More Scalable Ordered Set for ETS Using Adaptation

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What is ETS?

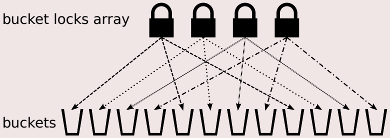
- Erlang Term Storage
- Key-value store
- In-memory database
- Shared memory

ETS Table Types and their Options

- Creates a new shared **hash based** table with **write concurrency** enabled

```
TID1 = ets:new(tab, [set, public,
                     {write_concurrency, true}])
```

- **write concurrency** enables fine grained locking



- Other hash based table types are **bag** and **duplicate bag**

ETS Table Types and their Options

- Creates a new **search tree based** table with **read concurrency** enabled

```
TID2 = ets:new(tab, [ordered_set, public,
                     {read_concurrency, true}])
```

- Current ordered set does not support fine grained locking
- read concurrency enables frequent-read-optimized readers-writer locks
  - One cache line per scheduler
  - Read only operations do not interfere each other

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Use of ETS

- Insert an Erlang tuple into a table

```
ets:insert(TID, {42, "A value"}),
```

Use of ETS

- Insert an Erlang tuple into a table

```
ets:insert(TID, {42, "A value"}),
```

- Lookup a value

```
ets:lookup(TID, 42),
```

Use of ETS

- Insert an Erlang tuple into a table

```
ets:insert(TID, {42, "A value"}),
```

- Lookup a value

```
ets:lookup(TID, 42),
```

- Find first element

```
FirstElem = ets:first(TID),
```

- Find next element

```
NextElem = ets:next(TID, FirstElem).
```

Use of ETS

- Insert an Erlang tuple into a table

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ets:insert(TID, {42, "A value"}),
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FirstElem = ets:first(TID),
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```

- Many other functions like **delete**, **match**, **foldl**, etc.

Current ETS Scalability Benchmark

Benchmark

- ets_bench from bencherl
- key range $[1, 2^{21}]$, $2^{21} \approx 2 * 10^6$
- Three phases:
  1. Insert phase: inserts 2^{20} random keys, $2^{20} \approx 10^6$
  2. Update and read phase, parameter for percentage update
  3. Delete phase: deletes 10^6 random keys

Machine

- **Four** Intel(R) Xeon(R) CPU E5-4650 CPUs (2.70GHz), **eight cores each**
  - total of 32 physical cores, each **with hyperthreading**
- The machine has 128GB of RAM and is running Debian Linux 3.10.17-amd64 and **Erlang/OTP release 17.0**

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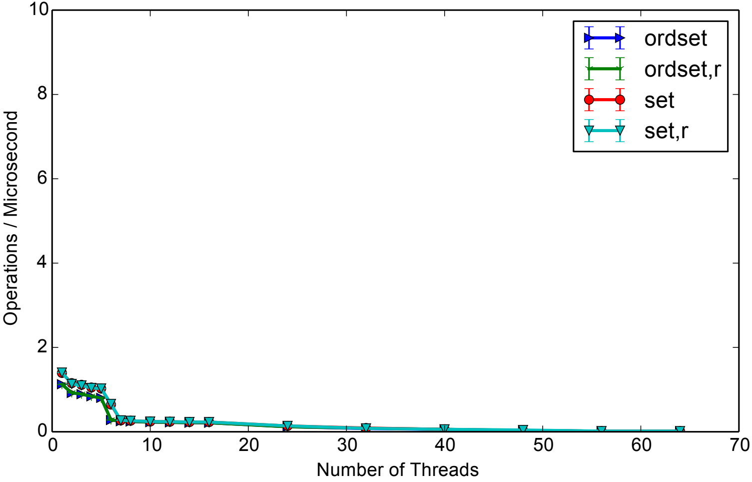
100% Updates



