華中科技大學
HUAZHONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

武汉光电国家研究中心
WUHAN NATIONAL LABORATORY FOR OPTOELECTRONICS

HBTree: an Efficient Index Structure Based on Hybrid DRAM-NVM

Yuanhui Zhou[1], Taotao Sheng[1], Jiguang Wan*[1,2]

1. WNLO, Huazhong University of Science and Technology, Wuhan,Hubei, China
2. Shenzhen Huazhong University of Science and Technology Research Institute

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Background

Background – Persistent Memory

- Emerging Npn-Volatile Memories(NVMs)
  - PCM, STT-MRAM, RRAM

- Characteristics of NVM
  - low latency
  - non-volatility
  - low power consumption
  - high storage capacity
  - byte addressing

- Optane DC PMM
  - first 3D X-Point persistent memory (PM) product

Background – Indexing structures

- Conventional indexing structures not suitable NVM

- Optimizing indexing structures for NVM based on conventional indexes
  - Optimize a single index structure to accommodate full NVM memory
    - Path Hash，Leveling Hash，NV-Tree ……
  - reduce the consistency overhead on NVM and speeds up failure recovery
    - FAST&FAIR，wB+Tree，CDDS-Tree……
  - study hybrid structure and use DRAM to optimize system performance
    - FPTree，HiKV，LB+Tree……

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Motivation

motivation

- B+Tree more suit NVM
  - Simple structure
  - Excellent Scan performance
  - Random Read and Write
- DRAM-NVM
- Challenges
  - Data consistency
  - Insert and Split overhead
  - Recovery time

