# Parallel Multi-split Extendible Hashing for Persistent Memory

**Jing Hu**, Jianxi Chen, Yifeng Zhu, Qing Yang, Zhouxuan Peng, Ya Yu

# Outline

- Background
  - Persistent Memory
  - Staic Hashing
  - Dynamic Hashing
- Design
  - Overview
  - Lock-free parallel
  - Multi-split
  - Instant recovery
- Evaluation
- Conclusion

# Background: Persistent Memory

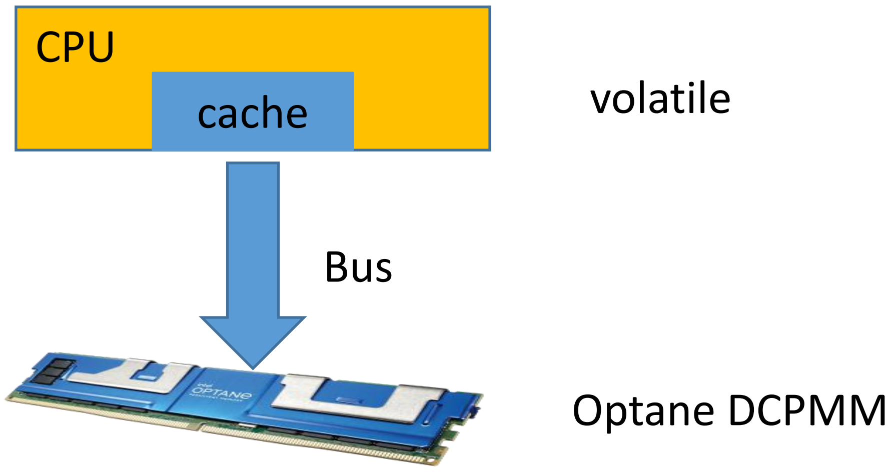
- **Pros:**
  - non-volatility - byte-addressable
  - high-density - near-zero standby power

- **cons:**
  - limited endurance
  - limited write bandwidth
    - 1/6 of DRAM
    - 1/3 read bandwidth of DRAM

**Intel Optane DC Persistent Memory**
512 GB per module at most
DIMM compatible

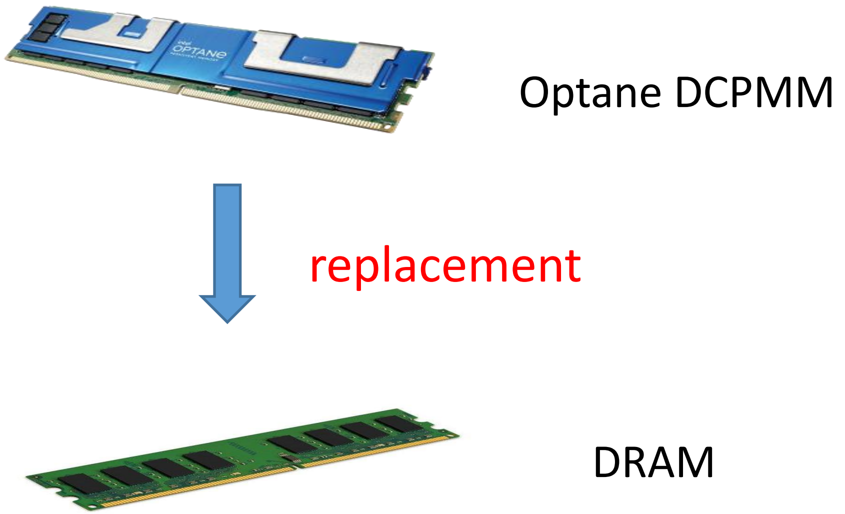
# Background: Persistent Memory

- **inconsistency due to large data :**
  - Cpu only support 8-byte atomic write (64-bit bus)
  - Larger than 8-byte: Copy on Write (COW) or Logging
  - Prevent Reorder: mfence and clflush