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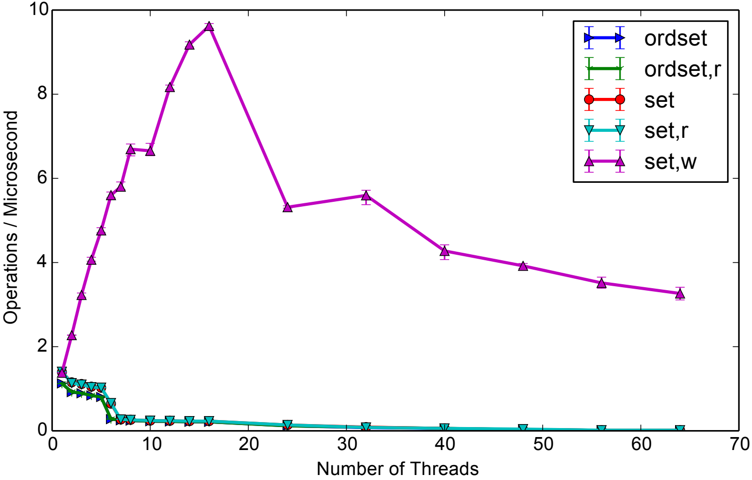
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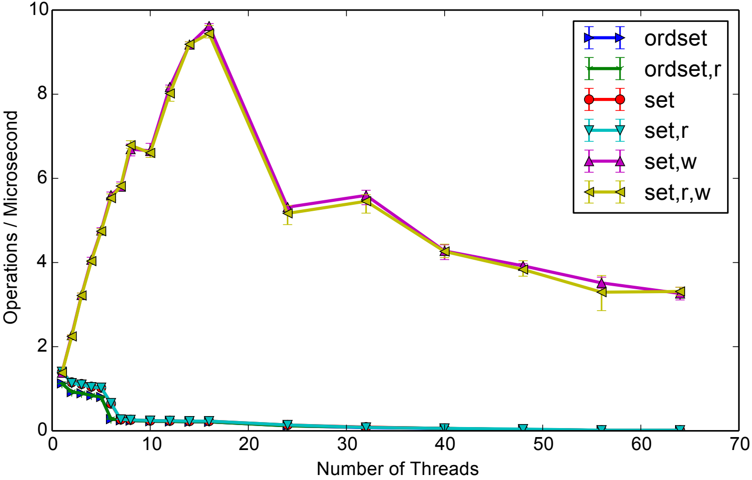

