Concurrent Robin Hood Hashing

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Motivations

- Make improvements on a 10 year old state of the art.
- Provide the first concurrent Robin Hood Hashing in the literature.

Contributions

- First linearisable concurrent variant of Robin Hood Hashing.
- Strong application of new *K-CAS* developments [Arbel-Raviv,, Brown; 2016]
- Competitive performance compared to state of the art concurrent hash tables.

General talk structure

- Hash table and Robin Hood background
- Challenges with concurrent Robin Hood
- What are the options?
- Solution
- Correctness/Progress
- Evaluation

Hash Tables

- Constant time O(1) set/map structures
- Set operations:

  1. **Contains(Key)**
  2. **Add(Key)**
  3. **Remove(Key)**

- No need for sorting of keys, unlike tree-based sets/maps
- Require a hash function for keys
- Applications: Search, Object representation in VMs/interpretors, caches...

Hash Tables

Divided into two camps: Open vs Closed Addressing.

Open Addressing.

- Items are stored in individual buckets only.
- If bucket is already taken find a new one: Collision algorithm.

Closed Addressing.

- Items are stored at original bucket only.
- Typically in a linked list structure.

Robin Hood Hashing (Open Addressing)

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Insertion: Linear probing with conditional recursive displacement.

If relocated item has bigger *DFB* than than current, kick current out, take spot, and recursively insert current further down the table.

Removal: Backward shifting. More on that later.

Linear Probing vs Robin Hood

Initial Table, inserting V.

$\varnothing$	X_0	Y_1	Z_1	W_1	$\varnothing$

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Key:

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- Less work

Robin Hood Table

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- Less distance variance

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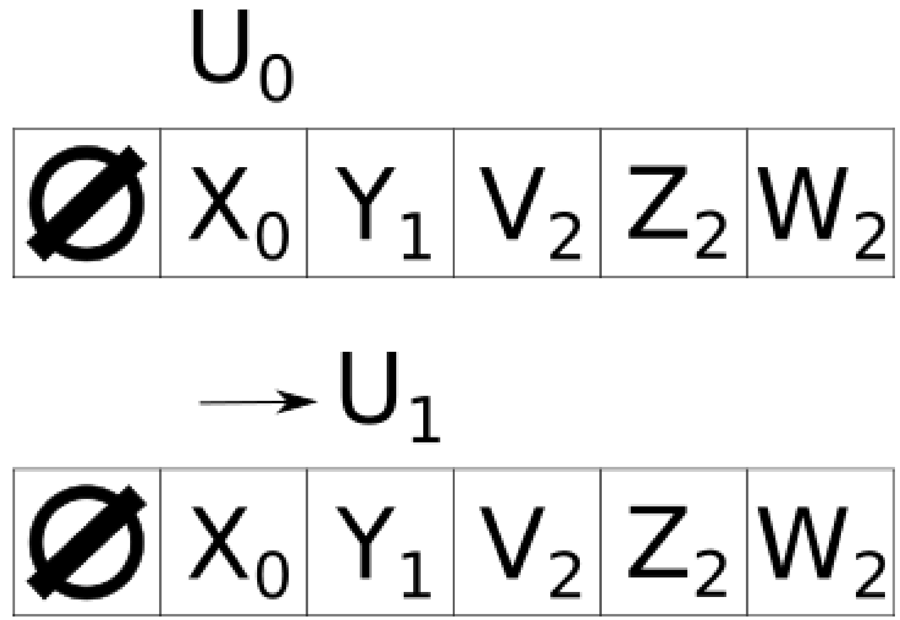

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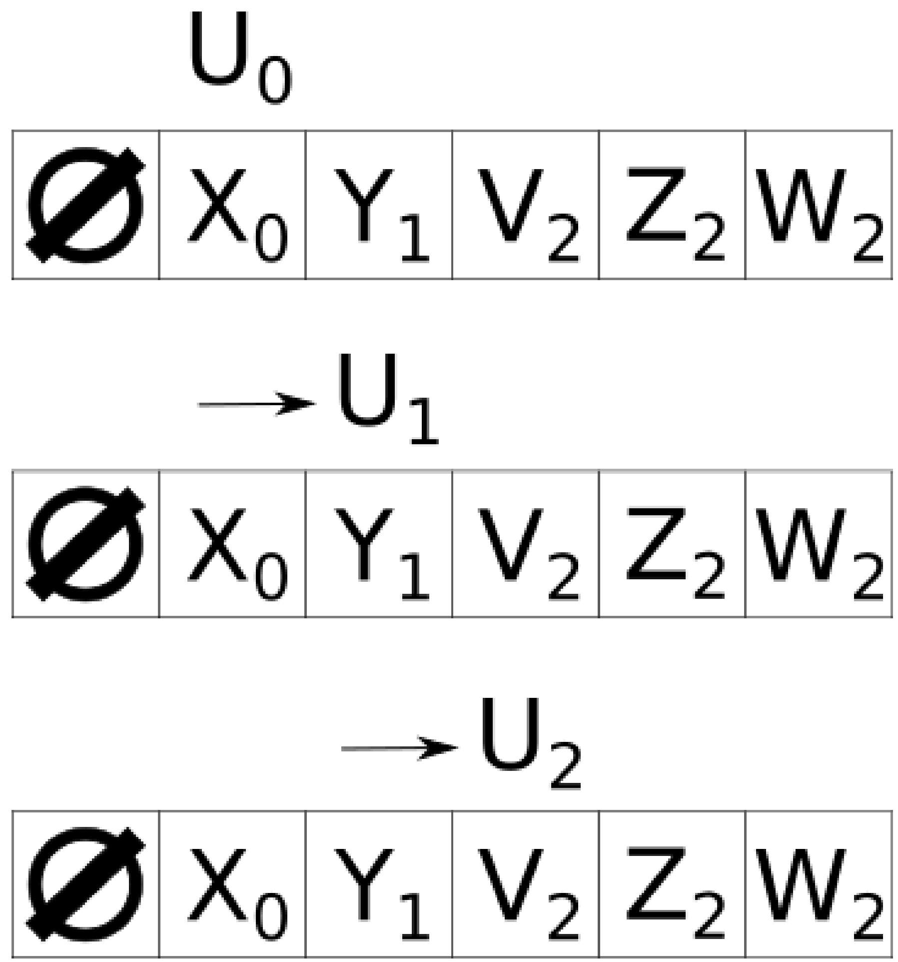

