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

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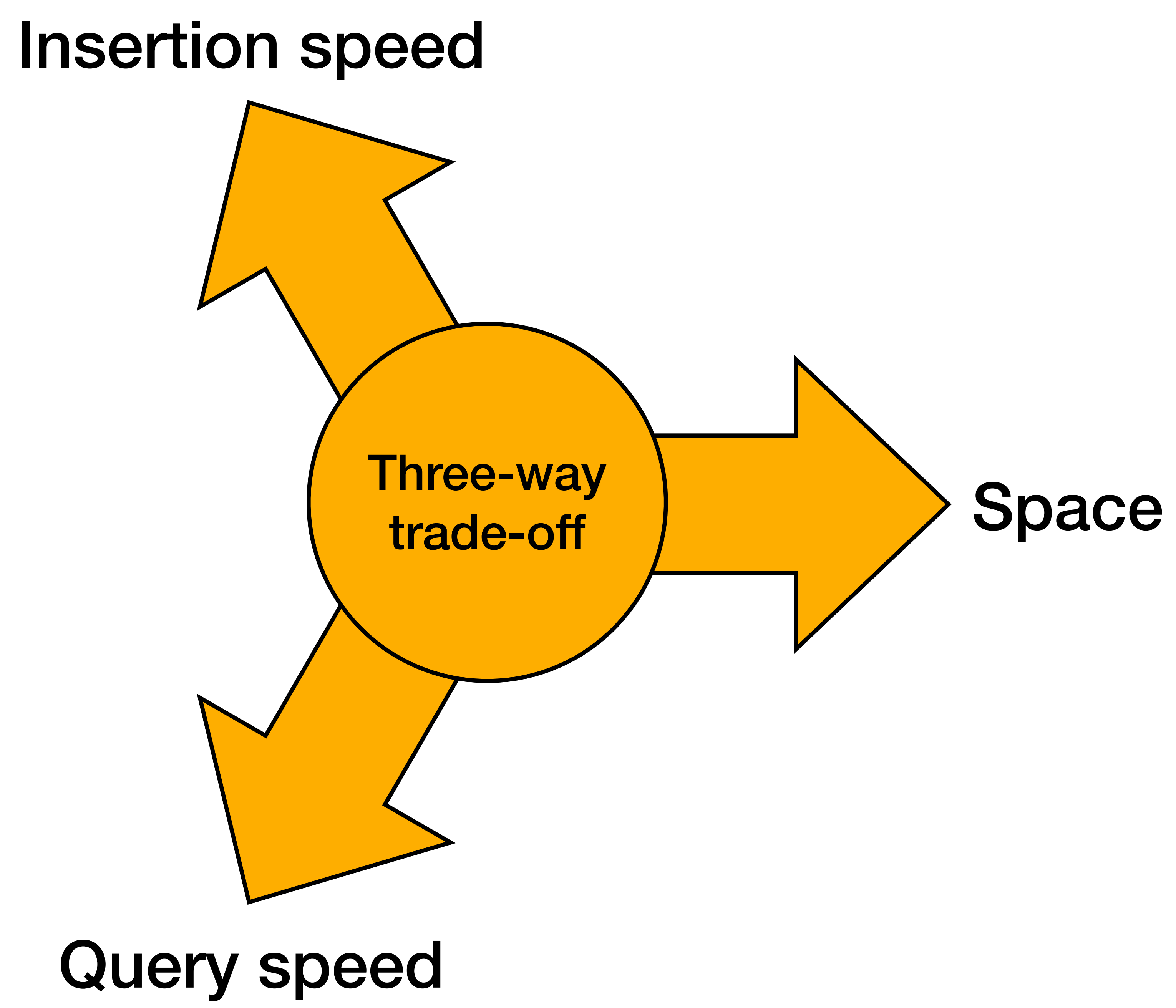
Hash tables are everywhere!

Built into many languages…

Built into many software packages…

And performance is critical to many applications.

Hash table performance criteria

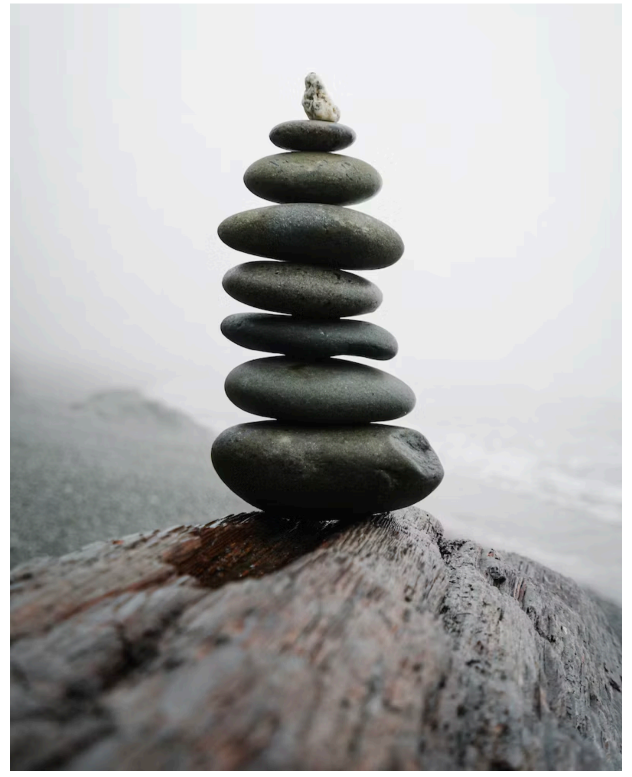


Hash table performance has a three-way trade off between insertion speed, query speed, and space.

Hash table 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

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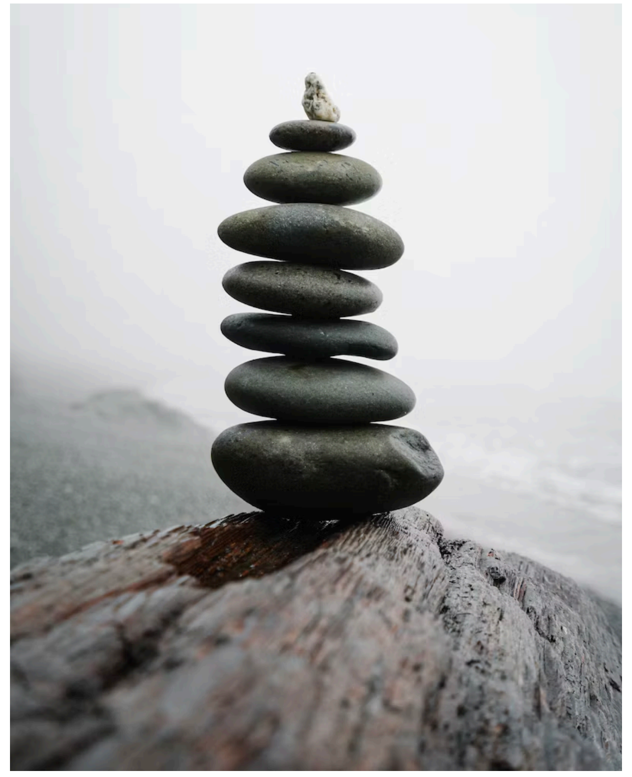

