IcebergHT: High-Performance Hash Tables Through Stability and Low Associativity

SIGMOD 2023

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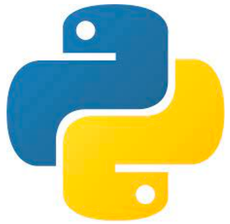
Hash tables are everywhere!

Built into many languages…

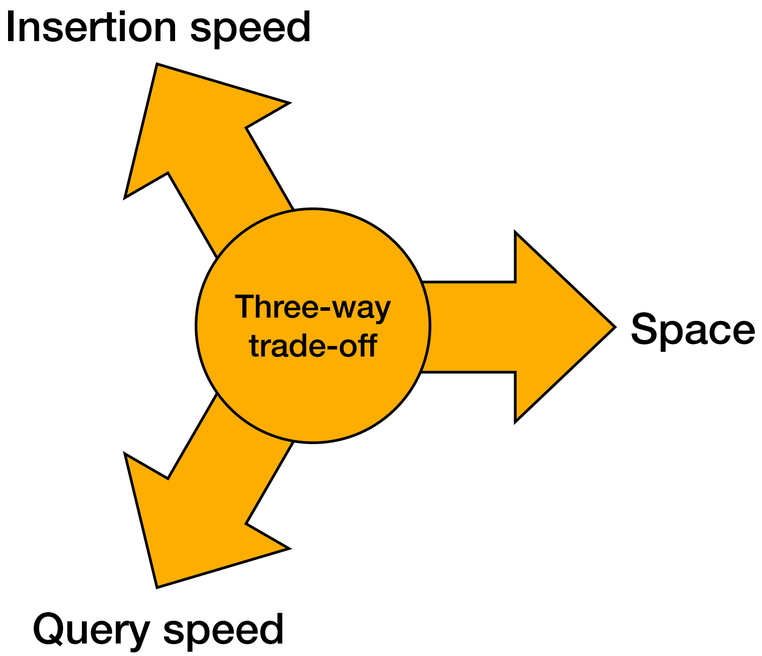



Built into many software packages…



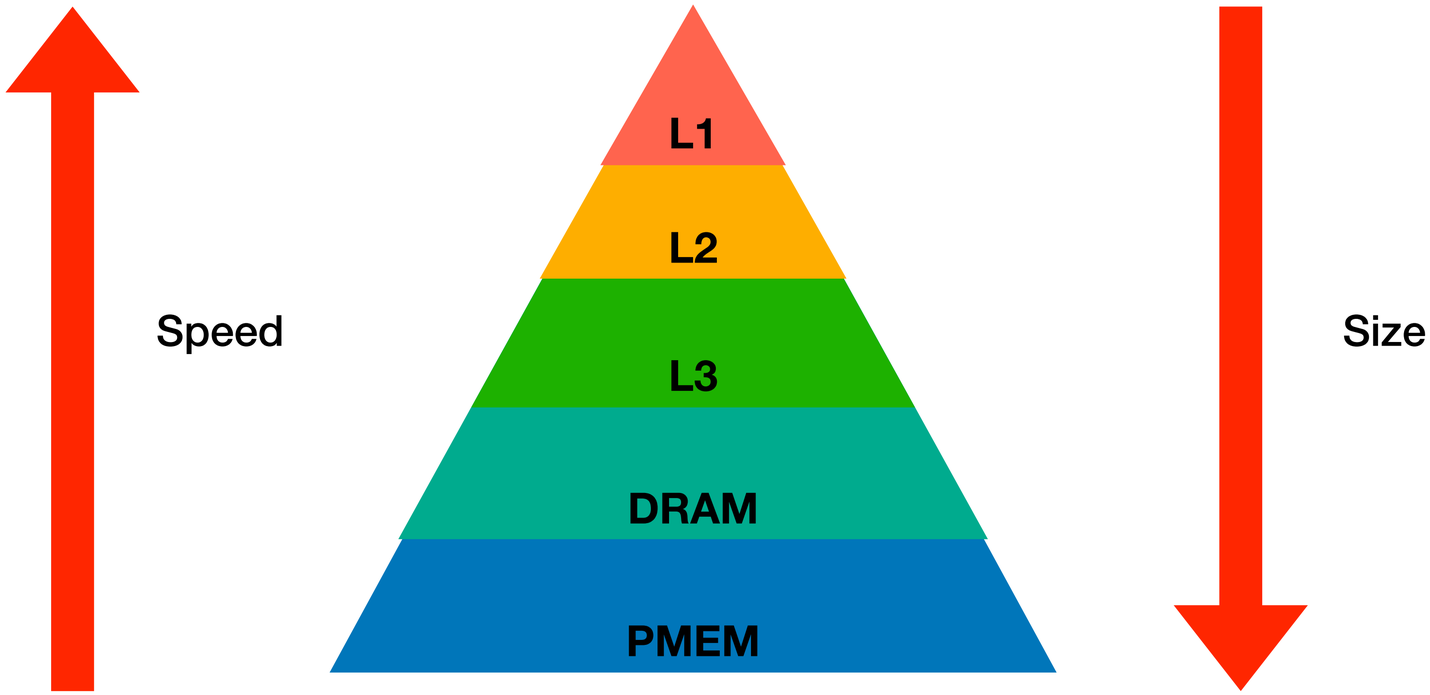

And performance is critical to many applications.