# Background: Hash Table

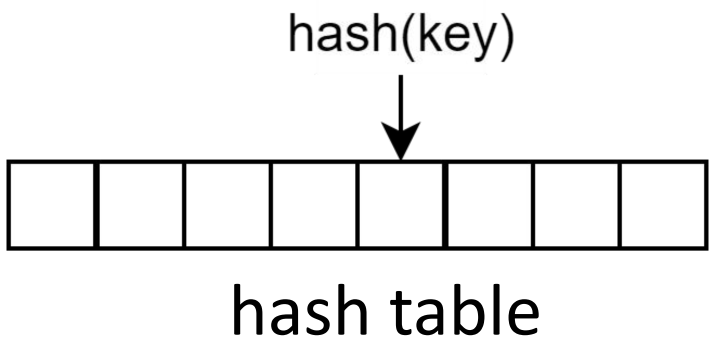
- PM is a promising replacement for DRAM.
- Hash table is widely used in main memory systems.
- Redesign hash table for PM is essential.

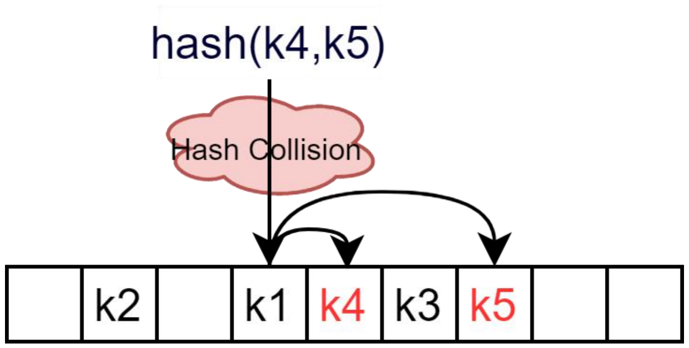


# Background: Hash Table

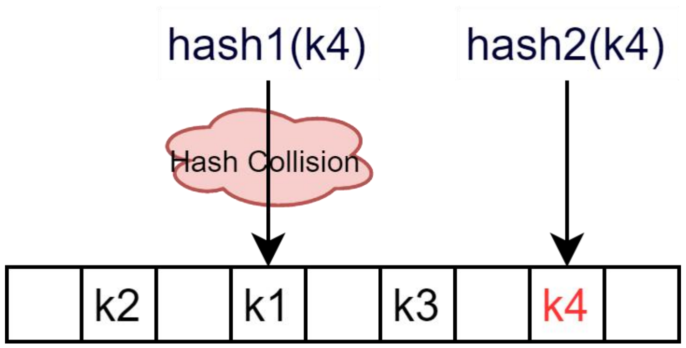
- **Hash Table:** a data structure that stores or retrieves data from the position calculated by the hash function.

- **Hash collision:**
  - Linear probing, chaining, double hashing
  - Resizing:
    - (1/3) Full table : static hashing
    - Non-full table : dynamic hashing