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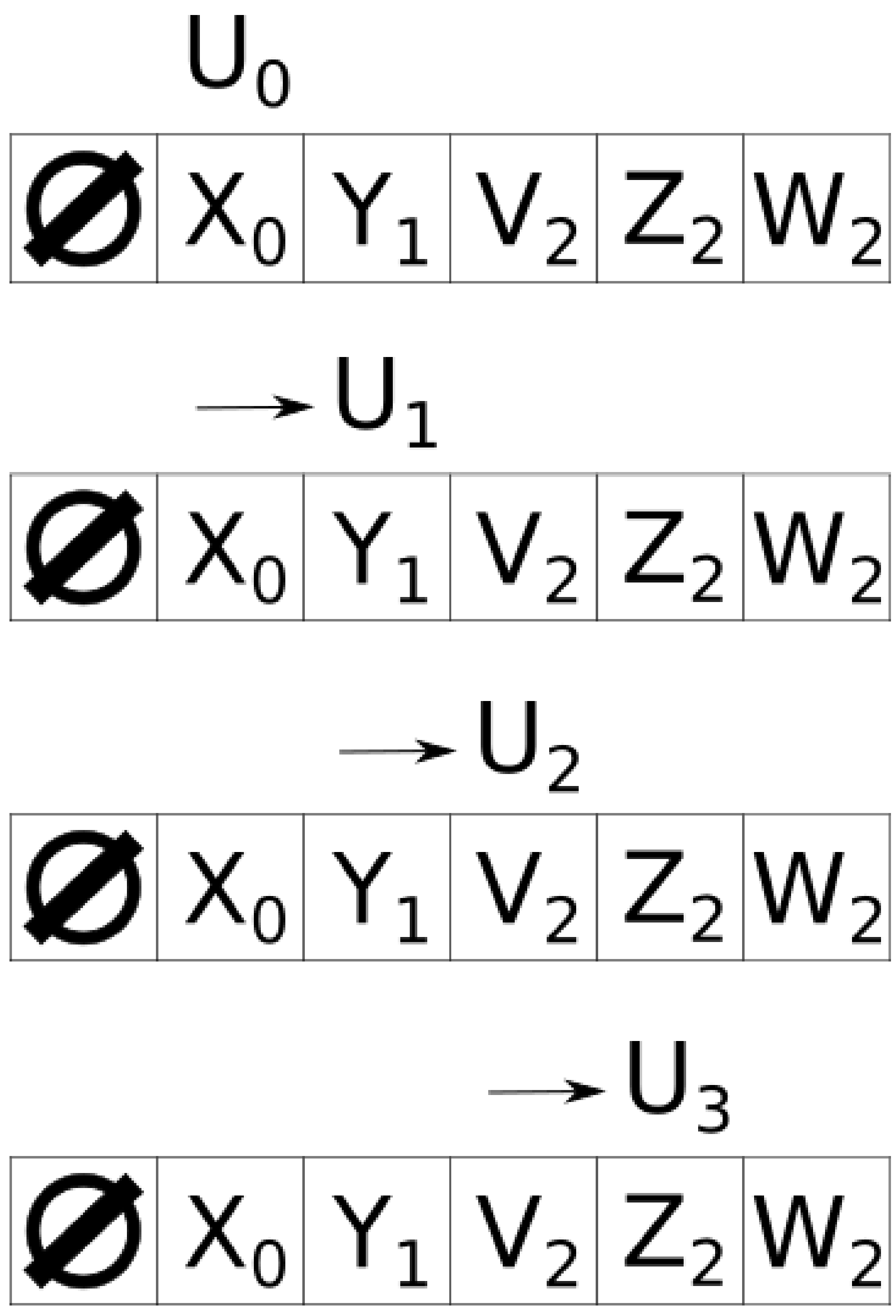

