Faster Concurrent Range Queries with Contention Adapting Search Trees Using Immutable Data

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Overview

- Background (Concurrent Data Structures)
- Contribution (New concurrent data structure)
- Related Work and Evaluation
- Conclusion
- Questions

Background

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  - fine-grained locks, lock-free techniques
- **Our focus:**
  Ordered Sets with support for linearizable range queries

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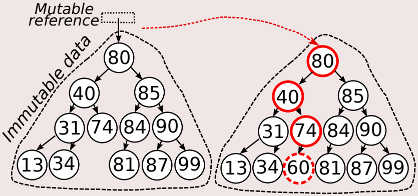
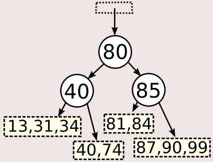
- Challenging
  - Large range queries + updates = **many collisions**

Coarse-grained – Mutable reference to immutable data



- Herlihy [PPoPP'90] (general method)
- SnapTree [PPoPP'10]

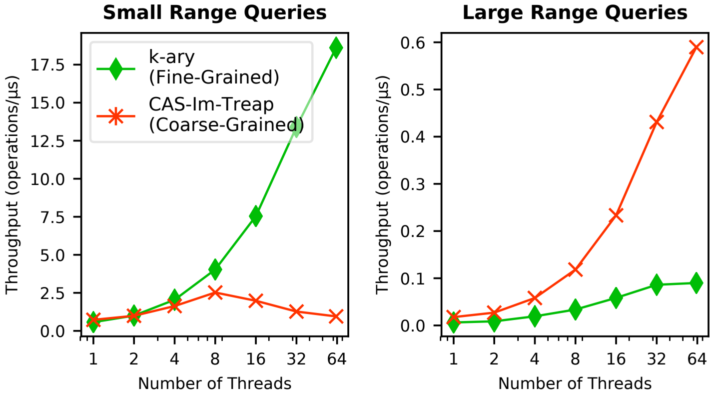
Fine-grained – Immutable leaf nodes



Immutable leaf nodes

- k-ary [PODC'11]
- Leaplist [PODC'13]

Fine-grained vs Coarse-grained – Trade-off



(a) Average #items/query ≈ 5 (b) Average #items/query ≈ 50K

Figure: 10% puts, 10% removes, 55% get, 25% range queries, ≈ 500K items

Contribution

- New concurrent ordered set with linearizable range queries
  - Dynamically adapt the sizes of its immutable parts
    - Contention
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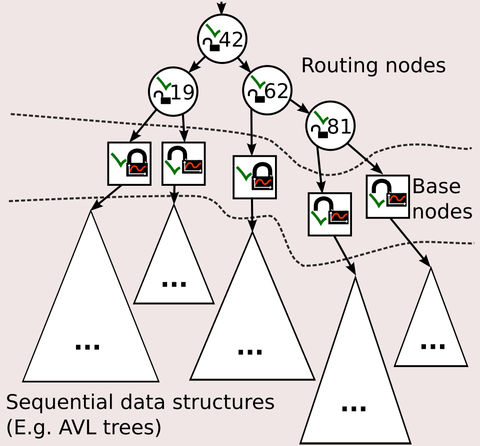
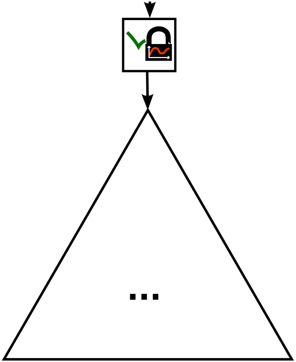
    - Contention
    - Number of items covered by range queries
  - Attempt to get the best of:
    - Coarse-grained approach
    - Fine-Grained approach
  - Based on:
    Contention Adapting Search Trees (**CA trees**)
    ISPDC'15, and LCPC'15

CA Tree Structure



CA Tree Animation



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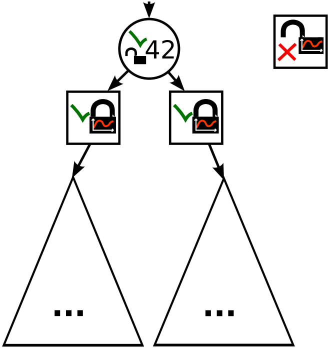

