Transactional Memory and concurrency

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The Context

Multicore

Parallel programming essential

Task parallelism
- **Explicit threads**
- **Synchronise via locks, messages**

Data parallelism
Operate simultaneously on bulk data

This talk

1.30pm today…

Task parallelism: state of play

- The state of the art in concurrent programming is 30 years old: locks and condition variables. (In Java/C#: synchronised methods, lock statements, Monitor.wait.)
- Locks and condition variables are fundamentally flawed: it's like building a sky-scraper out of bananas.
- **This presentation describes significant recent progress: bricks and mortar instead of bananas**

What's wrong with locks?

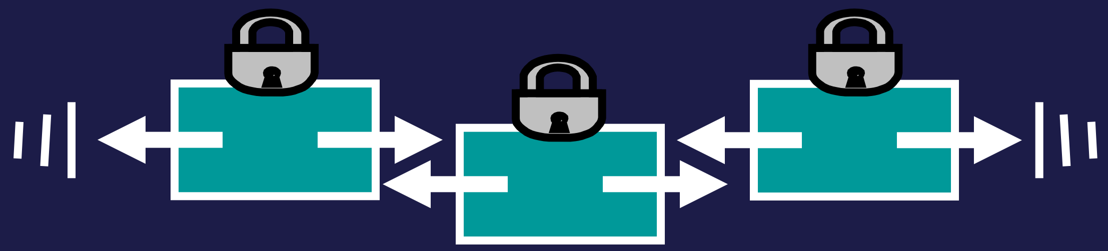
A 30-second review:

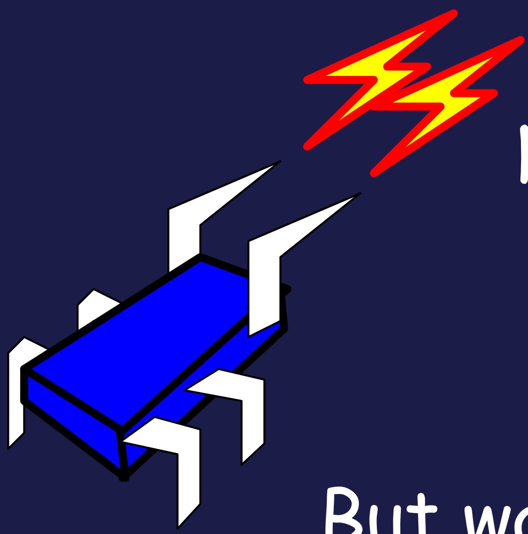
- **Races**: due to forgotten locks
- **Deadlock**: locks acquired in "wrong" order.
- **Lost wakeups:** forgotten notify to condition variable
- **Diabolical error recovery**: need to restore invariants and release locks in exception handlers

- These are serious problems. But even worse...

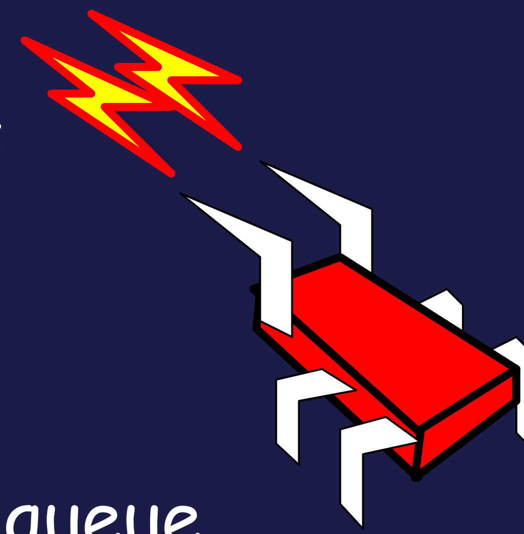
Locks are absurdly hard to get right

Scalable double-ended queue: one lock per cell





No interference if ends "far enough" apart



But watch out when the queue is 0, 1, or 2 elements long!