Operational Efficiency

- Rich KV operations
  - — Load/Put/Get/Delete

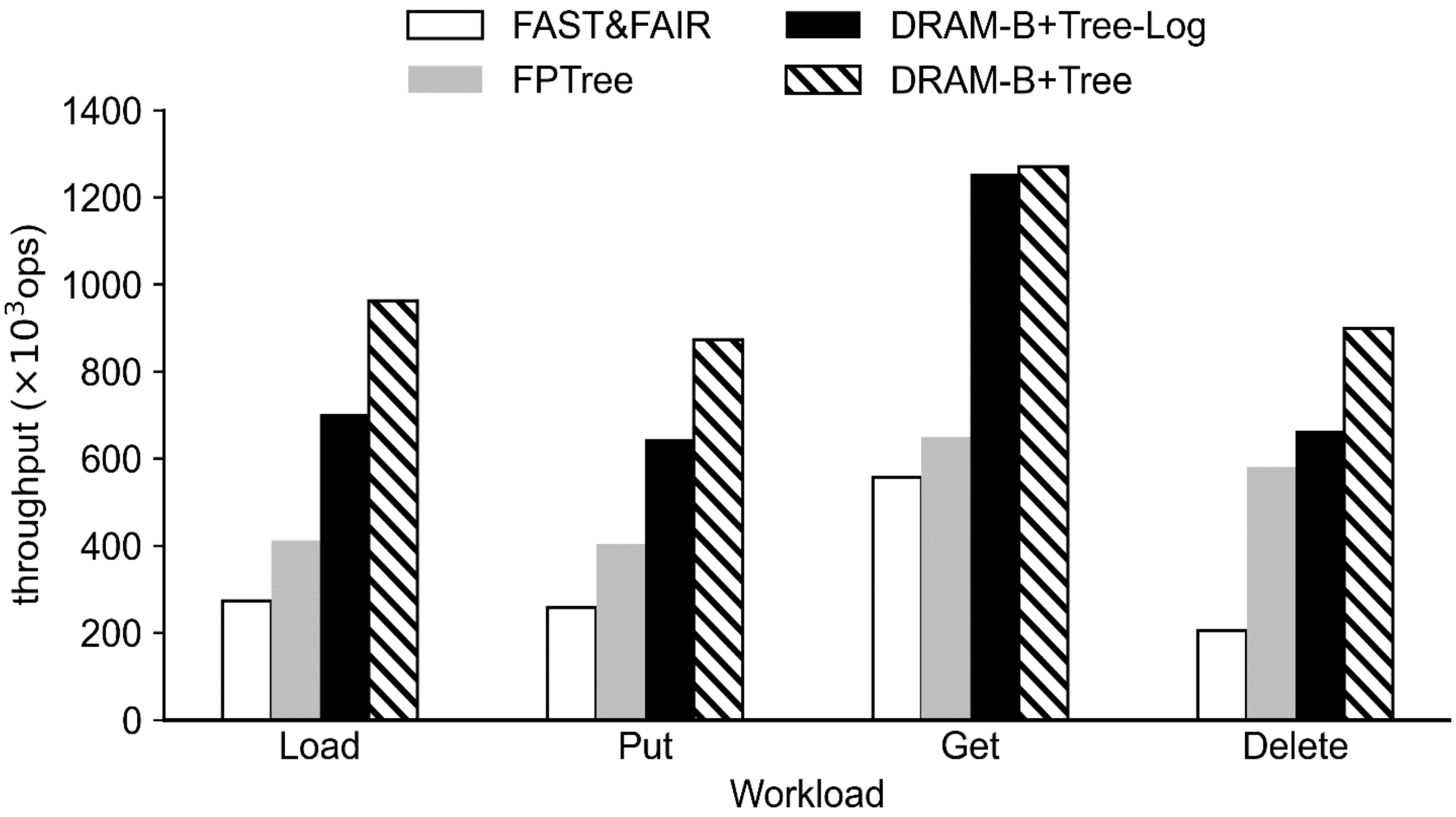
- observe

  DRAM-B+Tree (No persistence)

  > DRAM-B+Tree-log (log big)

  > FPTree

  > FAST&FAIR



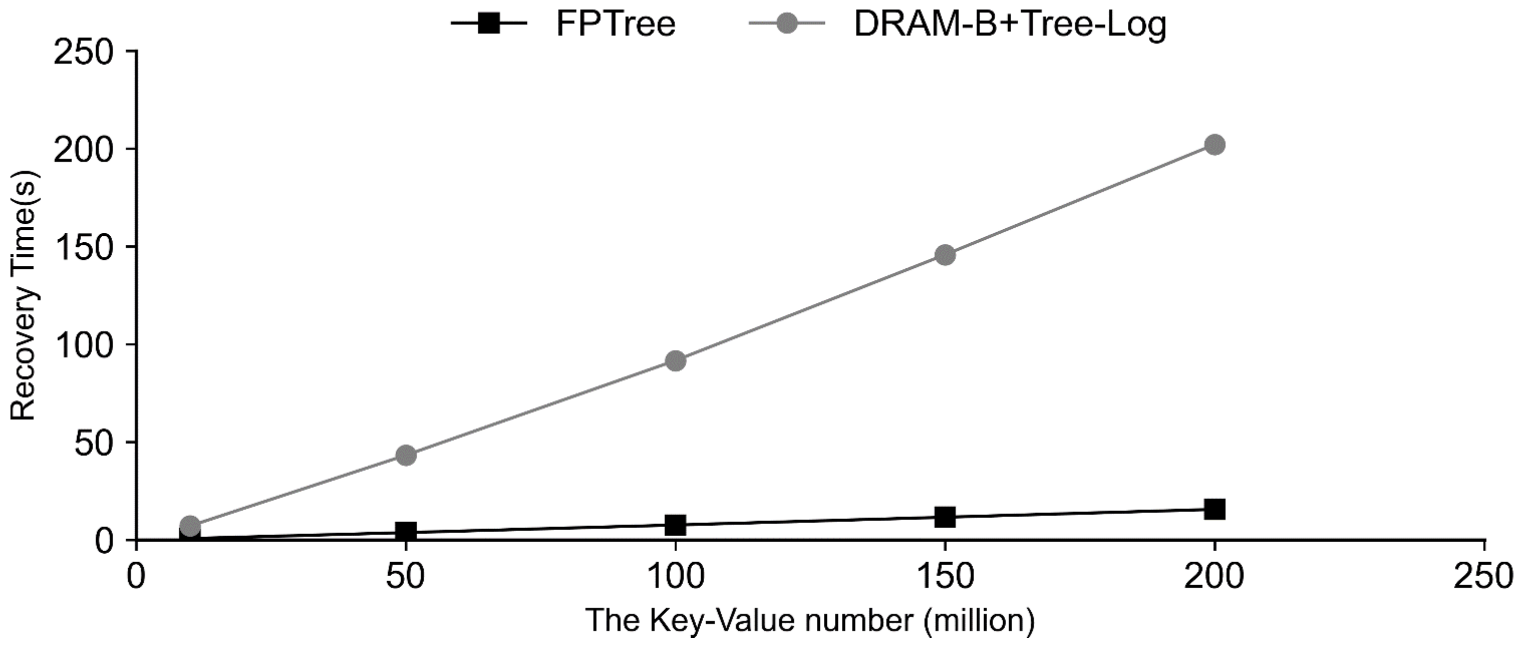
How to take advantage of the DRAM-NVM hybrid structure

Recovery Time

How to reduce the recovery time?

How to reduce the log?