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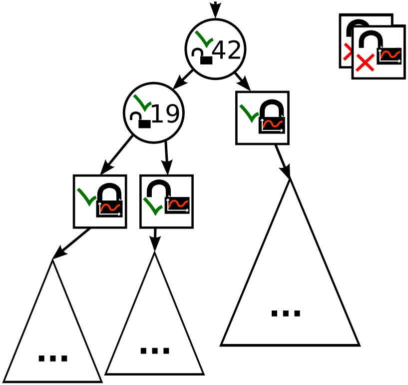

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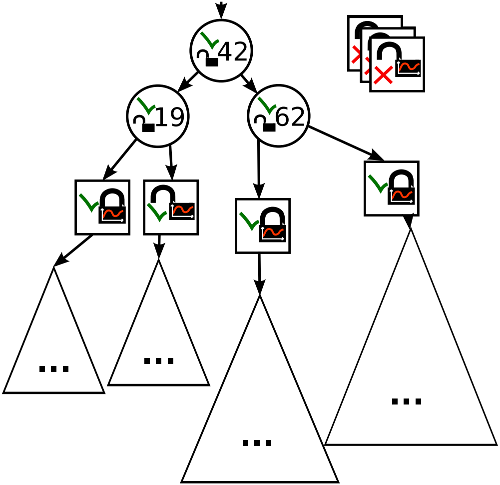

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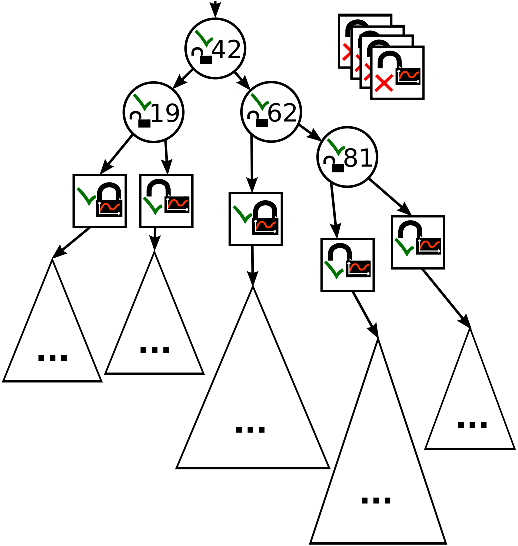

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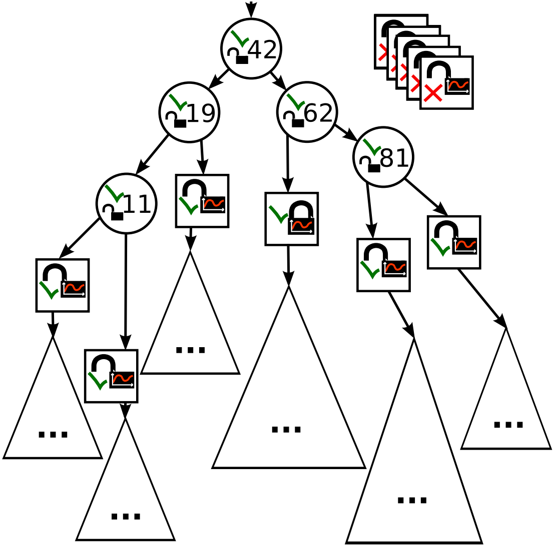

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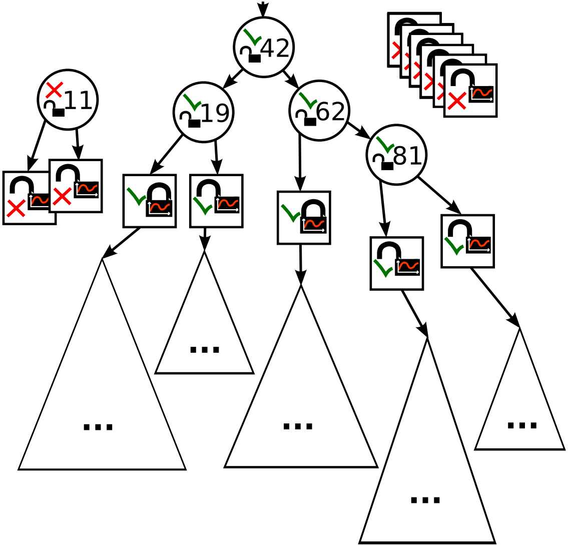