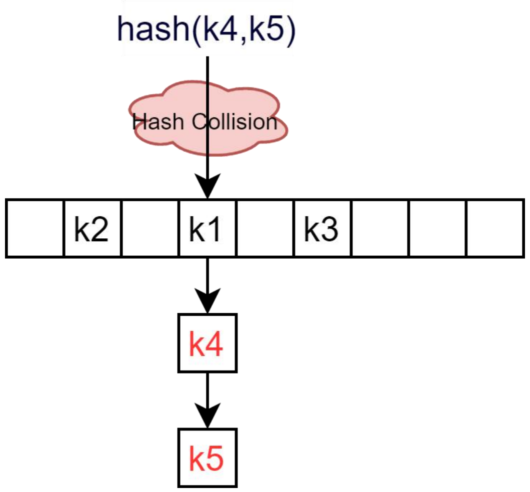



linear porbing




double hashing




chaining

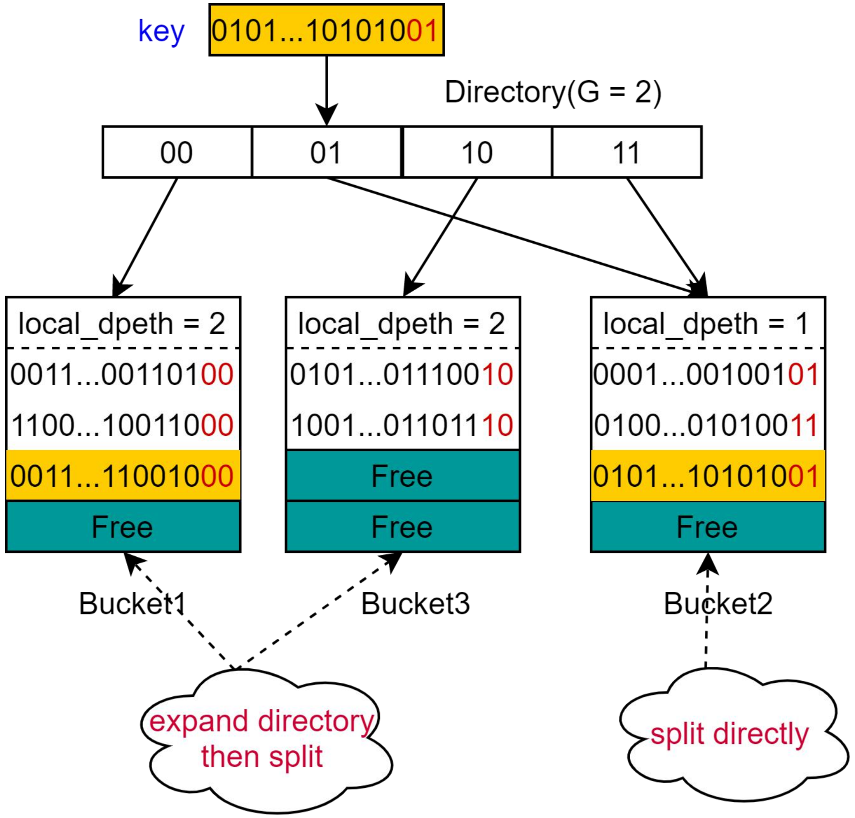
# Background: Static hashing

- **Long resizing latency and massive extra data movement:**
  - Rehash full table or 1/3 table

- **Low concurrency:**
  **- Level hashing:** slot lock for read/write (expensive lock overhead)
  **- Clevel hashing:** a single background thread to rehash(bottleneck)

# Background: Dynamic hashing

- Extendbile hashing(DRAM)
  - Non-full table rehashing
  - Hash collison:
    - Split a bucket directly
    - Allocate a new directory and then split a bucket (directory is small)




Extendible hashing

# Background: Dynamic hashing

- **Massive data movement:**
  - Rehash 1/2 table data
- **Low concurrency**
  - **- CCEH:** segment reader/writer lock (limited concurrency)
  - **- Dash**: bucket writer lock (limited concurrency)

# Outline

- ~~Background~~
  - ~~Persistent Memory~~
  - ~~Static Hashing~~
  - ~~Dynamic Hashing~~
  - ~~Motivation~~
- Design
  - Overview
  - Lock-free
  - Multi-split
  - Instant recovery
- Evaluation
- Conclusion