Make some data into NVM



Recover time for FPTree and DRAM-B+Tree-Log

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Design

Design ideas

- B+ tree index structure with DRAM-NVM hybrid Memory
- Cache hot data in DRAM to improve performance
- ensure data consistency
- speed up the system failure recovery

Overall Architecture of HBTree

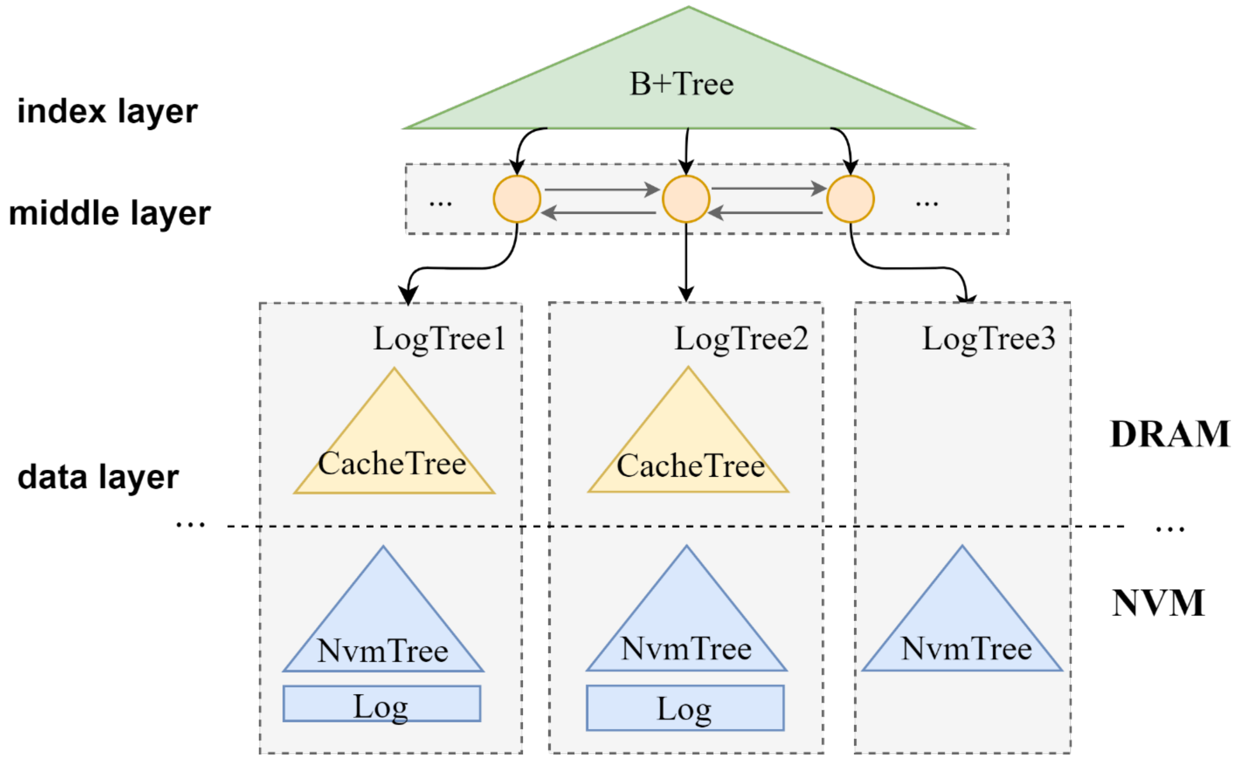
➢ HBTree: a hybrid three-layer persistent index

