Log-free concurrent data structures

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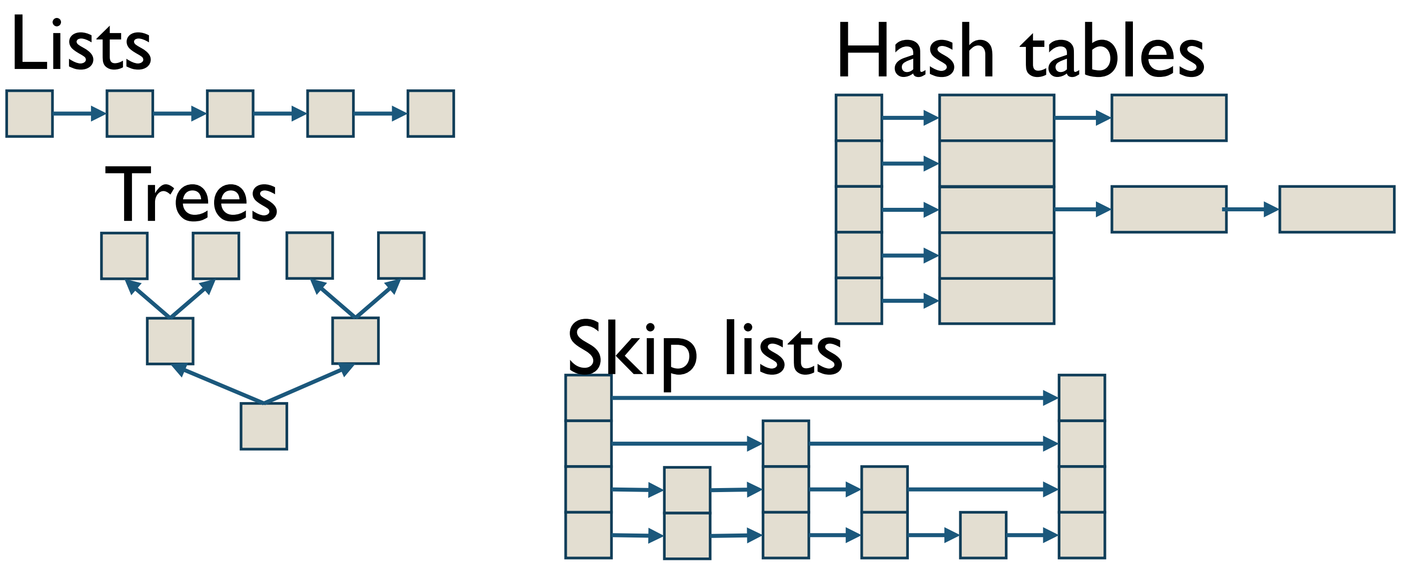
In-memory data structures – at the core of many systems



Interface:

- insert(k,v);
- remove(k);
- find(k);

Data structure performance – essential to system behavior

An ideal data structure:

- **fast**
- **scalable**
- **durable**

NV-RAM – expected to become ubiquitous

How can we ensure
performance + consistent durable state?

Upcoming technology: Non-volatile RAM

NV-RAM:

- Durable
- Byte-addressable
- Latencies – comparable with DRAM
- Programming model - map to area of virtual memory

Latencies:

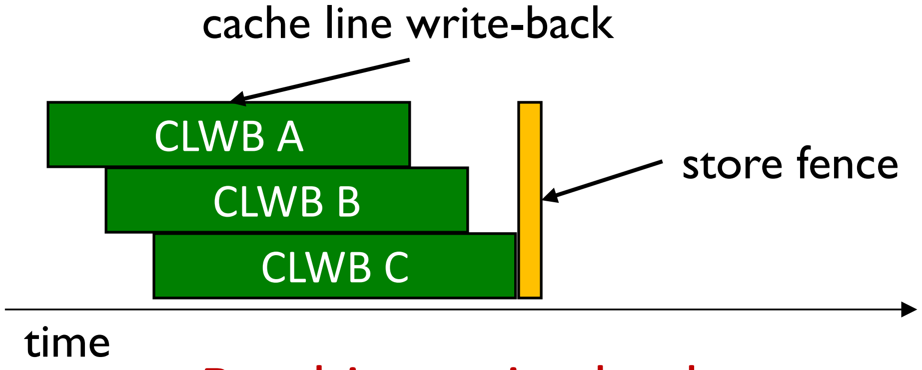
	L1 cache	L2 cache	L3 cache	DRAM	**FeRAM**	**PCM**	**MRAM**	**STT-RAM**
Read	1 ns	3 ns	10 ns	60 ns	**100 ns**	**70 ns**	**62 ns**	**60 ns**
Write	1 ns	3 ns	10 ns	60 ns	**125 ns**	**150 ns**	**62 ns**	**60 ns**

