Performance Improvement via Always-Abort HTM

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Hardware Transactional Memory

- Hardware transactional memory (HTM) is widely available in commercial hardware.
- HTM guarantees that
  - All code executed within the transaction appears as a single atomic action to other threads.
- If HTM transaction aborts, we guarantee that there will be no semantic side effects.

Idea: A New HTM Feature

- *Always abort HTM (AAHTM)*: Allow programs to specify that a HTM transaction should always abort

- Surprisingly, this can be a good idea.

Hardware Transactional Memory

- Hardware transactional memory (HTM) is widely available in commercial hardware.
- HTM guarantees that
  - All code executed within the transaction appears as a single atomic action to other threads.
- HTM is implemented by
  - Keeping changes private within the local caches
  - Leveraging the cache coherence protocol to detect conflicts
- HTM transactions abort due to
  - Cache line conflict
  - Cache capacity
  - Illegal instruction (I/O) or interrupt

HTM isn't enough

- On x86, there is no guarantee that an HTM transaction will succeed
  - Repeatedly overflow cache or long enough to get interrupted
- HTM is usually used in conjunction with a *fall-back lock*.
  - If you fail enough in HTM, grab the lock
- But how to synchronize between HTM and lock?

HTM and Fall-back Lock

- HTM transactions shouldn’t see inconsistent state from the middle of the lock protected critical section
- Lock protected execution shouldn’t see state from before and after the transaction

- We need to synchronize between lock protected and HTM transactions to serialize them
  - This is a trap we must consider once we introduce our contributions

Early Subscription

- HTM executions subscribe immediately to the lock on entering a critical section and verify it is unheld
- If the lock becomes held, the HTM execution aborts

- Problem: a lock acquisition might abort a lot of HTM executions, *even if no true conflict exists*.

Lazy Subscription – an erroneous optimization

- What if instead we subscribe to the lock at the end of the HTM execution?
- Use a sequence lock which increments at every lock acquire/release
- Verify the lock is unheld *before* entering HTM.
- Subscribe to the lock at the end of the HTM transaction, and verify lock has not changed during the execution
- If lock hasn't changed, HTM can commit (NOT!)

Lazy Subscription Problem

- The problem with lazy subscription is that the HTM transaction can read inconsistent state (it isn't opaque).
- Consequently, the transaction can jump anywhere in the program *including to a COMMIT instruction*.

- Fall-back locks and early subscription seem necessary to guarantee HTM correctness, barring significant hardware changes.

HTM has benefits besides parallelism

- Failed transactions have a "*prefetching effect*"
  - Warm up caches and branch predictor
- This effect accelerates subsequent executions of the critical section

- HTM can act as programmer requested thread-level speculation

Goal

- Use HTM to warm-up the hardware while waiting for any reason.

- Note: we need to avoid the lazy subscription problem when doing this.

Idea: A New HTM Feature

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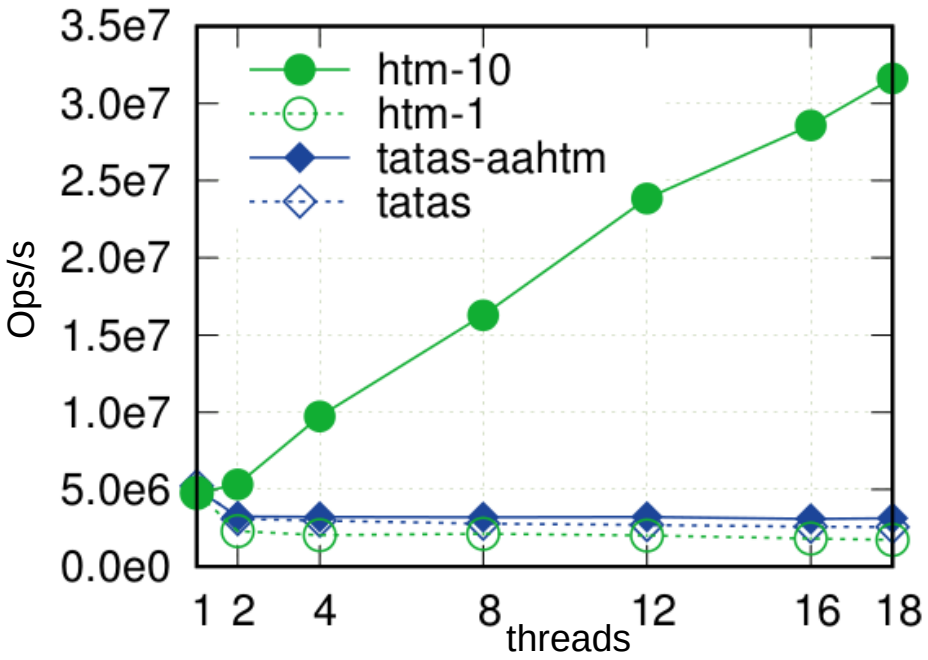
- Surprisingly, this can be a good idea.