Locks are absurdly hard to get right

Coding style	Difficulty of concurrent queue
Sequential code	Undergraduate

Locks are absurdly hard to get right

Coding style	Difficulty of concurrent queue
Sequential code	Undergraduate
Locks and condition variables	Publishable result at international conference

Atomic memory transactions

Coding style	Difficulty of concurrent queue
Sequential code	Undergraduate
Locks and condition variables	Publishable result at international conference
Atomic blocks	**Undergraduate**

Atomic memory transactions

Like database transactions

atomic { ... sequential get code ... }

- To a first approximation, just write the sequential code, and wrap **atomic** around it
- All-or-nothing semantics: **Atomic** commit
- Atomic block executes in **Isolation**
- Cannot deadlock (there are no locks!)
- Atomicity makes error recovery easy (e.g. exception thrown inside the **get** code)

ACID

How does it work?

Optimistic concurrency

atomic { ... <code> ... }

One possibility:

- Execute <code> without taking any locks
- Each read and write in <code> is logged to a thread-local transaction log
- Writes go to the log only, not to memory
- At the end, the transaction tries to **commit** to memory
- Commit may fail; then transaction is re-run

Blocking

```
atomic { if n_items == 0 then retry
                 else ...remove from queue... }
```

- **retry** says "abandon the current transaction and re-execute it from scratch"
- The implementation waits until n_items changes
- No condition variables, no lost wake-ups!

Blocking composes

```
atomic { x = queue1.getItem()
         ; queue2.putItem( x ) }
```

- If either **getItem** or **putItem** retries, the whole transaction retries
- So the transaction waits until **queue1** is not empty AND **queue2** is not full
- No need to re-code **getItem** or **putItem**
- (Lock-based code does not compose)

Choice

```
atomic { x = queue1.getItem()
            ; choose
                   queue2.putItem(x)
              orElse
                   queue3.putItem(x) }
```

- **orElse** tries two alternative paths
- If the first retries, it runs the second
- If both retry, the whole **orElse** retries.

Choice composes too

```
atomic { x = queue1.getItem()
         ; choose
               queue2.putItem(x)
           orElse
               queue3.putItem(x) }
```

- So the transaction waits until
  - queue1 is non-empty, AND
  - EITHER queue2 is not full OR queue3 is not full

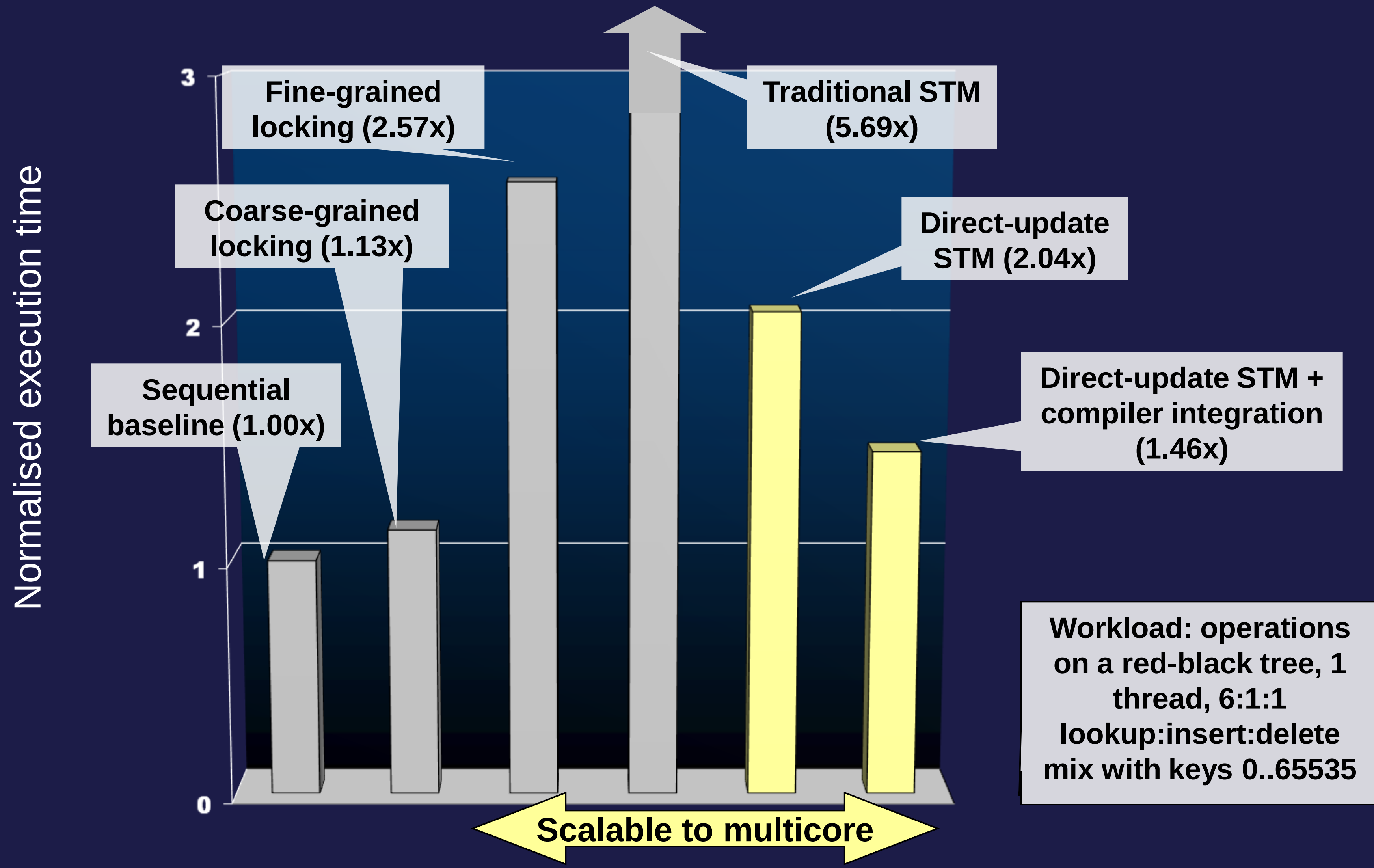
  without touching **getItem** or **putItem**