# Design: Overview

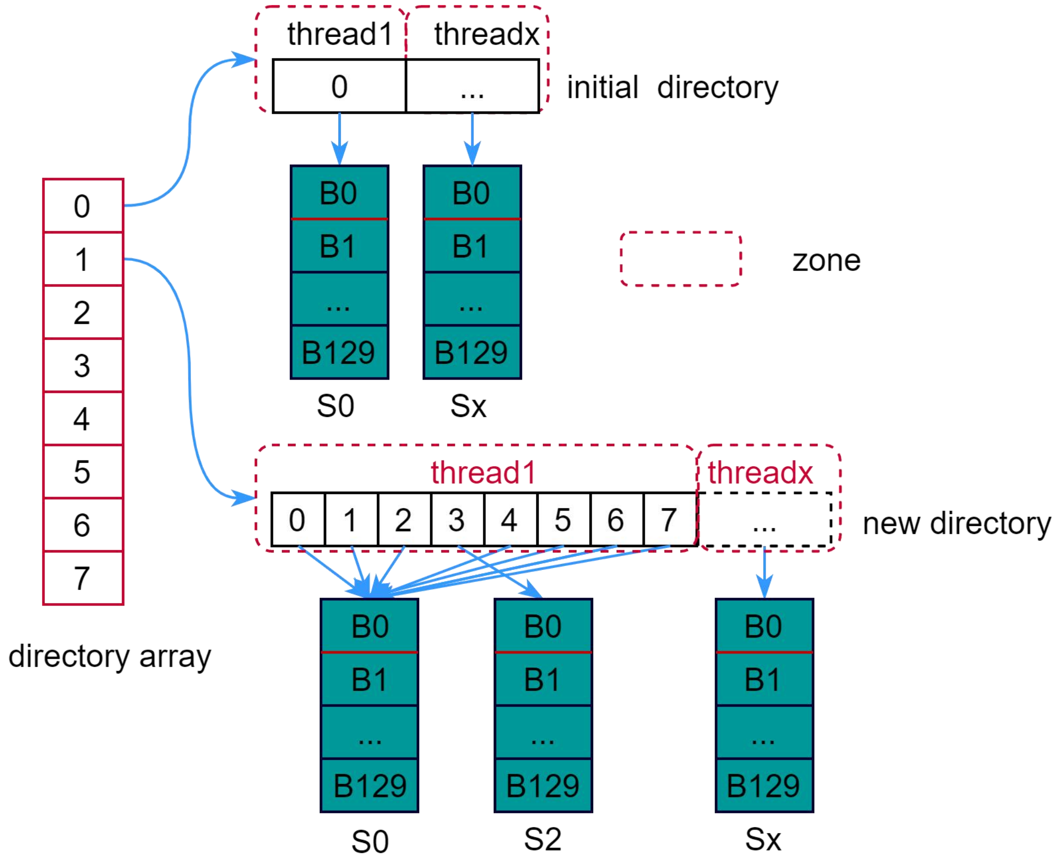
- **Existing hashing schemes:**
  - **Long rehashing latency**: static hashing
  - **Low concurrecy**: lock overhead or single thread bottleck
  - **Massive extra data movement** in rehashing

- **PMEH(**Parallel Multi-split Extendible Hashing for Persistent Memory**)**:
  - Dynamic hashing: short resizing latency
  - Eliminate lock overhead
  - Reduce the number of data movement in rehashing
  - Guarantee data consistency

