Lock-free Transactions without Rollbacks for Linked Data Structures

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Composite Operations

Example

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void Move(set a, set b, int key){
  a.Delete(key);
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- Composing linearizable operations is error-prone [Shacham et al., 2011]

Transactional Data Structures

Atomicity

If one operation fails, the entire transaction should abort.

Isolation

Concurrent execution of transactions appears to take effect in some sequential orders that respect real-time ordering.

Software Transactional Memory (STM)

An STM instruments threads' memory accesses, which records the locations a thread read in a *read set*, and the locations it writes in a *write set*. Conflicts are detected among the *read/write sets* of different threads. In the presence of conflicts, only one transaction is allowed to commit while the others are aborted and restarted.

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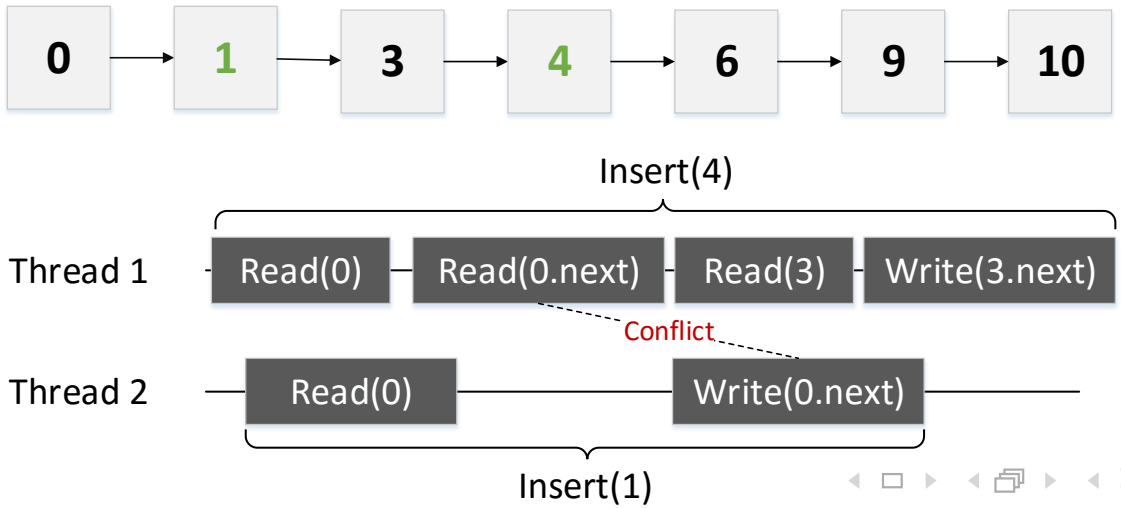
- Memory instrumentation exhibits large overhead
- Low-level memory conflicts do not translate to high-level semantic conflicts, which cause excessive aborts



Transactional Boosting [Herlihy and Koskinen, 2008]

Transactional boosting uses *abstract lock* to ensure that non-commutative method calls never occur concurrently. A transaction makes a sequence of invocation to the objects methods after acquiring the abstract lock associated with each one. It aborts when failed to acquire a lock and recovers from failure by invoking the *inverses* of already executed operations.

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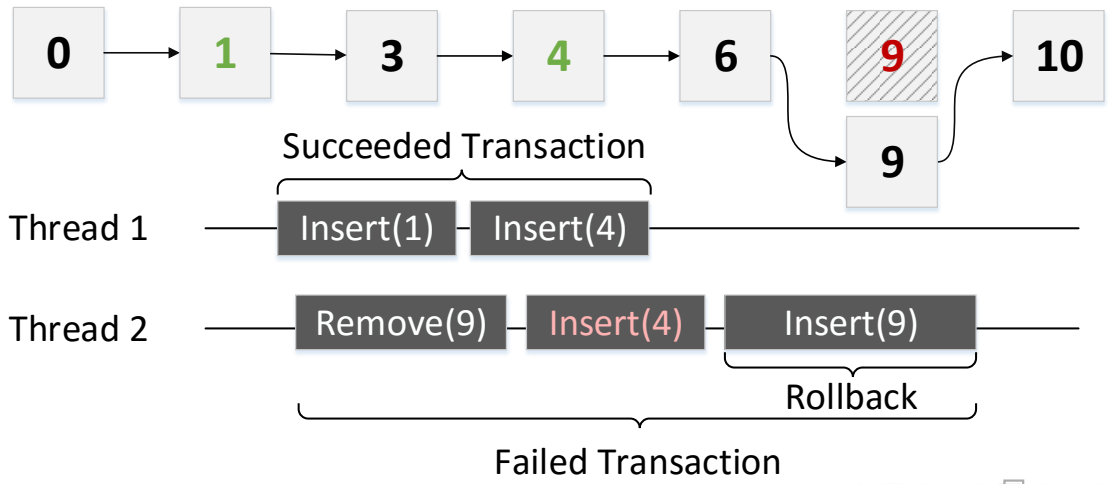
- Use of locks degrades the progress guarantee of lock-free data structures
- Upon transaction failure the rollback process causes overhead



Automatic Semantic Locking [Golan-Gueta et al, 2015]

