Performance Evaluation of Software Transactional Memory Implementations

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ICSEA 2025, Lisbon, Portugal
2025-10-01

Agenda

- What is Software Transactional Memory?
- Benchmarking STM implementations
- Our benchmarks
- Results and observations
- Future work

Software Transactional Memory (STM)

What is it?

- *Transactional:* like database transactions
  - ACI of "ACID" (atomicity, consistency, isolation)
- *Memory:* works on objects/pointers in main memory (RAM)
- *Software:* implemented in software
  - e.g., in the compiler, or as a library

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Why is it useful?

High level approach to concurrency and parallelism, without (most of) the downsides of using manual locks

- we can read/write multiple memory locations (intertwined with arbitrary logic), and the reads/writes appear to take effect atomically (on commit)
- i.e., we get thread safety, but it's easier to use than using locks directly

```
def incrementBoth(a: Ref[Int], b: Ref[Int]) = atomic { implicit txn =>
  a.set(a.get + 1)
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Benchmarking STM engines

STM is a general approach to concurrency/parallelism

- various algorithms and implementation strategies exist
- implementations (STM engines) are available for various programming languages (C, C++, Java, Scala, Haskell, …)

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Various benchmark suites are also available:

- data structure microbenchmarks
  - binary search trees (implemented with STM), …
- STM-specific benchmark suites:
  - STAMP, STMBench7
- Lee-TM:
  - Lee's algorithm, parallelized with STM
  - previously used to measure STMs implemented for C and Ruby

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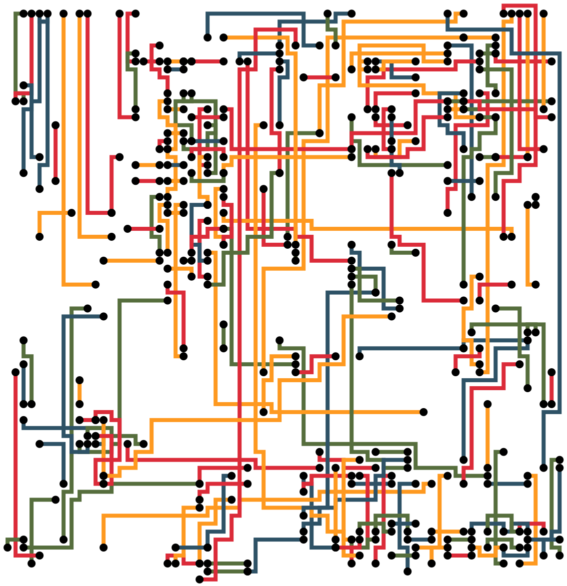
  - previously used to measure STMs implemented for C and Ruby
- We've also used Lee's algorithm…

Lee's Algorithm (overview)

- A well-known algorithm to solve the circuit-board routing problem
- Lays out "wires" on a circuit board
  - to connect source-destination endpoints
- Minimizes the *cost* of a route
  - longer routes cost more
  - crossing wires also cost more



Source of image: https://chrisseaton.com/truffleruby/ruby-stm/

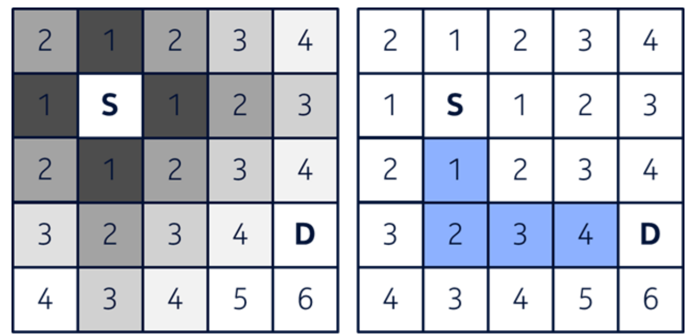
Lee's Algorithm (details)

Solve one route:

1. Expansion: start a "wave" from the source of the route
    - count the distance (longer wire costs more)
    - also take into account existing wires (crossing costs more)
    - stop when the destination is reached
2. Backtracking: go from destination back to source
    - always choose the lowest cost
3. Laying the route (it will count as an "existing" wire from now on)

Solve the whole board:

1. solve all routes; either one-by-one, or in parallel (solve 1 route – 1 transaction)



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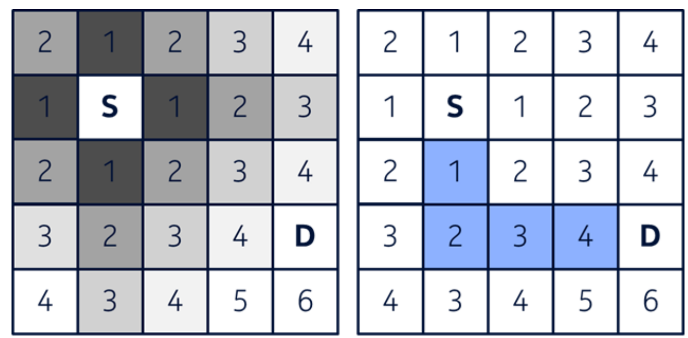

Good for benchmarking STM, because:

- Very hard to parallelize with manual locks; easy with STM
- We can vary transaction size and conflict rate by varying the input boards