# Design: Lock-free Parallel

- **Eliminating lock overhead:**

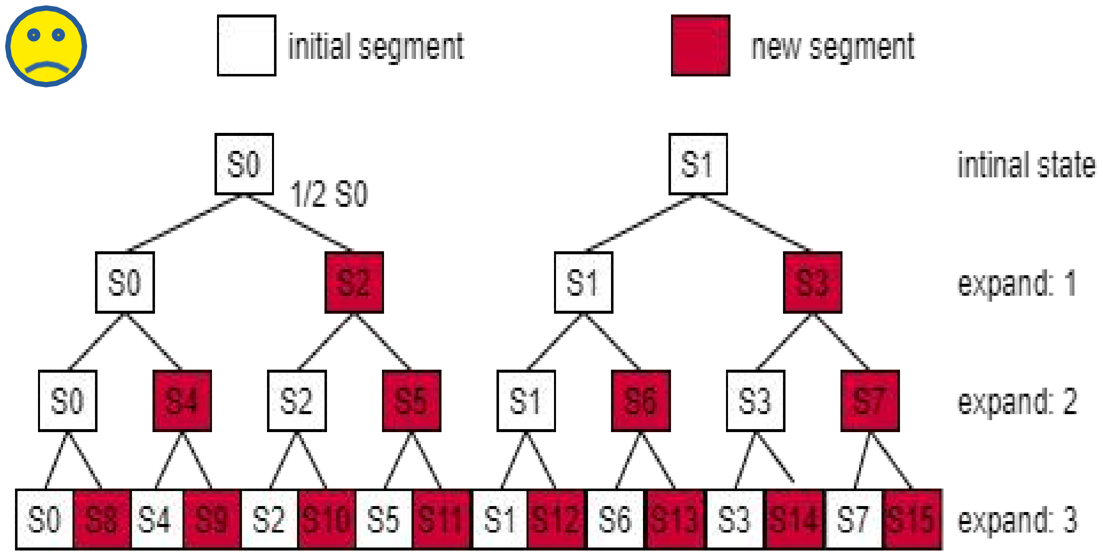
1. **Lock-free for segment:**
   - directory is divided into zones
   - one zone only is bound to one thread
2. **Lock-free for directory:**
   - introduce an extra directory array
   - multi-threads use CAS add a new directory to directory array.
   - directory entries updating: amortize into subsequent access of each thread



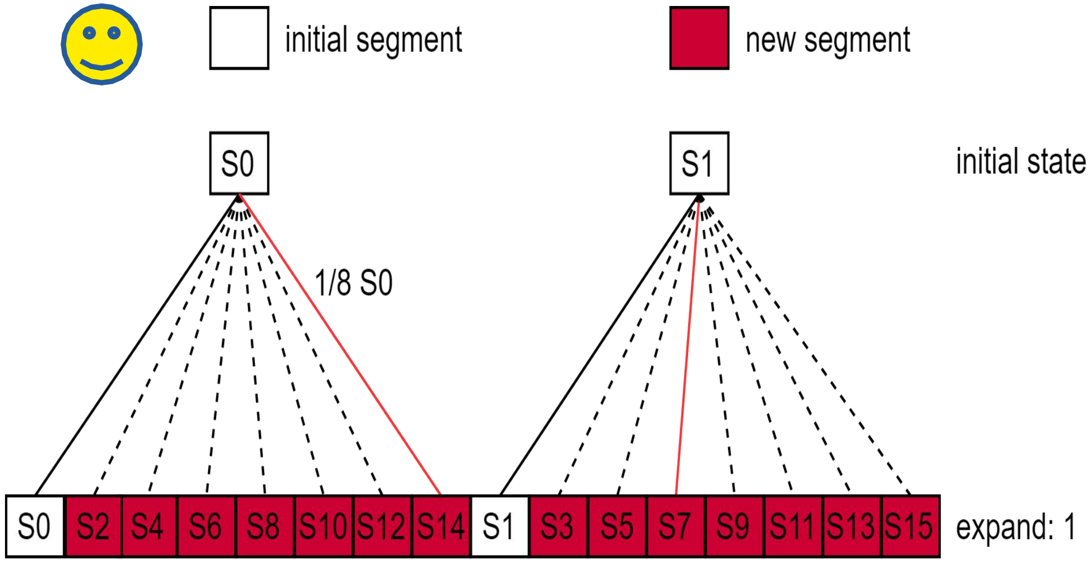

Lock-free parallel access in PMEH

# Design: Multi-split

- **reducing data movement:**
  - Using multi-split instead of 2-split
  - Reduce extra data movement (33%, 8-split vs 2-split )
  - Gradual split to reduce latency




Hash table expanded in 2-split




Hash table expanded in 8-split

# Design: Recovery

- **Guarantee Data Consistency:**

1. **Crash when inserting a record:**
   - (One-bit flag) in bucket: indicates whether finish inserting or not.
2. **Crash when segment splitting:**
   - (dirctory ID, entry ID, one-bit flag) : recorded for every segment splitting.
3. **Crash when directory expanding:**
   - (directory pointer) for every thread:
     - null: indicates that no new directory is allocated
     - non-null: indicates that a new directory is allocated