Fast insertion

Hash table design mechanism

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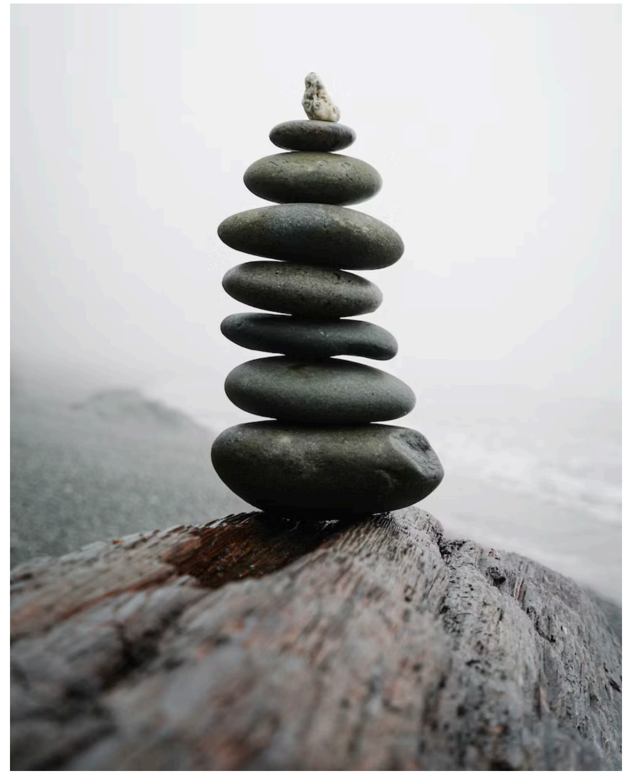

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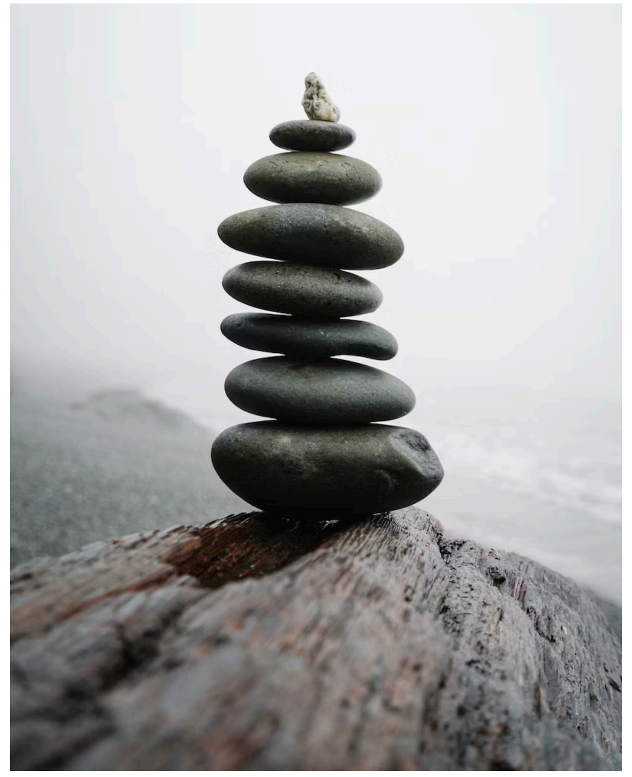

Fast insertion

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Map each item to one a small number of locations

Fast queries

Space efficiency

Minimum overhead from pointers or over provisioning

Low space

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

Our results:

Stability

Low associativity

Space efficiency

Insertion performance

Query performance

Space efficiency

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

20% to 2X faster on PMEM
Competitive on DRAM

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

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PMEM

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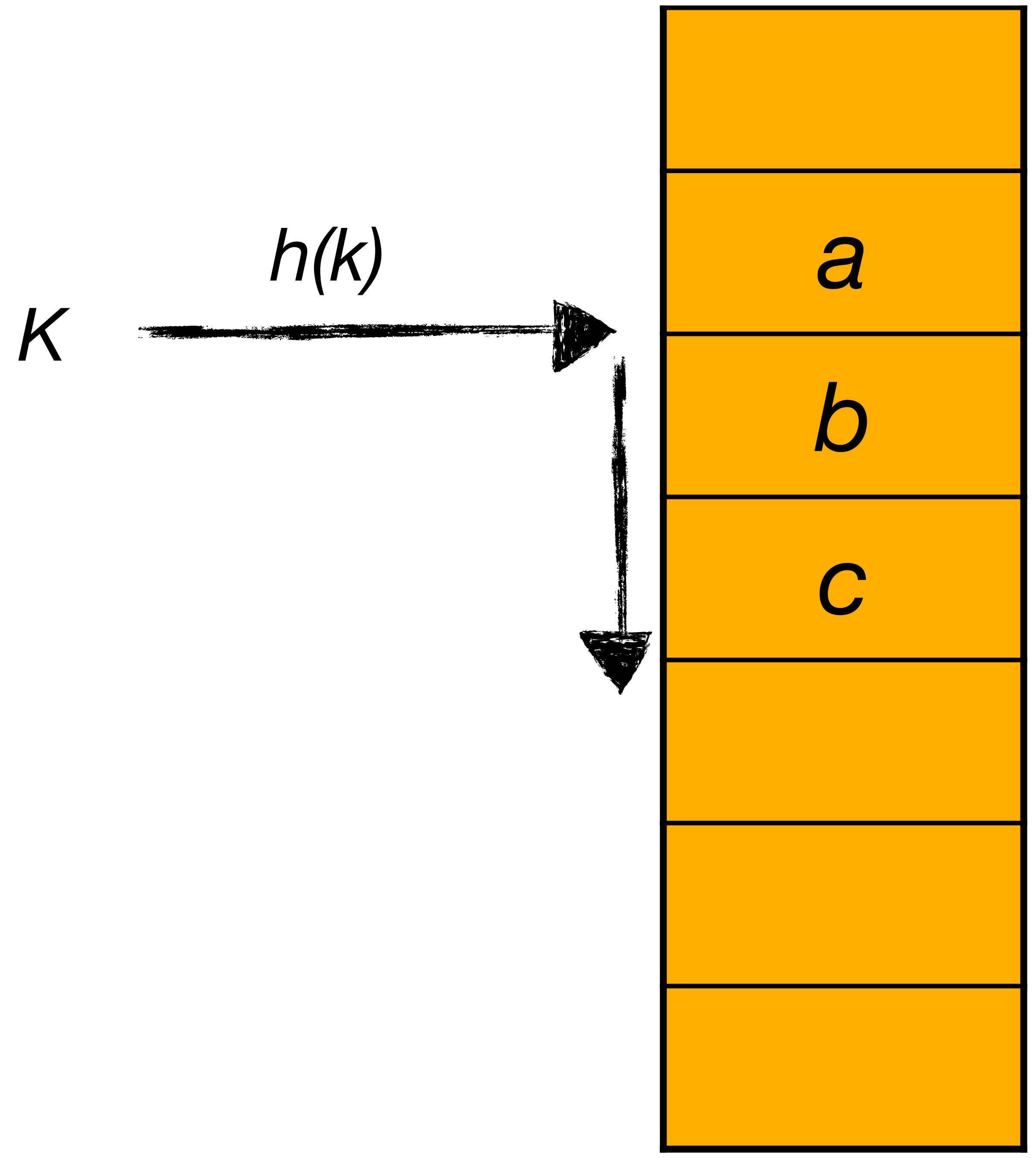
IcebergHT also achieves:

- 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

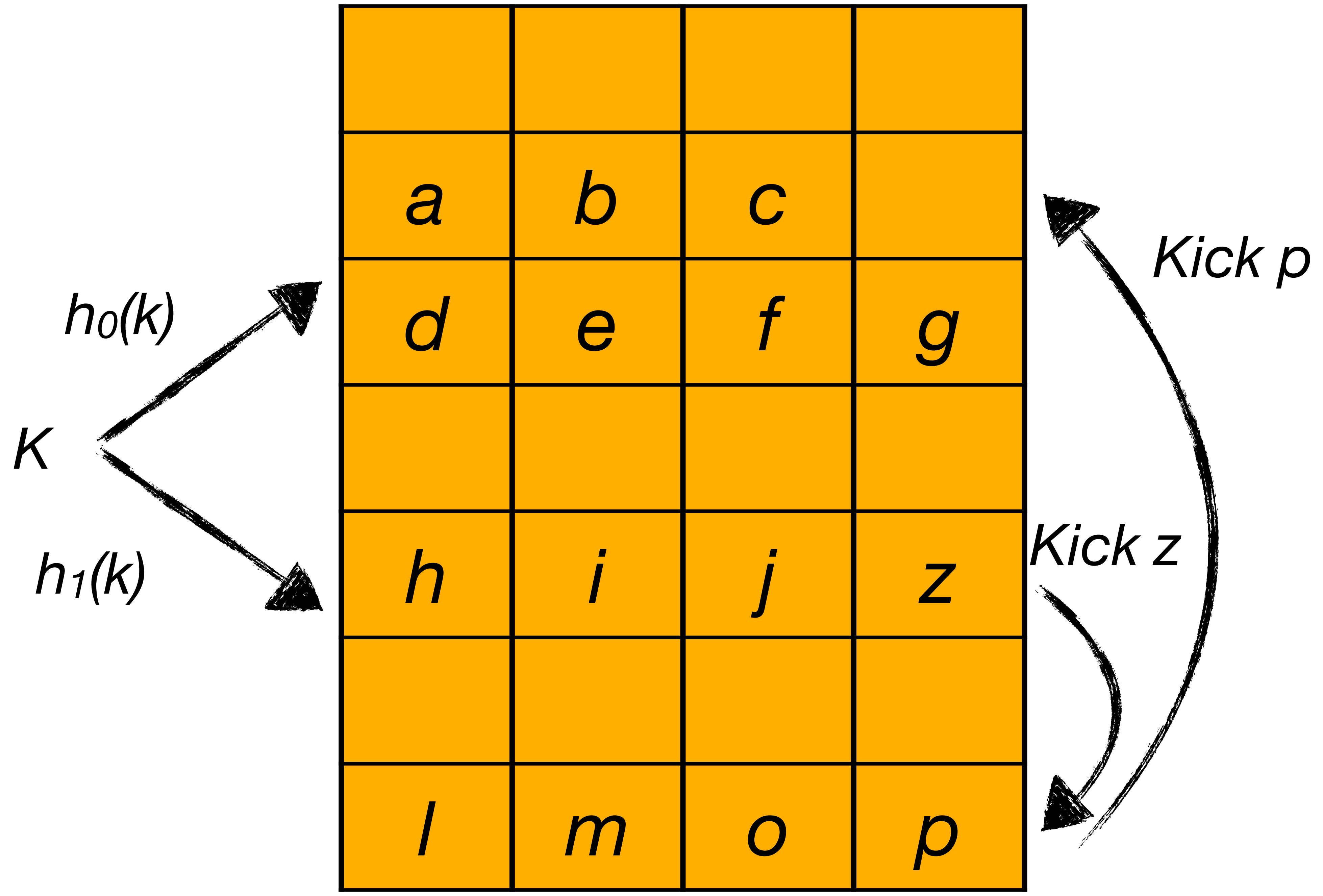
- Stable
- Associativity $\approx \dfrac{\log N}{(1-\alpha)^2}$ (α = load factor)
- E.g., N = 1Billion, α = 95%, associativity = 12000