Automatically enforces atomicity of given code fragments (multiple calls to different data structures) by inserting pessimistic *abstract locks*.

```
1   atomic {
2     set=map.get(id);
3     if(set==null) {
4       set=new Set(); map.put(id,
5     }
6     set.add(x); set.add(y);
7     if(flag) {
8       queue.enqueue(set);
9       map.remove(id);
10    }
11  }
```

```
1   atomic { map.lock({get(id),put(id,*),remove(id)});
2     set=map.get(id);
3     if(set==null) {
4       set=new Set(); map.put(id, set);
5     }
6     set.lock({add(*)}); set.add(x); set.add(y);
7     if(flag) { queue.lock({enqueue(set)});
8       queue.enqueue(set); queue.unlockAll();
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11    map.unlockAll(); set.unlockAll();
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- Need additional container to store key-lock map
- Lock acquiring is reordered to avoid rollbacks

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- Key contributions
  - Lock-free semantic conflict detection
  - Logical status interpretation eliminates rollbacks
  - Cooperative transaction execution minimizes aborts

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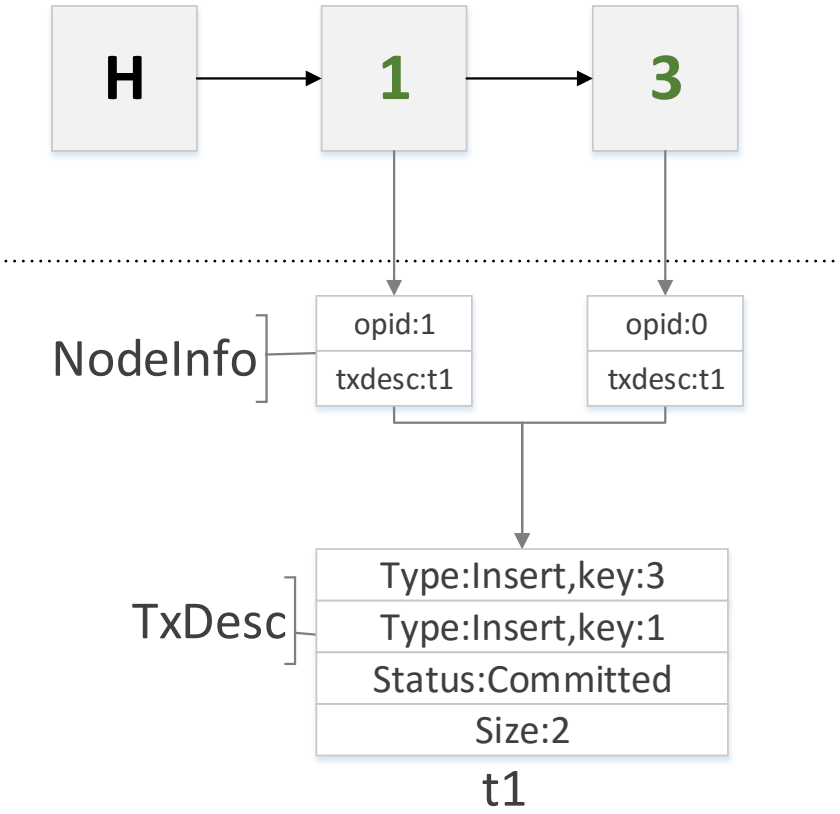
- Key contributions
  - Lock-free semantic conflict detection
  - Logical status interpretation eliminates rollbacks
  - Cooperative transaction execution minimizes aborts
- Applicable data structures