Hash table performance criteria



Hash table performance has a three-way trade off between insertion speed, query speed, and space.

Hash table performance criteria

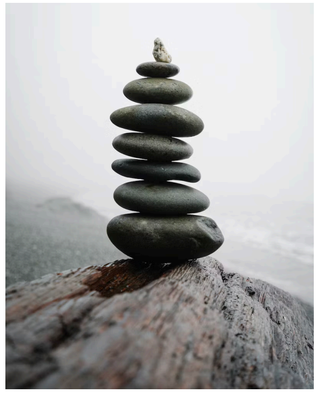


Hash table performance is almost entirely determined by the number of locations accessed by each operation.

Hash table design objectives

- Minimize the number of cache lines accessed by inserts/queries/deletes.
- Minimize the number of cache lines written by inserts/deletes.

Hash table design mechanism



Stability

Items don’t move after insertion

Low associativity

Map each item to one a small number of locations

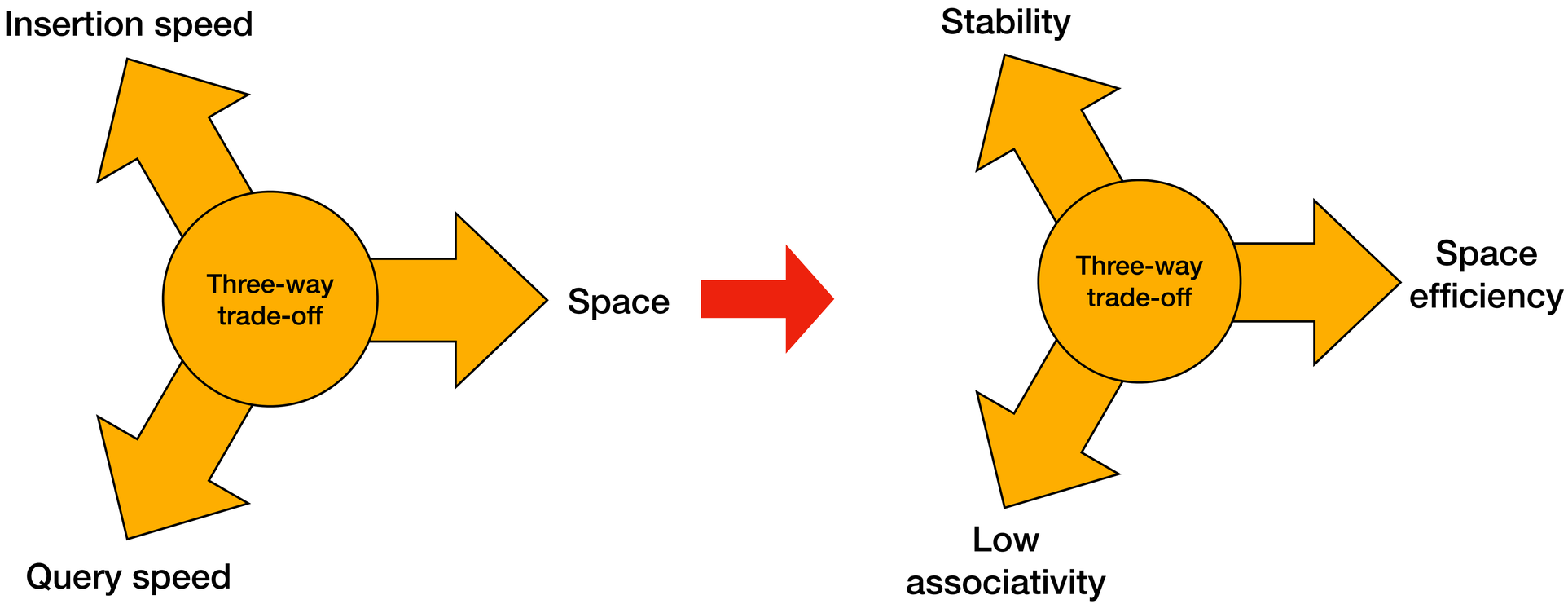
Space efficiency

Minimum overhead from pointers or over provisioning

Achieving all three is a long-standing open problem in hash table design.

Existing hash-table designs do not get all three at once.

Stability, associativity, and space efficiency



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Our results:

Stability

+

Low associativ

+

Space efficiency

Insertion performance

Space efficiency

50% to 3X faster on PMEM
Up to 2X faster on DRAM

PMEM
RAM

17% space overhead compared to 3X for other hash tables

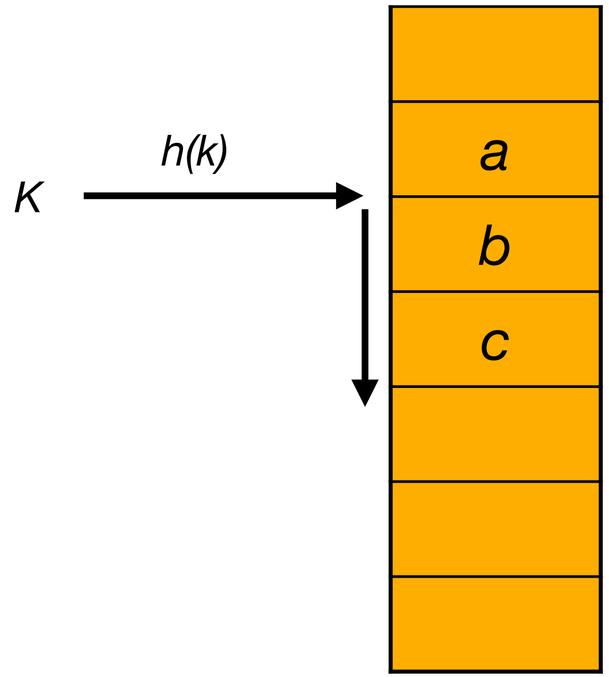
IcebergHT also achieves:

- **Almost linear scalability with increasing threads**
- **Fenceless crash safety on PMEM**

IcebergHT achieves stability, low associativity, and space efficiency at the same time.

For example: linear probing

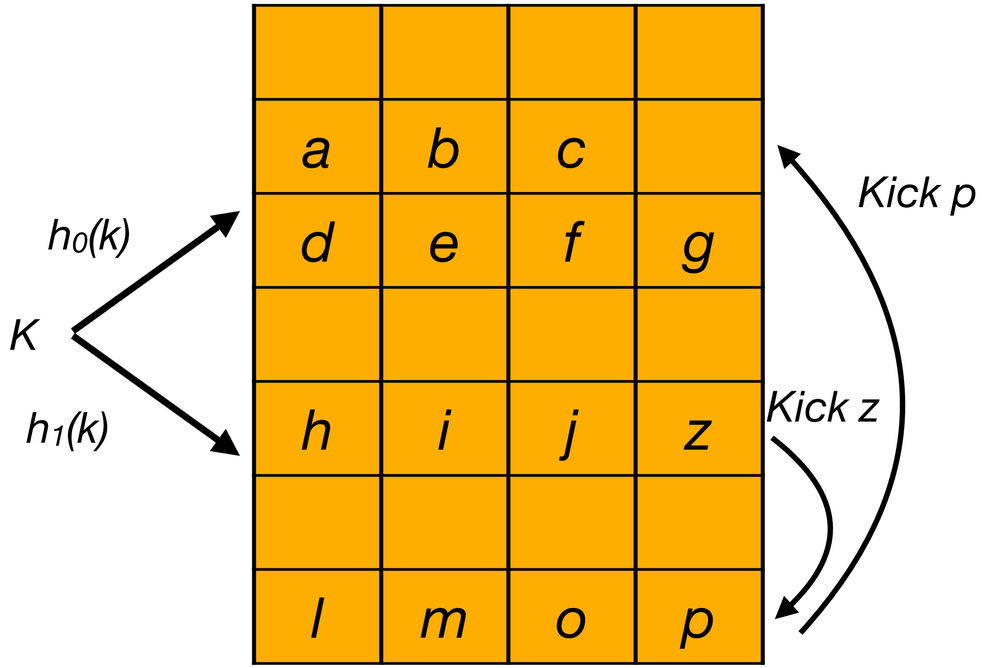
- Stable
- Associativity $\approx \frac{\log N}{(1-\alpha)^2}$ (α = load factor)
- E.g., N = 1Billion, α = 95%, associativity = 12000



Must choose between low associativity and space efficiency.

For example: cuckoo hashing

- Low associativity: queries must check only 2 cache lines
- Space efficient, load factor > 95%
- But not stable