# Outline

- ~~Background~~
  - ~~Persistent Memory~~
  - ~~Static Hashing~~
  - ~~Dynamic Hashing~~
  - ~~Motivation~~
- ~~Design~~
  - ~~Overview~~
  - ~~Lock-free~~
  - ~~Multi-split~~
  - ~~Instant recovery~~
- Evaluation
- Conclusion

# Evaluation: Experimental setup

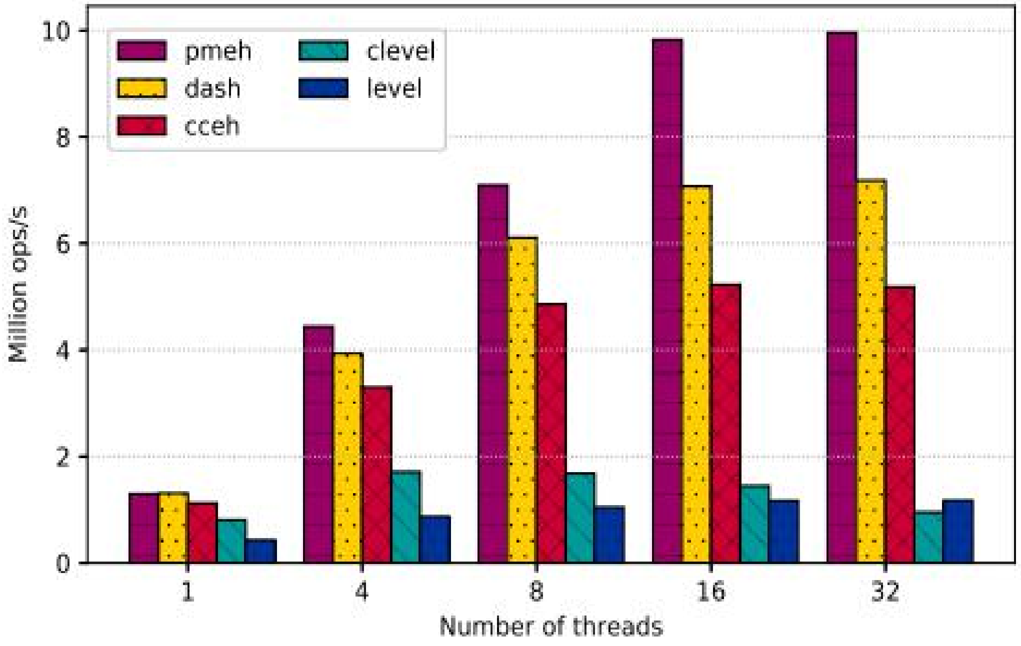
- **Platform：**
  - Intel Optane DCPMM 512 GB(4X128GB), APPDIRECT mode
  - PMDK

- **Comparisons:**
  - **DASH**: default version, 256-byte bucket, two stash buckets [VLDB’20]
  - **CLEVLE**: store key-value instead of pointer, 128-byte bucket [ATC’20]
  - **CCEH**: lazy deletion version, default probing distance four buckets [FAST’19]
  - **LEVEL**: bucket lock, 128-byte bucket [OSDI’18]
  - **PMEH**: our PMEH hashing

