Fachhochschule Münster University of Applied Sciences

Evaluation of Transactional Memory and Other Techniques to Improve the Performance of Algorithms in High Energy Physics for New Processor Architectures

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Agenda

Traditional Concurrency Control
- Introduction
- Mutual Exclusion
- Mutex Drawbacks
- Lock-free Data Structures
- Painful State of the Art

Transactional Memory
- Introduction
- Major Benefits
- Status
- Performance

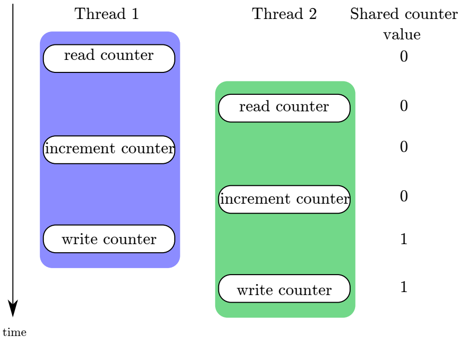
Conclusion and Outlook

Traditional Concurrency Control

Traditional Concurrency Control

Introduction

- Managing shared resources is critical
- Ensure ordered access to shared data
- Atomic hardware instructions
  - `Test-and-set`
  - `atomic-increment`
  - `CAS`
  - `LL/SC`
- Memory barriers
  - acquire barrier
  - release barrier
  - full barrier



Traditional Concurrency Control

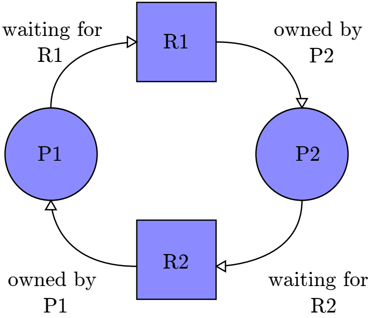
Mutual Exclusion

- Avoid data races
- Critical section executed by one thread at a time
- Serialise access to shared data
- Locking
  - Mutex
  - Spinlock
  - Readers-Writer lock

Traditional Concurrency Control

Mutex Drawbacks

- **Deadlock**
  - Processes lock a set of objects with two or more mutexes and they each wait for the lock owned by another thread.
- **Priority inversion**
  - A low priority process may hold a lock that is needed by a high priority process
- **Convoying**
  - A process may be descheduled or interrupted while holding a lock.



Traditional Concurrency Control

Lock-free Data Structures

- Mutual exclusion is based on blocking an active process, if necessary
  $\Rightarrow$ Lock-free and wait-free data structures

Maurice Herlihy:

Definition (Lock-free)

A concurrent data structure is **lock-free**, if a process is guaranteed to complete an operation on it after the system as a whole takes a finite number of steps.

Traditional Concurrency Control

Lock-free Data Structures

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Maurice Herlihy:

Definition (Lock-free)

A concurrent data structure is **lock-free**, if a process is guaranteed to complete an operation on it after the system as a whole takes a finite number of steps.

Definition (Wait-free)

A concurrent data structure is **wait-free**, if each process is guaranteed to complete an operation on it after taking a finite number of steps.

Traditional Concurrency Control

Lock-free Data Structures

- Lock-freedom has been subject to research for years
- Only few efficient and correct implementations to a very limited range of data structures are known
- A working algorithm is almost always a publishable result
- Wait-freedom with good performance is even harder to achieve
- **Extremely** complex to implement!
  - Herb Sutter talks:
    Atomic<> Weapons: The C++ Memory Model and Modern Hardware ▸ Video
    Lock-Free Programming (or, Juggling Razor Blades) ▸ Video

Traditional Concurrency Control

Painful State of the Art

- Joe Duffy: Solving 11 Likely Problems In Your Multithreaded Code ▸ Article
  - Forgotten Synchronization
  - Incorrect granularity
  - Read and write tearing
  - Lock-free reordering
  - Lock convoys
  - Priority inversion
  - Incomposability
  - ...

