A Study of Soft Error Consequences in Hard Disk Drives

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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

- Head
- Electronics
- Firmware
- Contamination
- Media defects
- Vibration
- Heat
- Motor
- Internal logs

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

Catastrophic
OK with redundancy
Concern about performance overhead

No response | Response
Error | No error
Soft error level

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

Contribution of the paper
Terminology

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)

Retries

- 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
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.

Results (All populations)

<table>
<thead>
<tr>
<th>ERP Step Cutoff</th>
<th>Total Heads</th>
<th>#Heads with HE</th>
<th>#Heads with SE</th>
<th>#Heads HE preceded by SE (% of all HE)</th>
<th>%Heads HE</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>387,840</td>
<td>157</td>
<td>1,052</td>
<td>61 (38.9%)</td>
<td>0.32%</td>
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</tr>
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<td>4</td>
<td>387,840</td>
<td>157</td>
<td>1,142</td>
<td>58 (36.9%)</td>
<td>0.52%</td>
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<td>387,840</td>
<td>157</td>
<td>1,131</td>
<td>57 (36.7%)</td>
<td>1.00%</td>
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<td>57 (36.7%)</td>
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<tr>
<td>7</td>
<td>387,840</td>
<td>157</td>
<td>1,090</td>
<td>50 (31.9%)</td>
<td>3.14%</td>
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<td>387,840</td>
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<td>1,094</td>
<td>50 (31.4%)</td>
<td>3.53%</td>
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<tr>
<td>9</td>
<td>387,840</td>
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<td>1,278</td>
<td>49 (31.2%)</td>
<td>3.94%</td>
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<td>12</td>
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<td>910</td>
<td>48 (30.6%)</td>
<td>5.28%</td>
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</tbody>
</table>

- 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 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

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%)

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Related work

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 (retry step)

- 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!

Host has limited soft error info (masked errors)

- 85.59% of request with 1 bad block
- 14.41% of requests with >1 bad block
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.