IndeXY: A Framework for Constructing Indexes Larger than Memory

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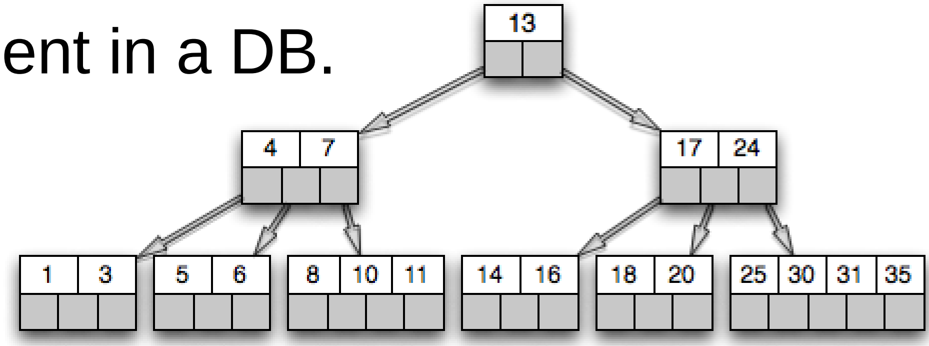
Insufficient Memory for Large Indexes

- Indexes are one of the most performance-critical component in a DB.



- Keep them all in the memory?
  - Usually too large:
    - For example, about 55% of the memory is occupied by the indexes in H-Store.
  - Often not necessary:
    - Not all parts of an index are accessed at a time.

- An apparent solution:
  - Use the disk as the memory extension
  - A large index spans memory and disk

State-of-the-art Practices - A Co-design approach

- In-memory databases:
  - migrate a selected subset of tuples out of the memory
    - E.g., Siberia and Anti-Caching.
  - migrate only subset of tuples, instead of index.
  - customized to database systems
    - E.g., respectively, Microsoft Hekaton and H-Store.

- On-disk databases:
  - cache the indexes in the memory
  - optimize the buffer cache management
    - For example, LeanStore uses pointer swizzling
  - use the common paged index structure for memory and disk
    - Not customized to the devices' different characterizations.

IndeXY: a Framework for Extensible Indexes

- Support integration of in-memory index (Index X) and on-disk index (Index Y).
  - Each can be independently selected
  - Each was designed for its target device.

- Provide a virtual-memory-like infrastructure at the key-value granularity.
  - The index becomes 'swappable'
  - Automate the process of maintaining a designated index memory limit by selecting keys for unloading to the disk.