  - Set: Insert(k), Delete(k), Find(k)
  - Linked data structures: list, skiplist, trees

Node-based Conflict Detection



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- TxDesc contains operation context and status

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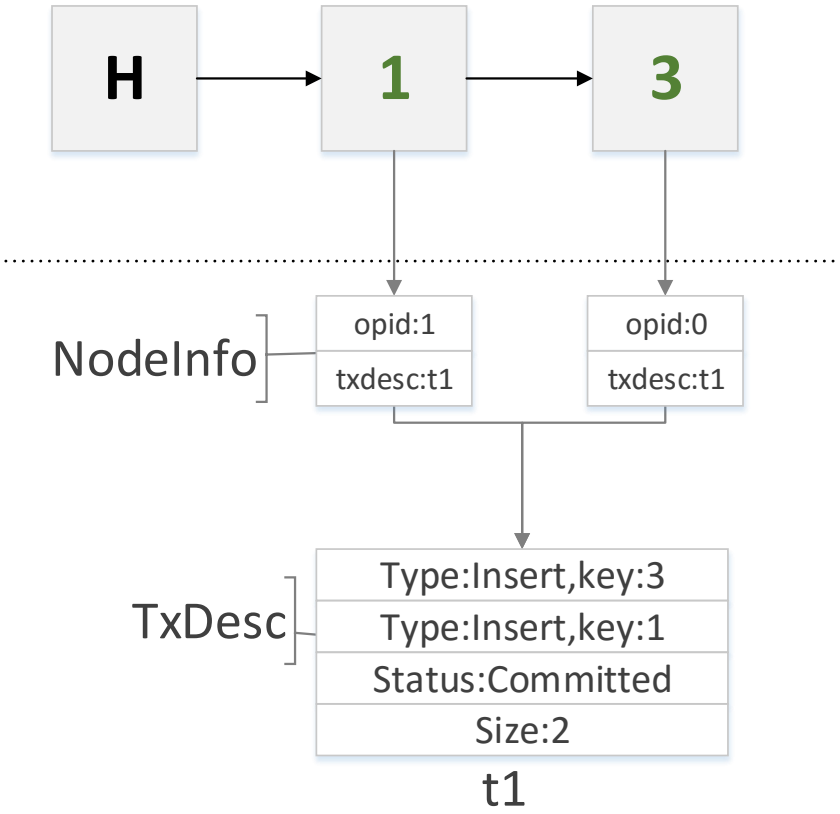
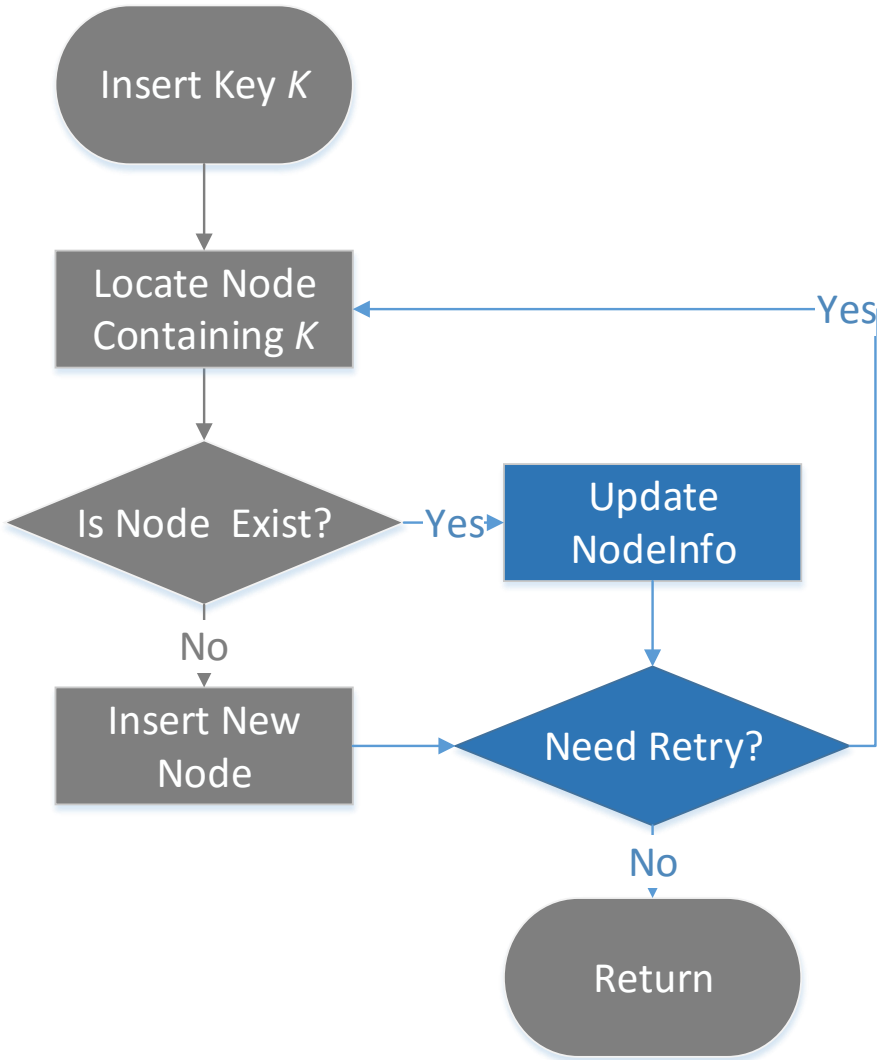


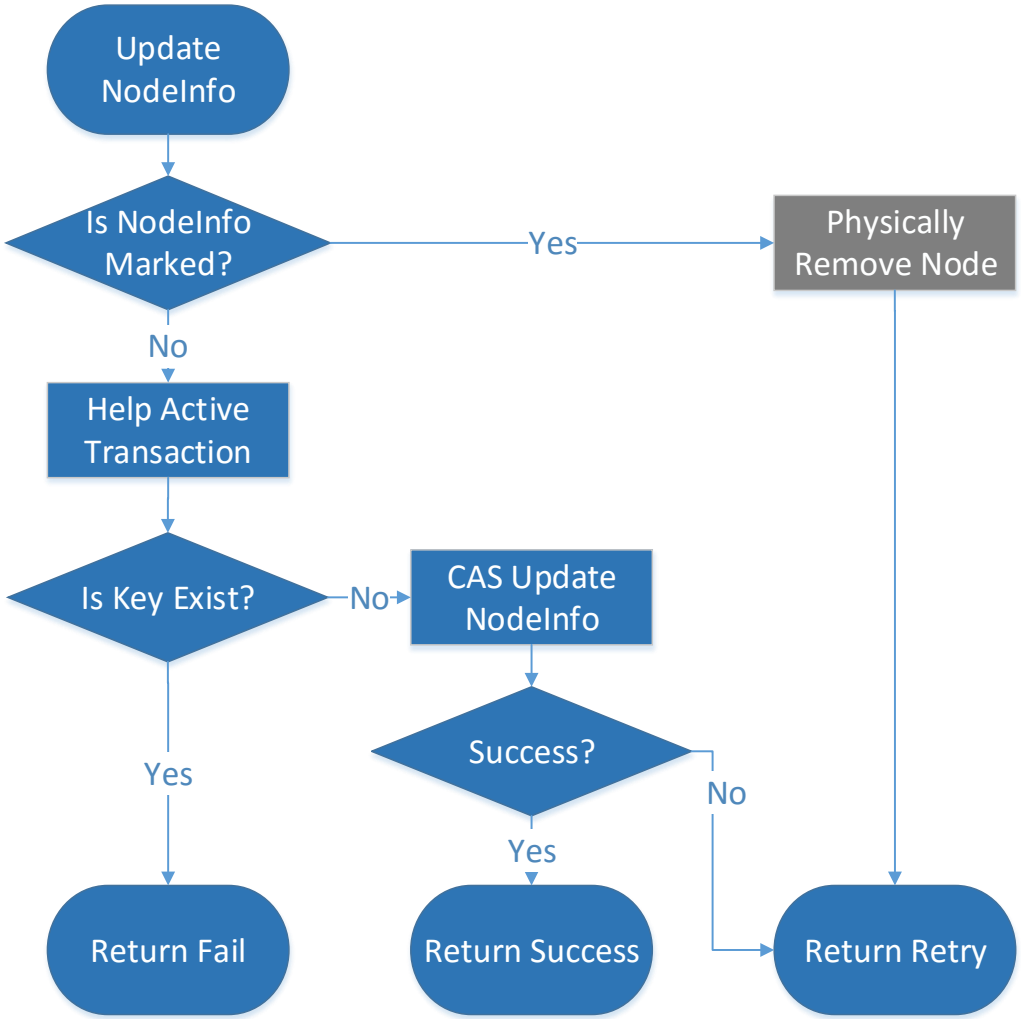
- Embed NodeInfo as a monitors
- TxDesc contains operation context and status
- Eager detection
- Key access = node access

Transformed INSERT Workflow



- Extract DO_LOCATEPRED, and DO_INSERT
- New code path to update NODEINFO

UpdateNodeInfo Workflow for Insert



- Physically remove node with marked NodeInfo