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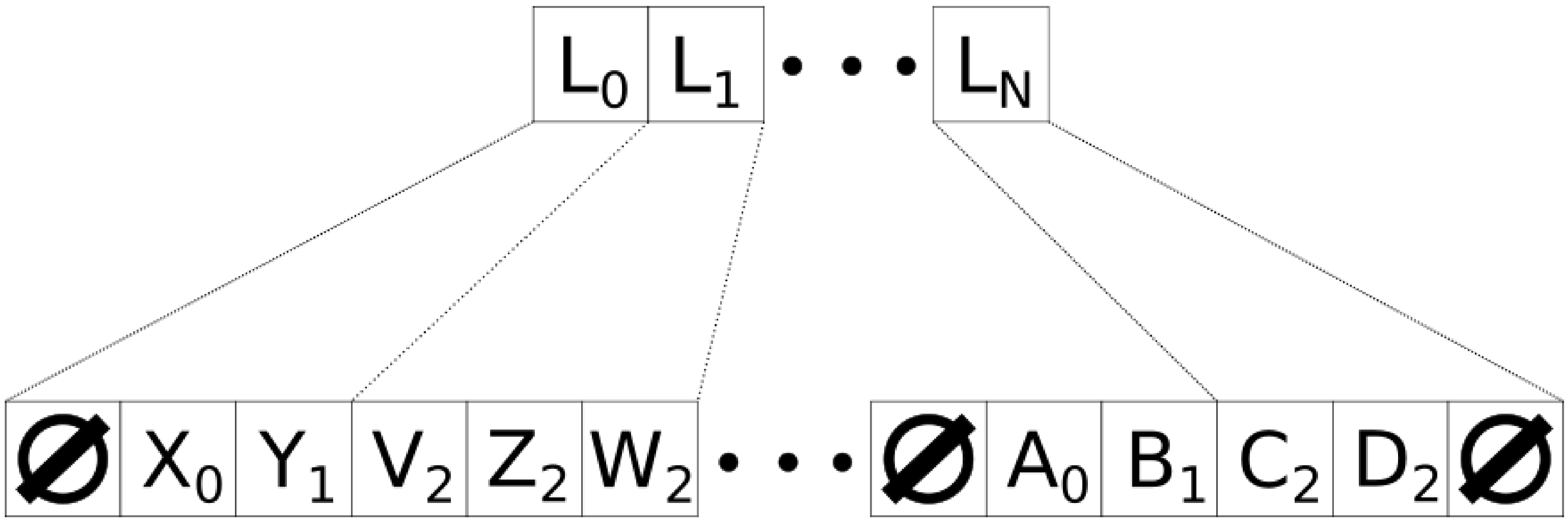
2. Relatively simple:
   - No linked list or pointer manipulation.
3. Cache efficient.
   - Flat data, low probes.
   - No dynamic allocation.
   - Probes are generally on a single cache line.

Standard Solution:
Sharded locks



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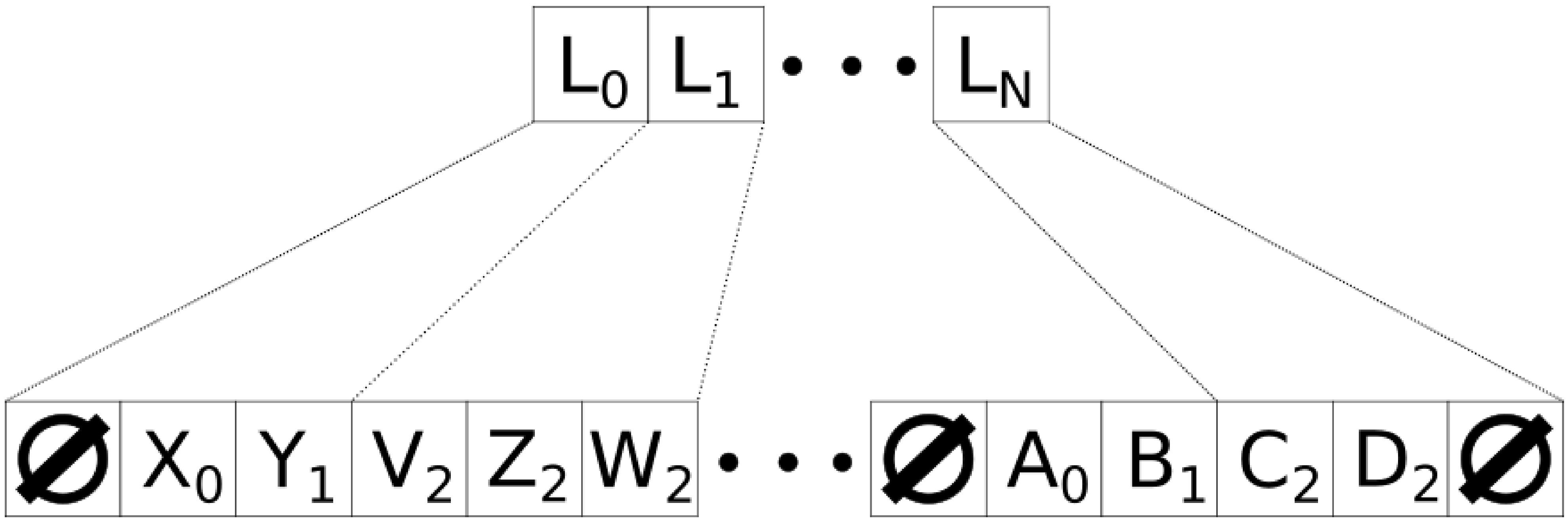