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

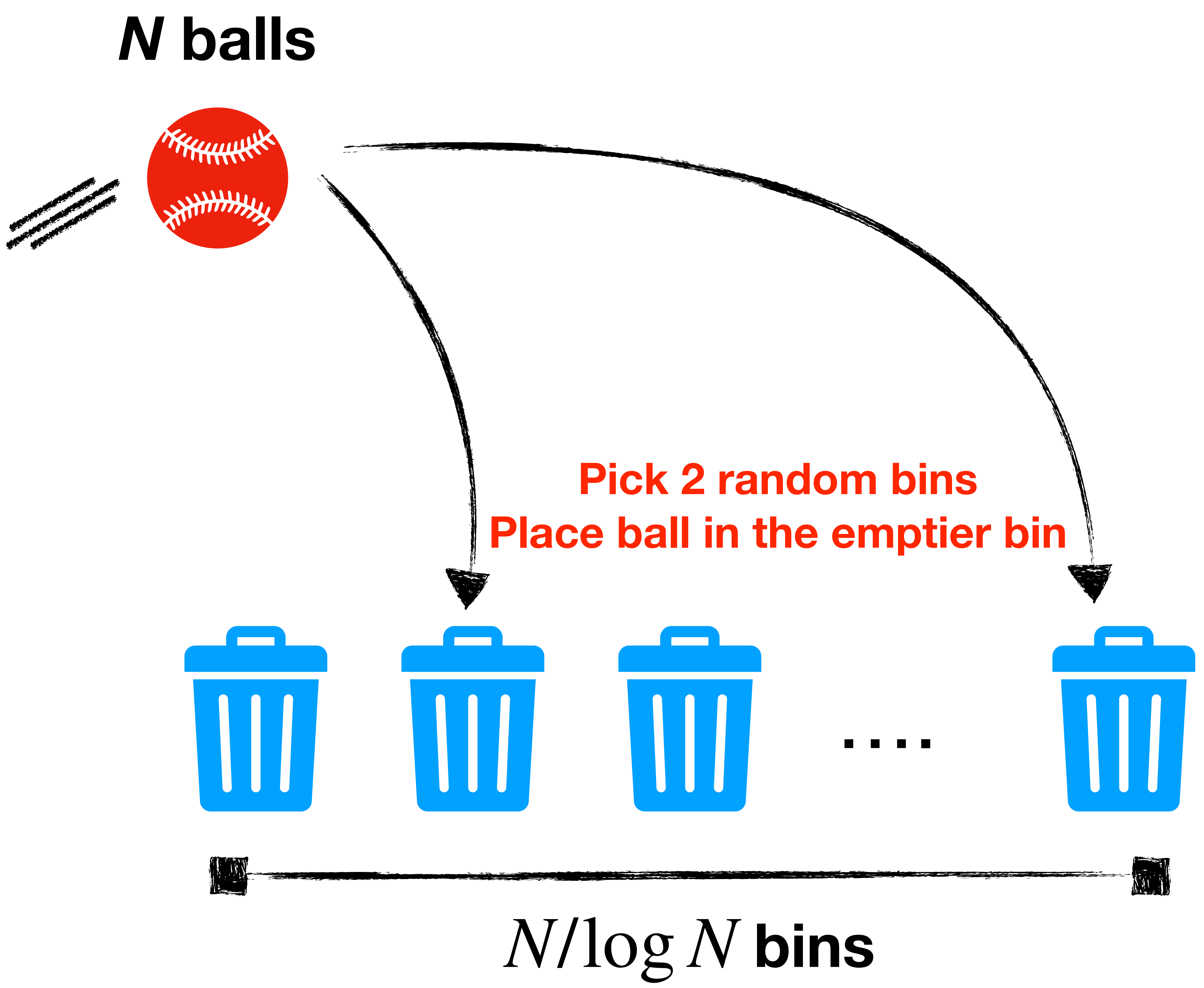


Insertion performance drops significantly due to excessive kicking at high load factors.

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

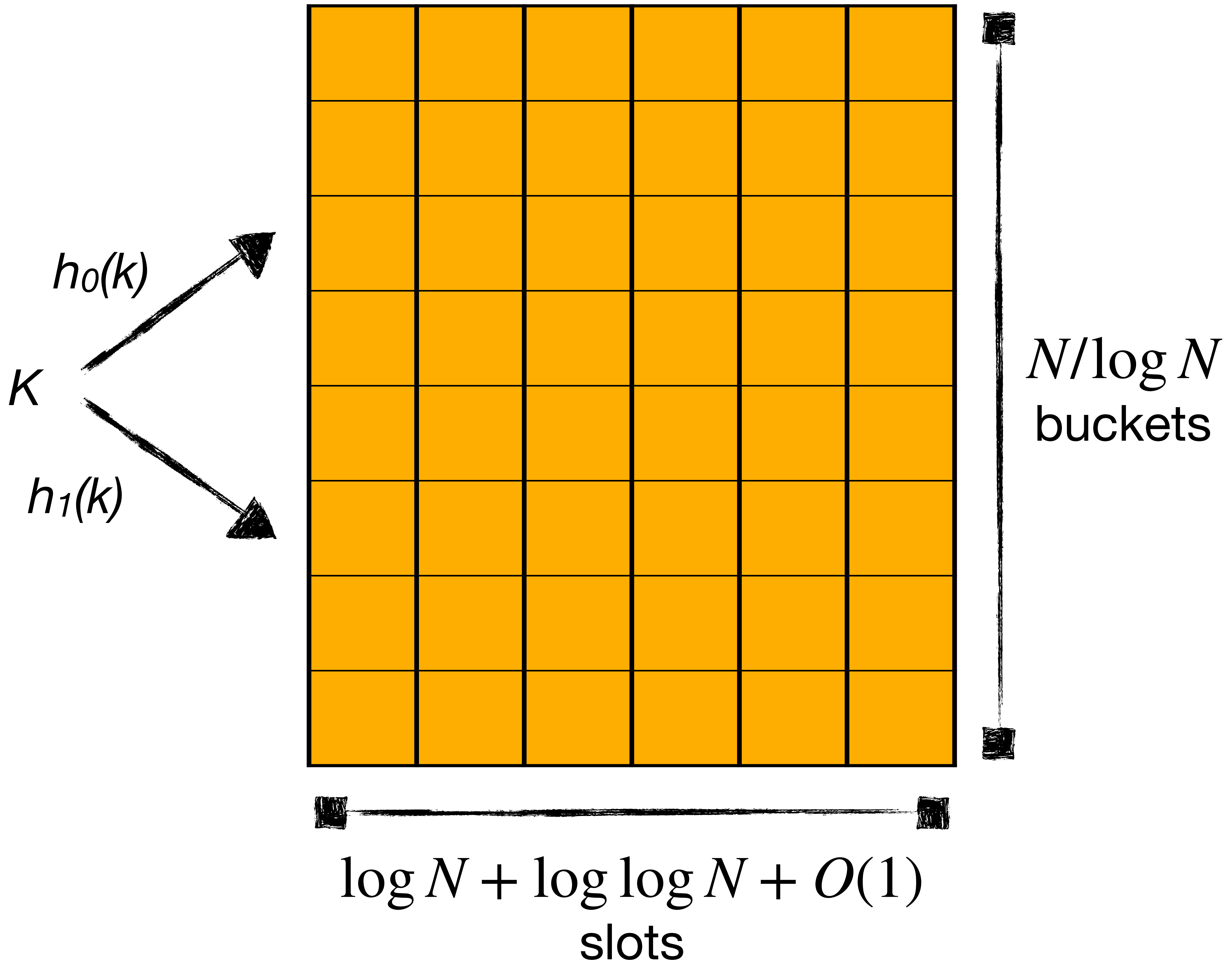


Theorem: if you throw *N* balls into $N/\log N$ bins using minimum of two choices, the fullest bin will have $\log N + \log\log N + O(1)$ balls W.H.P.