Lockfree-reordering

```
Initialization:
    bool gPrintFlag  = false;
    int  gPrintValue = 0;

Thread 1:
    gPrintValue = 2014;
    gPrintFlag  = true;

Thread 2:
    while (gPrintFlag == false) { }

    std::cout << gPrintValue;
```

Transactional Memory

Transactional Memory

Introduction

- "Transactional Memory: Architectural Support for Lock-Free Data Structures" Paper
- Database-style transactions working on shared memory
- ACI(D)
  - **Atomicity:** either all operations take effect, or nothing happens
  - **Consistency:** a transaction can only commit legal results, leaving the system in a valid state
  - **Isolation:** operations within a transaction are hidden from other, concurrently running transactions
  - **Durability:** when successfully committing, a transaction's changes are guaranteed to be permanent
- Optimistic speculation
- Extension to the cache-coherence protocol

Transactional Memory

Major Benefits

- Makes lock-free synchronization easily accessible
- Composability
  - "Generic Programming Needs Transactional Memory" ▸ Paper
- Easy to use

Transactional block

```
int shared_data[20];

int
set_shared_data(int index, int value)
{
    __transaction_atomic {
        shared_data[index] = value;
    }
}
```

Transactional Memory

Status

- Many Software Transactional Memory (STM) libraries available
- Intel released Transactional Synchronization Extensions (TSX) in the end of 2013
  - But it contains a bug ... PDF
- Velox stack Overview
  - Applications
  - Benchmarks
  - Compilers
  - Libraries, system libraries
  - Kernel scheduler
- Ongoing integration effort into the C++ standard

Transactional Memory

Performance

- STM deemed inefficient
- Performance is often not compared to traditional synchronization in literature
- Hardware TM as a solution?
- Evaluation of TM during my master thesis ▸ PDF
  - Experimental evaluation for queue and simple histogram
  - Results from other literature and research

Transactional Memory

Benchmark System

- Intel Core i7-4790, quad core CPU with eight threads
  - Each core runs at 3.60 GHz
  - 32 KB of L1 data cache
  - 64 bytes cache line size
  - 16 GB RAM

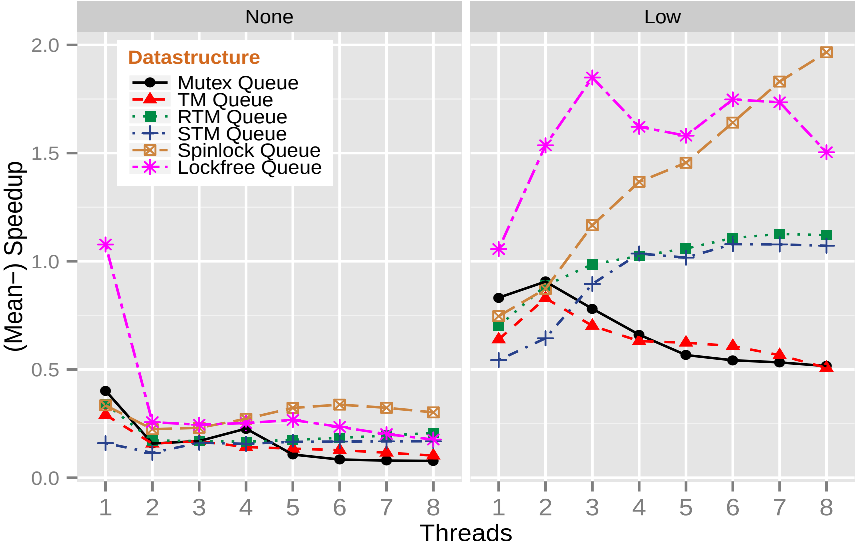
Transactional Memory

Benchmark Setup

- Queue and histogram
  - One million enqueue↔dequeue pairs / fill operations.
  - GCC TM
  - Intel TSX: Restricted Transactional Memory (RTM)
  - TinySTM
- Distribute work over 1-8 threads
- 10 warmup runs
- Take mean timing of 40 runs
- Regulate contention through a delay functor object
  - `LoadLevel::NONE` [0ns]
  - `LoadLevel::Low` [270ns]
  - `LoadLevel::Medium` [684ns]
  - `LoadLevel::High` [1554ns]

