Refereeing Conflicts in Hardware Transactional Memory

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Conflicts affect performance

**Conflict**: concurrent accesses to the same location from two different transactions where at least one is a write

- In the absence of conflicts, Hardware TM provides
  - low latency and high scalability
- With conflicts, performance can degrade significantly

![Graph showing normalized throughput vs. threads for low and high vacation scenarios.](image)
Conflicts can be common

We anticipate that as TM becomes popular
- large and long transactions will become common
- new intricate sharing patterns will introduce conflicts

<table>
<thead>
<tr>
<th>Application</th>
<th>txs w/ conflicts</th>
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<tbody>
<tr>
<td>Bayes</td>
<td>85%</td>
</tr>
<tr>
<td>Delaunay</td>
<td>85%</td>
</tr>
<tr>
<td>Intruder</td>
<td>90%</td>
</tr>
<tr>
<td>Kmeans</td>
<td>15%</td>
</tr>
<tr>
<td>Vacation</td>
<td>73%</td>
</tr>
<tr>
<td>STMBench7</td>
<td>68%</td>
</tr>
</tbody>
</table>
Conflict Management Primer

- **Conflict Type**
  - what type of accesses?
  - read-write, write-read, write-write

- **Conflict Detection**
  - when to resolve?
  - Eager (at access), Lazy (at commit)
Conflict Management Primer

- **Conflict Type**
  - what type of accesses?
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- **Conflict Detection**
  - when to resolve?
  - Eager (at access), Lazy (at commit)

- **Contention Management**
  - How to choose loser?
  - priority, timestamp, etc.

- **Action**
  - What action to take?
  - stall, abort self, abort other etc.
Our Contributions

- Comprehensive study of policy in HTMs
  - conflict detection and conflict management interplay
  - quantify effect on application performance

- Is Lazy better than Eager?
  - can we do better?

- How does the contention manager help?
  - is it important?
Experimental Platform

- **FlexTM [ISCA’08]**
  - allows conflict detection to be controlled in software
  - permits pluggable software contention managers

- **TM Hardware: 16 core CMP, Private L1s, Shared L2**
  - signatures for conflict detection
  - private L1s for speculative buffering
    - overflow handled by hardware controller
  - transaction commit protocol
    - allows parallel transaction commits
    - no centralized arbiter
Workloads

- **TM Workloads**
  - STAMP (Stanford)
  - STMBench7 database (EPFL)
  - Web-cache and Graph stress tests (U.Rochester)

- **TM Policies**
  - Conflict detection: Lazy, Eager, and Mixed
  - Contention Management: w/ and w/o stalling, timestamps, access sets, aborts
Is Lazy better than Eager?

Can we do better? : Mixed

Is the contention manager important?
Conflict Detection

- **Eager (manages conflict at access time)**
  
  **Goal:** If transactions can’t commit together, save work
  - to progress, transactions abort enemies
  - transactions can stall and try to elide the conflict

- **Lazy (manages conflict at commit)**
  
  **Goal:** postpone detection hoping conflict disappears
  - to commit, writers abort enemies
  - writers can stall to elide reader conflicts
Eager’s Performance Limitations

- Futile aborts waste work and hinder progress
  - Stalling access may help avoid the conflict

- Inability to overlap conflicting transactions
Eager w/ Stalling

- Can reduce occurrence of futile aborts (livelock ?)
  - reduces wasted work due to aborts

- Is it good enough ?
  - cannot exploit concurrency in application
Lazy’s Benefits (1/2)

Small Contention Window

- Conflicts checked only at commit
  - reduces likelihood of conflict winner being aborted
  - can reduce the occurrence of futile aborts
  - prioritizing the committer avoids livelock in practice

Also observed in Software TMs by Spear et al. [PPOPP’09]
Lazy's Benefits (2/2): More commits

- Even transactions with overlapping accesses
  - can execute concurrently
  - can commit concurrently

![Diagram showing transactions T1, T2, and T3]

- T1: Load R, Load A
- T2: Load R, Load B
- T3: Load R, Store R
Lazy’s Benefits (2/2): More commits

- Even transactions with overlapping accesses
  - can execute concurrently
  - can commit concurrently

- Caveat: Can waste more work than Eager
  - postponing conflict detection was futile (T2 commits first)
  - may be solved by stalling commit
Lazy performs better than Eager

- Lazy improves performance over Eager (Avg. 40% , Max. 2x)
- Ensures progress in non-scalable workloads
- Lazy may lose performance due to wasted work (STMBench7)
  - postponing dueling read-write conflicts is futile

Lazy w/ Stalling
Eager w/ Stalling

Normalized Throughput

Bayes | Delaunay | Intruder | Vacation | STMBench7 | LFUCache | Graph
---|---|---|---|---|---|---
Eager w/ Stalling: 7, 6, 4, 6, 6, 4, 1
Lazy w/ Stalling: 8, 7, 5, 8, 8, 6, 2
Is Lazy better than Eager?

Can we do better? : Mixed

Is the contention manager important?
Mixed Conflict Detection

Tunes detection based on conflict type
- Detects Write-Write conflicts eagerly
  - may save wasted work, if winner commits
- Detects Read-Write and Write-Read conflicts lazily
  - allows useful concurrency

Added Benefit: complexity-effective implementation
- needs to support only single-writer and/or multiple-readers
- at most two versions of data, speculative and non-speculative
Mixed improves performance by ~40% in STMBench7
- saves wasted work on conflicts between long and short writers
- exploits reader-writer concurrency like Lazy
Mixed’s Problem

- Mixed can suffer from weaker progress conditions than Lazy
  - inherited from Eager write-write detection
  - can be solved with appropriate contention managers
Is Lazy better than Eager?

Can we do better? : Mixed

Is the contention manager important?
Contention Management

- Is a priority scheme that chooses winner in a conflict
  - can help progress by prioritizing starving transactions
  - simplified in Hardware TMs since transactions are visible

- Priority arbitration (our implementation)
  - always stall before making a decision
  - higher priority transaction always make’s progress
  - lower priority transaction can stall or abort itself
  - priority changed on various dynamic events, hardware performance counters to reduce overheads
Priority Schemes

- **Age** (similar to Greedy [Guerraroui, PODC’05])
  - global timestamp acquired by transaction at begin, retained on aborts, discarded on commits
  - ensures progress of the oldest transaction

- **Aborts**
  - local abort counter
  - tries to ensure progress of starving transaction
  - theoretically, transaction could always get beaten

- **Size** (similar to Polka [Scherer, PODC’05])
  - local read set counter, retained on aborts (like Karma)
  - prioritizes transactions which have made progress
Centralized Priority (Age)

- Implemented in software
- Timestamp suffers from scalability issues
- Hinders concurrency in Eager by convoying readers behind a writer (performance drops ~10%)
Distributed Priority (Size and Aborts)

- Cheaper to implement, no centralized mechanisms
- Weaker progress guarantees
  - no provable starvation or livelock freedom
- Size is highest performing manager
  - maximizes parallelism ensuring reader sharers make progress
  - ensures writers don’t starve in practice
Summary
Policy important in HTMs, tradeoffs similar to STMs

- Lazy performs better than Eager (Avg. 40% increase)
  - narrows contention window and ensures progress
  - exploits reader-writer parallelism to attain more throughput

- Mixed is a good tradeoff between desire to exploit concurrency and implementation complexity

- Contention manager
  - less important in Lazy
  - can help with progress in Eager and Mixed
Summary

Look at paper for details on
1) conflict patterns in our TM workloads
2) implementation tradeoff discussion

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http://www.cs.rochester.edu/research/synchronization