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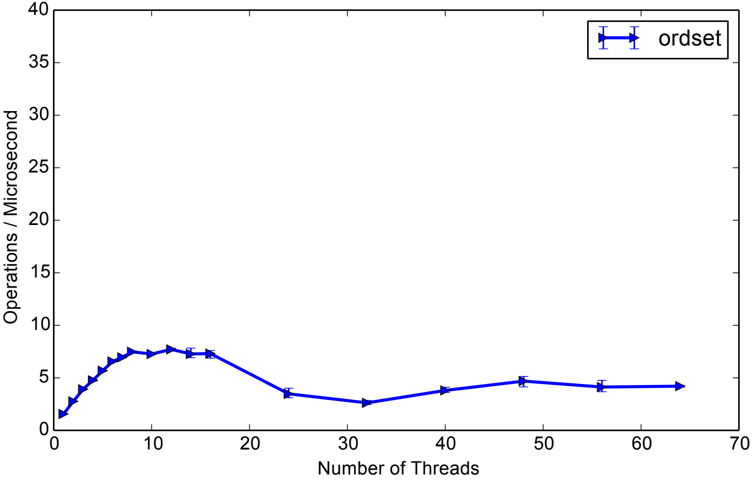
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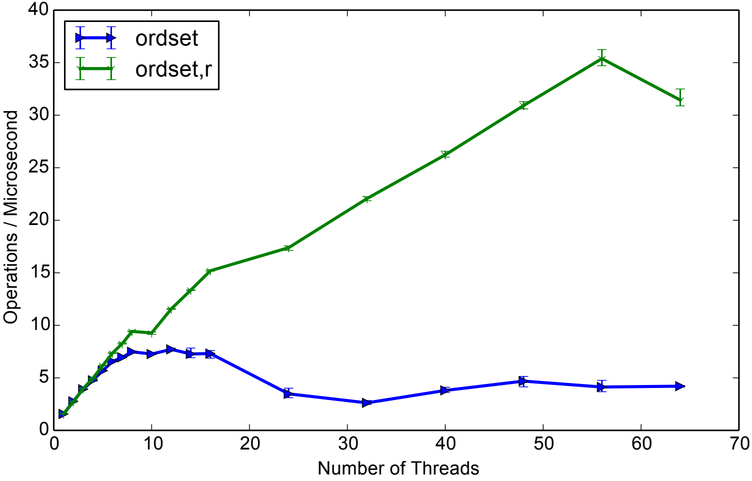
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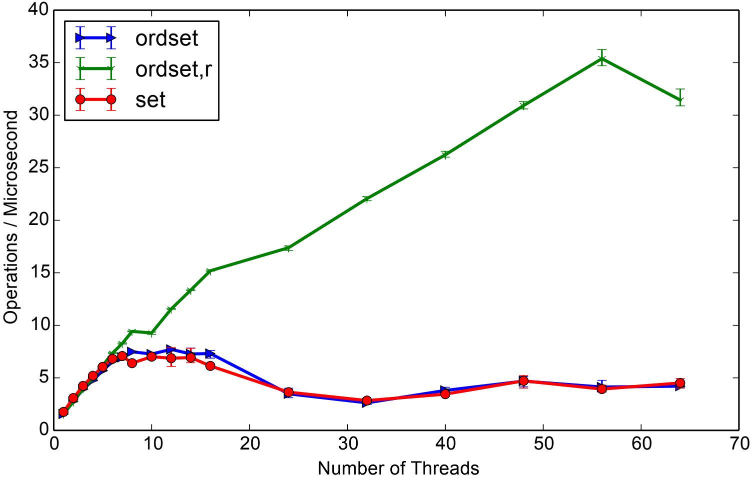
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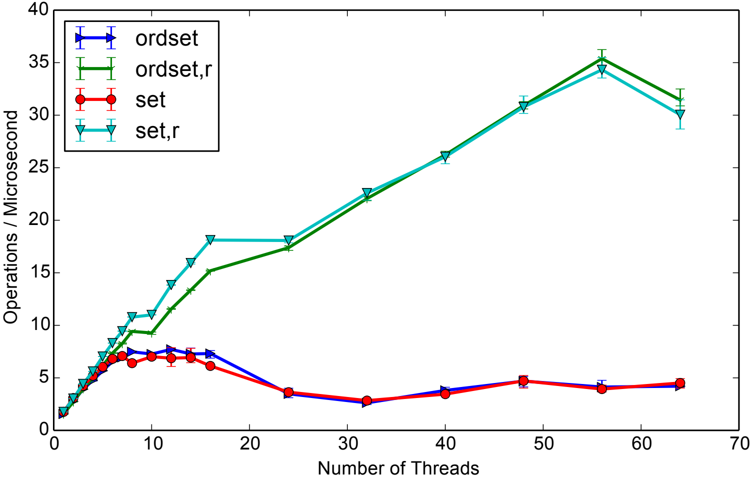
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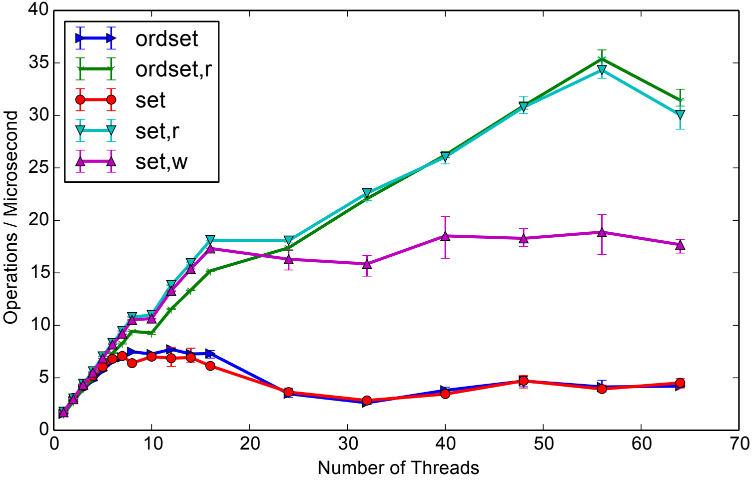

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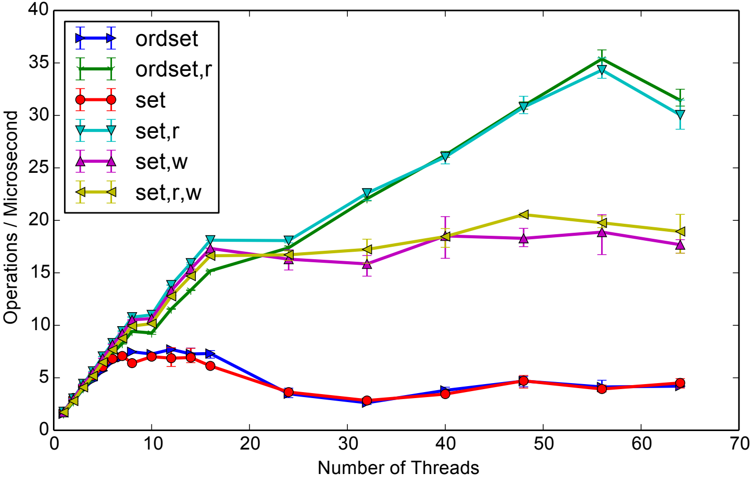
100% Lookups