Our benchmarks

- Benchmarked STM implementations on the JVM (Java Virtual Machine)
- Selected various STM engines for functional programming languages:
  - 5 Scala: Cats STM, CHOAM, Kyo STM, ScalaSTM, ZSTM
  - 1 Kotlin: arrow-fx-stm
- Implemented Lee's algorithm with all of these
- Additionally (where applicable) implemented some variants:
  - optimization by weakened consistency (lack of *opacity*; *early release*)
  - functional API wrapper of an imperative STM API (ScalaSTM)

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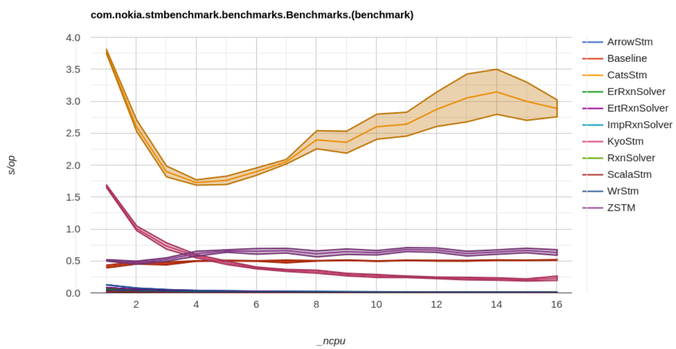
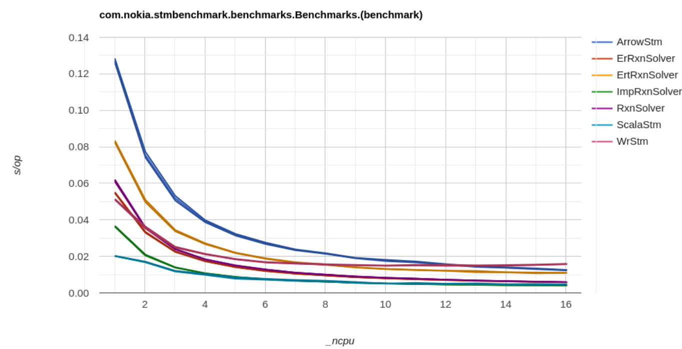
Experimental setup:

- Scala 3.7.0, OpenJDK 21
- 2× Intel Xeon E5-2680 with 12 physical cores (i.e., 24 cores in total)
- performed measurements with JMH (Java Microbenchmark Harness)
- measured the time needed to lay out routes for
  - various circuit boards
  - using a varying number of cores/threads

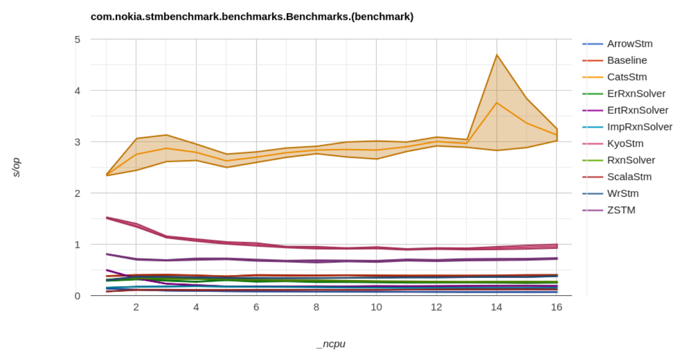
Results



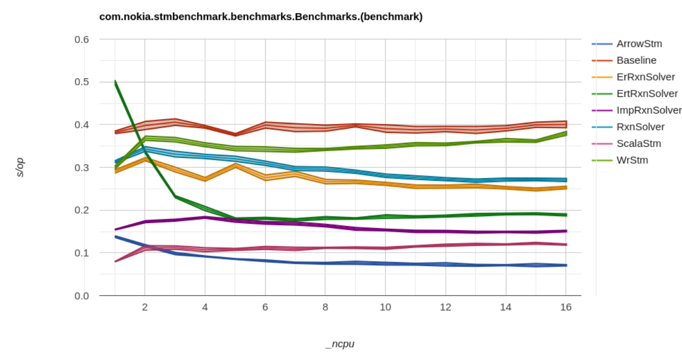
Short routes, no conflicts



Short routes, no conflicts (zoomed)



More realistic board



More realistic board (zoomed)

Observations

- STM engines with purely *functional* APIs tend to be slower than ones with *imperative* APIs
  - GC (garbage collector) pressure
  - interpretation overhead
- The Kotlin STM engine (arrow-fx-stm) beats most of the Scala ones
  - runs on Kotlin coroutines (vs. Scala fibers)
  - see also previous point (imperative vs. functional)
- Weakening consistency and *early release* are useful optimizations
  - especially on inputs with lots of conflicts
- Maintaining transaction logs (read/write sets) can be expensive
  - specifically for ZSTM and Cats STM

Future work

- More profiling
- Optimizing some of these STM engines

Thank you!

Benchmark code is open source at: https://github.com/nokia/stm-benchmark

Questions?

Extra slides

Imperative vs. Functional STM APIs

Imperative API (example):

```
def incrementBoth(a: Ref[Int], b: Ref[Int]) = atomic { implicit txn =>
  a.set(a.get + 1)
  b.set(b.get + 1)
}
```

Functional API (example):

```
def incrementBoth(a: Ref[Int], b: Ref[Int]) = {
  a.update(x => x + 1) *> b.update(x => x + 1)
}

incrementBoth(a, b).run
```

Opacity

- A consistency property specifically for STM systems
- Guarantees that *any* transaction *always* sees a consistent view of memory
- Even if it will later abort/retry

With no opacity, a transaction can observe inconsistent states (and then later abort/retry)

- This can be used for optimizations
  - non-opaque reads are typically cheaper
- But can be dangerous

Early release

- An STM engine typically "logs" memory locations read and written
  - "read set" and "write set"
- *Early release* is a mechanism to remove items from the read set of a transaction
  - i.e., releasing those memory locations *earlier* than the commit of the transaction
- Good: reduces transaction conflicts
- Can be bad: the released memory locations won't be checked for consistency when committing
  - i.e., early release is another way of weakening consistency for improving performance