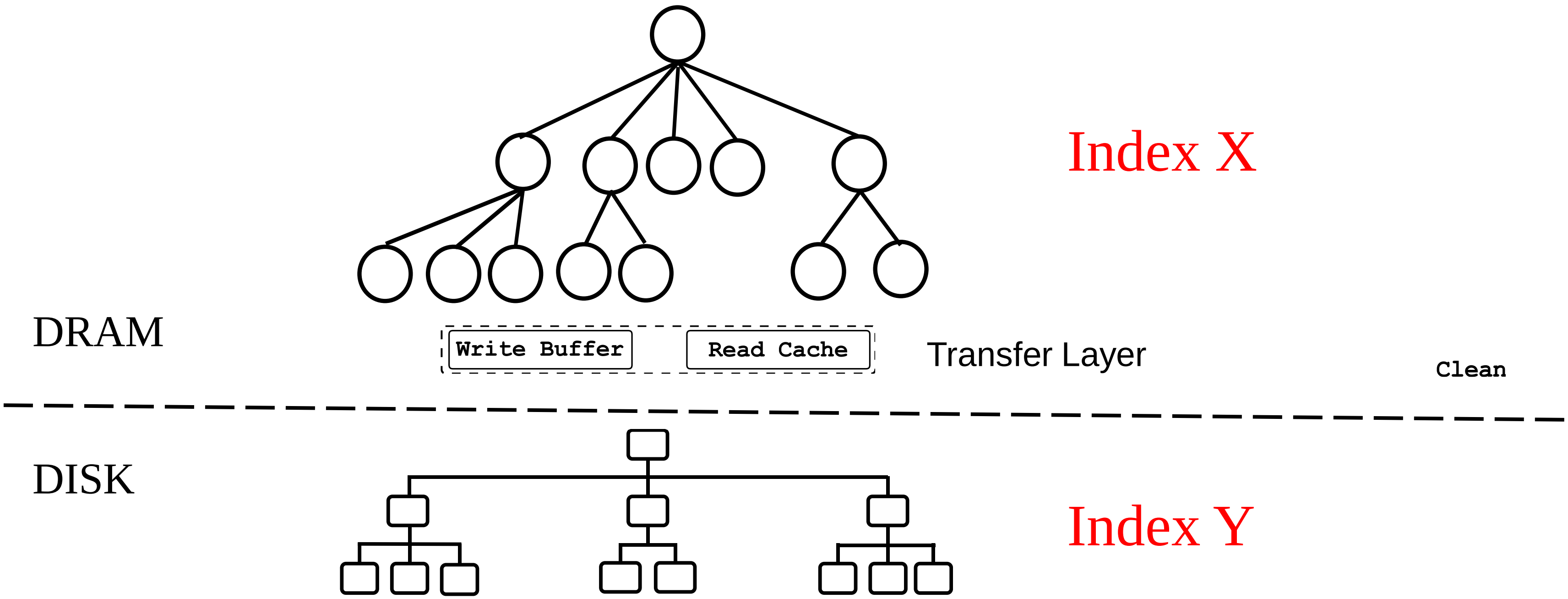
The Design Challenges

- How to minimize the changes to the existing Indexes X and Y?
  - No structural change to their data structures.
  - No logic change to the access algorithms.

- How to efficiently track access hotness?
  - Access unit is small (individual keys).