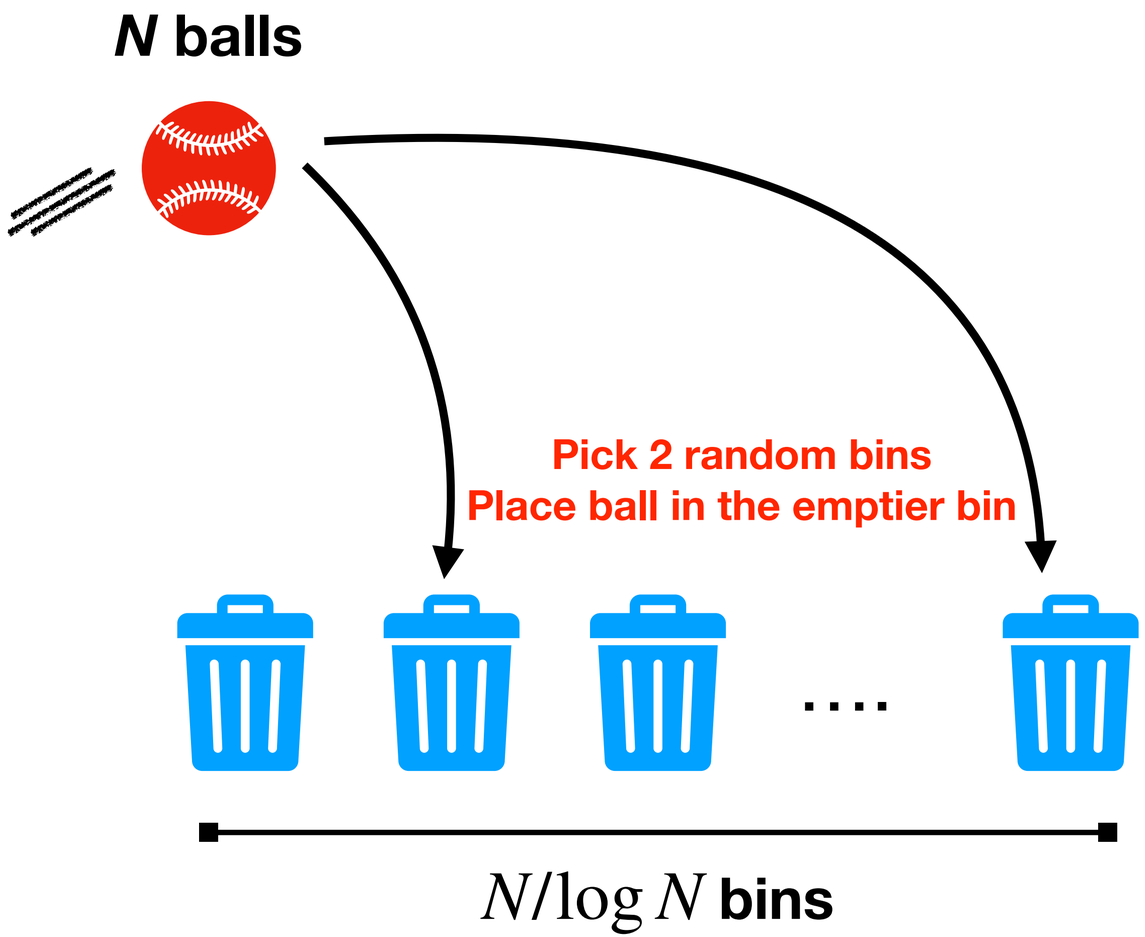


Insertion performance drops significantly due to excessive kicking at high load factors.

Other hashing schemes:

- Other hashing schemes also lack one or more of these properties
- **Chaining**: not low associativity
- **Robin hood**: not stable and not low associativity at high load factors
- **Hopscotch**: not stable
- **Quadratic probing**: not stable and not low associativity at high load factors

Two choice hashing



Theorem: if you throw *N* balls into $N/\log N$ bins using minimum of two choices, the fullest bin will have $\log N + \log\log N + O(1)$ balls W.H.P.

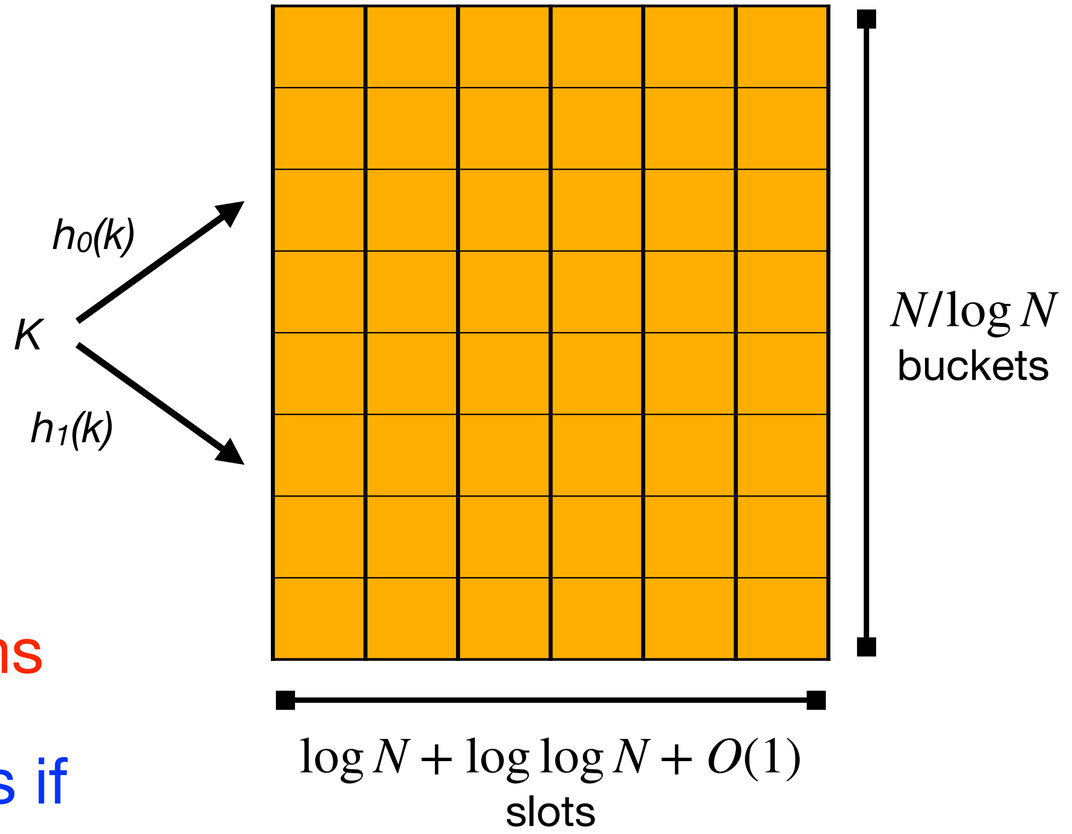
- By Berenbrink, Czumaj, Steger, Vöcking 2000