- Enforce serialization through helping
- Interpret logical status using IsKeyExisit
- Returns a tri-state value

Interpretation-based Logical Rollback

Table: IsKeyExist Predicate

Operation \ TxStatus	Committed	Aborted	Active
Insert	True	False	True (same transaction)
Delete	False	True	False (same transaction)
Find	True	True	True

Cooperative Transaction Execution

- Process
  - Invoke the sequence of operation in TxDesc
  - Update the transaction status using CAS
  - Mark NodeInfo on successfully deleted nodes

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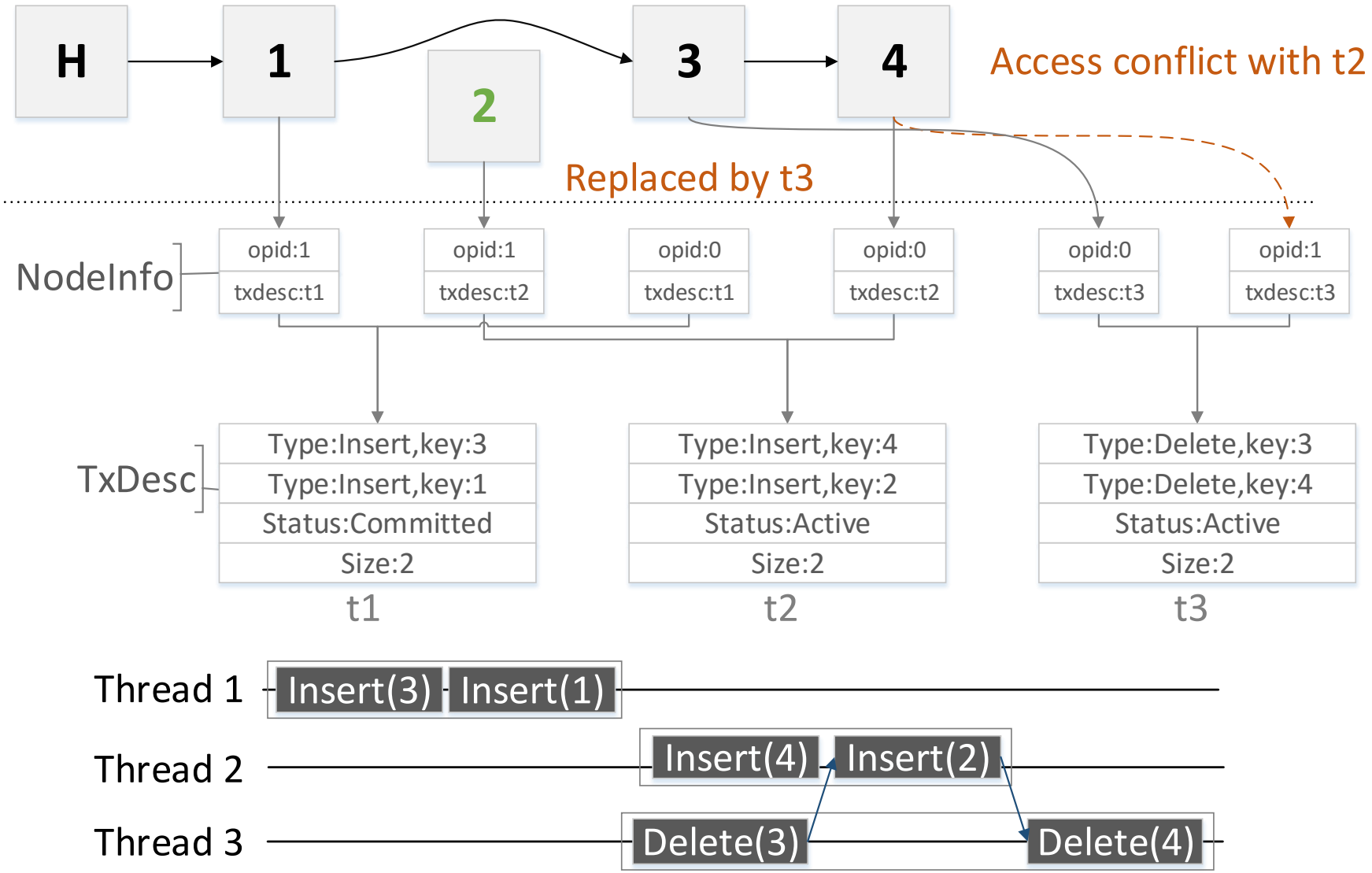
- Nuances
  - Cyclic dependency check and recovery
    - Duplicate descriptor in HelpStack
  - No help = obstruction-freedom