Source: "nv_malloc: Memory Allocation for NVRAM", Schwalb et al., 2015

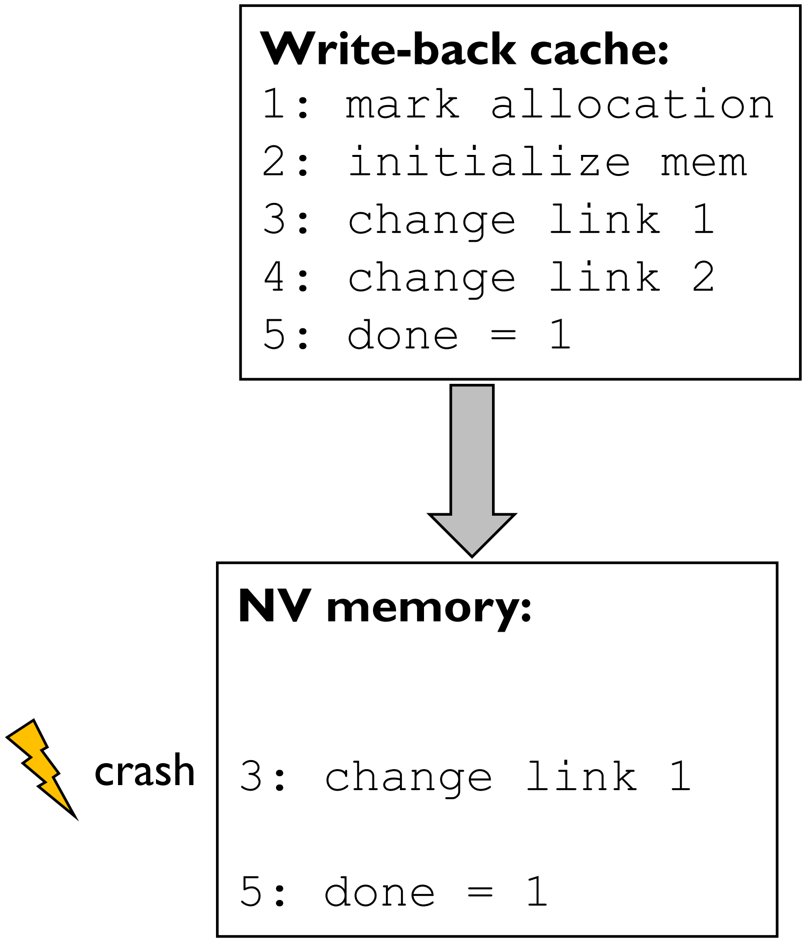
Persistent, fast and correct software – not trivial

```
1: mark memory as allocated
2: persist allocation
3: initialize memory
4: persist memory content
5: change link of node 1
6: persist new link
7: change link of node 2
8: persist modified link
9: done = 1
```

```
2: initialize memory
3: change link of node 1
4: change link of node 2
5: done = 1
```



Batching write-backs:
beneficial for performance



Upon restart: incorrect state

Persistent, fast and correct software – not trivial

```
1: log[0] = starting transaction X
2: persist log[0]
3: log[1] = allocating a node at address A
4: persist log[1]
5: mark memory as allocated
6: persist allocation
7: initialize memory
8: persist memory content
9: log[2] = previous value of link
10: persist log[2]
11: change link 1
12: persist modified link
13: log[3] = previous value of link
14: persist log[3]
15: change link 2
16: persist modified link
17: done = 1
18: persist done
19: mark transaction X as finished
```

Write-back cache:

1: mark allocation
2: initialize mem
3: change link 1
4: change link 2
5: done = 1

crash

NV memory:

1: mark allocation
2: initialize mem
3: change link 1

Upon restart:
undo incomplete operations

Frequent waiting for data to be persisted

Persist latency >> cache latency

For performance – minimize time waiting for data to be persisted;

Logging – problematic:

- We need to issue write-back to the log before each update;
- The log entry must be persisted before we perform the update;

Our work: minimize logging and write backs in data structures

Our techniques for fast durable data structures

1. Link-and-persist:

Use lock-free algorithms: they never leave the structure in an inconsistent state

$\Rightarrow$ **no logging in the data structure algorithm**

Correctness: **link-and-persist**

2. Link cache:

Buffer updates;

When one must be persisted, batch write-backs;

3. NV-epochs: coarse-grain memory management:

Track active memory areas, don't log individual allocations;

Avoid work at run-time if it can be delayed for recovery time;

Log-free concurrent data structures

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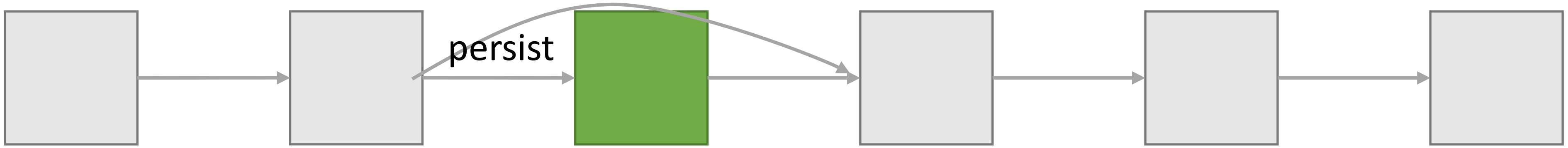
Correct durable implementations?

Correctness condition: durable linearizability

After a restart, the structure reflects:

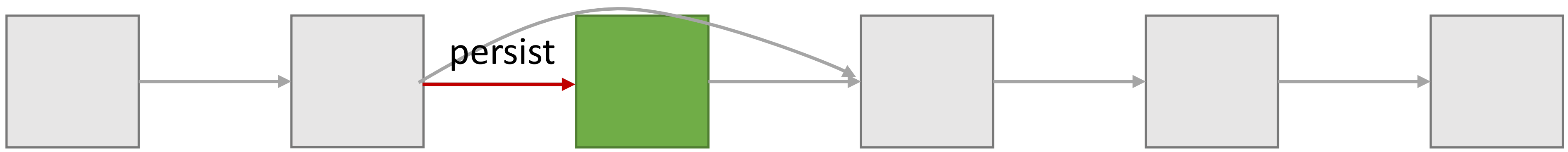
- all operations completed (linearized) before the crash;
- (potentially) some operations that were ongoing when the crash occurred;



If crash between steps 2 and 3, violation of durable linearizability

1. Persistently allocate and initialize node
2. Add link to new node
3. Persist link to new node

Link-and-persist: achieving correctness



1. Persistently allocate and initialize node
2. Add **marked** link to new node
3. Persist link to new node
4. Remove mark

