Fast, Flexible, and Comprehensive Bug Detection for Persistent Memory Programs

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Introduction

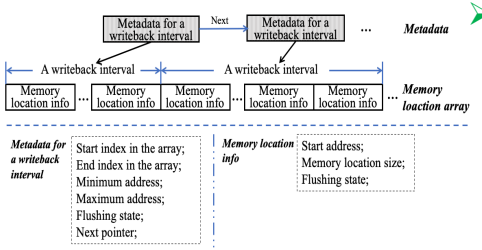
- Developing a crash-consistent PM application is challenging.
  - ✓Bugs are easily caused by missing data durability or violating ordering guarantee.
- PM debuggers are often slow, which makes bug detection infeasible.
  - ✓Pmemcheck: 218x slowdown (two hours).
  - ✓XFDetector: 1000x slowdown (nine hours).
- Some debuggers such as PMTest are fast but has low bug coverage.

Characterization of PM Programs

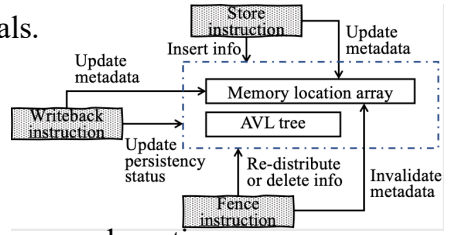
- We study store, writeback and fence instructions, and characterize how they are interleaved and distributed.
- **Pattern 1:** for most stores, the data durability is guaranteed by the nearest fence.
- **Inspiration from pattern 1:** tree re-organization in the traditional bookkeeping has few opportunities to gain performance benefit, because information of most stores is deleted in a short term.
- **Pattern 2:** stores in a writeback interval are highly likely to be flushed together by the same single writeback.
- **Inspiration from pattern 2:** it is promising to collectively maintain and update persistency status of memory locations for high performance.
- **Pattern 3:** store happens much more frequently than writeback and fence.
- **Inspiration from pattern 3:** we must efficiently process store instructions.

Design of PMDebugger

- PMDebugger instruments memory store, writeback and fence instructions.
- **A hybrid PM-aware data structure.** PMDebugger uses a combination of an array (named memory location array) and an AVL tree.



- The memory location array consists of metadata and memory location information.
  - ✓The memory location information is collected from store instructions.
  - ✓The metadata maintains the information for writeback intervals.



- **Processing instructions.**
  - ✓The key idea is to use the metadata to collectively maintain memory location information in the array.
- **Supporting relaxed persistency models.**
  - ✓Epoch model: add a flag to indicate if the store is in an epoch section.
  - ✓Strand model: set up our hybrid PM-aware data structure for each strand section.
- **Detecting bugs.** PMDebugger automatically checks memory location information according to bug-checking rules.

Evaluation

- **Performance.**
  - ✓Compared with Pmemcheck: 2.5x speedup.
  - ✓Compared with XFDetector: 49.3x speedup.
  - ✓Compared with PMTest: less than 2x slowdown but more bug coverage.
- **Bug detection capability.** Using a dataset containing 78 bugs to evaluate.
  - ✓Pmemcheck detects 55 bugs; PMTest detects 61 bugs; PMDebugger detects 78 bugs.
- **New bugs.** PMDebugger finds 21 new bug and these bugs were not reported before by state-of-the-arts.
  - ✓19 new bugs in Memcached.
  - ✓2 new bugs in PMDK.

Contribution Summary

- We characterize PM programs and get three PM program patterns, then we introduce a fast, flexible and comprehensive PM debugger based on these PM program characterizations.
- Compared with XFDetector and Pmemcheck, PMDebugger leads to 49.3x and 2.5x speedup; compared with PMTest, PMDebugger has comparable performance, without heavily relying on programmer annotations, and detects 38 more bugs.
- PMDebugger finds 21 new bugs in PMDK and Memcached.

Artifact is available at:
https://github.com/PASAUCMerced/PMDebugger

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