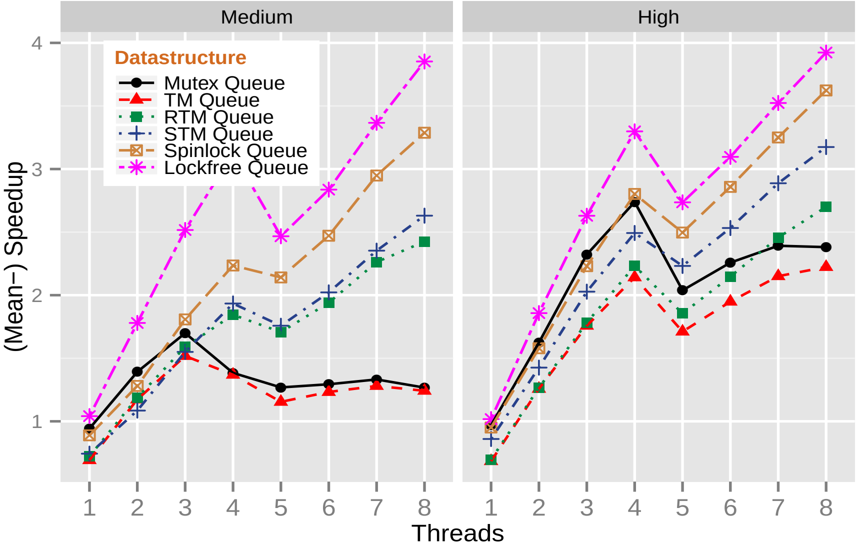
Transactional Memory

Queue Benchmark



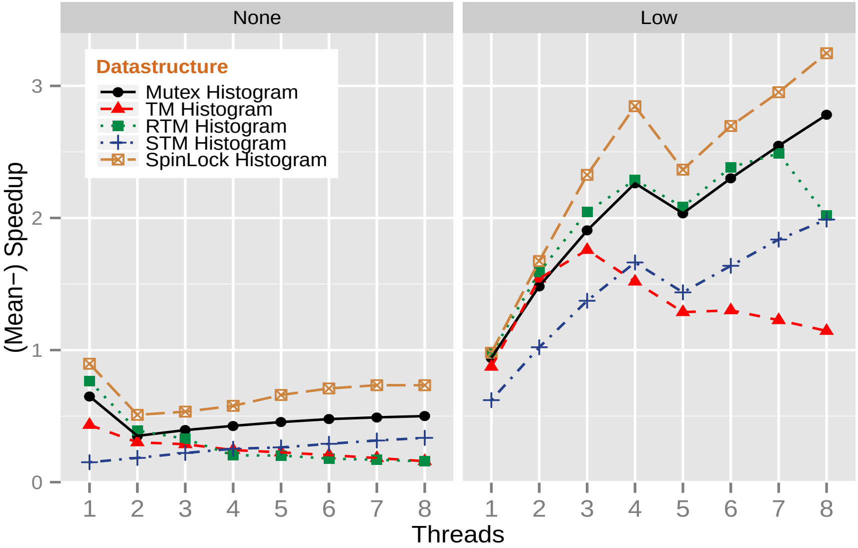
Transactional Memory

Queue Benchmark



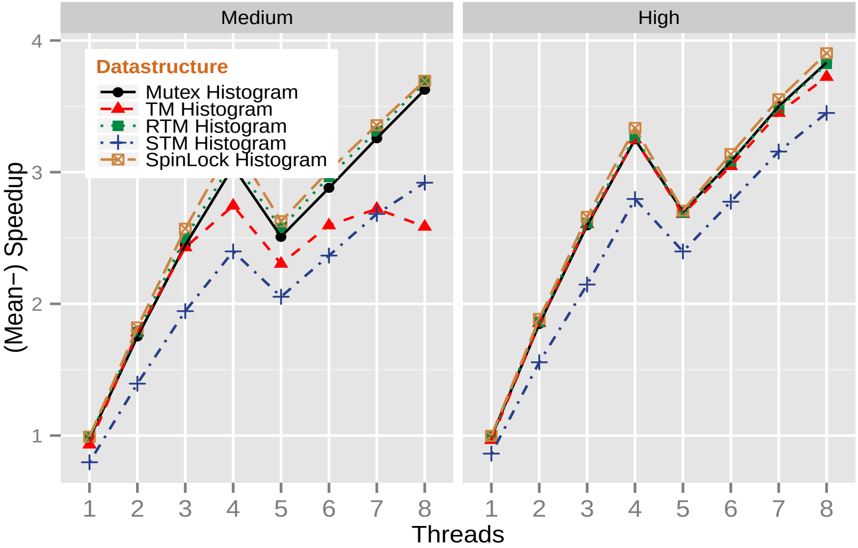
Transactional Memory

Histogram Benchmark



Transactional Memory

Histogram Benchmark



Transactional Memory

Experimental Evaluation in Literature

- Experimental evaluation of TM, especially hardware TM is rare
- No common conclusion has been drawn w.r.t. its feasibility
- Benchmark suite Lee-TM
  $\Rightarrow$ authors observe STM on par with coarse-grained locking ▸ Paper
- In general, STM is not outperforming conventional locking techniques
- "Peformance Evaluation of Intel TSX for High-Performance Computing" ▸ Paper
  - Sometimes outperforms even fine-grained locking solutions
  - But it sometimes performs worse than STM, when not optimized

Conclusion and Outlook

Conclusion and Outlook

- TM feasible?
  - As usual: it depends...
- Mutexes: Spend more time on debugging
- TM: Spend more time on making code faster
- New hardware implementations may improve performance
- Wait for C++ language extension and transaction safe STL

Thank you for your attention