- 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 $1 - o(1)$



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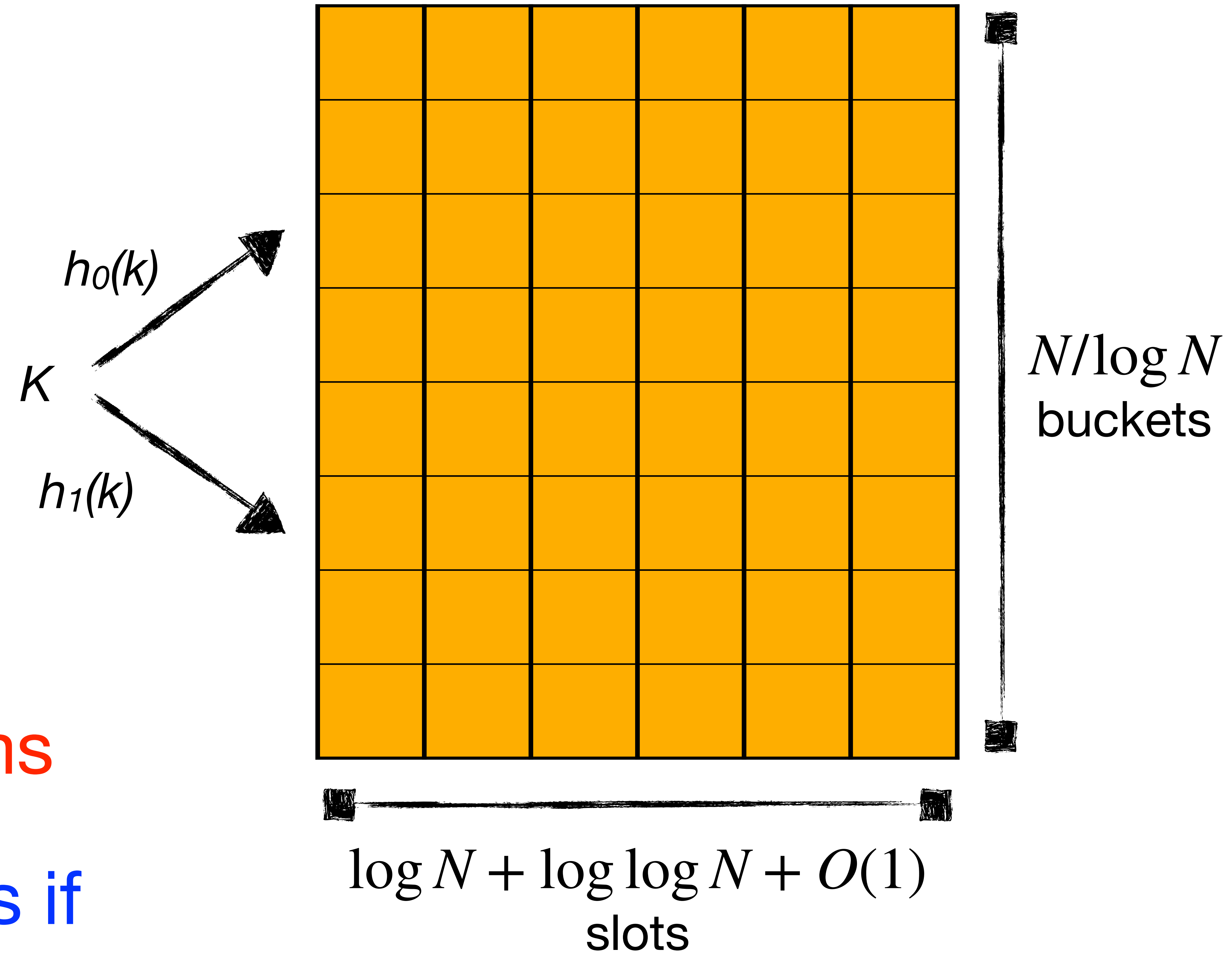
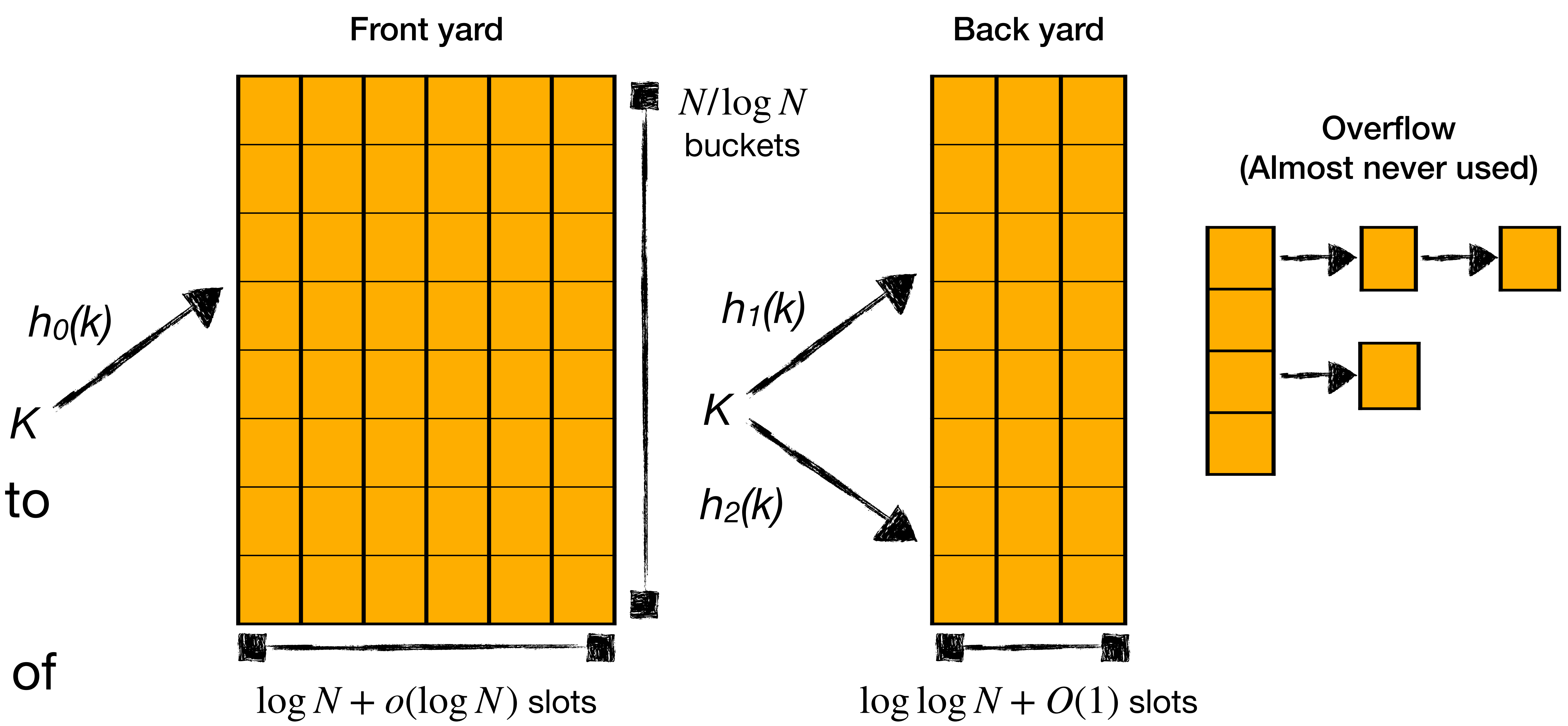