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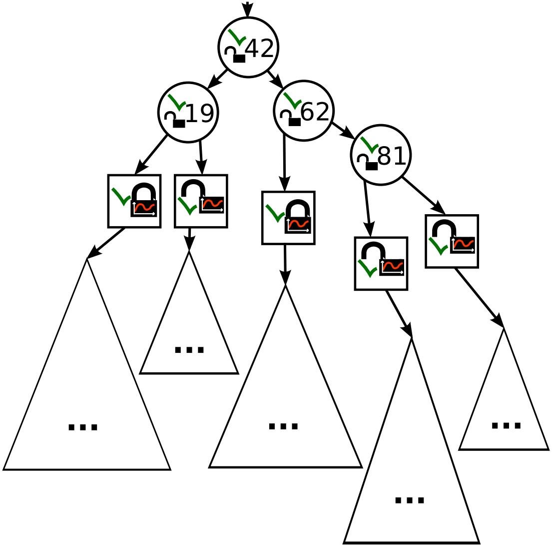
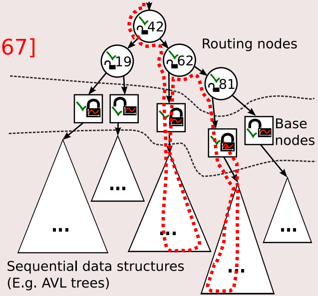


Range Queries in CA trees (**the old way**)

1. Find base node containing first key in the range
2. Travese to and lock subsequent base nodes
   - Until base node with key greater than end of range or until the last base node has been found
3. Perform range query in sequential data structures
4. Unlock base node locks and decrease statistics counters if more than one base node

range: [58,67]



☹

Long time period in which conflicts can happen

Range Queries in CA trees (**the new way**)

- **Implement sequential data structure as a mutable reference to an immutable data structure**

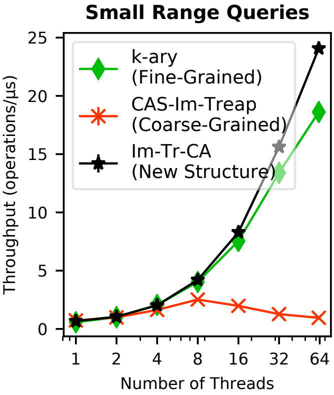
1. Find base node containing first key in the range
2. Traverse to and lock subsequent base nodes
   - Until base node with key greater than end of range or until the last base node has been found
3. ~~Perform range query in sequential data structures~~
   Copy references to sequential data structures
4. Unlock base node locks and
   decrease statistics counters if more than one base node
5. Perform range query in the sequential data structures

☺ **Much shorter time period for conflicts**

Implementation

- Immutable Treap (balanced binary search tree)
- items stored in fat leaf nodes
  - Up to 64 items in arrays
  - Improves cache locality

How does the new method perform?



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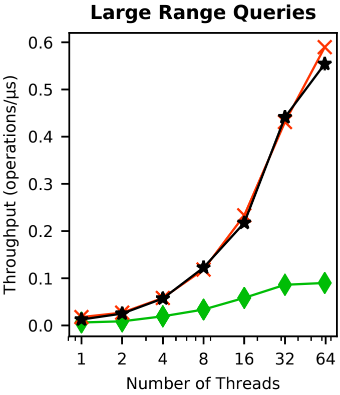

(b) Average #items/query ≈ 50K

Figure: 10% puts, 10% removes, 55% get, 25% range queries, ≈ 500K items

Fine-Grained Approach

- **k-ary** – up to k items in immutable leaf nodes
  Brown and Avni [PODC'11]

Coarse-Grained Approach

- **SnapTree** – Fast snapshots based on copy-on-write
  Bronson, Casper, Chafi and Olukotun [PPoPP'10]

Others

- **Old CA tree** – items in mutablbe Skiplists with fat nodes
  Saganos, and Winblad [LCPC'15]
- **KiWi** – Global version number counter for range queries
  Basin et al. [PPoPP'17]
- See paper for more related work... (Bronson [PPoPP'10], Avni et al. [PODC'13], Chatterjee [ICDCN'17])