An almost solution: two choice hashing

- **2-choice hashing**: hash to two buckets and put item in emptier bucket
- Stable: no kicking
- Low associativity: $O(\log N)$
- Space efficient: load factor $1 - o(1)$

Problem: it does not hold when we delete items

Opportunity: theorem does hold with deletions if average bucket occupancy is $O(1)$

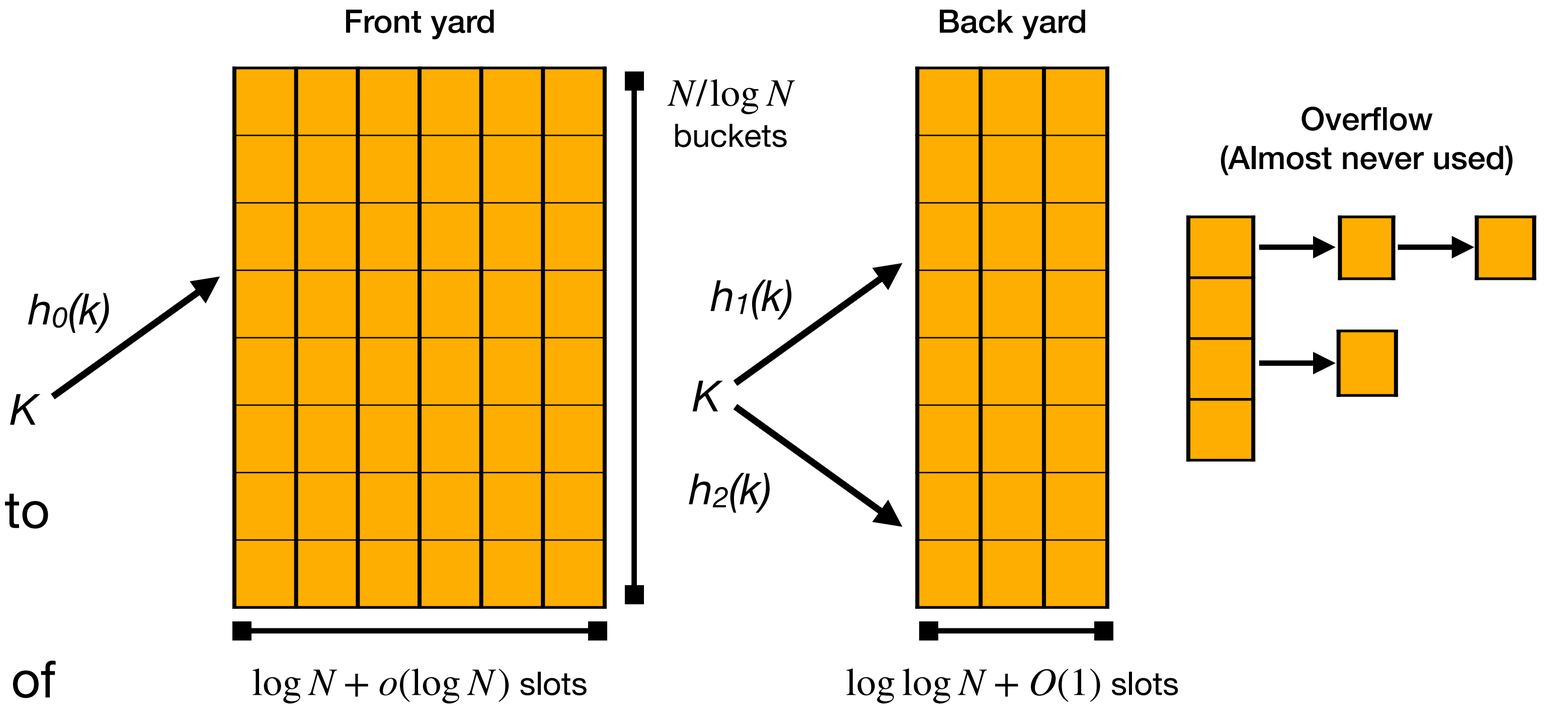


Iceberg hashing

- **Iceberg theorem**: if you throw N balls into $N/\log N$ bins of size $\log N + o(\log N)$, the number of overflow balls will be $O(N/\log N)$