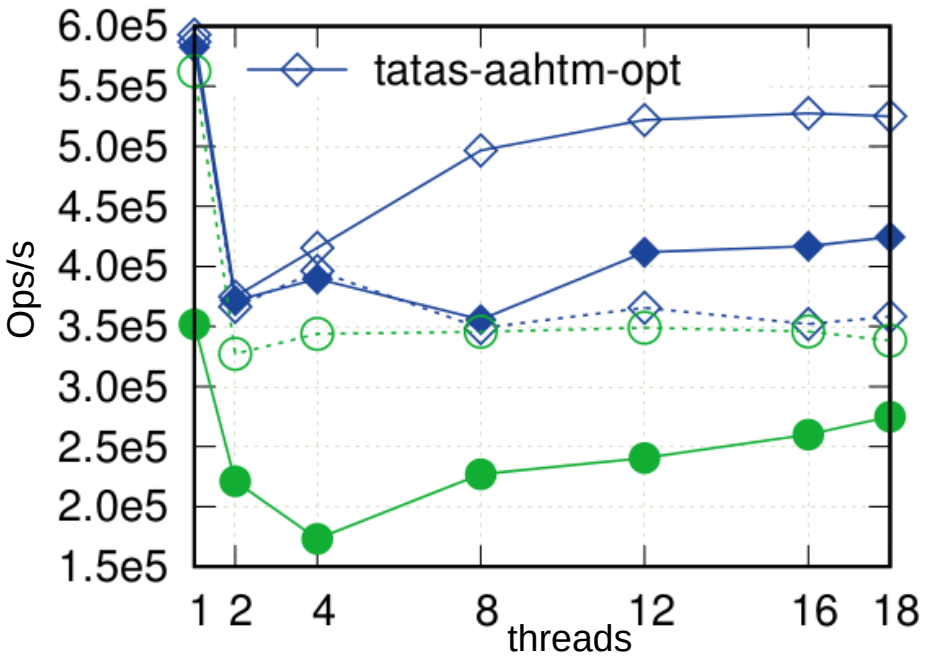
Always-Abort HTM

- Idea
  - Use HTM as a programmer requested prefetcher while blocking
  - “Always-abort” guarantees no side effects due to lazy subscription
- Uses
  - Integrate always abort HTM (AAHTM) into locks, barriers, and synchronous communication
- Benefits
  - Can outperform both traditional HTM and lock based solutions.
  - Use wasted cycles for programmer directed prefetch
  - Can distinguish between AAHTM and regular executions to follow a different code path (e.g. avoid high contention accesses)
  - Simple hardware implementation

Exploratory Results: Array Bench



write to 10 random locations / txn



write A[0], plus 100 random locations / txn

AAHTM Usage

- Works best when
  - Large memory footprint -> prefetching has a benefit
  - HTM fails often (high contention, large transaction memory footprint, or illegal instructions)

Implementation

- API
  - AAHTM_BEGIN
  - AAHTM_TEST
  - XABORT
  - XEND (illegal) = XABORT
- Hardware cost
  - Minimal on machine with HTM already implemented
  - One architectural state bit / hardware thread
  - Set by AAHTM_BEGIN, queried by AAHTM_TEST

Lock Designs

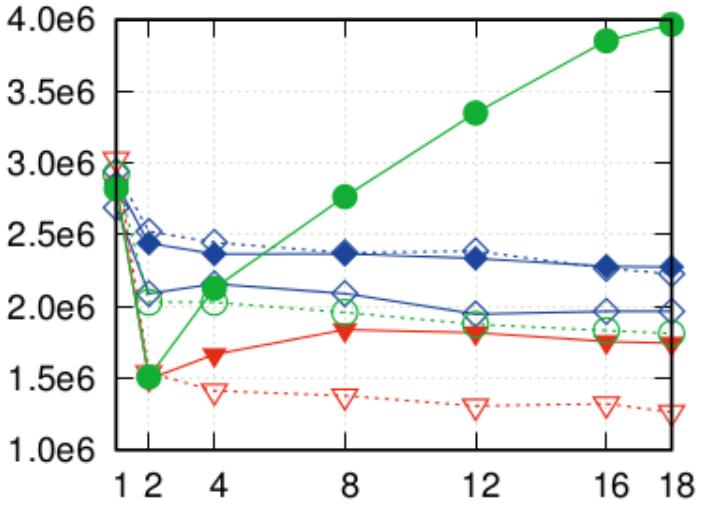
- TAS Lock
  - Use AAHTM when lock acquisition fails.
  - Arbitrary number of speculating threads -> contention
  - Threads that have speculated (*warm threads*) might not get the lock -> no prefetching benefit