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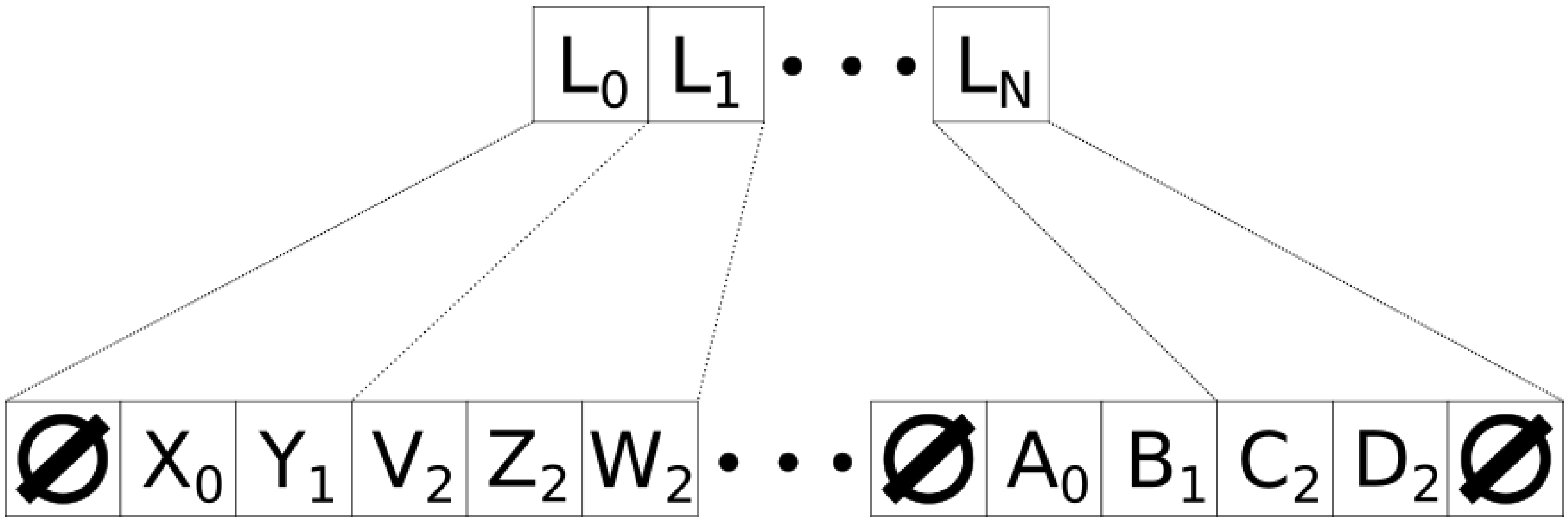

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- Could result in deadlock, if allowed to wrap around.
- Not very clean for our case: Need extra phantom segment to stop deadlock.
- Hacky. Slow. Lots of contention.

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Great source of contention.

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Possible Solutions

- Bespoke non-blocking solution
- Transactional Memory
- *K-CAS* (Multi-word compare and swap)