Problem: it does not hold when we delete items

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 $O(1)$



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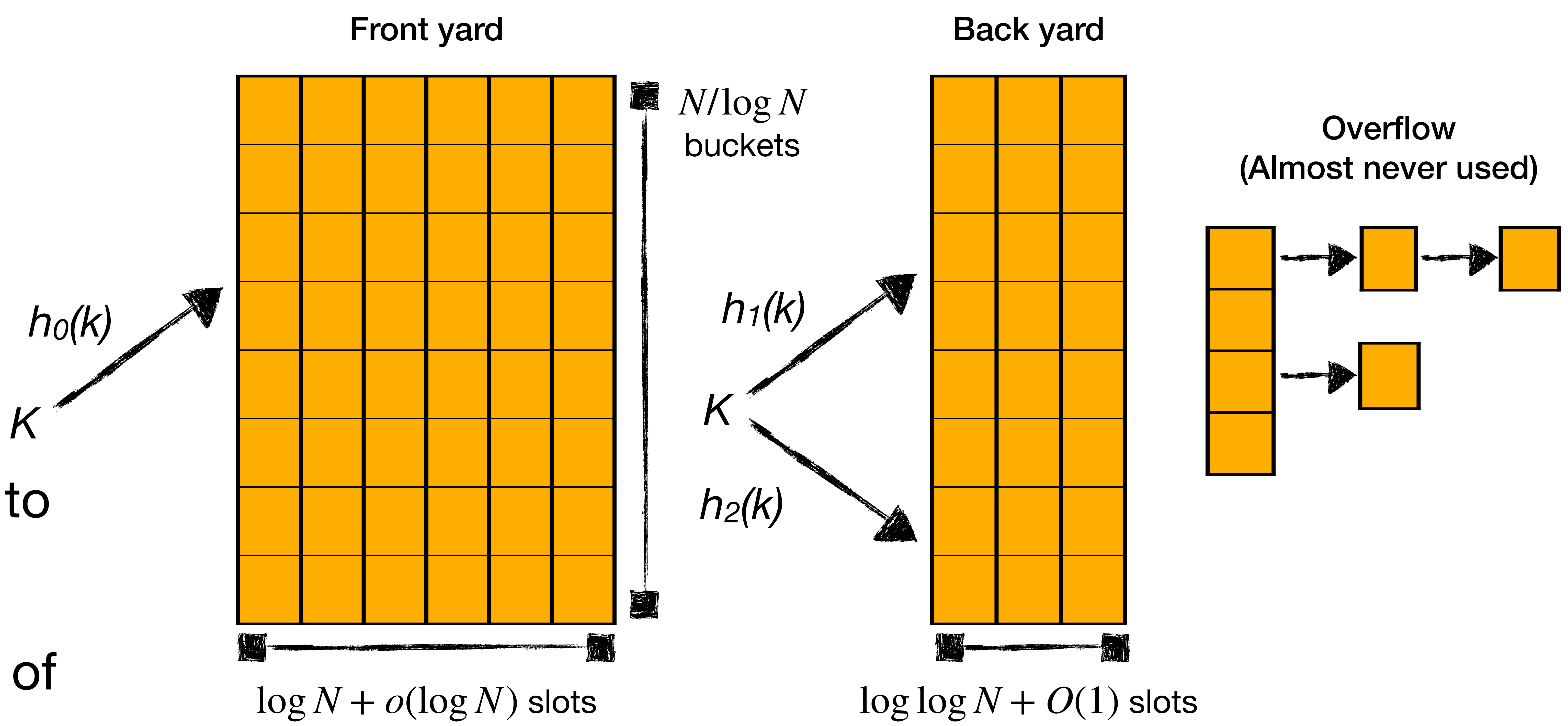
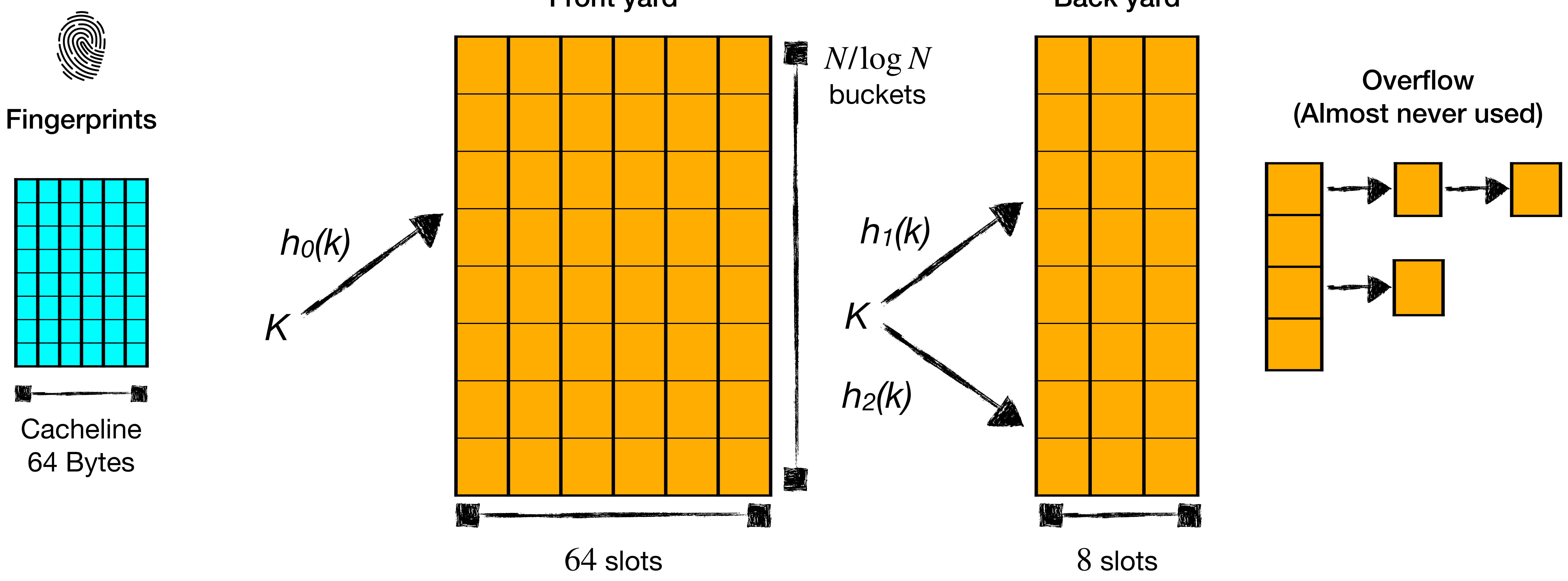


Problem: buckets in the front yard span many cache lines, so queries must load many cache lines.

