Brief Announcement: Optimizing Persistent Transactions

Tingzhe Zhou
Lehigh University
tiz214@lehigh.edu

Pantea Zardoshti
Lehigh University
zardoshti@lehigh.edu

Michael Spear
Lehigh University
spear@lehigh.edu

ABSTRACT
There is a mechanical transformation by which algorithms for software transactional memory can be transformed to work with persistent memory. While correct, this transformation does not take into account differences between the persistent and volatile programming models. We show that fundamental properties of the data regions accessed by a persistent software transaction allow for a variety of optimizations not available in the volatile setting, and these lead to significant performance gains.

KEYWORDS
Transactional Memory, Concurrency, Persistence

ACM Reference Format:

1 INTRODUCTION

Transactional Memory (TM) [8] allows programmers to identify lexically-scoped transactions that must appear to execute in an atomic, isolated, and consistent manner, and then a run-time system monitors the behavior of concurrent transactions as they run. When transactions have non-conflicting memory accesses, they are allowed to complete. When transactions conflict, some subset of conflicting transactions are aborted, undone, and retried, to ensure that the behavior of the program is equivalent to one in which transactions ran sequentially.

Persistent memory (PM), such as 3D-Xpoint [10], fundamentally reshapes the memory and storage hierarchies by providing a single memory that is dense, byte-addressable, fast, and able to retain its contents without consuming energy. With PM, data does not persist until it exits the CPU cache and crosses some persistence threshold. A programmer can use special instructions (e.g., clwb) to force a cache line to persist, but cannot persist multiple lines of data without additional instrumentation. The overlap between TM and PM instrumentation is substantial, leading to several concurrent persistent TM (PTM) libraries [2, 3, 11].

There are two main approaches to PTM. With undo, a persistent transaction (PTx) writing to location \( W_i \) must first write the current value at \( W_i \) to its undo log. Then it must persist that write (via clwb and a memory fence). Finally, it can update \( W_i \) with a new value. In this manner, if the system crashes before the PTx completes, all of its \( W_i \) can be restored to its state prior to the PTx’s execution. When the PTx completes, it simply discards its undo log. In contrast, with redo, a PTx writing to \( W_i \) places the new value in a private redo log. Subsequent reads of \( W_i \) must check the log to ensure processor consistency. When the PTx is ready to complete, it must persist the log (via clwb instructions and a memory fence), then replay its writes from the log. If the system crashes before the replay is complete, then the replay must be re-done after the system restarts. Note that even when a PTM does not support concurrent transactions, it must use either undo or redo.

2 NONVOLATILE CONSIDERATIONS

Yoo et al. showed that TM implementations must incur significant overhead to contend with the idiosyncrasies of modern programs [7]. Privatization refers to an idiom in which a datum transitions from a state where it is accessed via transactions to a state where it is accessed without transactional synchronization (e.g., because it becomes logically private to a single thread). Granular lost updates occur when a TM algorithm performs its undo or redo logging at too coarse of a granularity. Consider a program in which \( B_1 \) and \( B_2 \) are adjacent bytes. If \( B_1 \) is private to thread \( T_1 \), but \( B_2 \) is accessible to all threads’ transactions, then a transaction cannot perform undo or redo logging at cache-line or word granularity, lest its logging reads and writes of \( B_1 \) race with \( T_1 \). TM also must support irrevocability [4], where a transaction wishing to perform I/O or use code that cannot be rolled back first serializes all transactions, then runs in isolation without per-access instrumentation.

We observe a fundamental difference between PM and TM. In TM, the instrumentation requirements of a location are a dynamic property of how that location is used. In PM, the instrumentation requirements of a location derive from the physical characteristics of the underlying device. Languages are likely to require that all accesses to PM are performed from transactions, and hence every access to the PM will be instrumented. Thus the above concerns do not apply to PTM transactions, except in the unlikely case that they also access shared volatile memory. Thus in the common case, the following optimizations become possible:

1. Undo and redo logging can occur at a coarse granularity (e.g., half cache line) without risking granular lost updates.
2. Privatization-related overheads at the end of transactions will not be necessary.
3. Irrevocability-related overheads at the beginning of transactions can be eliminated.

Note that (1) will reduce a constant overhead that occurs on every access in redo-based systems, (2) will reduce an overhead that is linear in the number of threads, and (3) will eliminate a memory fence and branch.
3 EVALUATION

We measure the impact of these changes on a Dell PowerEdge R640 with two 2.1GHz Intel Xeon Platinum 8160 processors and 192GB of RAM. Each processor has 24 cores / 48 threads, runs Red Hat Linux server 7.4, and LLVM/Clang 6.0 with O3 optimization. Experiments are the average of five trials; to avoid NUMA effects, we limited execution to a single CPU socket. Note that on this system, the RAM is not persistent, but c16bw incurs accurate latencies.

We compare variants of four TM algorithms. In CGL, every transaction is protected by the same coarse-grained lock. In Orec, locations hash to entries in a table of 1M locks [6]. NOrec detects conflicts using values instead of locks [1]. Ring uses bit vectors to express the read and write sets of transactions [5]. Our default version of each algorithm is privatization-safe. “Eager” indicates undo, and “lazy” indicates redo. NOrec and Ring are always lazy. All experiments are run on the STAMP benchmark suite [9].

Figure 1 presents results for our unoptimized PTM algorithms. Our first finding is that latencies due to persistence are much more significant than latencies due to concurrency: persistent, concurrent TM outperforms persistent lock-based code as early as 2 threads, whereas non-persistent, concurrent TM cannot outperform non-persistent lock-based code until 4-8 threads. From this, we conclude that TM has the potential to be much more valuable in the persistent setting than in the non-persistent setting. The second finding is that redo substantially outperforms undo, except when there is a high incidence of read-only and read-mostly transactions (genome).

Table 1 presents preliminary speedup results for a data structure microbenchmark (RBTree, 16-bit keys, 80% lookup), with each PTM optimized according to Section 2. We observe two trends. The first is that coarsening the granularity of logging has a more significant impact on lazy algorithms. The second is that avoiding quiescence (only applicable to Orec PTM) is a powerful optimization, which appears to favor Orec-Lazy in all cases. In future work, we plan to complete our experimentation with STAMP to determine if the same result holds true across more varied workloads, and to explore additional optimizations to PTM.

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REFERENCES