Lock Designs

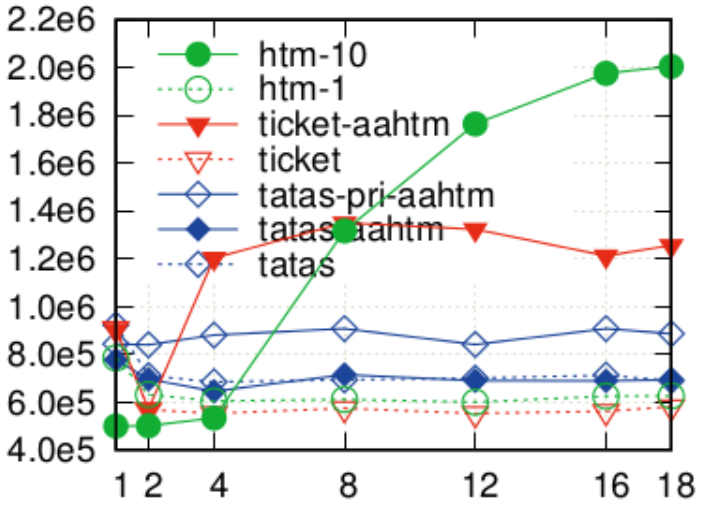
- TAS Priority Lock
  - Two additional counters colocated with lock
  - Use FAI() to monitor number of speculating, number of warm threads
  - Warm threads have strict priority over cold threads

Lock Designs

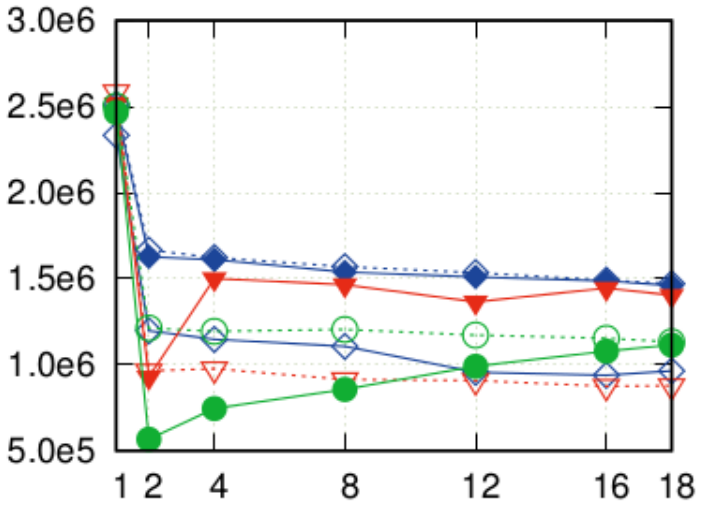
- Ticket Lock
  - Threads monitor distance to lock acquisition
  - Can tightly control when threads start speculating (e.g., when they are 3rd in line) and how many.



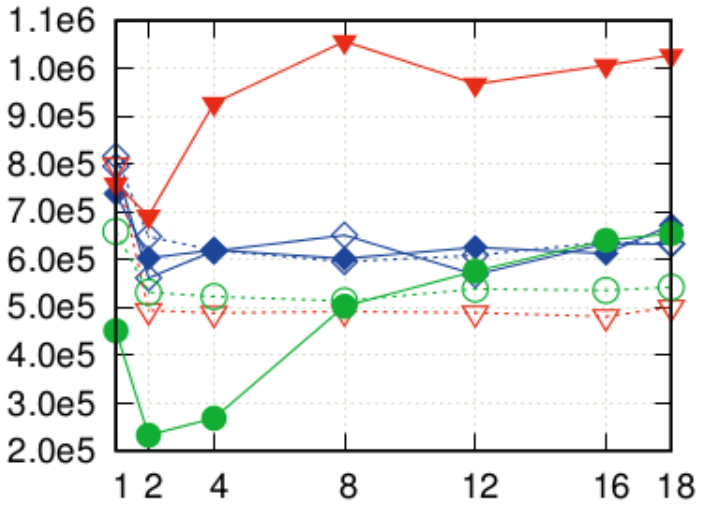
(a) 10K elements, 10% writes.



(b) 10M elements, 10% writes



(c) 10K elements, 50% writes.



(d) 10M elements, 50% writes

Single lock protecting std::map (red-black tree)

Barrier Design

- Use AAHTM if not last thread to arrive
- Last thread to arrive sets flag monitored by all speculators
- Less contention than with lock because threads are expected not to synchronize within barrier protected phases

input	offshore.mtx (75)			inline_1.mtx (288)			thermal2.mtx (991)		
thd #	baseline	aahtm	speedup	baseline	aahtm	speedup	baseline	aahtm	speedup
1	2.28	2.28	0.00%	3.18	3.18	0.00%	3.83	3.83	0.00%
2	3.87	4.02	3.88%	6.16	6.19	0.49%	3.50	3.51	0.29%
4	5.84	6.75	15.58%	11.26	11.40	1.24%	5.92	6.51	9.97%
8	7.14	8.01	12.18%	19.99	20.53	2.70%	10.46	11.66	11.47%
12	6.40	7.09	10.78%	26.55	27.09	2.03%	13.67	14.97	9.51%
16	5.27	5.43	3.04%	31.60	33.42	5.76%	14.77	16.37	10.83%

Figure: Backward Sparse Triangular Solver using AAHTM barrier (GB/sec)

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Future Work

- Other benchmarks
- Other types of waiting (synchronous communication, hardware accelerators)

Conclusion

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