    - Contention management: aggressive, polite, karma

LFTT in Action



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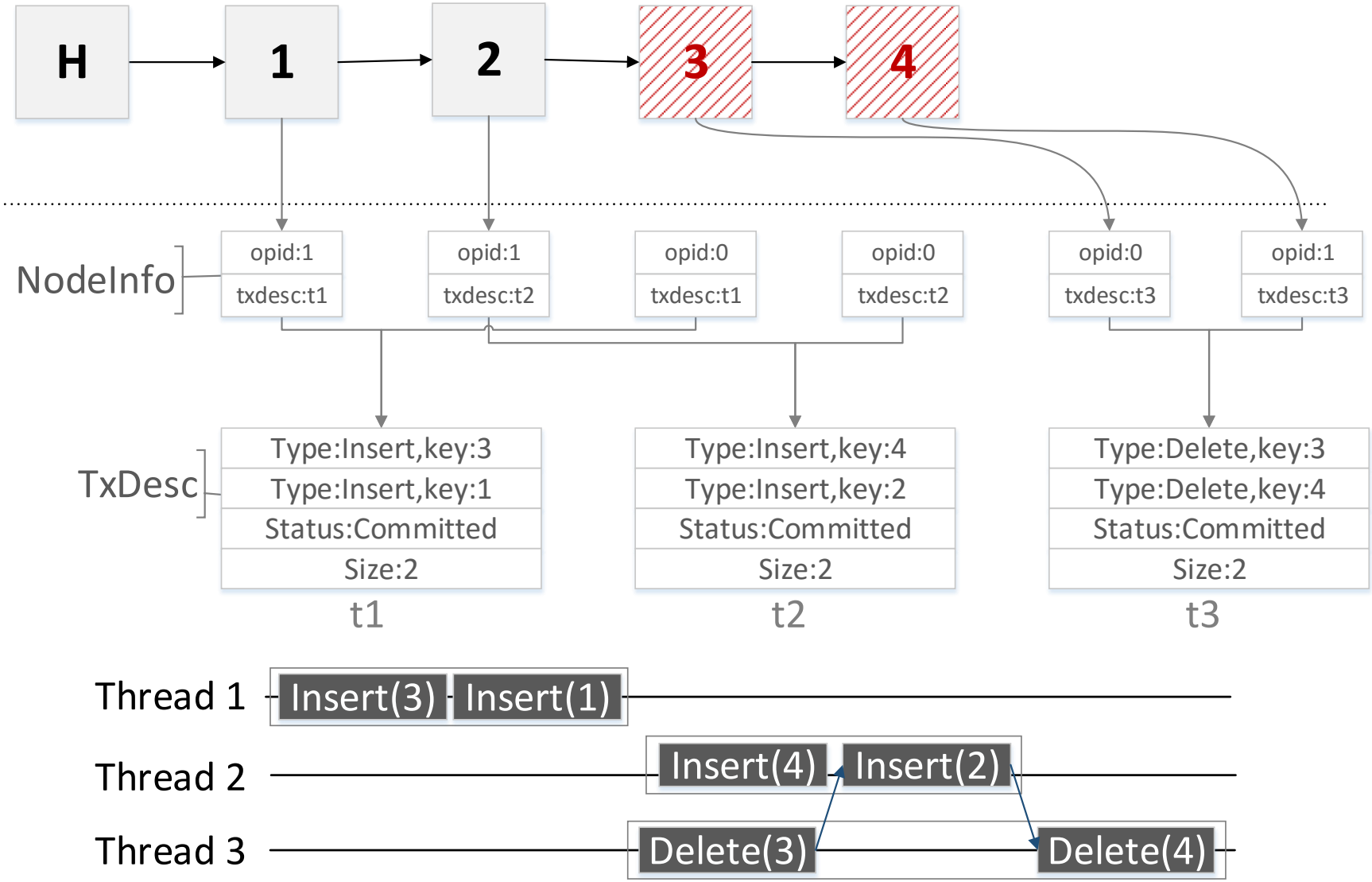

Environment

- Hardware
  - 64-core NUMA (4 AMD Opteron @2.1GHz)
- Micro-benchmark
  - GCC 4.7 w/ O3
  - 1, 2, 4, 8, and 16 operations per transaction
  - Write-dominated, read-dominated, and mixed workloads

Alternatives

- Transactional skiplist [Fraser, 2004]
  - Object-based STM (OTM) [Fraser, 2004]
  - Transactional boosting (BST)
  - Lock-free Transactional Transformation (LFT)
- Transactional linked list [Harris, 2001]
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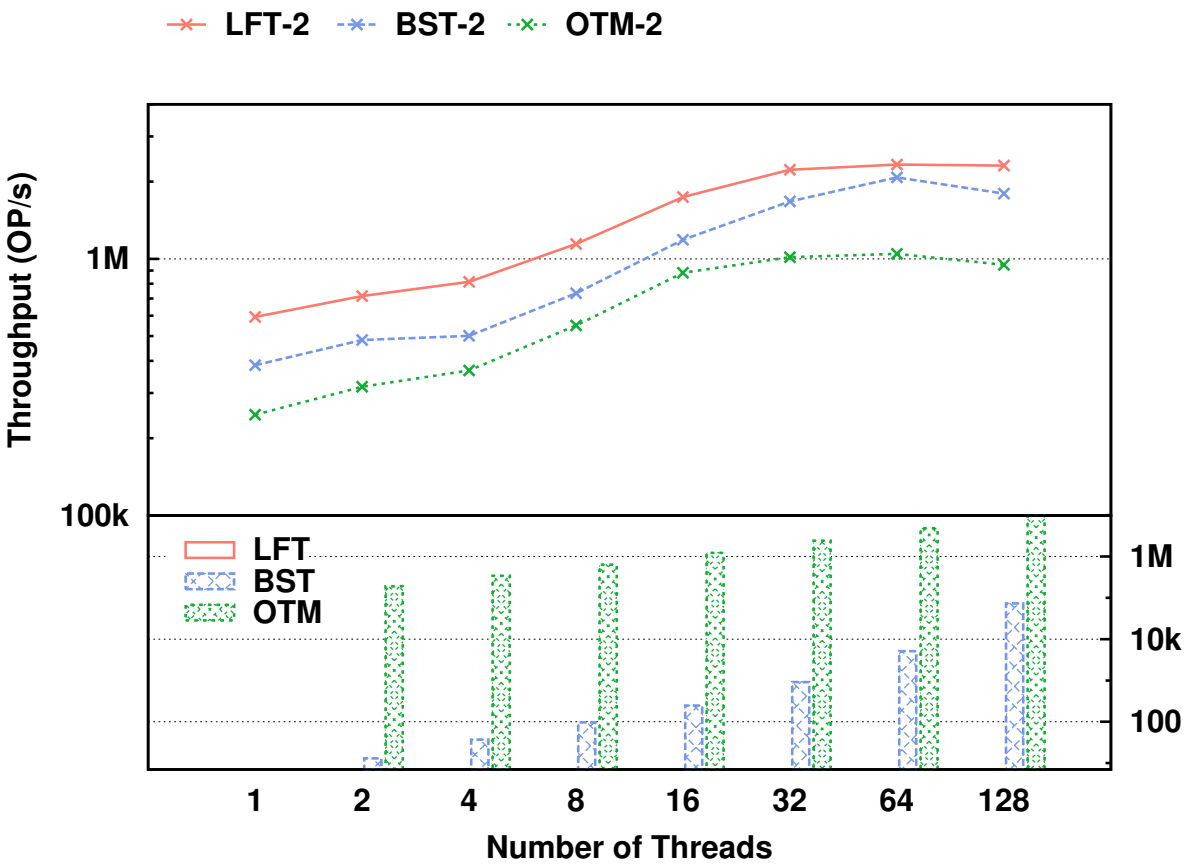