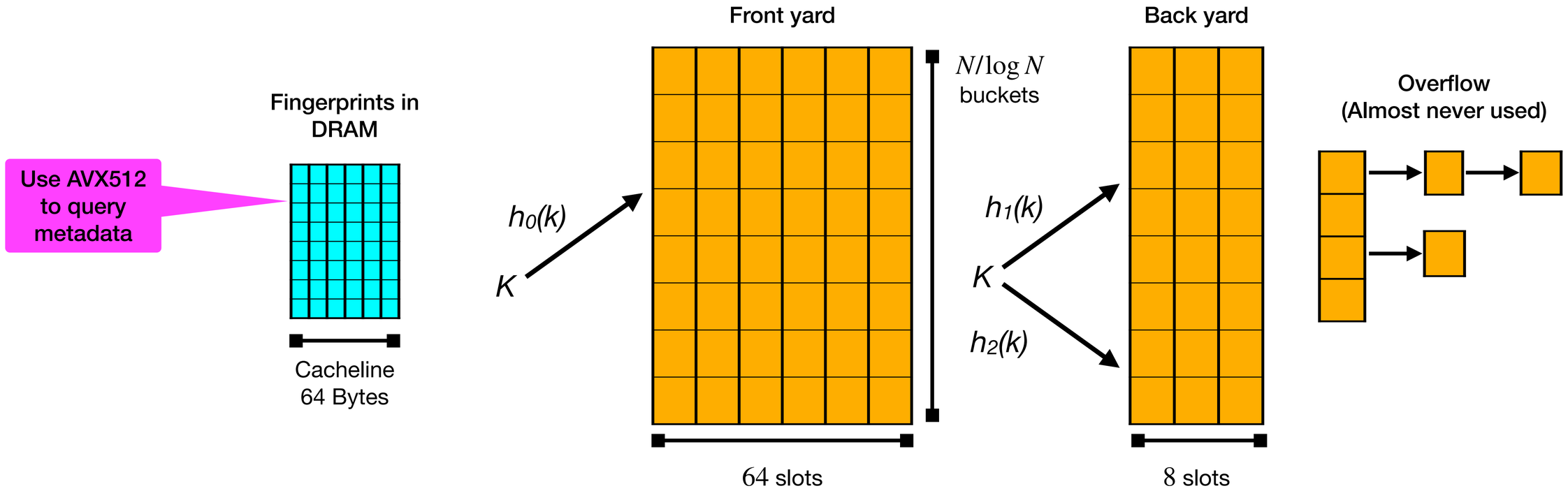
- **Idea**: use single-choice front yard to absorb most items

- Backyard has average occupancy of $O(1)$



Problem: buckets in the front yard span many cache lines, so queries must load many cache lines.

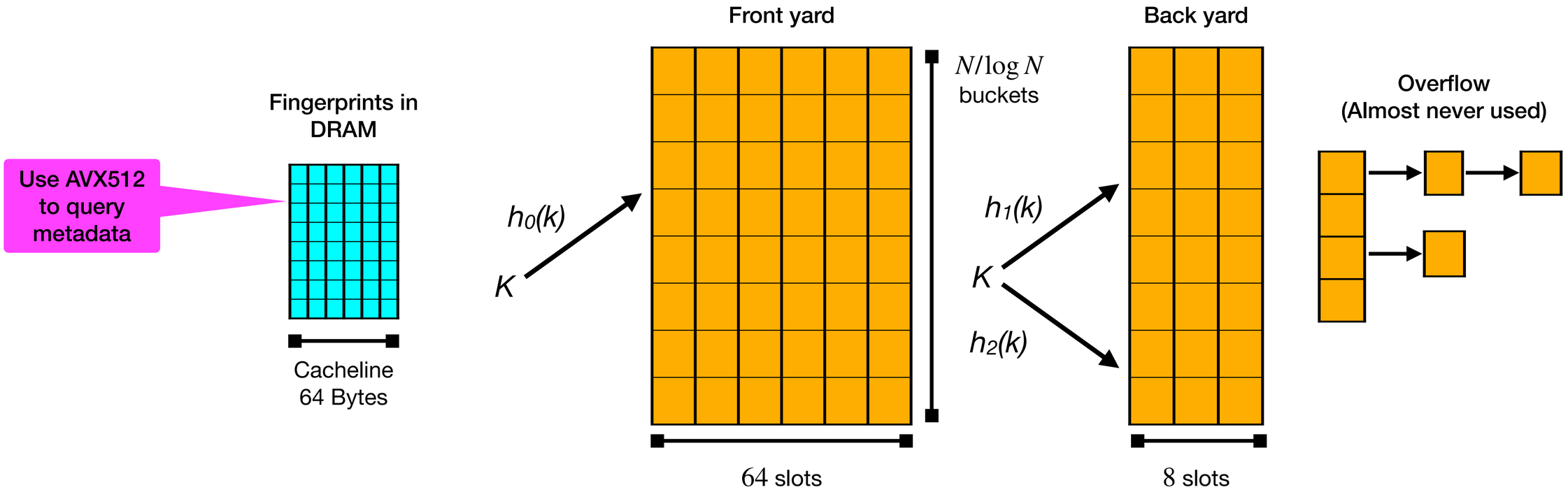
Iceberg hashing: metadata to reduce associativity



Problem: buckets in the front yard span many cache lines, so queries must load many cache lines.

Solution: store a fingerprint table in DRAM.