Index layer

- a B+tree on DRAM
- Does not persistent

Middle layer

Data layer



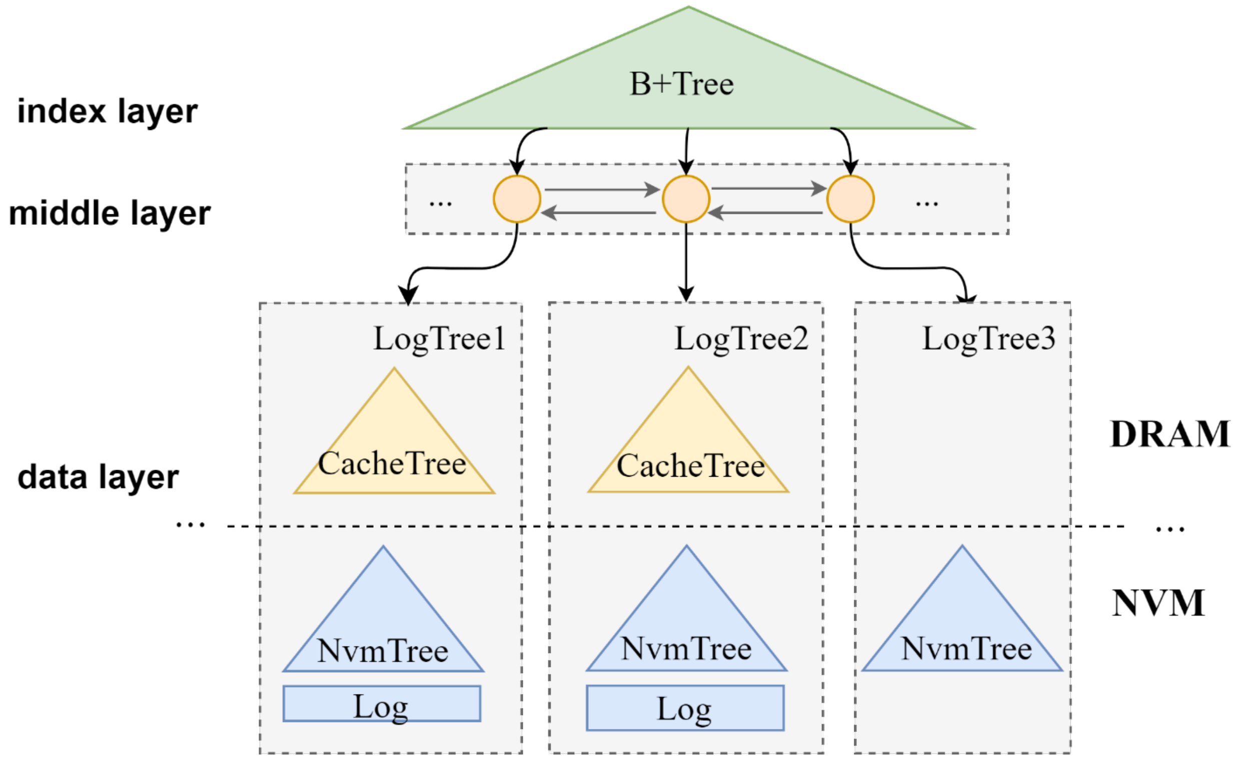
Hotspot Statistica Algorithm

➢ HBTree: a hybrid three-layer persistent index

- Index layer
- **Middle layer**
  - Stores LogTree metadata
  - Identify hot NVMTree

    $$T_{(t+\Delta t)} = A * T_t + Operate_{\Delta t}$$

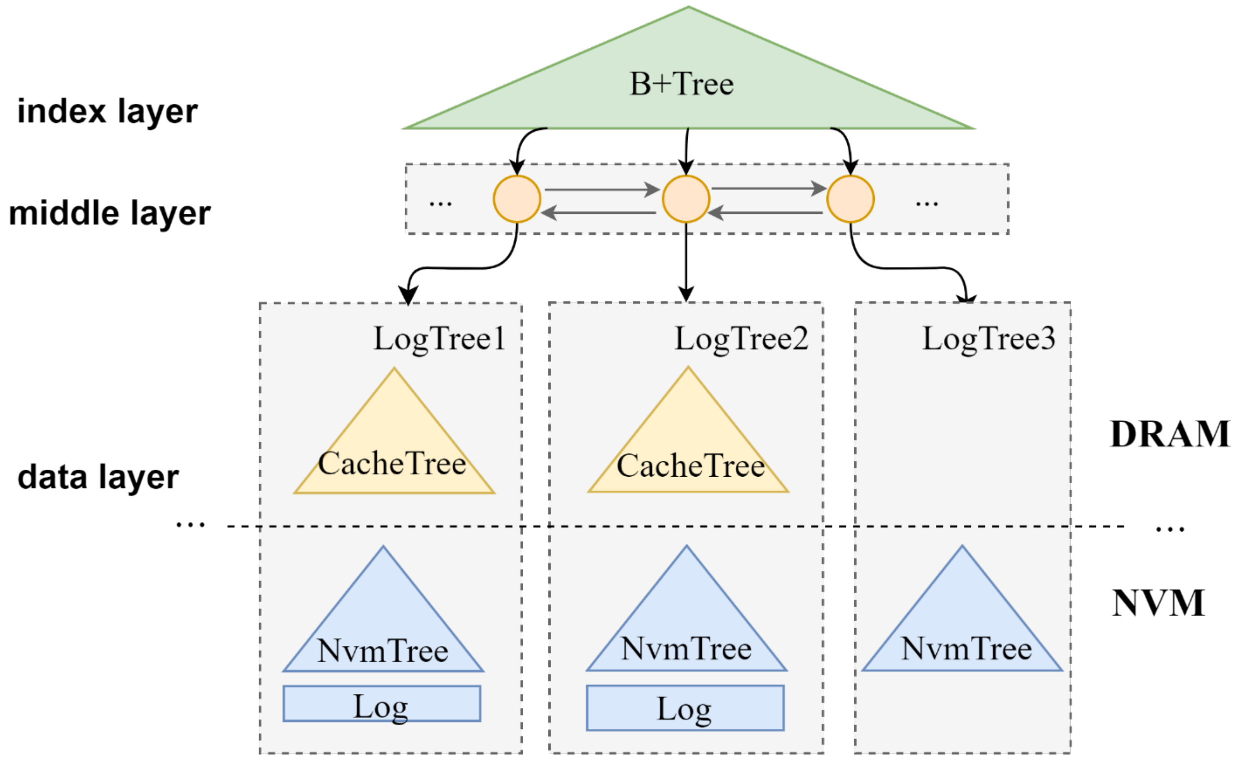
    A default 0.5
  - backup to NVM
- Data layer