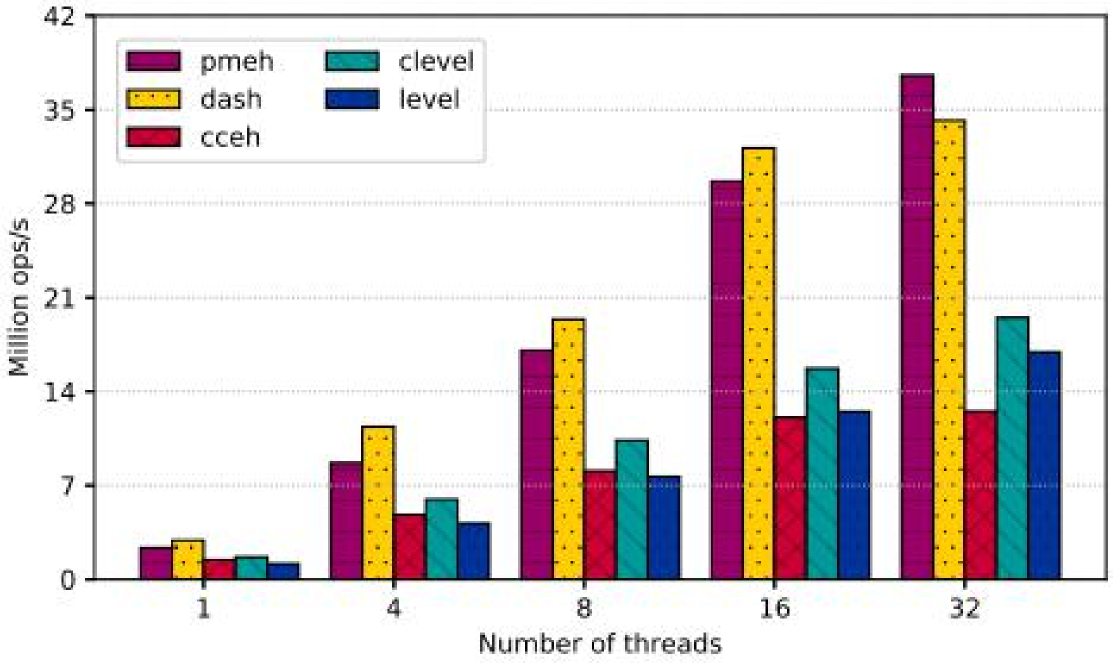
- **Benchmark：** YCSB

# Evaluation: Scalability

- PMEH is up to 1.38x and 1.10x faster than Dash for Insertion and search, respectively.