Performance

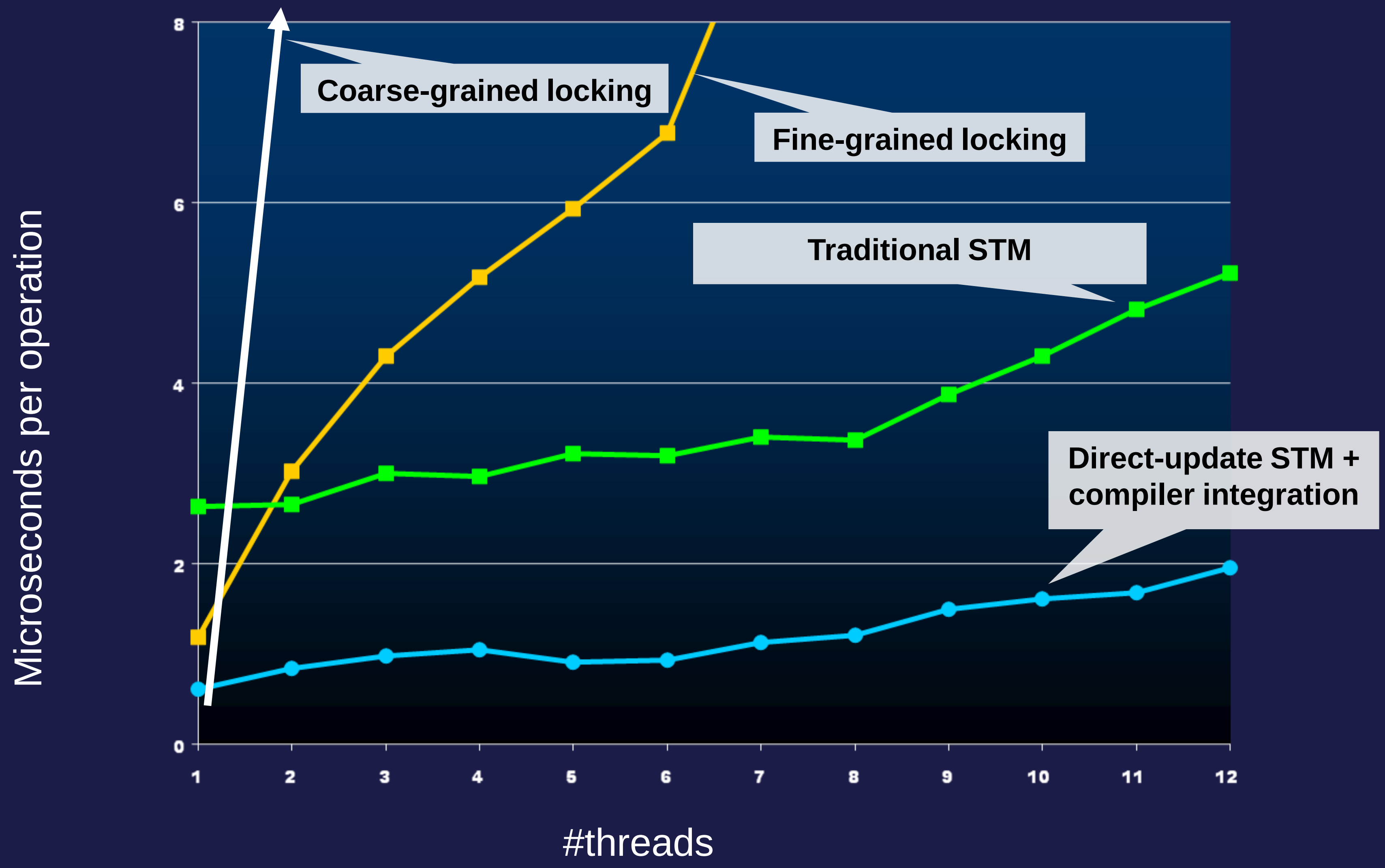
There's a run-time cost for TM, but

- Compiler technology and hardware support can reduce it a lot
- A "faster" program that doesn't work right is useless
- TM allows much finer-grain locking without losing correctness, so performance may be **better** than when using locks

Results: concurrency control overhead



Results: scalability



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Remember this

- Atomic blocks (atomic, retry, orElse) are a real step forward
- **It's like using a high-level language instead of assembly code**: whole classes of low-level errors are eliminated.
- Not a silver bullet:
  - you can still write buggy programs;
  - concurrent programs are still harder to write than sequential ones;
  - aimed at shared memory
- Very hot research area – expect developments
- Available in STM Haskell today: http://haskell.org/ghc

