STM Contention Management: from Multiprocessors to Distributed Systems

Danny Hendler
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What is TM contention management?

"When two or more transactions attempt to access the same block of transactional memory concurrently, at least one transaction must be aborted. The decision of which transaction to abort, and under what conditions, is the *contention management problem*"

[Scherer and Scott, contention management in dynamic STM, DISC'04]

"STM for dynamic-sized data structures", Herlihy, Luchangco, Moir & Scherer PODC'03
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The mechanisms used by TM implementations to ensure forward progress – to avoid livelock and starvation, and to promote throughput and fairness.

[Spear, Dalesandro, Marathe & Scott, A comprehensive strategy for contention management in STM, PPoPP'09]
Talk outline

- Preliminaries
  - Multiprocessor contention management
    - Conflict resolution policies
    - TM schedulers
  - Distributed TM (DTM)
    - Design space and principles
    - Example replicated DTM implementations
    - Contention management considerations
“Conventional” conflict resolution policies

TM system

Contention Manager

Contestion Detection

TM threads

Abort/retry, wait

proceed

arbitrate

“STM for dynamic-sized data structures”, [Herlihy, Luchangco, Moir & Scherer PODC'03]

“Polymorphic contention management”, [Guerraoui, Herlihy & Pochon DISC'05]

Danny Hendler

5th workshop on the Theory of Transactional Memory, Oct 14, 2013, Jerusalem
Conventional conflict resolution policies are often insufficient

- Loser resumes execution after pre-determined waiting period
  - May resume execution too early
  - May resume execution too late

- Repeated collisions occur under high contention
  - Livelocks
  - Performance may become worse than single lock

Scheduling-based CM to the rescue.
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TM schedulers: rationale

- Transactional threads controlled by **TM-aware scheduler**
  - Kernel-level, user-level

- Richer “tool-box” for reducing and/or preventing transaction conflicts

**Improve performance under high-contention**
The first TM schedulers

- “Adaptive Transaction Scheduling for transactional memory systems”, Yoo & Lee, SPAA'08

- “CAR-STM: Scheduling-based collision avoidance and resolution for software transactional memory”, Dolev, Hendler & Suissa, PODC '08

- “Steal-on-abort: dynamic transaction reordering to reduce conflicts in transactional memory”, Ansari, Jarvis, Kirkham, Kotsedilis, Lujan and Watson, HiPEAC'09
Adaptive Transaction Scheduling (ATS)
Yoo & Lee, SPAA'08

- A single scheduling queue

- Per-thread **Contention Intensity** (CI) computed

- Adaptive mechanism
  - CI below threshold $\Rightarrow$ transaction begins normally
  - CI above threshold $\Rightarrow$ transaction serialized (queued)
ATX: adaptive parallelism control

Transactions begin execution without resorting to the scheduler
As contention starts to increase, some transactions call the scheduler
As more transactions get serialized, contention intensity starts to decrease
Contention intensity subsides below threshold
More transactions start without the scheduler to exploit more parallelism

ATS adaptively varies the number of concurrent transactions according to the dynamic contention feedback

Yoo & Lee, Transaction Scheduling.
- Per-core transaction queues
- Serialize conflicting transactions
- Contention avoidance: attempt to avoid even first collision
Additional TM scheduling work

- “Abort Free SemanticTM by Dependency Aware Scheduling of Transactional Instructions”, Dolev, Fatourou & Kosmas, WTTM'13
- “Transaction scheduling using dynamic conflict avoidance” Nicácio, Baldassín & Araújo, IJPP'13
- “On the impact of serializing contention management on STM performance” Heber, Hendler & Suissa, JPDC'12
- “Transactional scheduling for read-dominated workloads” Attiya & Milani, JPDC’12
- “Window-based greedy contention management for TM” Sharma, Estrade & Busch, DC’12
- “Kernel-assisted Scheduling and Deadline Support for STM” Maldonado, Marlier, Felber, Lawall, Muller & Riviere, DSN'11
- “Adaptive thread scheduling techniques for improving scalability of STM” Chan, Lam & Wang, 2011
- “Scheduling support for transactional memory contention management” Maldonado, Felber, Suissa, Hendler, Fedorova, Lawall & Muller, PPoPP'10
- “Improving performance by reducing aborts in HTM” Ansari, Khan, Lujan, Kotselidis, Kirkham and Watson, HIPEAC'10
- ...
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Distributed Transactional Memory (DTM)