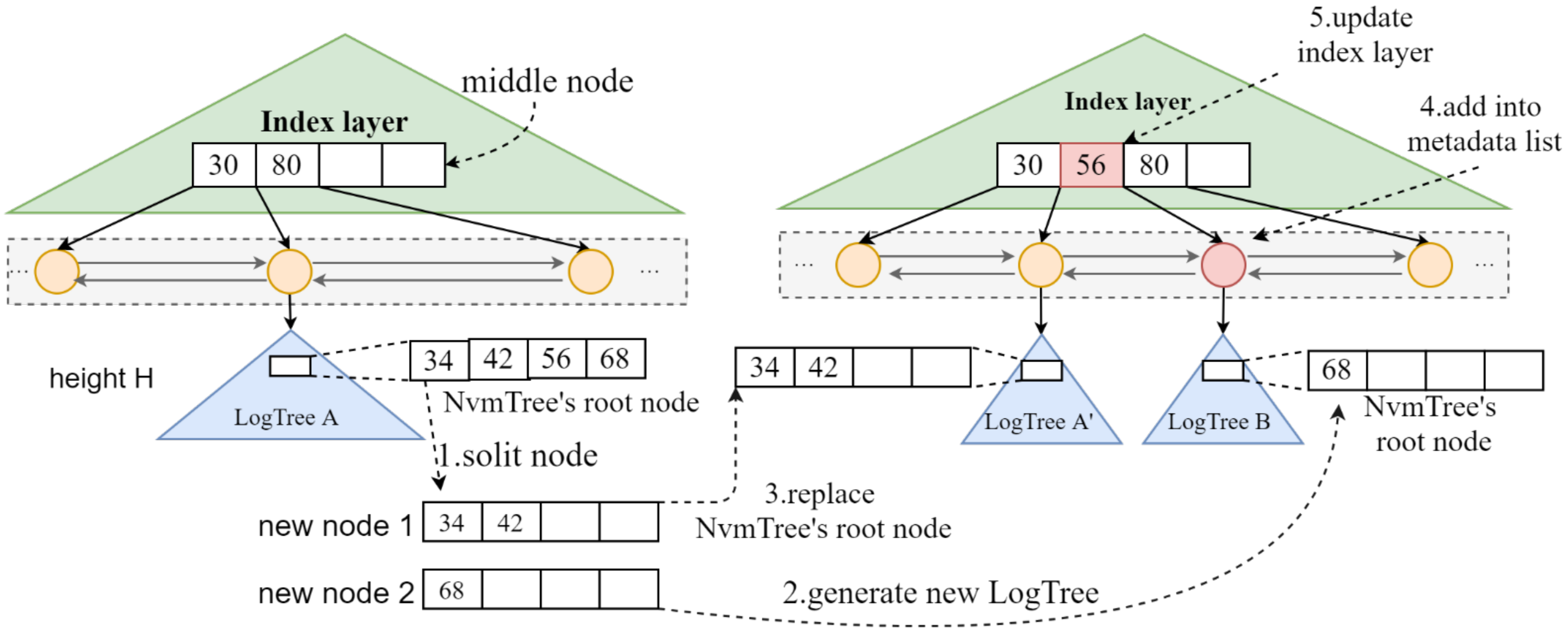
LogTrees

➢ HBTree: a hybrid three-layer persistent index

- Index layer
- Middle layer
- **Data layer**
  - Data persistence
  - Fast recovery
  - Highspeed access
  - Consistency



Dynamic Extension



CacheTree Management

- CacheTree Create
  - Copy NVMTree to DRAM to generate CacheTree
    - Write operation is recorded in a log
    - The read request first looks for the log and then the NVMTree
  - Log be played back to CacheTree
- CacheTree Syschronization
  - Only data marked dirty is synchronized
  - Old log is replaced by new log
- CacheTree Recycle
  - Read paused and update dirty data to NVMTree
  - Release CacheTree nodes and log record to replay
  - NVMTree work and delete log

Consistency

- Copy-on-write
  - NVMTree: over 8B write
  - CacheTree Syschronization and CacheTree Recycle

- The log is exploited to ensure consistency

Recovery

- Middle layer Recovery
  - traversing the persistent metadata node linked list in NVM
  - The NVMTree in the split continues
- LogTree Recovery
  - Playback logs ensure the integrity of the NVMTree
  - Create CacheTree based on middle layer hot data information
  - Playback logs to recovery CacheTree
- The index layer be recreated directly through the middle layer

- NOTE:
  - CacheTree recovery within different LogTrees can be performed concurrently

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Evaluation

Evaluation methodology

- Platform:
  - CPU: two 24-core Intel Xeon Gold 5218R CPUs(2.3GHz)
  - DRAM: DDR4 64GB
  - OS： linux (kernel version 5.10.1)
  - NVM: Intel Optane DC Persistent Memory 128G * 2
- Workloads
  - YCSB： 8B key, 8B value