Throughput — Skiplist Mixed Workload



1M Key, 33% Insert, 33% Delete, 34% Find

- Average of 60% speedup over boosting
- 3 times speedup over STM
- No spurious aborts

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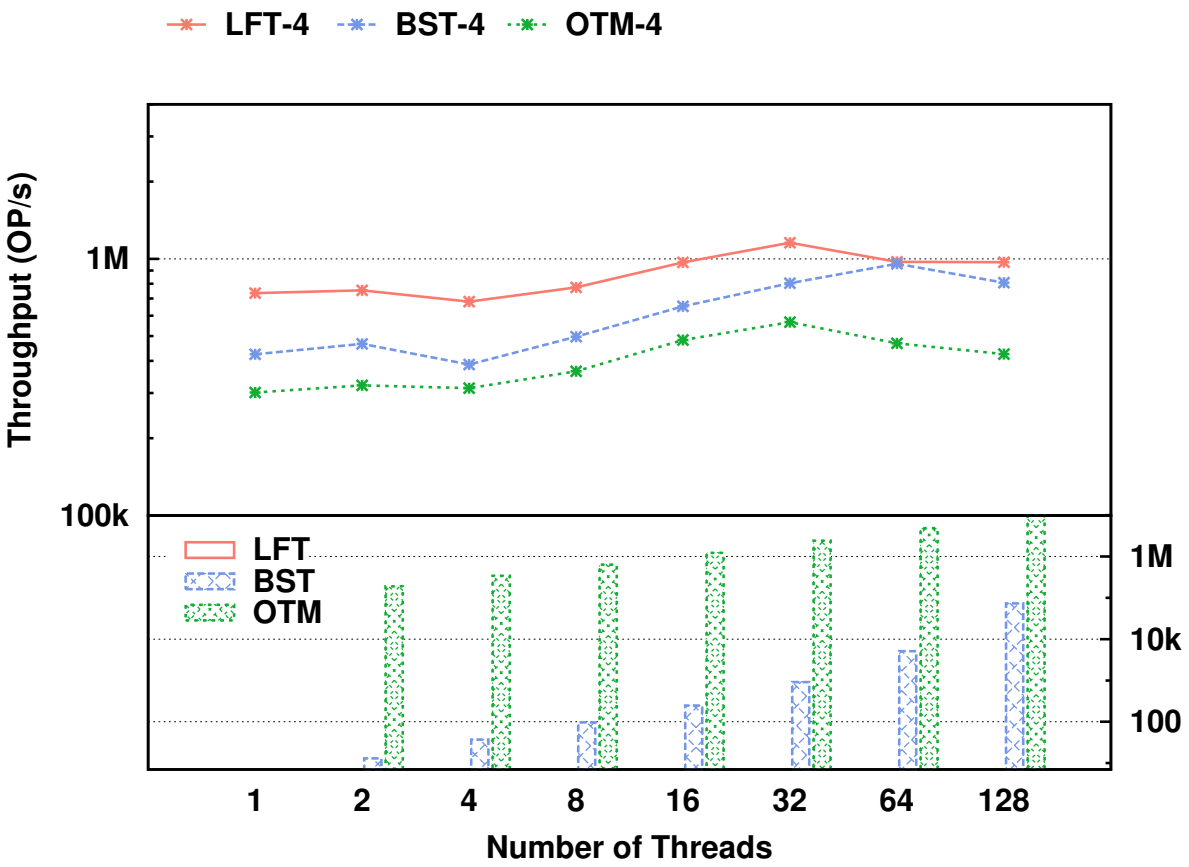

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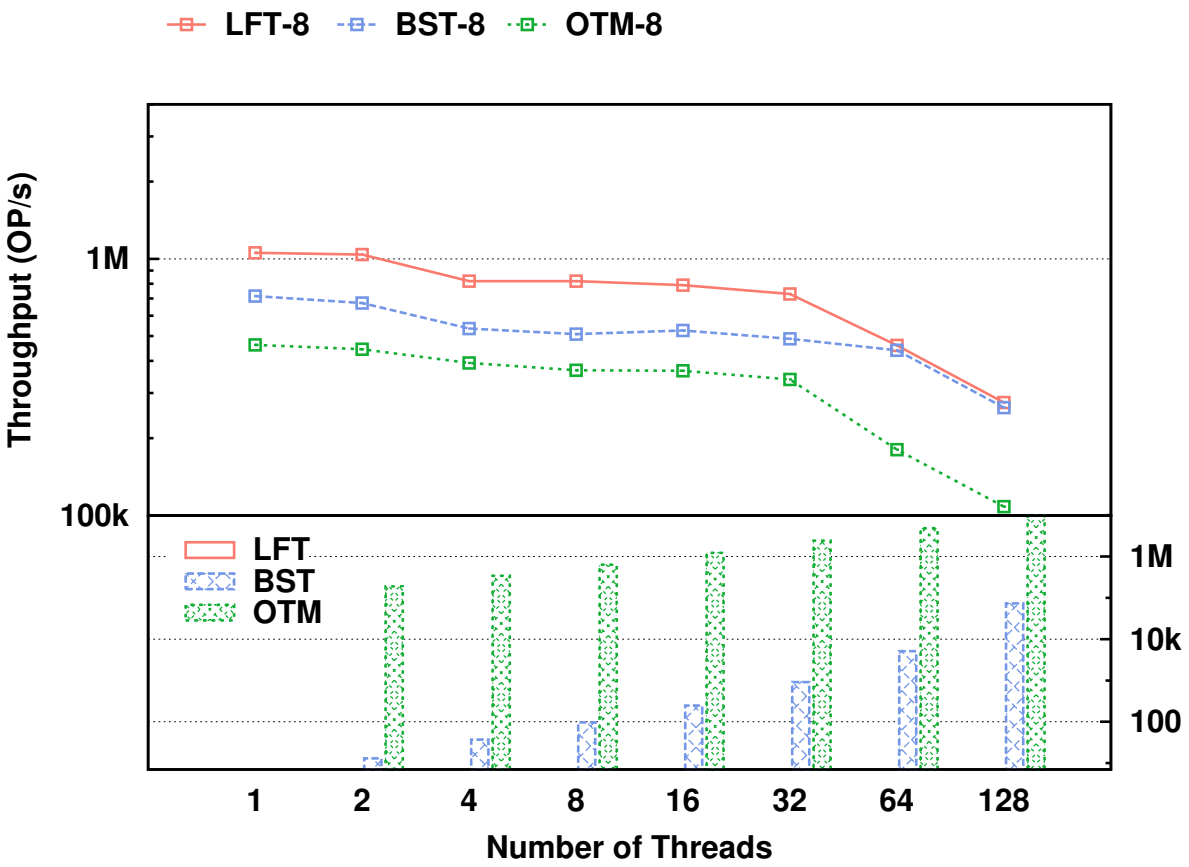

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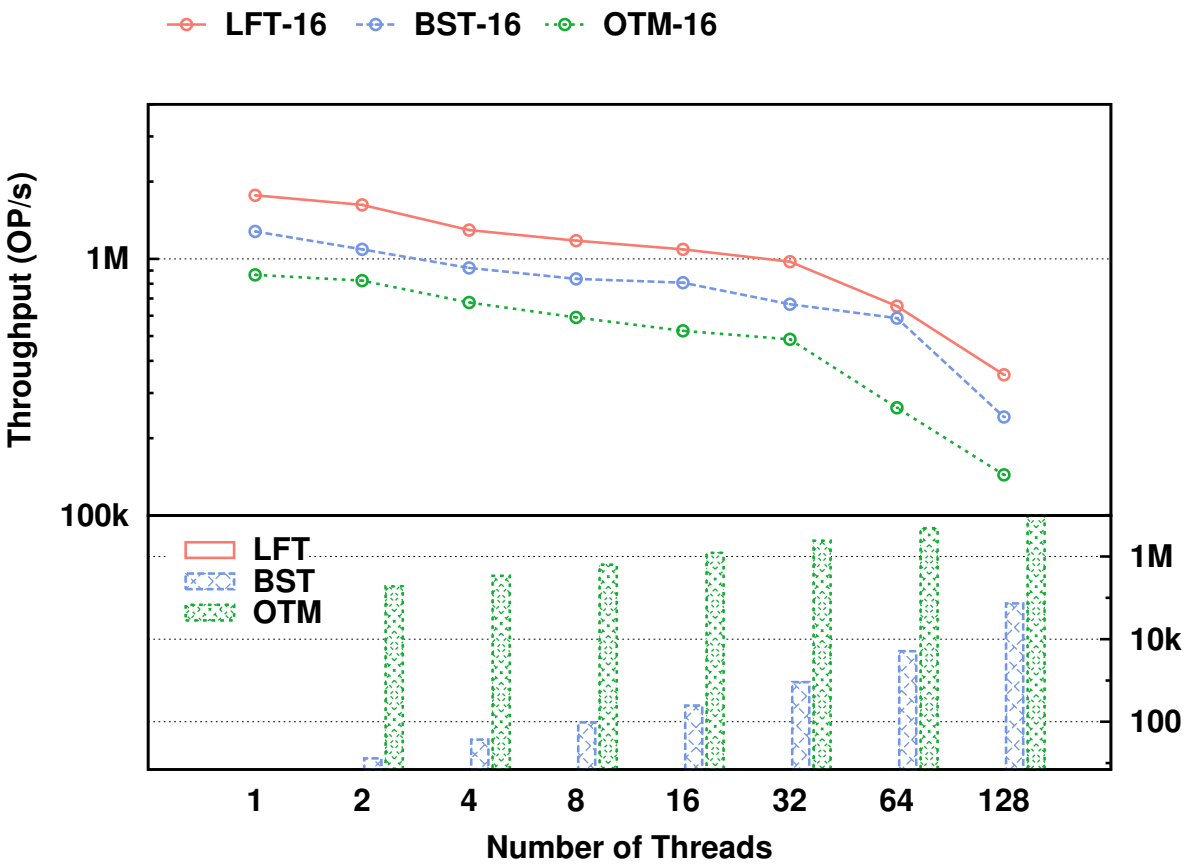

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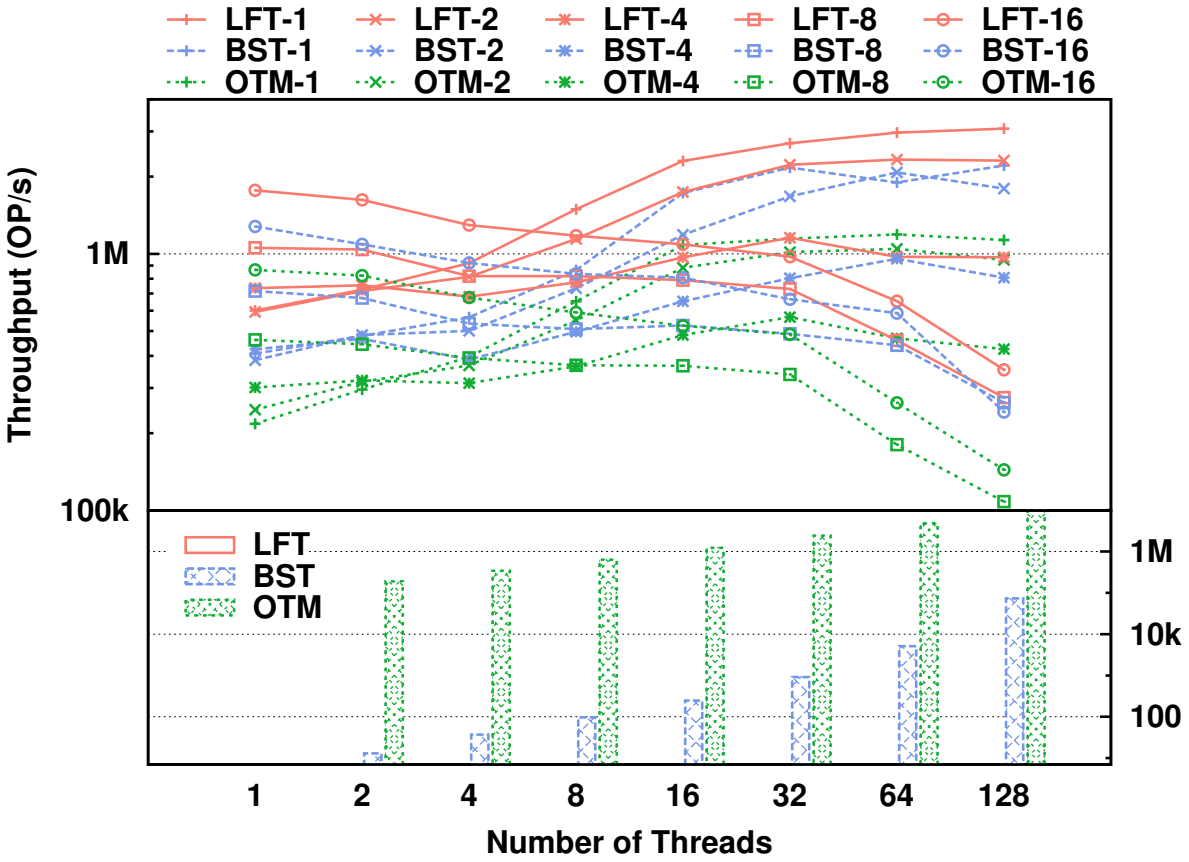

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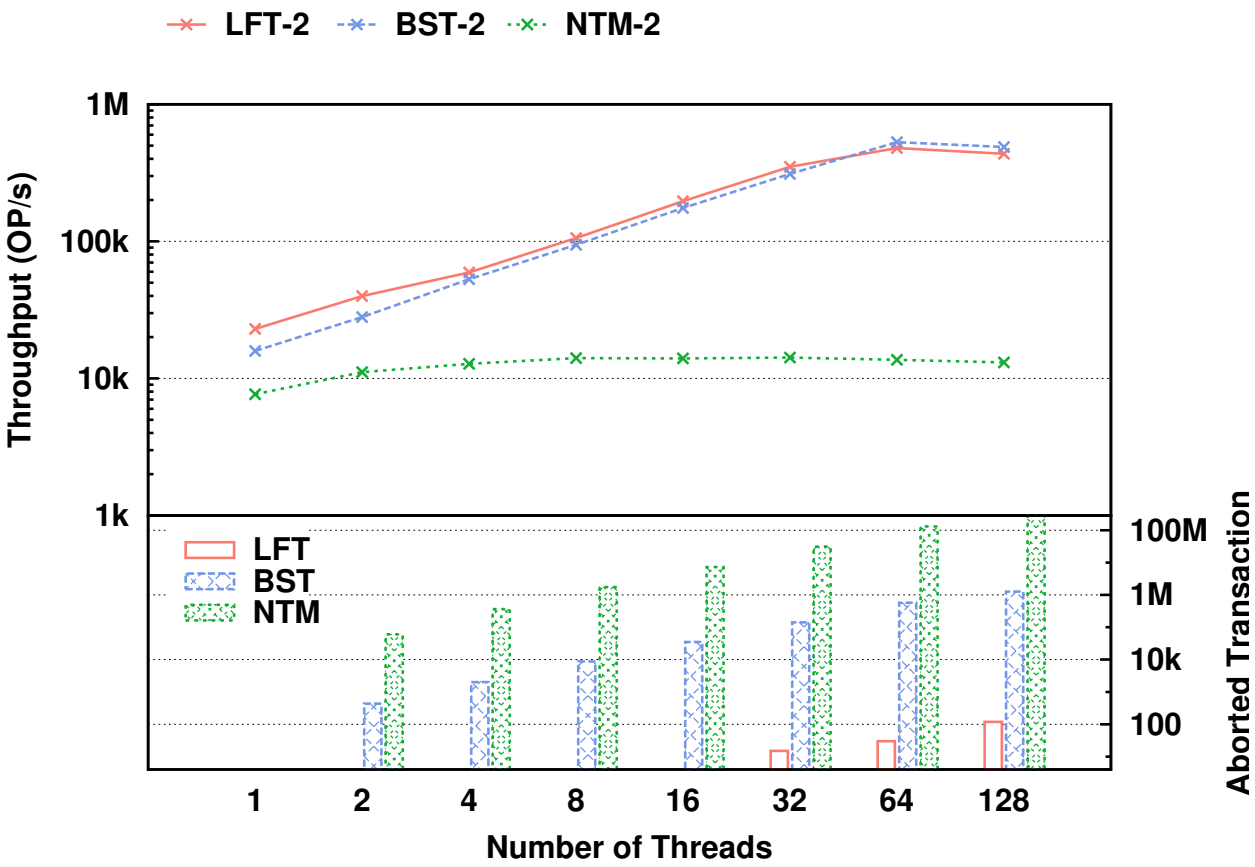

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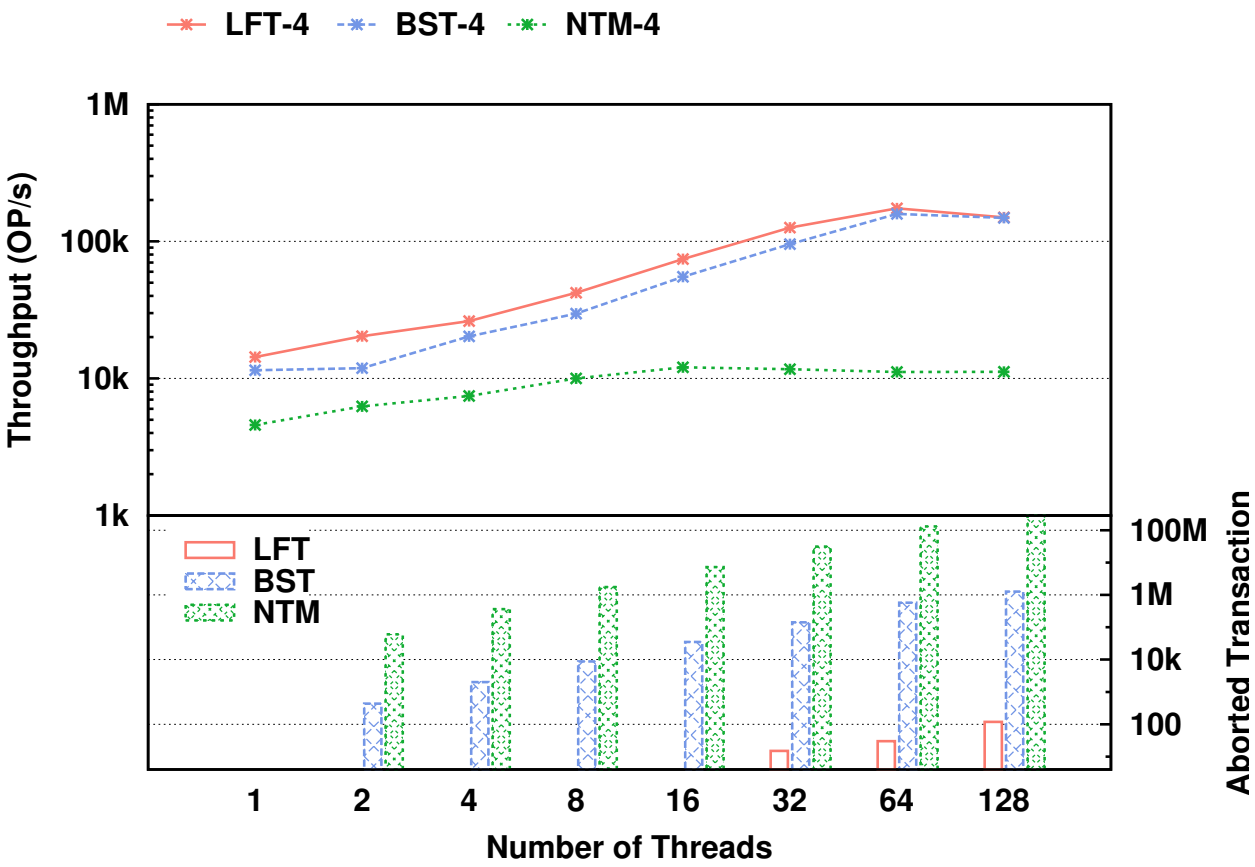