Backup slides

Starvation

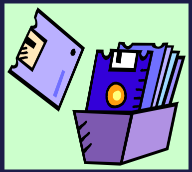
- A worry: could the system "thrash" by continually colliding and re-executing?
- No: one transaction can be forced to re-execute only if another succeeds in committing. That gives a strong progress guarantee.
- But a particular thread could perhaps starve.
- No automatic solution can possibly be adequate

No I/O inside transactions

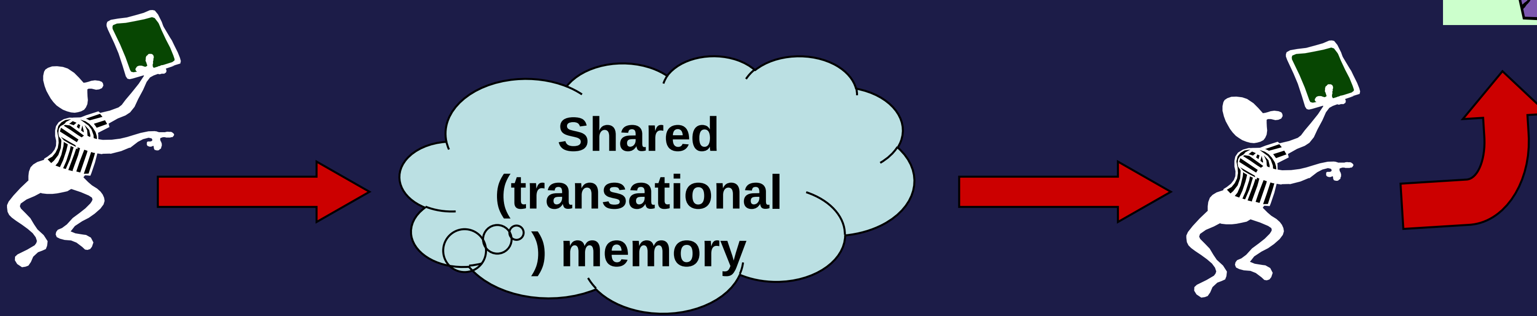
atomic { if (x>y) then launchMissiles }

- The transaction might see (x>y) because it pauses between reading x and reading y
- So we must not call **launchMissiles** until the transaction commits
- Simple story: no I/O inside transactions

Input/output



- Transactional output is easy:



Transactional output

I/O thread

- Input is a bit harder, because of the need to make sure the transactional input buffer is filled enough