  - Both time and space overhead needs to be considered.

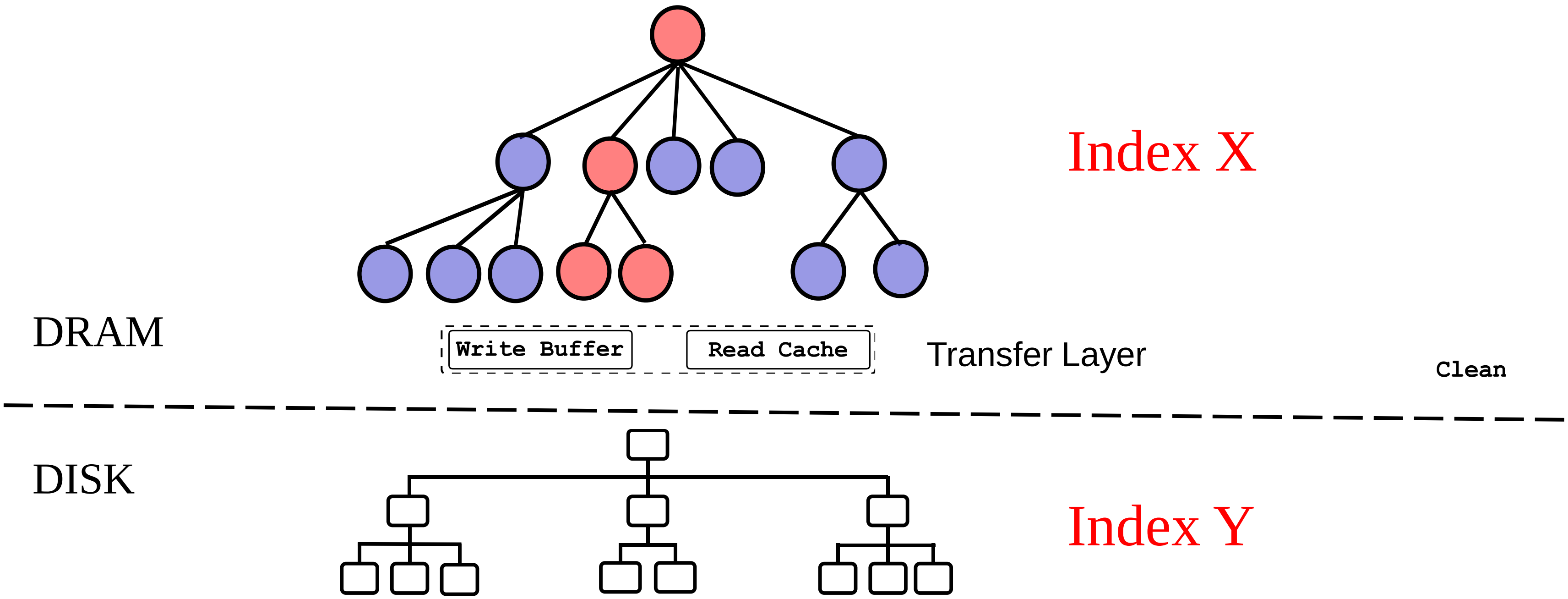
- How to generate high-performance write requests to Index Y?
  - Sequential writes are friendly to disk performance.
  - Both temporal and spatial locality needs to be considered.