Iceberg hashing: metadata to reduce associativity

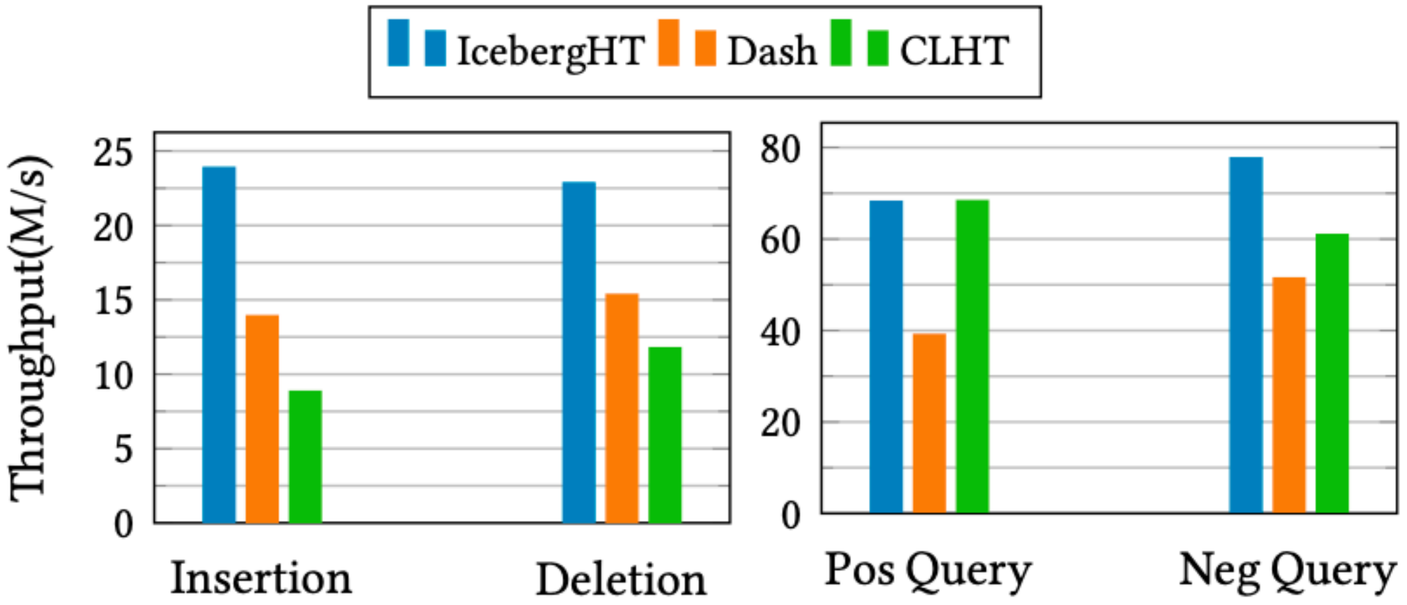


# probes: query	1 cacheline	1 cacheline		2 cacheline
# writes: insert	1 cacheline	1 cacheline	or	1cacheline

IcebergHT implementation

- **Highly concurrent** operations
- IcebergHT supports **in-place resizing**; reduces peak memory usage
  - Multi-threaded resizes are implemented using distributed reader-writer locks
- **Crash safety is trivial**
  - Using CLWB; no need for a fence between key & value writes
  - Metadata stays in DRAM and is reconstructed during recovery

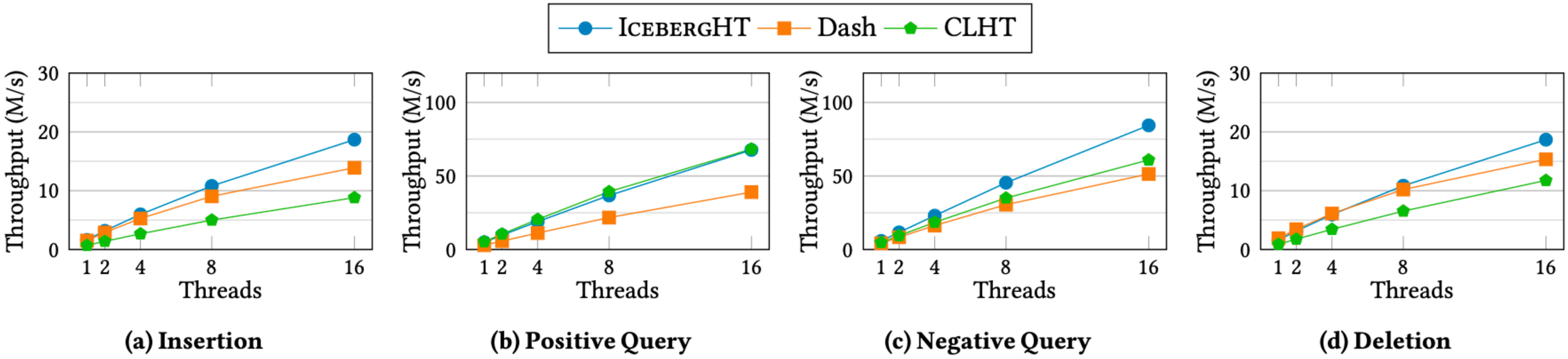
PMEM performance: operation throughput



Performance using 16 threads for PMEM hash tables.

Iceberg outperforms state-of-the-art hash tables across all operations.

PMEM performance: thread scalability



Performance with increasing number of threads for PMEM hash tables.

