**
  - 85.59% of request with 1 bad block
  - 14.41% of requests with >1 bad block
- **Blocks with soft errors, because some requests have multiple "hidden" soft errors.**
  - 27.15% of soft errors are hidden ← These soft errors are hidden from the host!



Conclusions

- **This paper sheds light on some characteristics of the relationship between soft errors and hard errors. It should motivate and provide hints for additional research on this topic.**
- **Key points**
  - Some hard errors are not preceded by any soft errors (96 out of 157 = 61%) → limited ability of those soft errors to predict hard errors.
    - There are additional facets of soft errors that may be fruitful to study, e.g., CHS info to identify media errors.
    - The combination of soft errors with other telemetry may yield better results, but the most useful telemetry is only available within the HDD.
  - Many soft errors occur sufficiently in advance of a subsequent hard error to allow time for preparation.