- Context
- **Motivation**
- CA Trees
- Performance
- Future Work
- Conclusion



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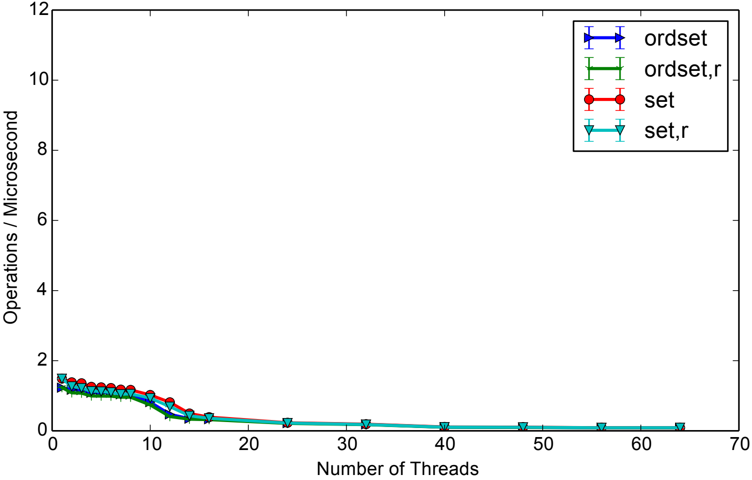
50% Lookups, 50% Updates



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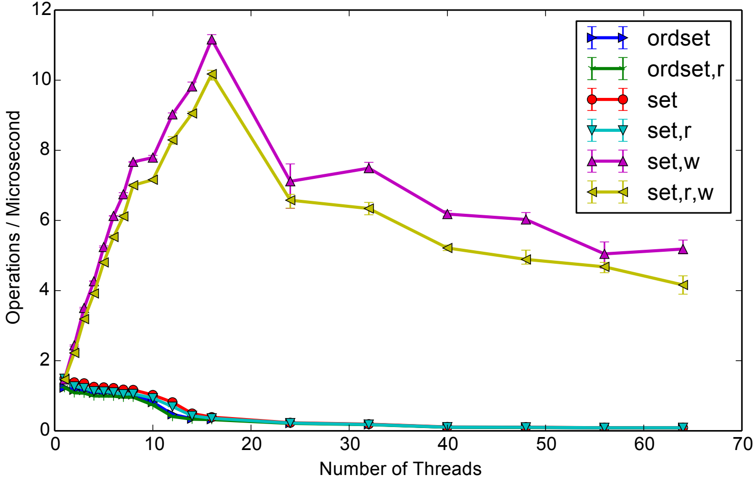
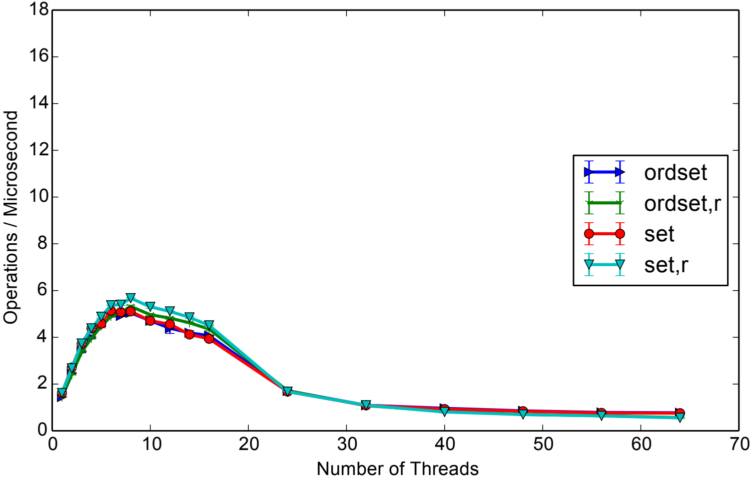
50% Lookups, 50% Updates