Other threads - persist marked link if needed

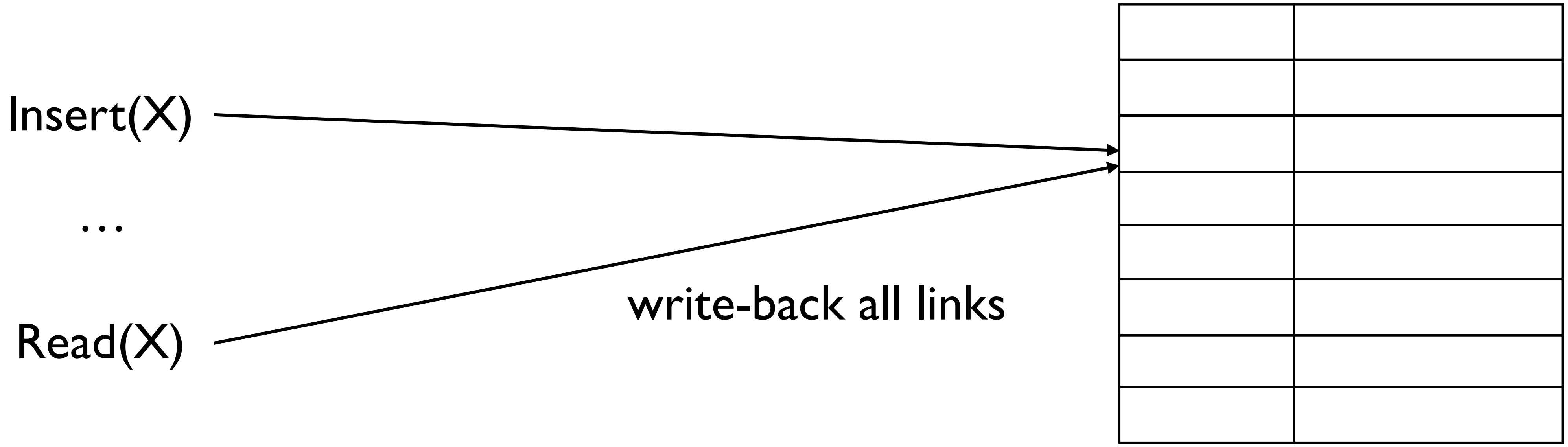
Link-and-persist: atomic "modify" and "persist" link

Going further: defer persisting links

A link only needs to be persisted when an operation depends on it

Store all un-persisted links in a fast concurrent cache

When an operation directly depends on a link in the cache:
batch write-backs of all links in the cache (and empty the cache)



The link cache: batch write-backs of links

Memory allocation and reclamation

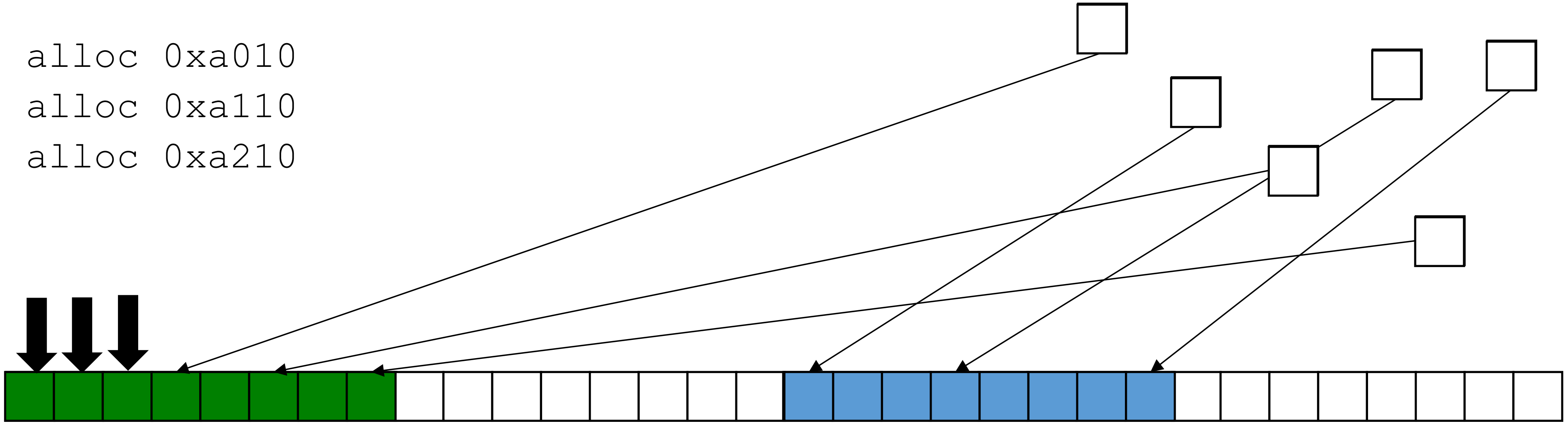
Insertion

```
1: log alloc_and_link
2: allocate and initialize new node;
3: link into data structure;
```

Deletion

```
1: log unlink_and_free
2: unlink node;
…
3: free the node;
```

```
alloc 0xa010
alloc 0xa110
alloc 0xa210
```