Iceberg hashing: metadata to reduce associativity



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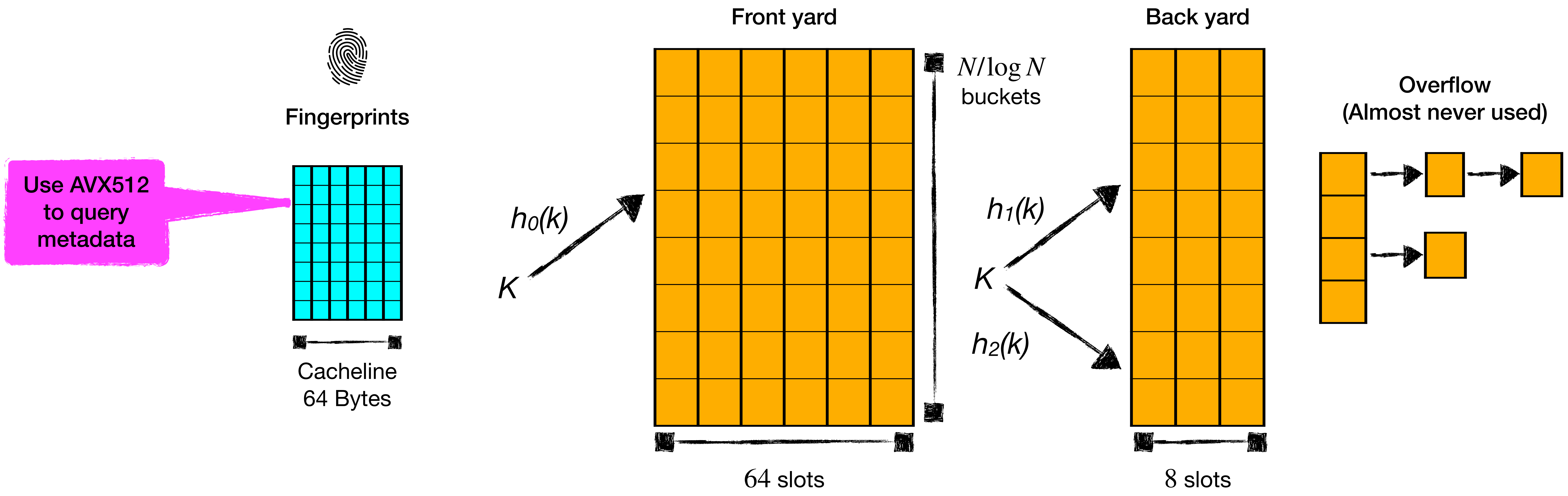
Solution: store a fingerprint table.

Iceberg hashing: metadata to reduce associativity



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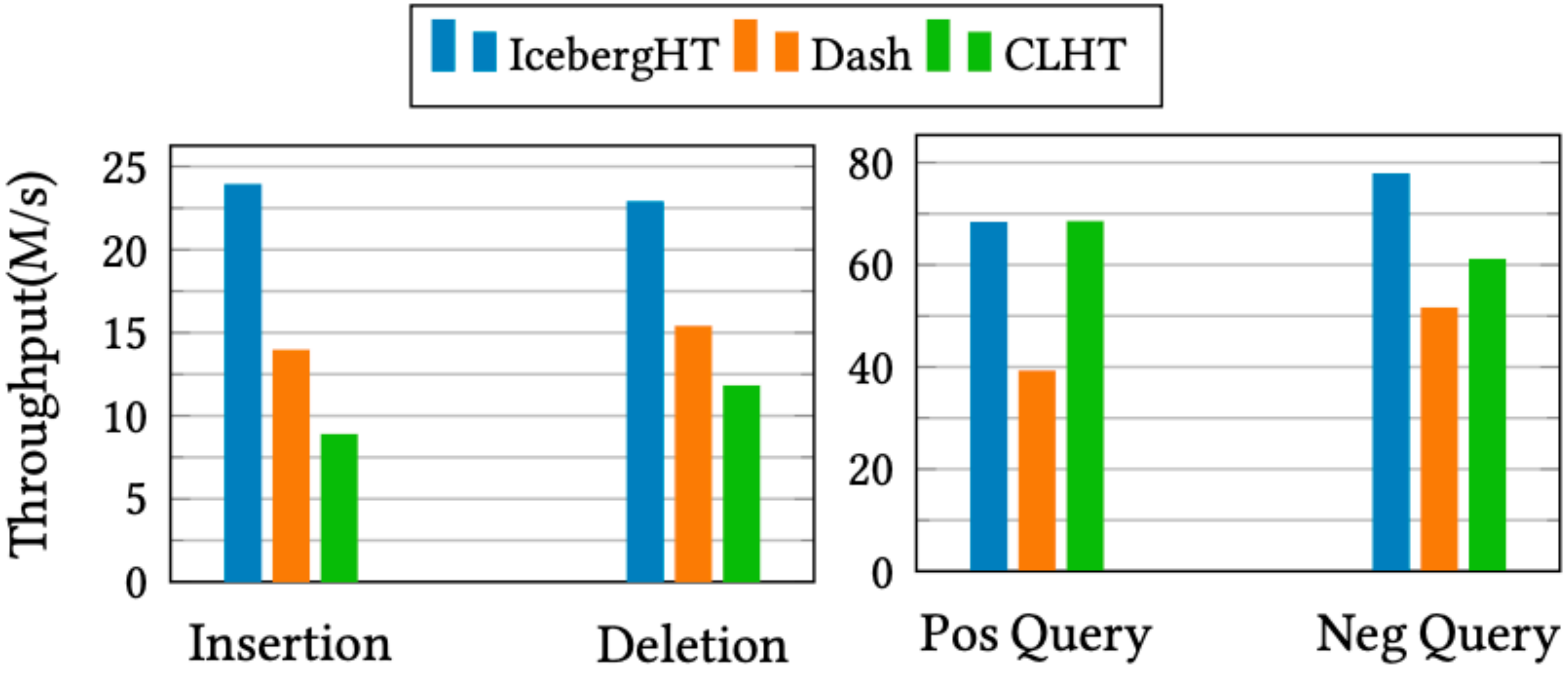
IcebergHT implementation

- **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.