99% Lookups, 1% Updates



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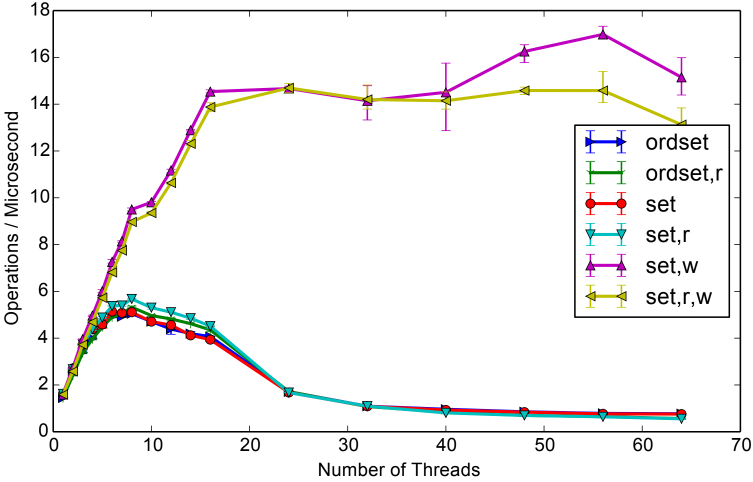
99% Lookups, 1% Updates



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Summary of Current ETS Scalability

- **Something needs to be done with ordered set to make it scale when there are parallel writes!**
  - Huge slow down even with 99% reads

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We Want

Wish list for ordered set

- Good scalability
- Reuse code from the current ETS implementation
- Low overhead in sequential case
    - Current algorithms for concurrent ordered sets sacrifice sequential performance and memory consumption for scalability

Contention Adapting Binary Search Trees (CA trees)

Key Ideas

- Start with sequential binary search tree protected by a lock
- Collect statistics from the lock
- Adapt the tree according to the statistics

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CA Tree Components

Statistics Collecting Lock

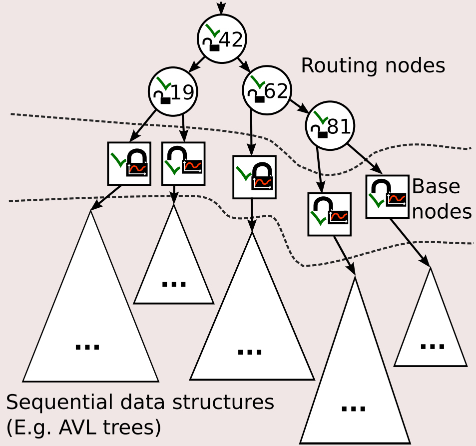
- The lock has an associated counter `C`
- `C += 250` **if** needed to wait to acquire the lock
- `C -= 1` **if not** needed to wait to acquire the lock
- Adapt when `C` reach thresholds
  - E.g. -1000 and 1000

CA Tree Components

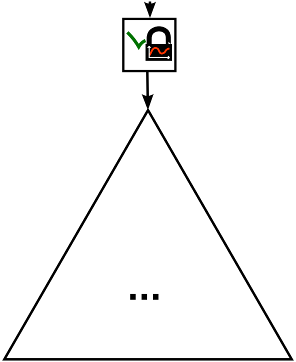
Sequential Ordered Set Data Structure

- Requires support for split and join
  - The **split** operation splits a tree into two so that all keys in one tree are smaller than the keys in the other
  - The **join** operation merges two trees given that all keys in one tree are smaller than the keys in the other
  - $\mathcal{O}(log(N))$ implementations for **AVL trees**, **Red-Black trees**, **Treaps**, etc.

CA Tree Structure



CA Tree Animation



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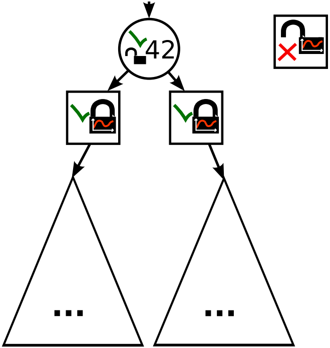
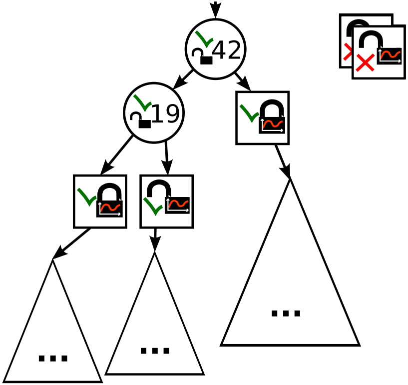
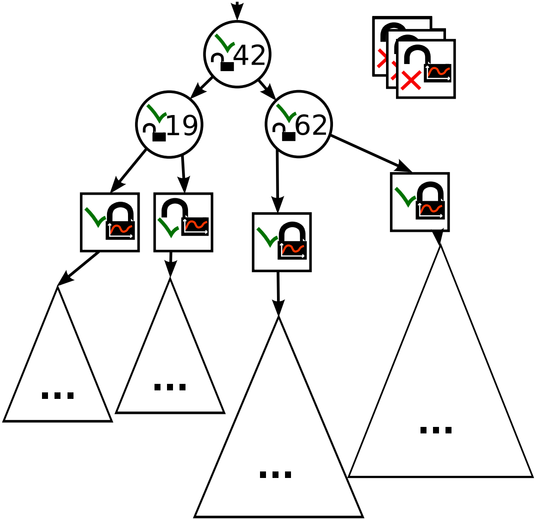
CA Tree Animation