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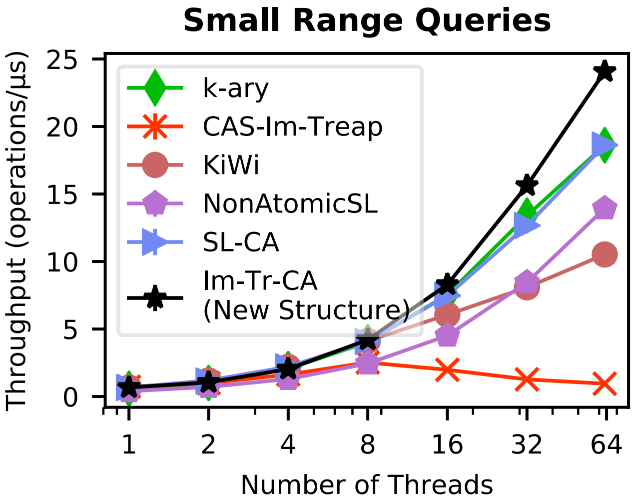
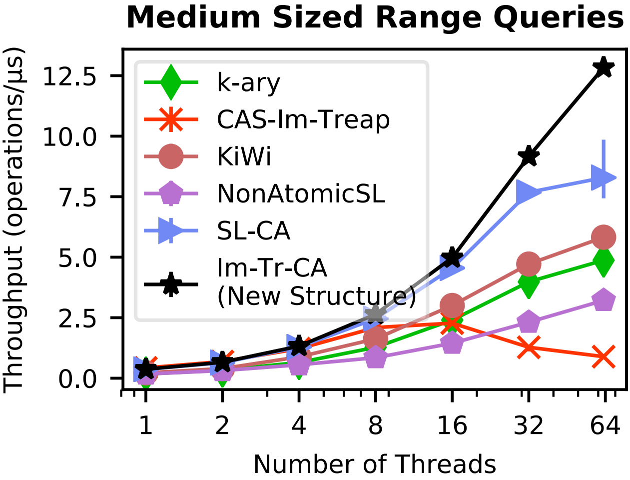
Evaluation

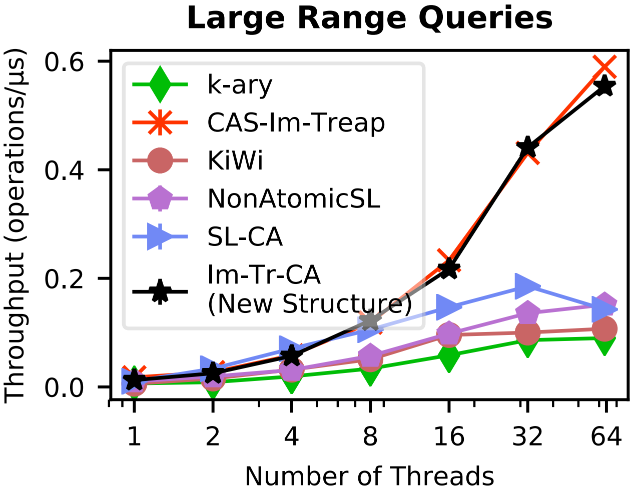
- Benchmark with a mix of
  - Inserts
  - Removes
  - Lookups
  - **Range Queries of size up to** *max*
- Platform
  - NUMA with four Intel Xeon E5-4650 CPUs (2.70GHz)
    8 cores each with hypherthreading = **64 logical cores**
- Implementation in Java
- See paper for other benchmark and more data structures...



$\approx$ 500K items, Inserts:10%, Removes:10%, Lookups:55%, **Queries:25%-max:10**



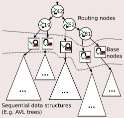
≈ 500K items, Inserts:10%, Removes:10%, Lookups:55%,
Queries:25%-max:1000



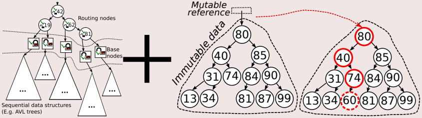
$\approx$ 500K items, Inserts:10%, Removes:10%, Lookups:55%, **Queries:25%-max:100000**

Final Remarks

- CA trees
  - Key advantage:
    Adapts to contention and range queries



- **New CA tree variant using Immutable Data**



  - Quick traverse of shared mutable data
    - Conflicts less costly
  - Scales much better than old variants and related work

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Contention Statistics Collecting Lock

```
struct StatLock {
  Lock lock;
  int statistics;
}

void statLock(StatLock slock) {
  if (tryLock(slock.lock)) {
    slock.statistics -= SUCCESS_CONTRIBUTION;
    return;
  }
  lock(slock.lock);
  slock.statistics += FAIL_CONTRIBUTION;
}
```

Contention Adaptation

```
...
statLock(base.lock)

performOperation(base.root, parameters...);

if (base.lock.statistics > MAX_CONTENTION) {
  highContentionSplit(tree, base, prevNode);
} else if (base.lock.statistics < MIN_CONTENTION) {
  lowContentionJoin(tree, base, prevNode);
}
statUnlock(base.lock)
```