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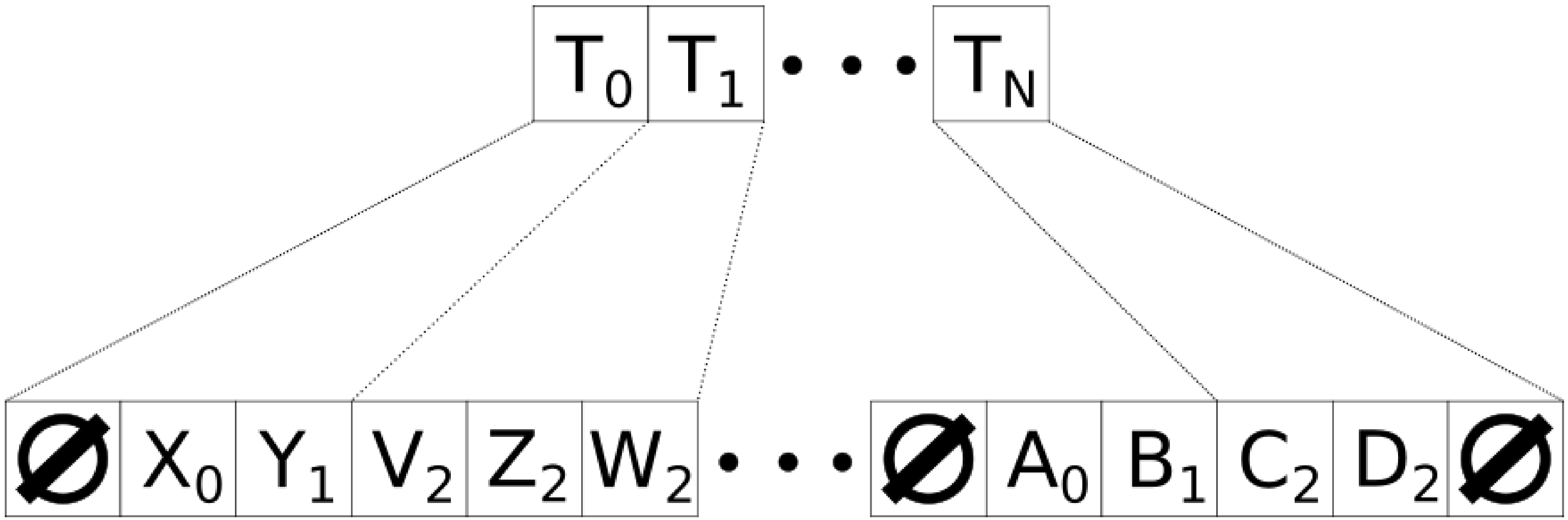
Method Chosen: *K-CAS*

K-CAS is a *multi-word compare-and-swap* primitive. Each table operation is described as one large *K-CAS*.

Our Solution:
Sharded timestamps



Similar to lock-base *sharding*. Groups of timestamps *protect* the table.

Each relocation operation increments the timestamp. Except relocations can be done in bulk.

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Delete Y. Move V back. Find Z, exit.

V_2

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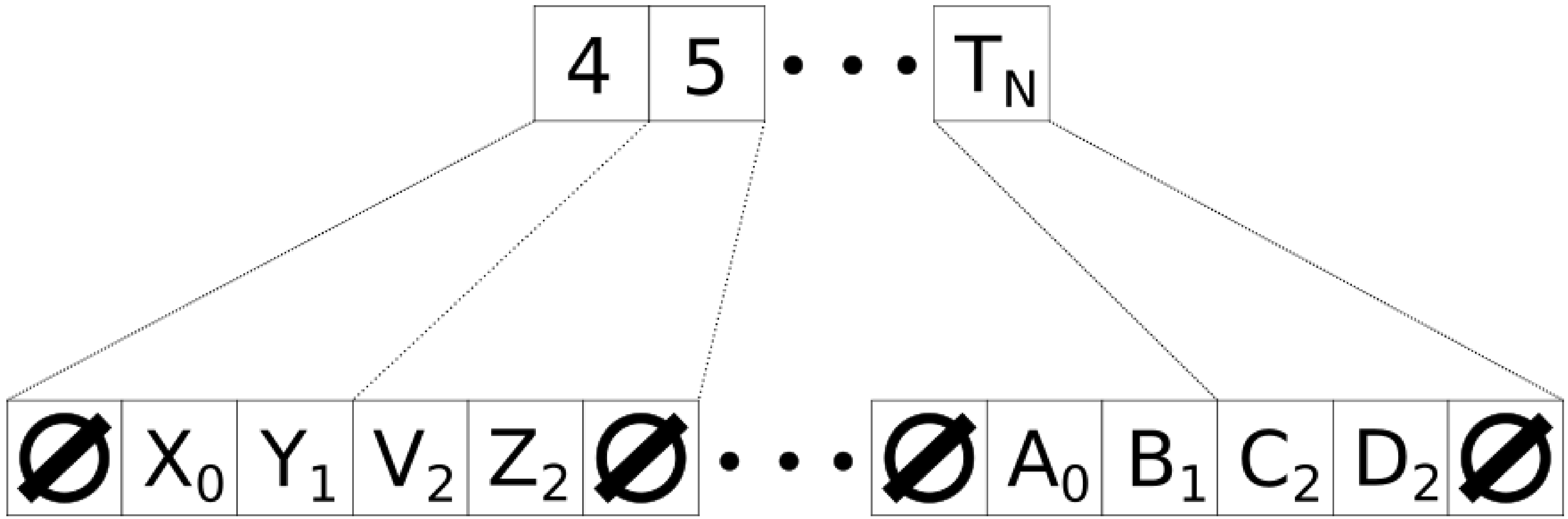
Our Solution: Example



Going to delete Y from table, with concurrent reader.