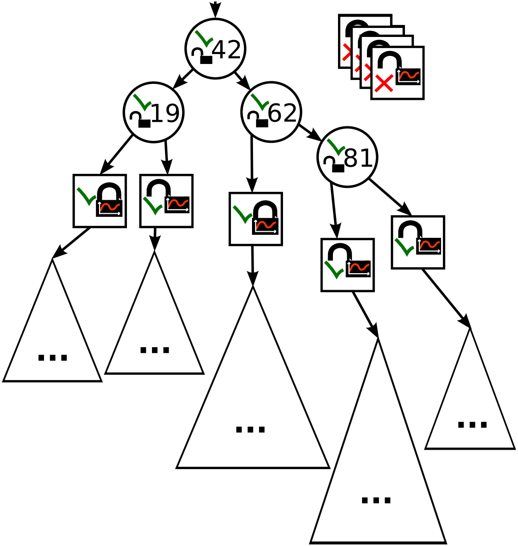
CA Tree Animation



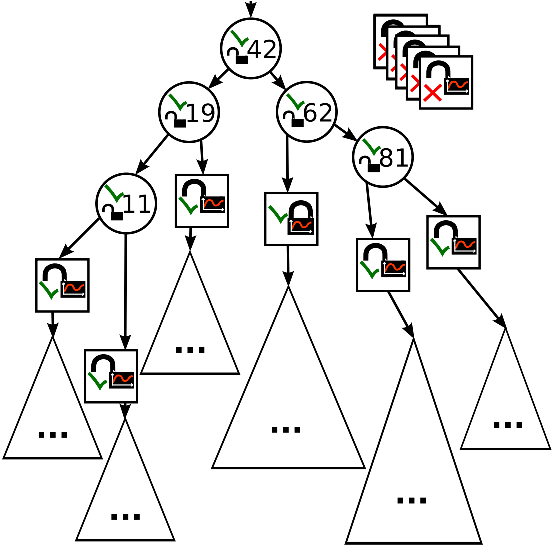
CA Tree Animation



CA Tree Animation



CA Tree Animation



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Motivation
CA Trees
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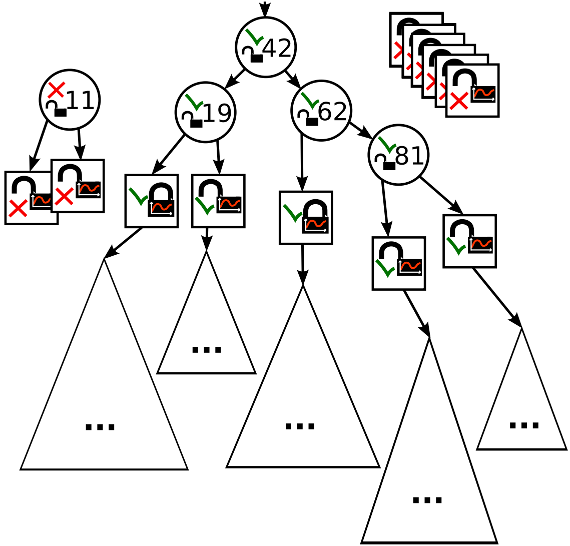
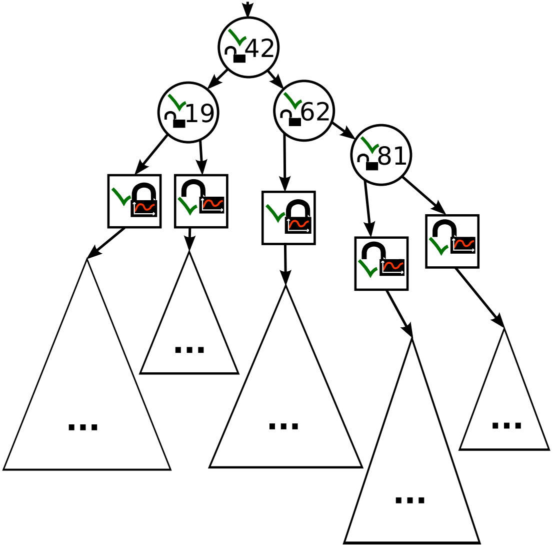
CA Tree Animation



