Concurrent Datastructure Design for Software Transactional Memory

Bachelor Project

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Outline

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Introduction

In the multi- and many-core area, we need *parallelisation* to fully utilise available machines.

Definition

Parallel computing is a programming paradigm in which multiple parallel processes or *threads* execute at the same period of time.

Parallel computing is used to speed up computation on a multi-core system.

Synchronisation

Synchronisation refers to how concurrent threads manage and operate on shared data.

Concurrent execution should not:

- Overwrite others
- See inconsistent states

Possible ways to achieve synchronisation: locks, lock-free primitives, transactions

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Locking

Locks provide a way to achieve *mutual exclusion* by guarding *critical sections* – a block of code only a single thread is allowed to execute at a time.

Locks provide (at least) two operations: `lock()` and `unlock()`

Programming with locks is generally hard and difficult to debug

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Lock-Free Primitives

Lock-free primitives provide safe access the shared data without the use of locks.

Practical if hardware-assisted, like Compare-and-Swap (Intel) or Load-link/Store-conditional (ARM)

Compare-and-Swap(A, E, V)

Execute atomically the following: if the value at A is E then set it to V and return true, else do nothing and return false.

Load-link/Store-conditional

LL instruction loads the value at address A. Subsequent SC call with some value V succeeds only if the value of A has not changed since.

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Transactional Memory

Introduced by Herlihy and Moss in 1993 [1]

Definition

Transactions consist of a set of instructions and are *atomic* and *serializable*.

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If an inconsistent state is encountered, the transaction *aborts* and can be retried.

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Thesis Goals

- Compare the different variants of Software Transactional Memory
- Investigate how transactional programming can be applied to concurrent datastructure design

Research Questions

- How does the locking scheme of lock-based STM implementations affect the insertion performance of concurrent Red-Black Trees and Skiplists?
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Most Transactional Memory implementations make use of hardware-assist and are mostly implemented in software.

In this thesis, we focus on Software Transactional Memory introduced by Shavit and Touitou in 1996 [2]

Two main approaches: *non-blocking* and *blocking* STM

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Two main approaches: *non-blocking* and *blocking* STM

Non-Blocking STM

Early STM implementations were *non-blocking*.

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An algorithm is **non-blocking** if the delay of one thread does not stop others from making progress.

Non-blocking algorithms utilise lock-free primitives to achieve synchronisation.

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Blocking STM

- Blocking (lock-based) STM implementations lock transactional objects when they wish to modify them
- There are two main approaches on how to do that:

Definition

Encounter-order transactions lock object as they are encountered.

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Transactional Programming: Interface

```
template<class T>
struct Transaction {
    virtual void begin()          = 0;
    virtual void write(T *, T)    = 0;
    virtual T    read(T *)        = 0;
    virtual bool commit()         = 0;
    virtual void abort()          = 0;
};
```

Transactional Programming: Example

```
Transaction Tx;
bool done = false;
while (!done) {
    try {
        Tx.begin();

        /* atomic block */

        done = Tx.commit();
    }
    catch (AbortException&) {
        Tx.abort();
        done = false;
    }
}
```

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Transactional Datastructures

- Two transactional datastructures, a Red-Black Tree and a Skiplist have been implemented
- With underlying encounter-order and commit-time transactions taking care of concurrent insertions
- Commit-time transactions cannot successfully be applied to Red-Black Trees, as there are direct dependencies between the transactional writes
- Such restrictions do not exist for Skiplists
- However, the transactional insertion algorithm for both is much simpler than the lock-based or lock-free approaches

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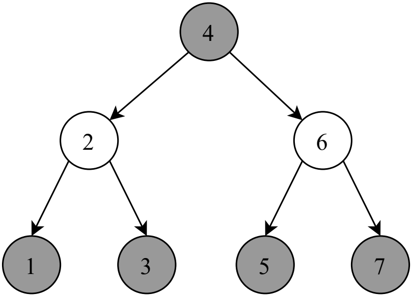
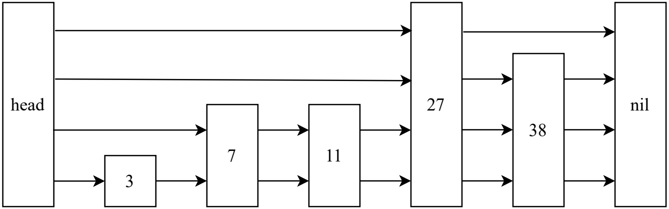
Red-Black Trees



Properties of Red-Black Trees:

- Every node is either red or black
- The root and leaf nodes are black
- Every red node's children must be black
- From each node to its descendant leaves, all paths contain the same number of black nodes

Skiplists



Properties of Skiplists:

- Each node has a certain height h chosen with probability p
- Nodes are organised into levels of linked lists
- Maximum level L is bounded by the number of elements N

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Evaluation

In order to evaluate the performance of the lock-based STM variants, the following metrics are measured:

- Time of 10k insertions into the datastructures
- Abort rate of the transactional insertion
- Speedup per thread compared to the sequential execution
- Relative execution time of the transactional API operations

The tests were run on 1, 2, 4, 8 and 16 threads respectively on the DAS5 [4]