Locality of allocations/deallocations

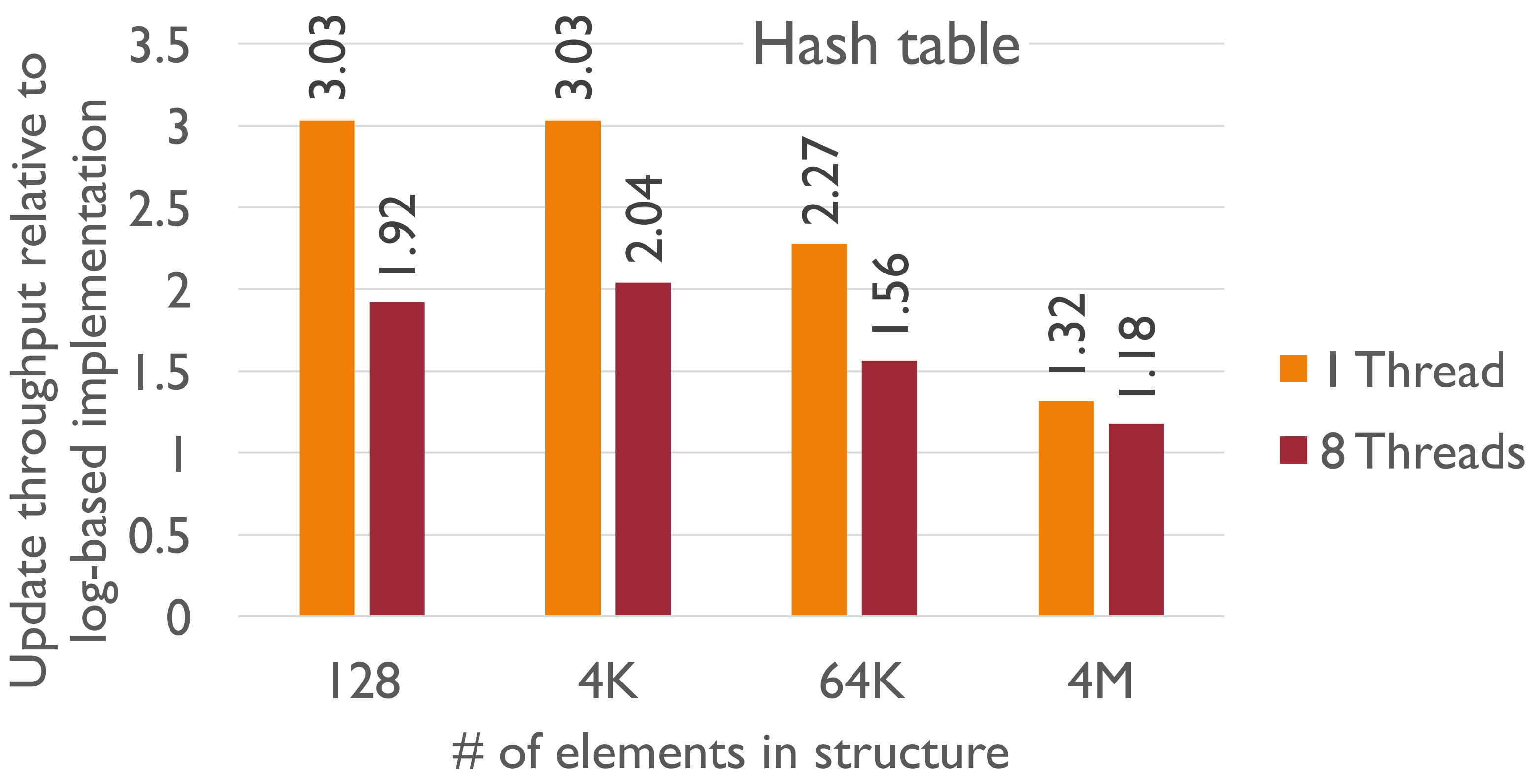
Instead of logging each allocation, keep track of recently used memory areas

At recovery, traverse nodes in active areas at the moment of the crash/restart

Experimental evaluation

- No fast byte-addressable NV-RAM for now;
- Inject latencies of flushes and write-backs to NV-RAM based on published values;
  - Shown experiments:125 ns;
- Comparison with redo-log-based implementations
  - Also provide durable linearizability;