    Load: 200 million, others: 10 million
- Compared systems：
  - FPTree
  - FAST&FIRE

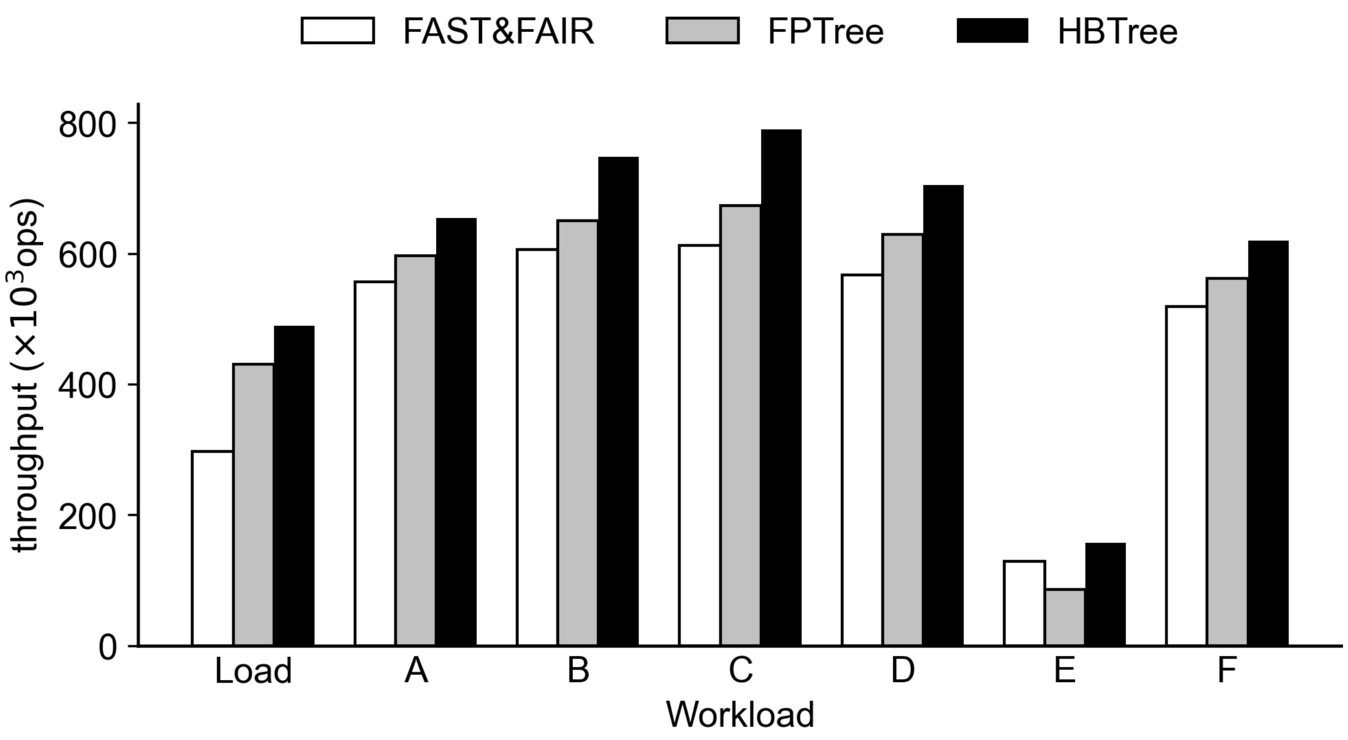
Worklaods	Requestdistribution	Op
Load	Uniform	100% Put
A	Zipfian	50%Get，50%Update
B	Zipfian	95%Get，5%Update
C	Zipfian	100%Get
D	Latest	95%Get，5%Put
E	Zipfain/Uniform	95%Scan，5%Put
F	Zipfian	50%Put，50%RMW