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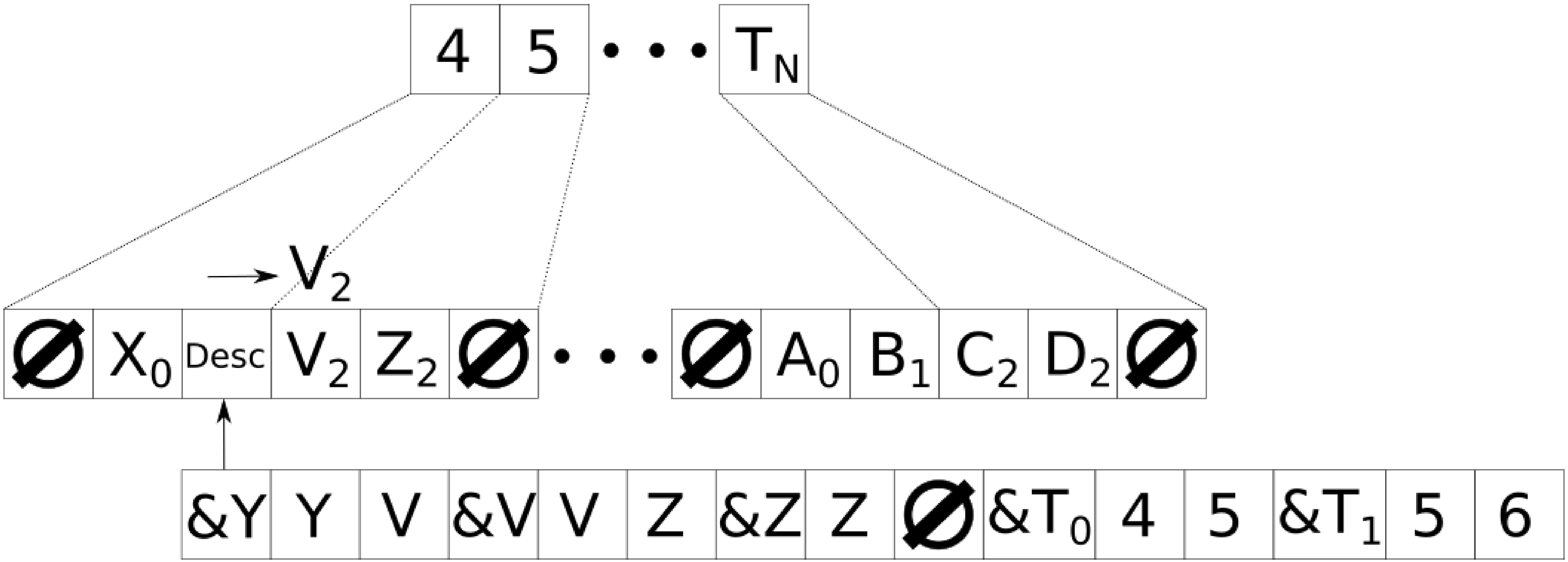

Ugly little array is a deletion descriptor.

Moves items. Increments two timestamps.

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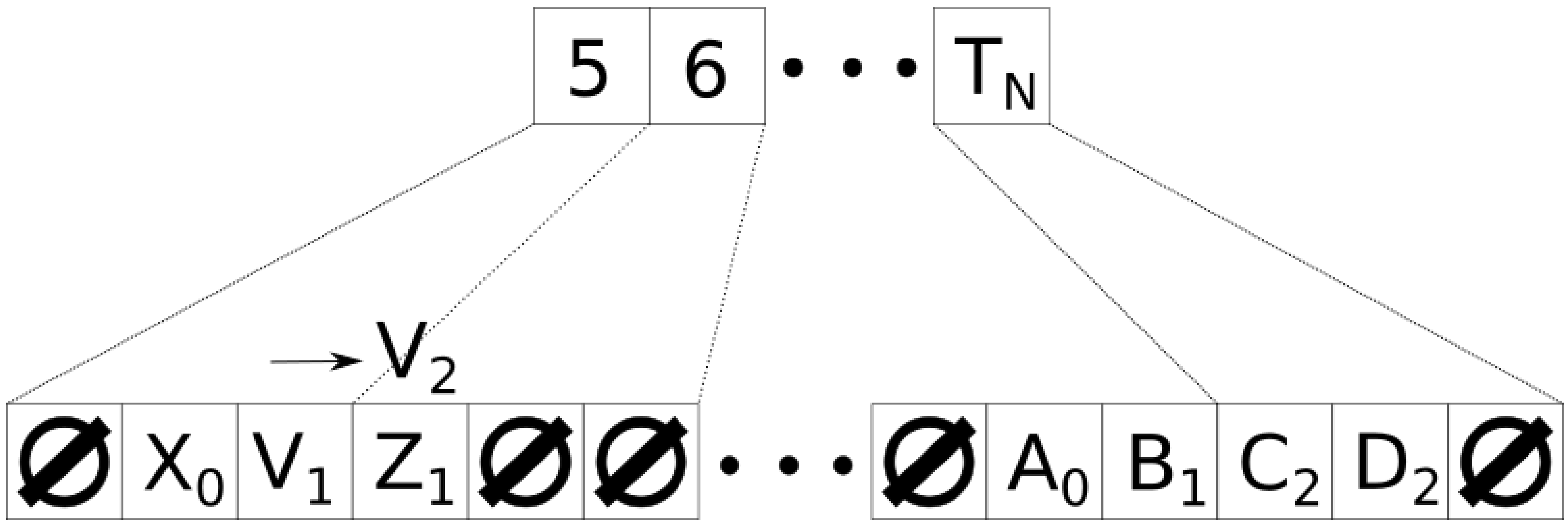

Reader misses V, due to deletion of Y.