CA Tree Animation



Integration into ETS

- Reuse code from current `ordered_set`

Integration into ETS

- Reuse code from current `ordered_set`
- Routing layer needs special memory management
  - Currently quiescent state based reclamation
  - Better to reuse memory reclamation system for lock free data structures that is already integrated into the Erlang runtime system

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Performance of CA Tree Optimized ETS

The same benchmark again

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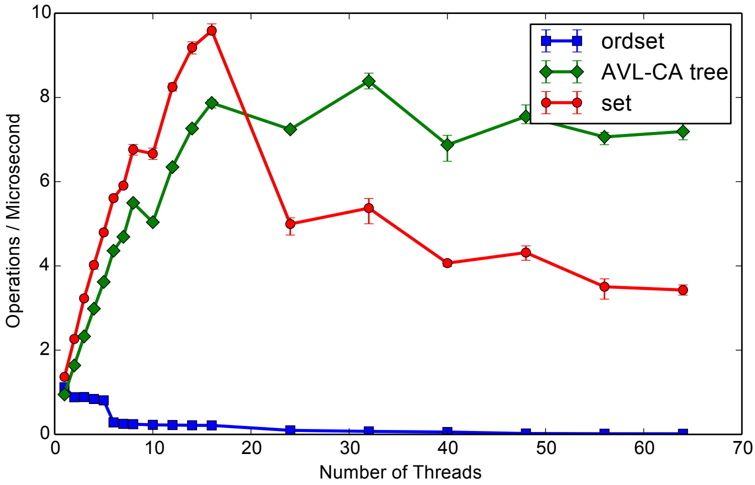
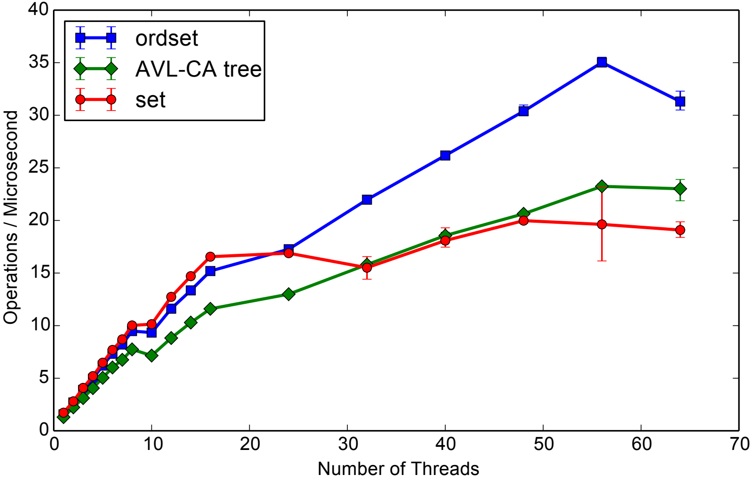
100% Updates