Operation Efficiency

B+Tree node is 512B

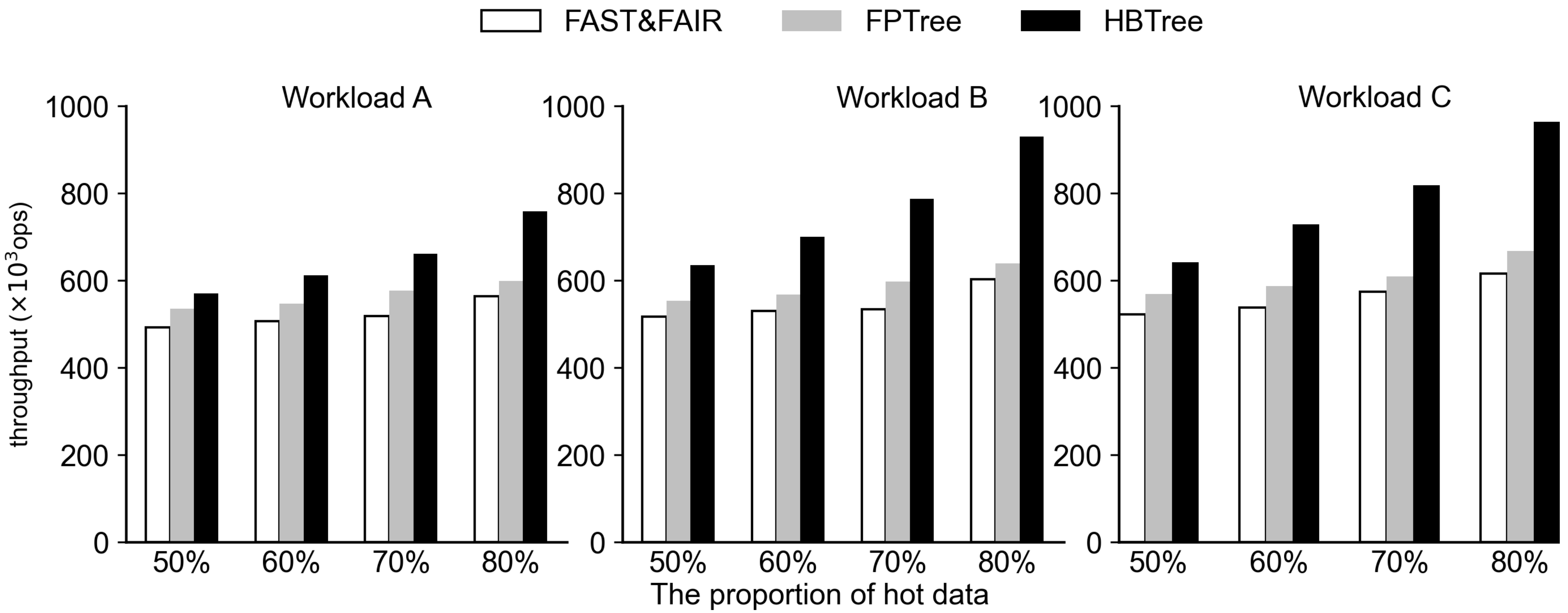
DRAM cache size is 500MB

- Load
  - Better than FAST&FAIR
- write more (A、F)
  - improvement small
- Read more (B、C、D or E)
  - Better