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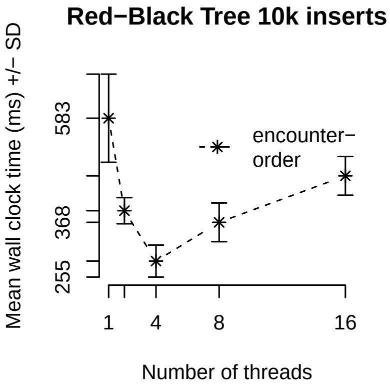
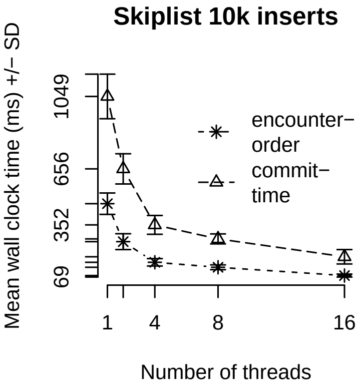
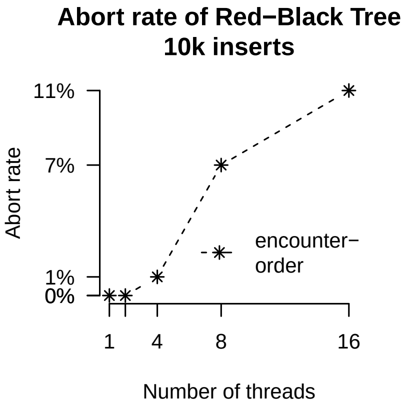
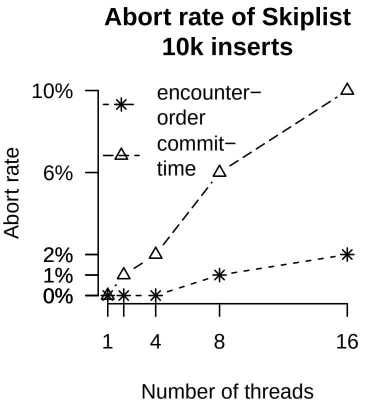
10k Insertions



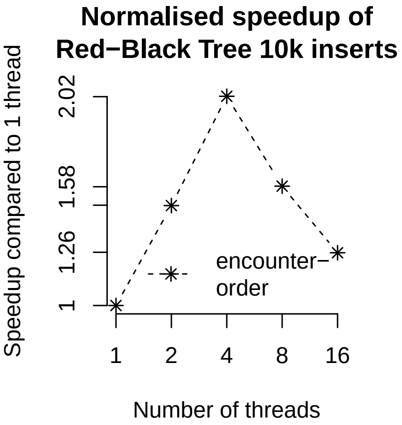


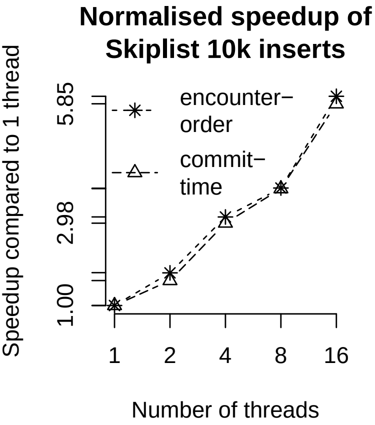
Abort Rate of 10k Insertions



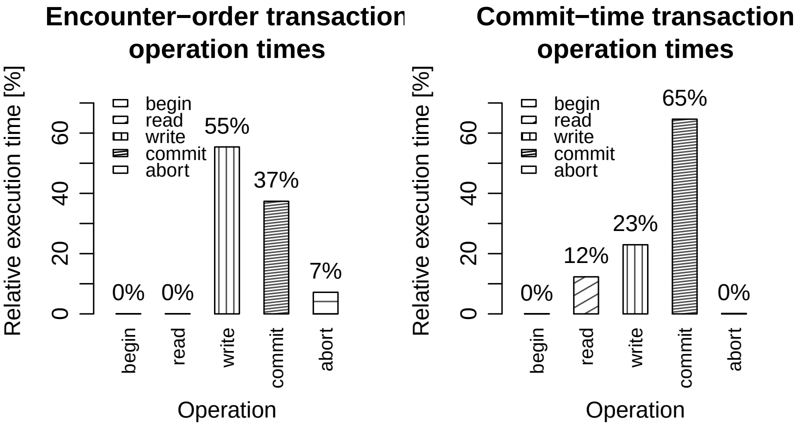


Speedup


Normalised speedup of
Red−Black Tree 10k inserts
Speedup compared to 1 thread
1
1.26
1.58
2.02
1
2
4
8
16
encounter−
order
Number of threads


Normalised speedup of
Skiplist 10k inserts
Speedup compared to 1 thread
1.00
2.98
5.85
1
2
4
8
16
encounter−
order
commit−
time
Number of threads

Operation Times



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Conclusion

- In this thesis the transactional approach for concurrent datastructure design was investigated
- For Red-Black Trees, the application of commit-time transactions proved unsuccessful
- For Skiplists, both encounter-order and commit-time transactions had optimal scaling properties
- As opposed to other papers like [5-6], encounter-order transactions outperformed commit-time transactions by a factor of two on all metrics
- Limitations of transactional design is its performance
- Further research can investigate other common datastructures

References

[1] Maurice Herlihy and J. Eliot B. Moss. “Transactional Memory: Architectural Support for Lock-Free Data Structures”. In:Proceedings ofthe 20th Annual International Symposium on Computer Architecture.ISCA ’93. San Diego, California, USA: Association for Computing Ma-chinery, 1993, pp. 289–300

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Thank you for your attention!

Questions?