Reader sees timestamp change, restarts operation.

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Use of *K-CAS* allows for thread collaboration. Well defined non-blocking progress guarantees.

Bulk relocation greatly reduces contention. Fast.

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Every modifying operation is a *K-CAS* operation. Cannot be seen midway.

Every reader must *remember* every timestamp seen.

Before any actions attempts to take effect they re-read timestamps. If any discrepancies are seen, retry operation.

Our Solution: Progress

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Every operation checks timestamps before the operation completes. Timestamps are coarse so operations can impede each other.

The impeding of **Contains** means potentially no **Contains** will pass, but *at least* one **Add** or **Remove** will get through.

Benchmarking setup

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Hardware

- 4 x Intel® Xeon® CPU E7-8890 v3, 18 cores each, 2 threads per core, 144 threads in total
- HyperThreading avoided until the end
- PAPI used to measure various CPU artefacts
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Software

- Microbenchmark measuring operations per microsecond
- A number of strong performing concurrent hash tables
- Four load factors of 20%, 40%, 60%, and 80%
- Two read/write workloads of 10% and 20%

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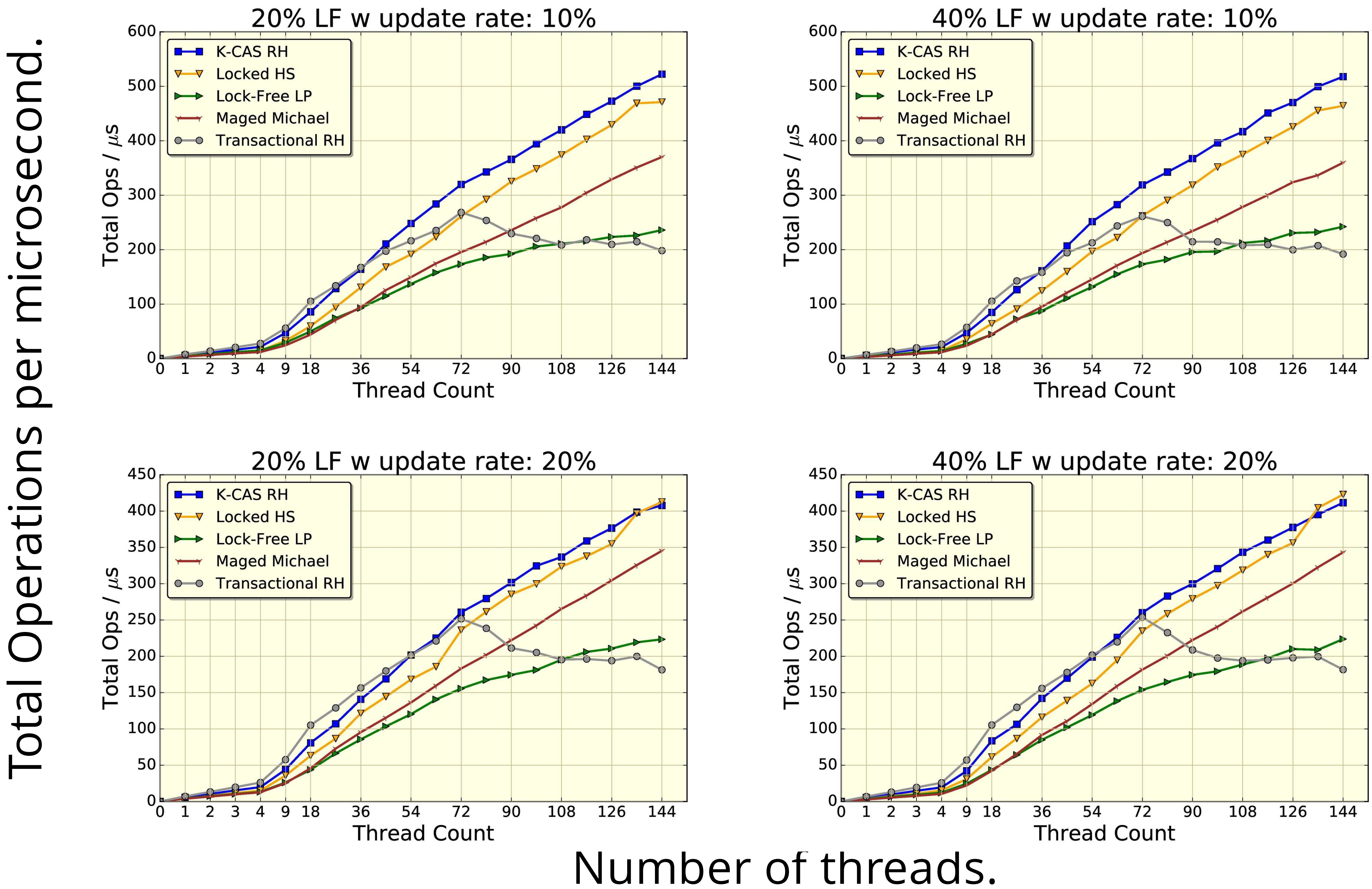
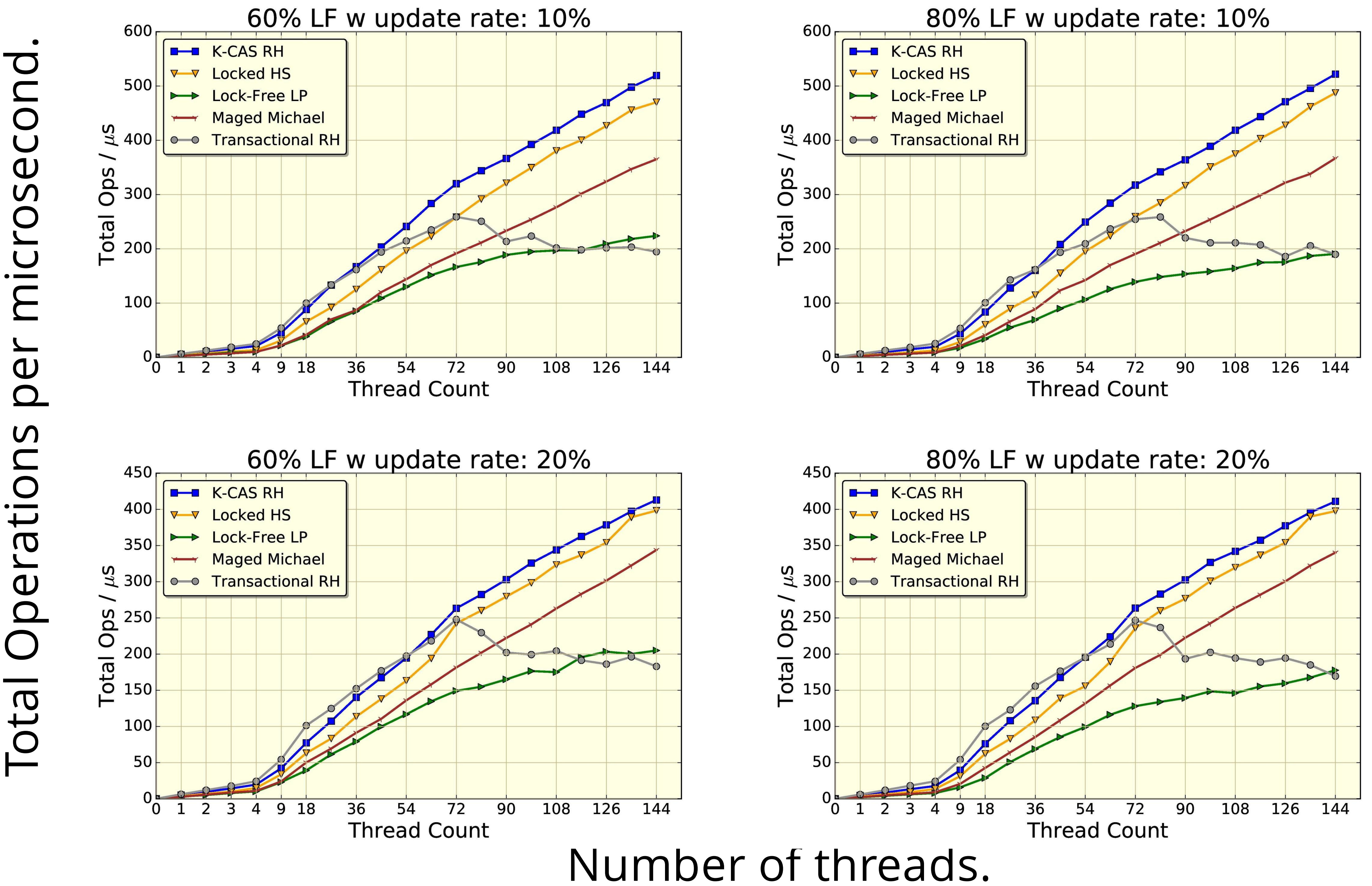
- Separate Chaining [Maged Michael; 2003]: Per-bucket lock-free linked lists.
- Lock-Elision Robin Hood. Serial algorithm with hardware transactional lock-elision wrapper
- *K-CAS* Robin Hood Hash. *K-CAS* with sharded timestamps.

Performance 20%/40%



Performance 60%/80%



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Robin Hood dominates other concurrent hash tables.
Gap narrows during Hyperthreading.

Transactional Robin Hood scales very strongly until Hyperthreading. Then it dies and never recovers.

Conclusion

- First linearisable concurrent variant of Robin Hood Hashing.
- Strong application of new *K-CAS* developments.
- Competitive performance compared to state of the art concurrent hash tables.

Future Work

- Extended Robin Hood work (different timestamp encodings/placements, cache aware, vectorised, various lock-based solutions)
- Yahoo benchmark (YCSB)

Thank you!

Questions and Comments?