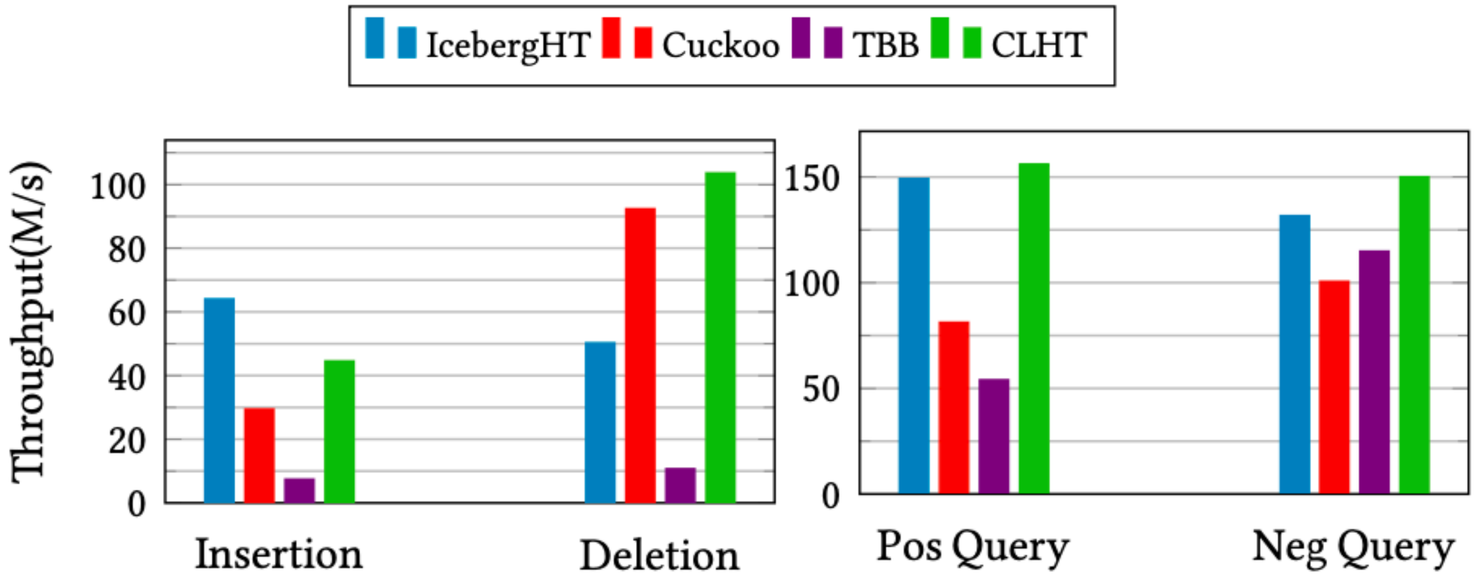
Iceberg operation throughput scales better (or similar) to other hash tables.

PMEM performance: space efficiency

Hash tables	Space efficiency
IcebergHT	85%
Dash	69%
CLHT	33%

IcebergHT offers higher space efficiency compared to Dash (extendible) and CLHT (chaining) hash tables.

DRAM performance: operation throughput

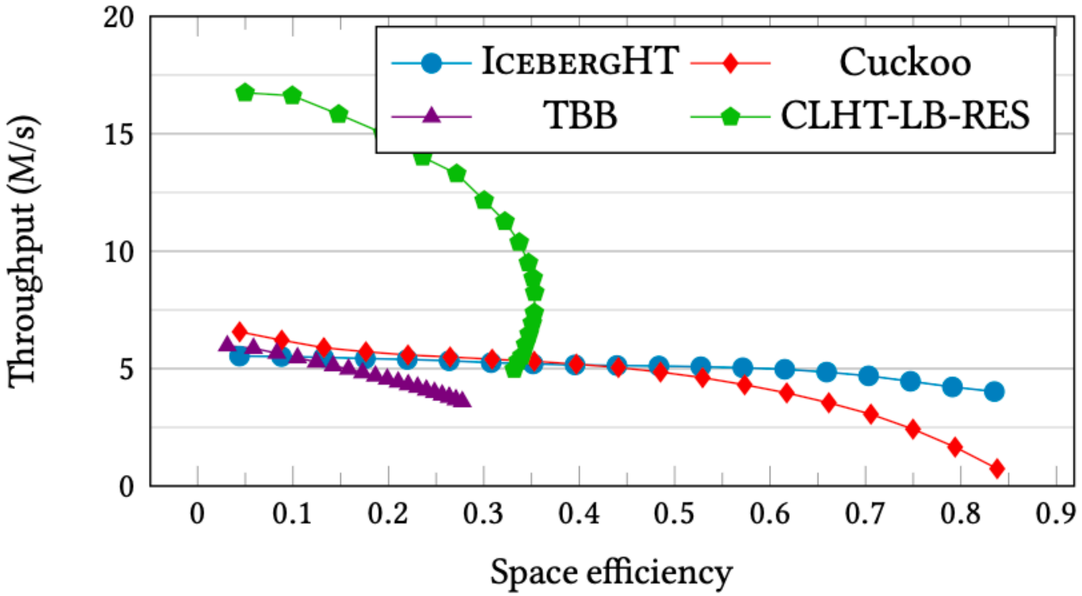


Performance using 16 threads for DRAM hash tables.

Iceberg outperforms state-of-the-art hash tables for insertions and offers similar performance to CLHT for queries.

IcebergHT deletes are slower.

DRAM performance: space efficiency



IcebergHT can achieve high space efficiency and maintain insertion throughput.

CLHT space efficiency drops quickly.

CuckooHT insertion throughput drops at high load factor.

Takeaways

- Stability yields:
  - Fast updates (especially on PMEM)
  - Good scalability with threads
  - Crash safety (please refer to paper)
- Low associativity yields:
  - Fast lookups
  - Small metadata

Source code:
https://github.com/splatlab/iceberghashtable

- Iceberg hashing gives both high performance and high space utilization
- Also, supports resizing without drop in instantaneous latency
- Metadata scheme is also an example of general **maplet** data structure