Throughput on the YCSB workloads

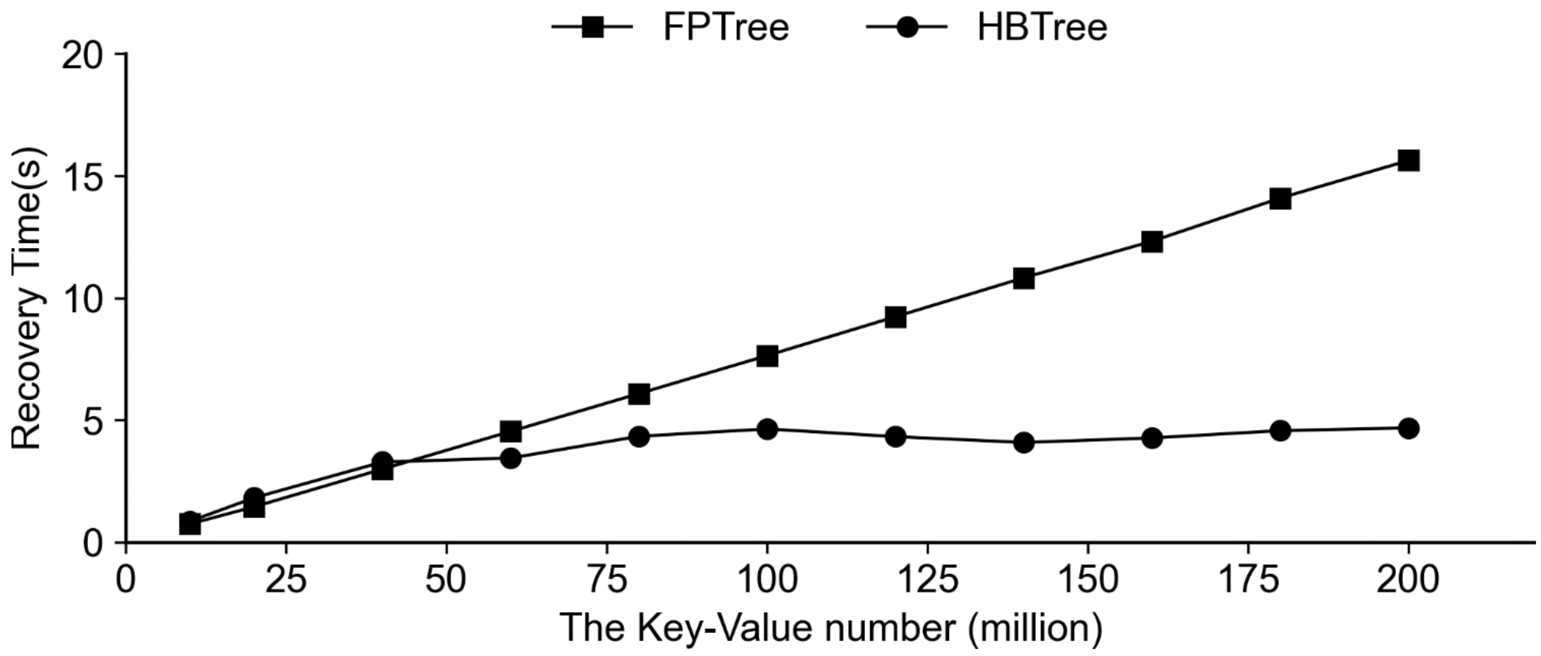
Performance with Hotness Data



Throughput under different data hotspots

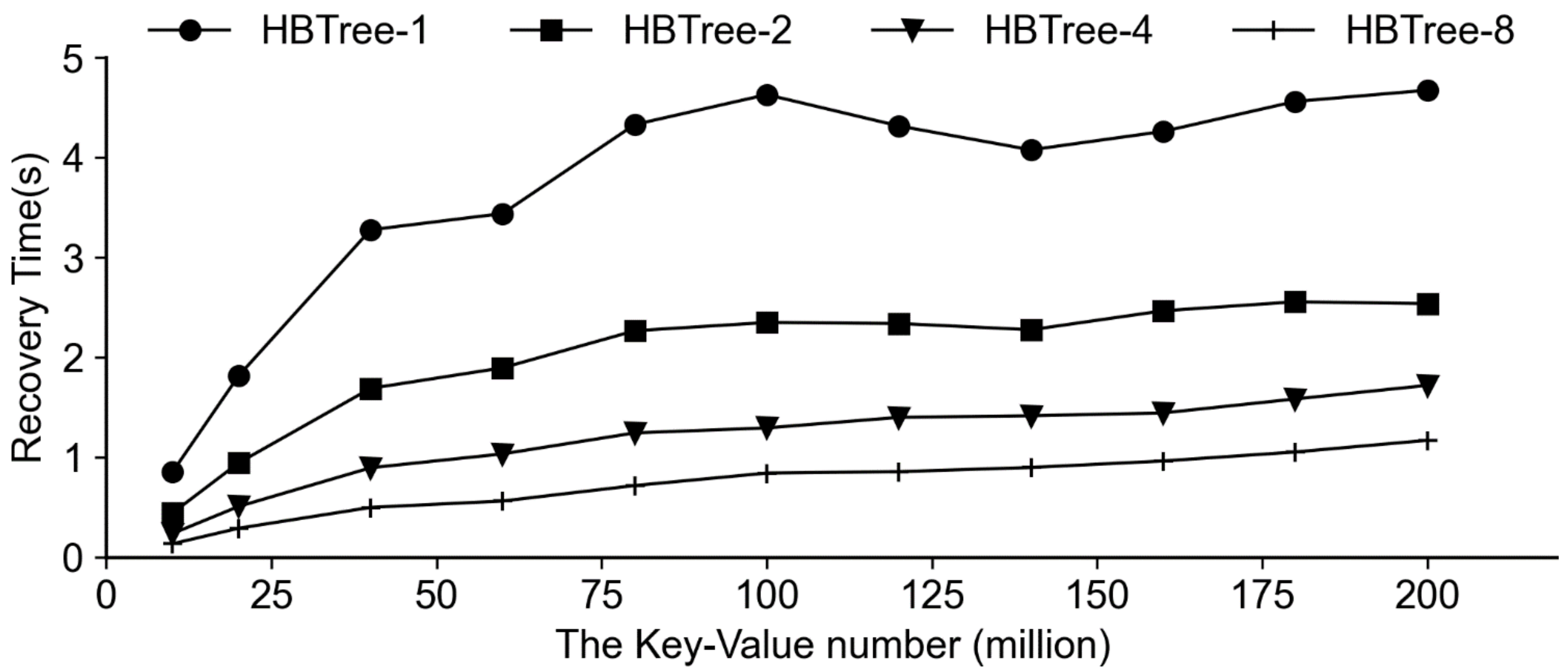
Recovry Time

- When the data volume is small
  - HBTree is closer to FPTree
- With the increasing data
  - HBTree remains level
  - FPTree is still increasing
- 30%



Recovery time for HBTree and FPTree in various data volumes

Recovry Time



Recovery time for different threads of HBTree

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Thanks listening

Yuanhui Zhou zhouyuanhui@hust.edu.cn

Taotao Sheng

Jiguang Wan* jgwan@hust.edu.cn