- Extends the reach of TM abstraction to distributed applications
- Enhanced scalability, high-availability and fault-tolerance
- Large design space
DTM design choices: memory abstraction

- Uniform global address space
  - Simple programming model
  - Same API as multiprocessor TM
  - No programmatic control of data/code locality

- Partitioned Global Address Space (PGAS)
  - Explicit distinction between local and remote partitions allows optimizing for locality
  - Complicates programming model
DTM design choices: memory abstraction

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DTM design choices: execution model

- **Control flow (objects statically assigned to home nodes)**
  - ✓ Fast data location
  - ✓ Easy integration of caching schemes
  - x Poor data locality

- **Data flow (transactional code immobile)**
  - ✓ Potentially good data locality
  - ✓ Local validation & commit possible
  - x Locating and mobilizing data may be costly
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DTM design choices: replication
Replicated DTM: advantages & challenges

√ Fault-tolerance
√ Read-only transactions may avoid remote communication

x Communication required for maintaining data consistency
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Dependable Distributed STM (D2STM)
Coucerio, Romano, Carvalho & Rodrigues, PRDC'09

Application

D2STM API wrapper

JVSTM

Replication manager

Atomic broadcast (Total-order broadcast)

Group communication system (GCS)

Network

“Tutorial on Distributed Transactional Memories”, Romano & Rodrigues
“Versioned boxes as the basis for memory transactions”, Cachopo & Silva, SCP'06
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Multiversioned, Commit-time conflict detection

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JVSTM

Replication manager

Implements distributed coordination

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Coordination protocol

R1

Execute T

R2

R3
Coordination protocol

R1

R2

R3
Coordination protocol

R1

Execute T  Commit  Local
start    validation

R2

R3
Commit start
Local validation

Execute T

Atomic broadcast of T's read & write sets (*)

(*) In practice, only a Bloom filter of the read set is broadcast.
Coordination protocol

- Execute T
- Commit start
- Local validation

Atomic broadcast of T's read & write sets (*)

Remote Validation
Commit

R1

R2

R3
Coordination protocol

Atomic broadcast of T's read & write sets (*)

R1

R2

R3

Execute T
Commit start
Local validation
Remote Validation
Commit
Remote Validation
Commit
Coordination protocol

Atomic broadcast of T's read & write sets (*)

Execute T Commit start  Local validation  Remote Validation  Commit

R1  R2  R3
Asynchronous Lease-based Replication (ALC)

Carvalho, Romano & Rodrigues, Middleware'10

- Fully replicated DTM

- Nodes dynamically establish data ownership using leases
  - Write permission granted to lease-holder
  - Transactions sheltered from remote collisions

- Only write-set broadcast upon commit
A transaction is processed locally

Upon commit, check if lease on TX data owned

Yes

Establish lease

No

Validate transaction

Failure

Re-execute transaction while holding the lease

Success

Send write-set using URB

ALC TX execution lifecycle
Fully replicated DTM, builds on ALC
  - First to support execution migration

Performance gains for workloads exhibiting data locality

“Exploiting locality in lease-based replicated TM via task migration”, Hendler, Naiman, Peluso, Quaglia, Romano & Suissa

“Asynchronous lease-based replication of STM”, Carvalho, Romano & Rodrigues, Middleware’10
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- Remote contention management coordination only at commit time
  - Some remote conflicts may be detected during execution

- Contention management for local threads managed by STM
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- Contention management for local threads managed by STM

Aggressive
Polite
Karma
greedy
Passive
Polka
TM schedulers
How to improve DTM contention mgmt?

- Better local & remote contention management synergy
  - Take lease ownership into consideration when resolving local conflicts?

- Serialize transactions across nodes?

- Migrate leases or TX execution?
Summary

- Multiprocessor-TM contention management
  - “Conventional” conflict resolution policies
  - Scheduling-based (e.g. serialization) CM for high-contention workloads

- DTM uses local contention managers “as is”

- DTM performance may benefit from better local-remote contention management synergy
Thank you.