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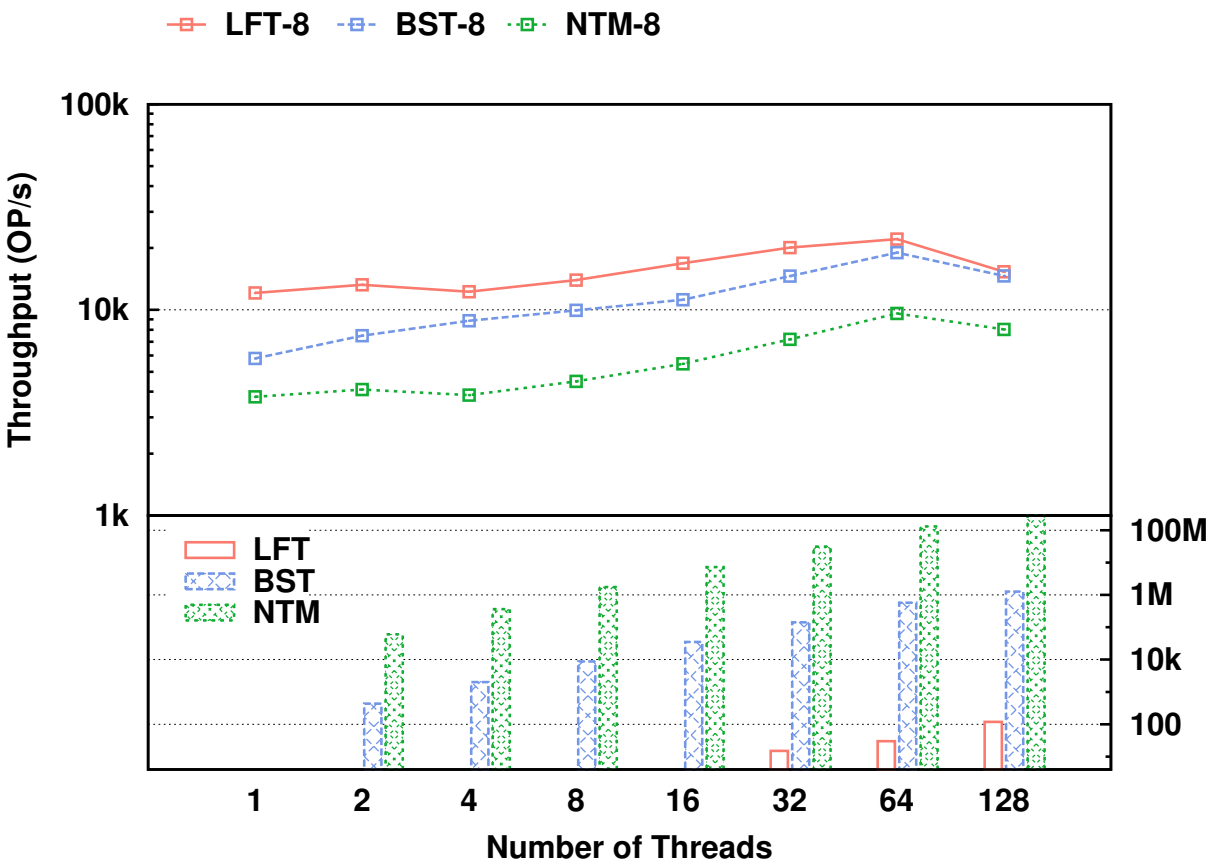

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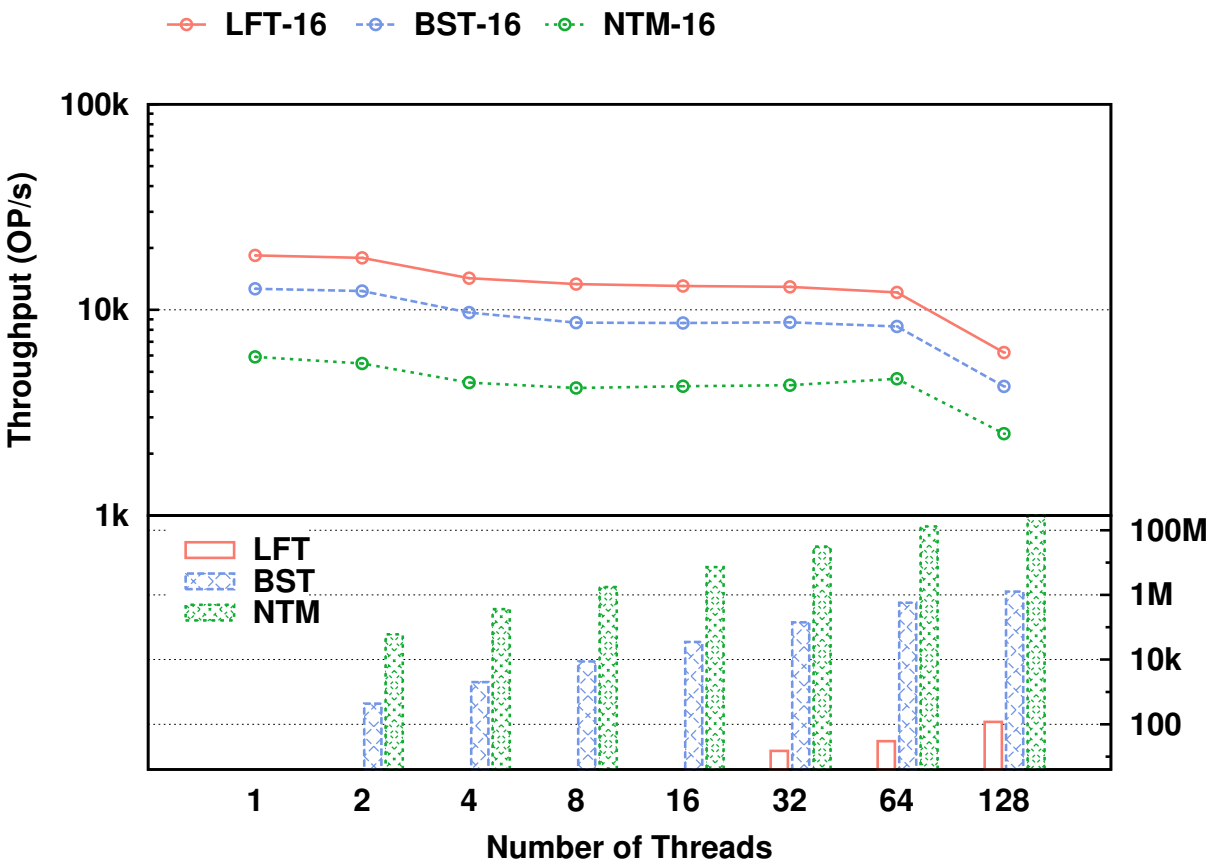

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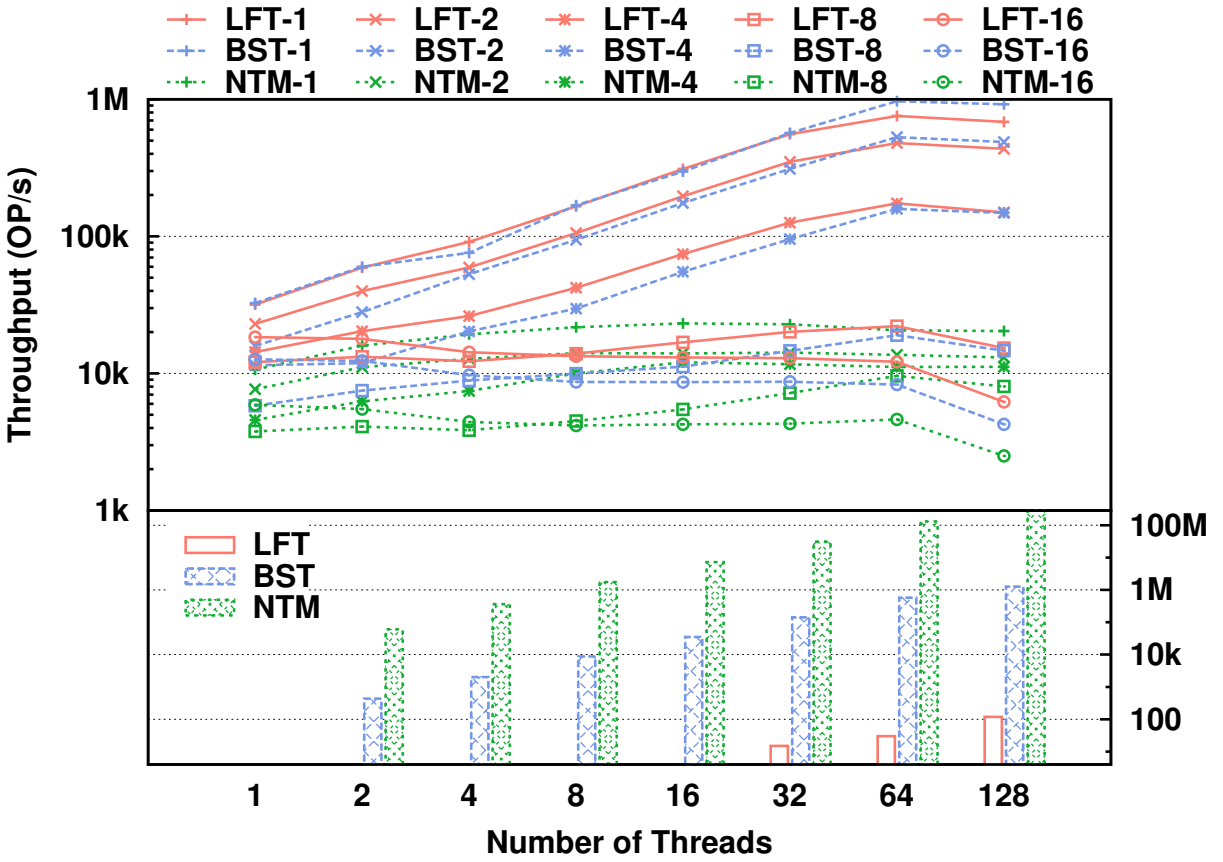

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Summary

- LFTT characteristics
  - Built-in transaction support for lock-free sets
  - Excels at large transactions
  - Greater success rate with minimal spurious aborts
- Future work
  - Support map abstract data type
  - Support wait-free data structures
- Library of transactional data structures
  - Cross-container transactions
  - http://cse.eecs.ucf.edu/gitlab/deli/libtxd