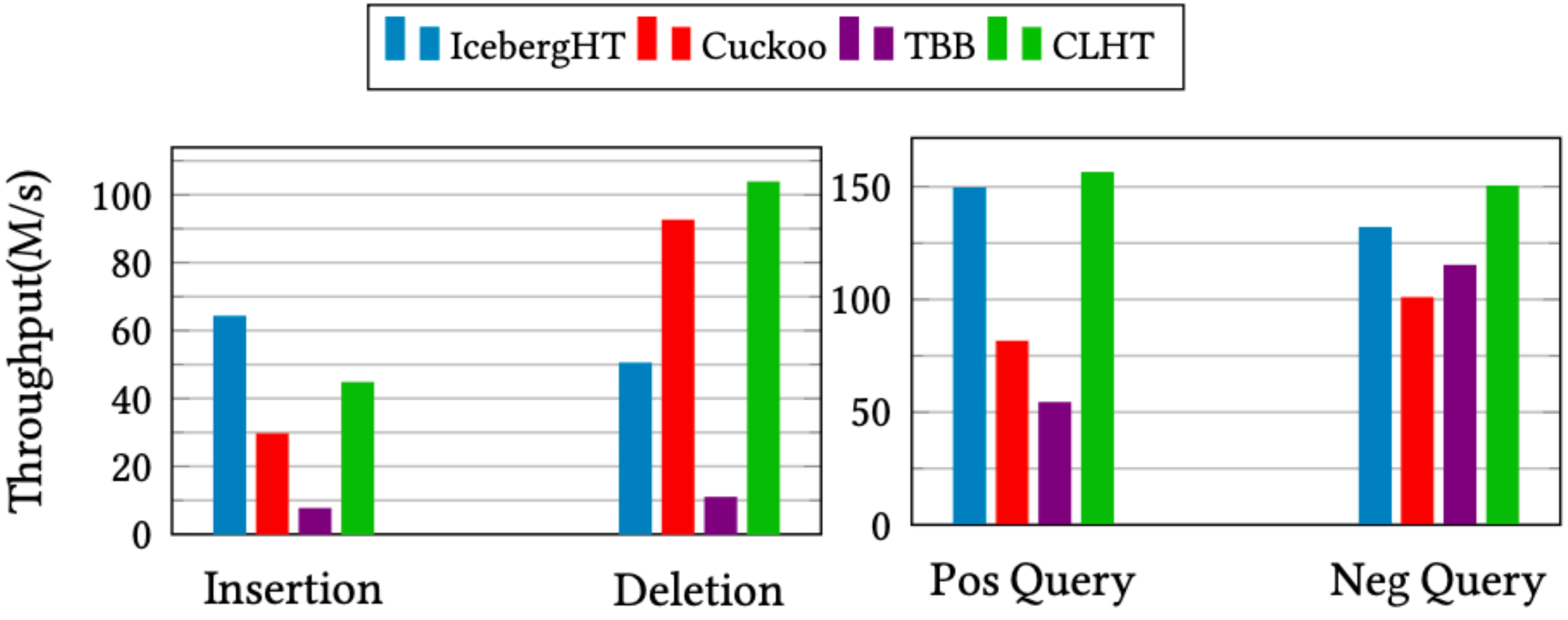
Iceberg outperforms state-of-the-art hash tables across all operations.

PMEM performance: 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

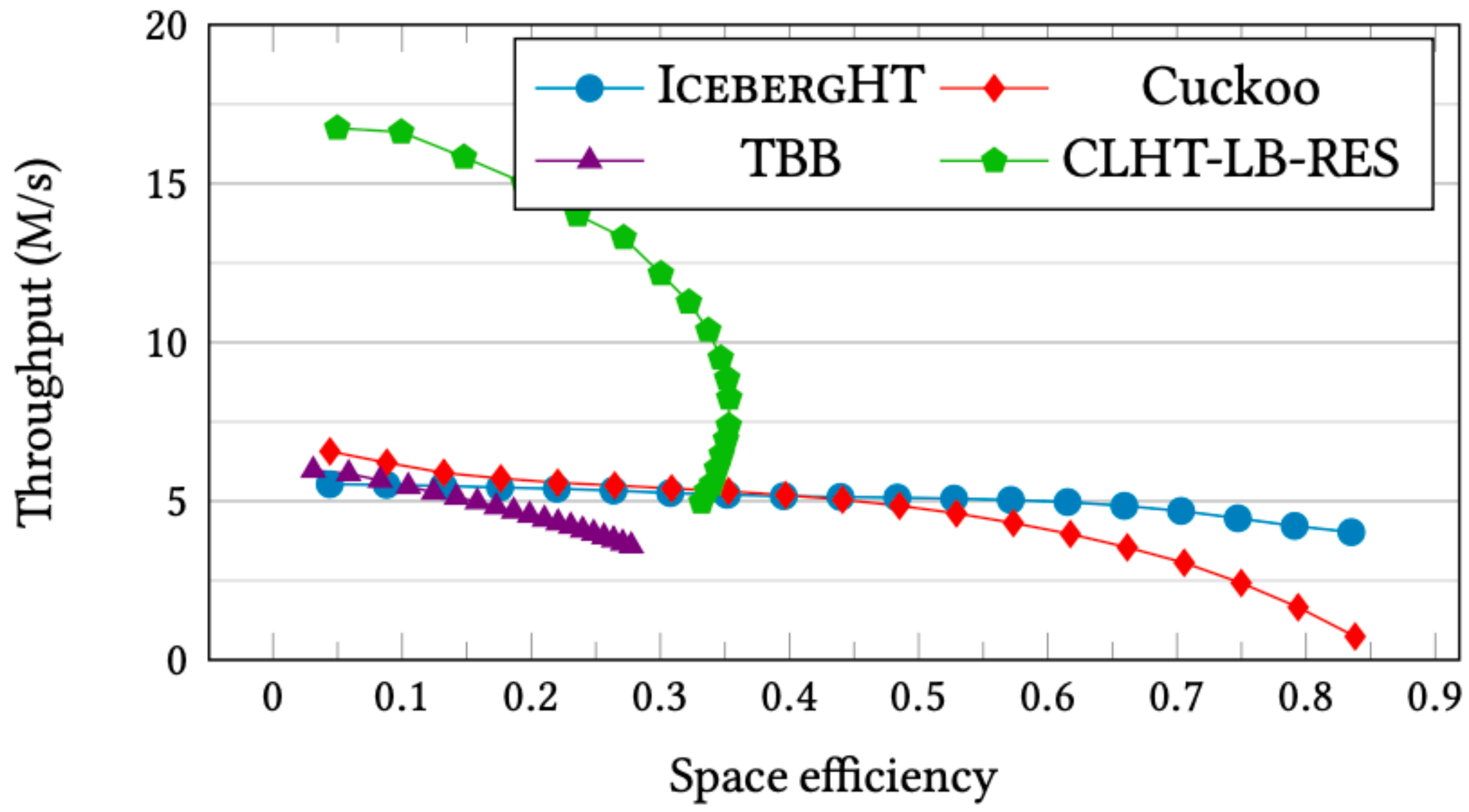


Performance using 16 threads for DRAM hash tables.

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
- 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

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