Throughput vs. transactional redo-log-based



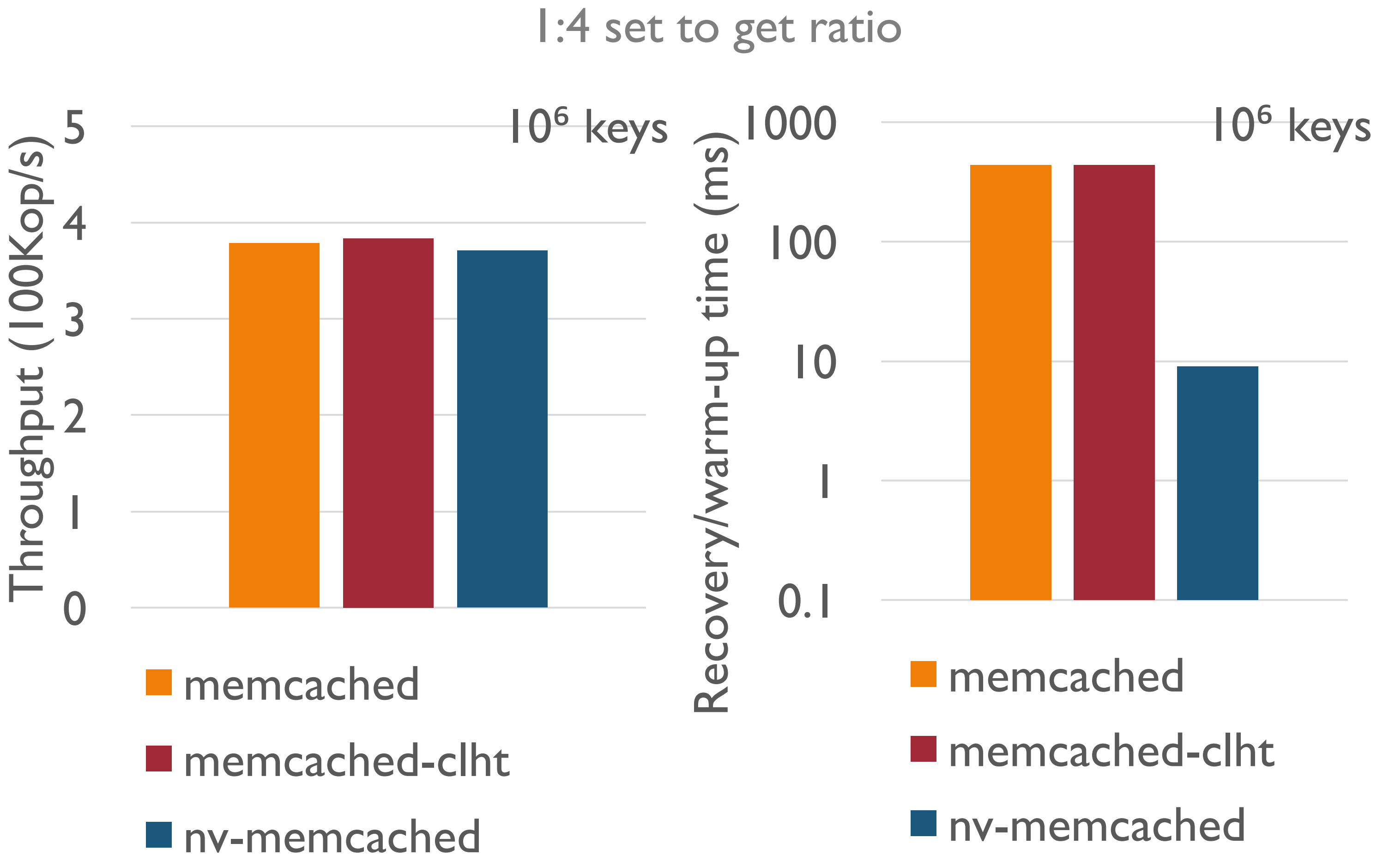
Linked lists, BSTs, skip lists in the paper

Consistently faster than log-based data structures

Particularly suited to small and medium sized data structures

NV-Memcached

1. Lock-free Memcached: Memcached-clht
2. Replace hash table & slab allocator with durable versions



Similar throughput, much lower recovery time

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Up to several times throughput improvement

Thank you!