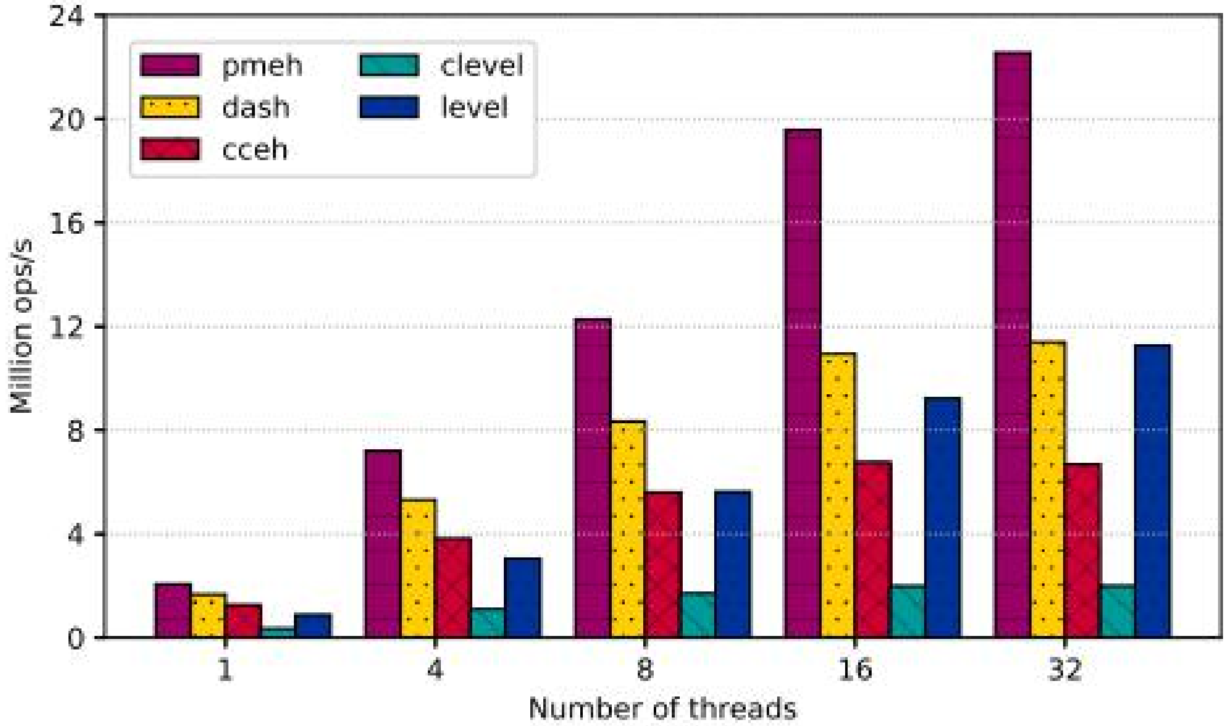

insert throughput




search throughput

# Evaluation: Scalability

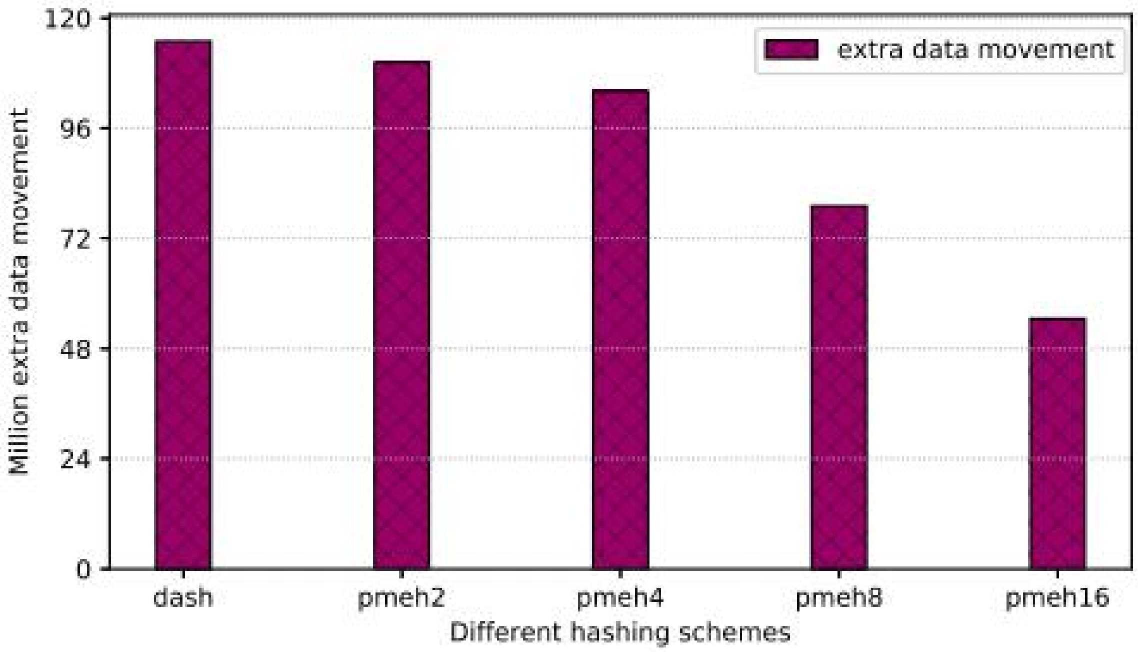
- PMEH is up to 1.97x faster than Dash for deletion in 32 threads
- In conclusion, PMEH has better scalability than other hashing schemes.




Delete throughput

# Evalution: Extra data movement

- PMEH can reduce 52% extra data movement than Dash .




Extra data movements for Dash and PMEH

# Conclusion

- Existing hashing schemes have low concurrecy and massive extra data movement in rehashing
- PMEH
  - Lock-free parallel
  - Multi-split
  - Instant recovery
- 1.38x faster for insertion, 1.97x faster for deletion, and 52% reduction for extra data movement.

# Thank you!