100% Lookups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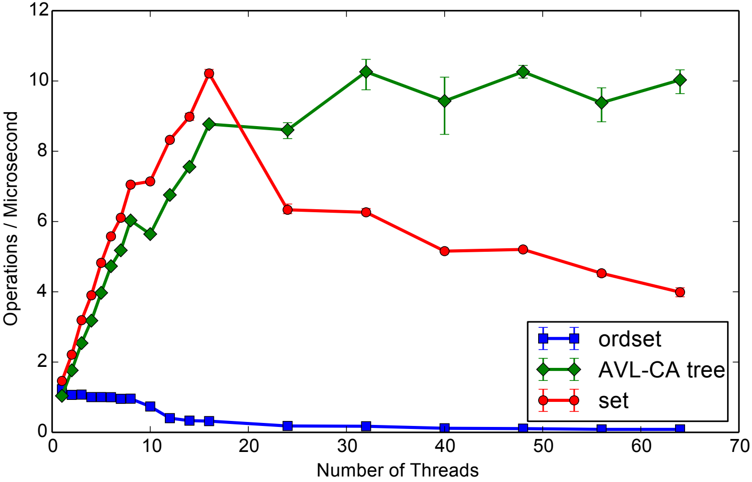
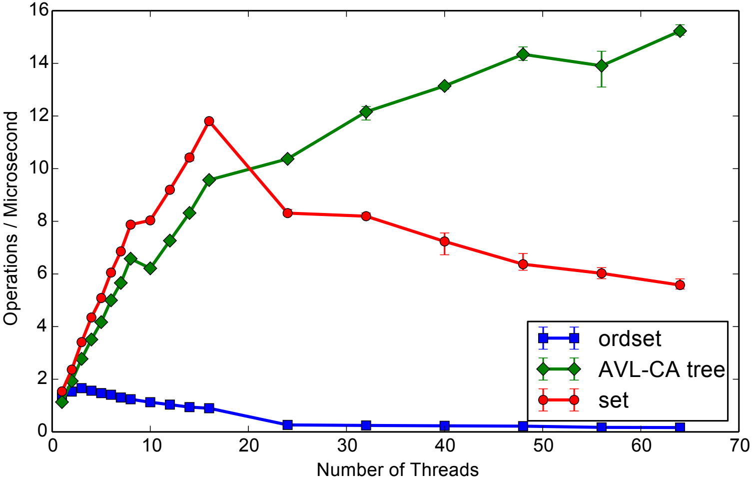
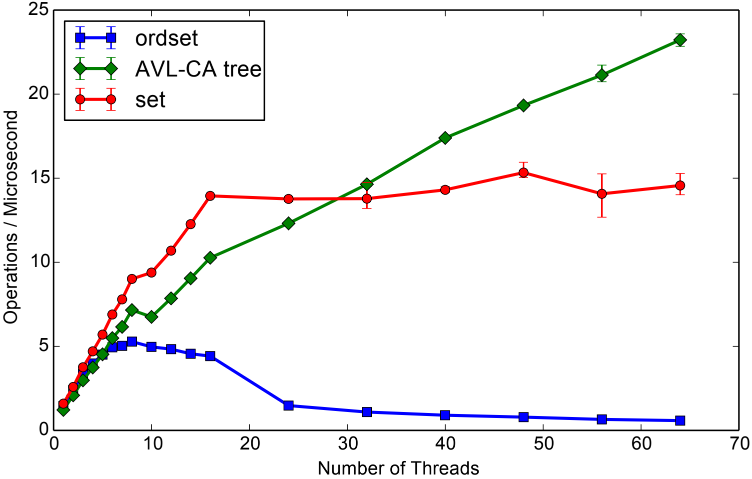
50% Update 50% Lookup Scalabilty



20% Update 80% Lookup Scalabilty



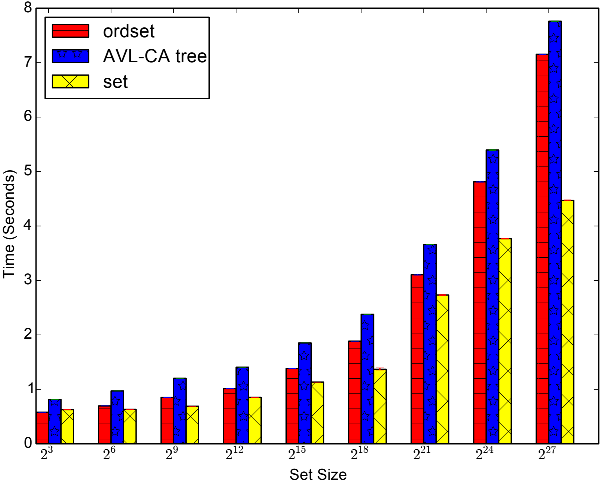
1% Update 99% Lookup Scalabilty



Summary of Scalability Improvements

- The CA trees does not suffer from large slow down
- Scales reasonably well on one chip
- Update heavy scenarios scale far from perfect on NUMA
  - Centralized statistics counter in memory management
  - set has even more problems on NUMA

Sequential Performance, 80% reads



Future Work

To integrate into ETS

- Implement the whole ETS interface
  - Code can be reused from current implementation
- Decide how to integrate it into ETS
  - Always activate on `public` tables
    - Read only case might suffer
  - Only activate when `write_concurrency` is specified

More Information

Work Already Done

- Compare to other concurrent ordered set data structures
- Investigate optimization for read heavy scenarios
  - RW-locks, Sequence Lock, Hardware Lock Elision (HLE)
- Discuss algorithm in detail

More in a Technical Report

http://www.it.uu.se/research/group/languages/software/ca_tree

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- Context
- Motivation
- CA Trees
- Performance
- Future Work
- **Conclusion**

Concluding Remarks

- Performance of concurrent writes on ordered set can be substantially improved in ETS
- CA tree based table scales even better than the current hash based implementation on a NUMA system
- good scalability with low sequential overhead

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Questions?