The Big Picture



The framework’s major features are integrated into Index X.

The Big Picture



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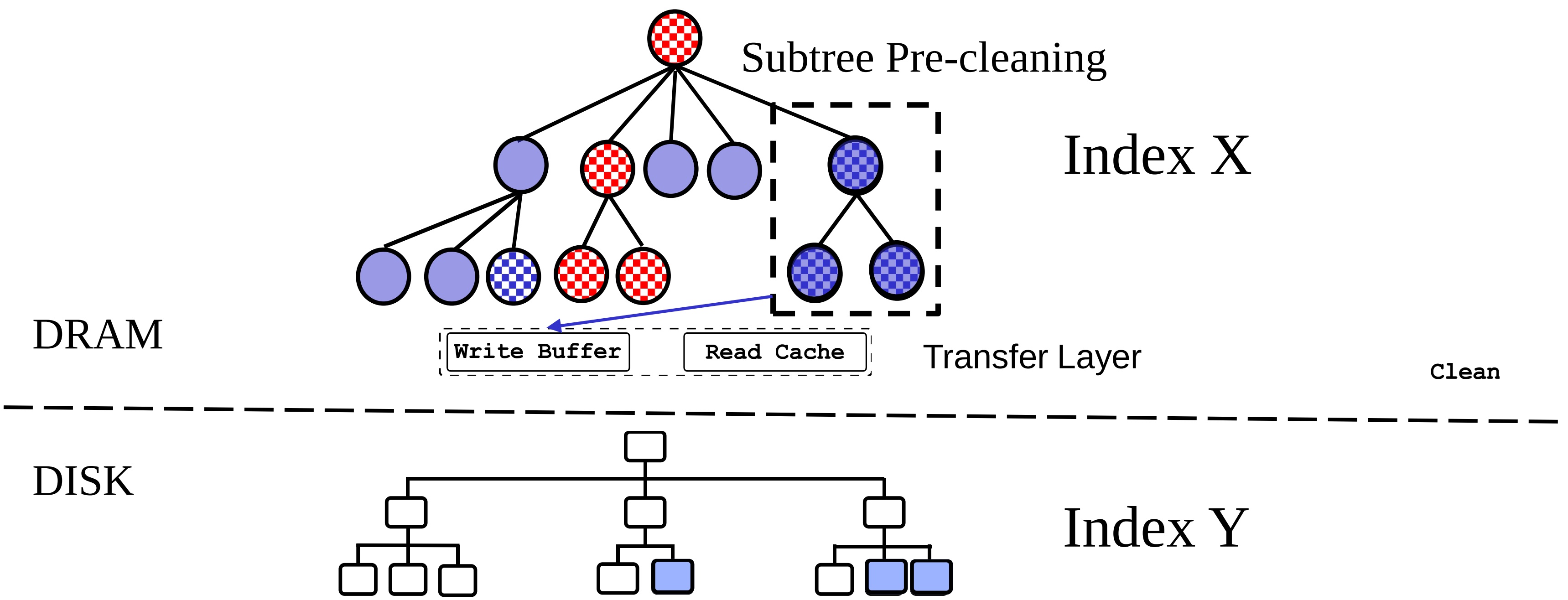
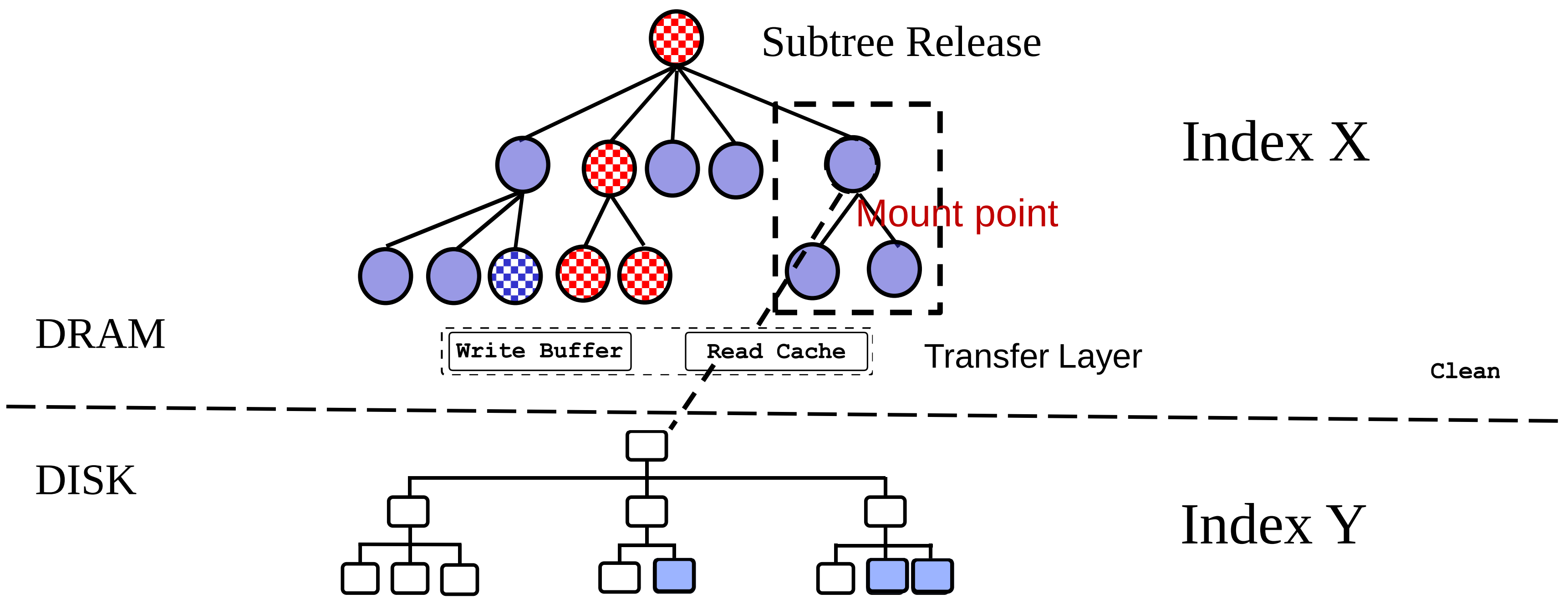


Not actively dirty sub-trees will be cleaned.

- a background pre-cleaning process
- prepare for later quick space reclamation.

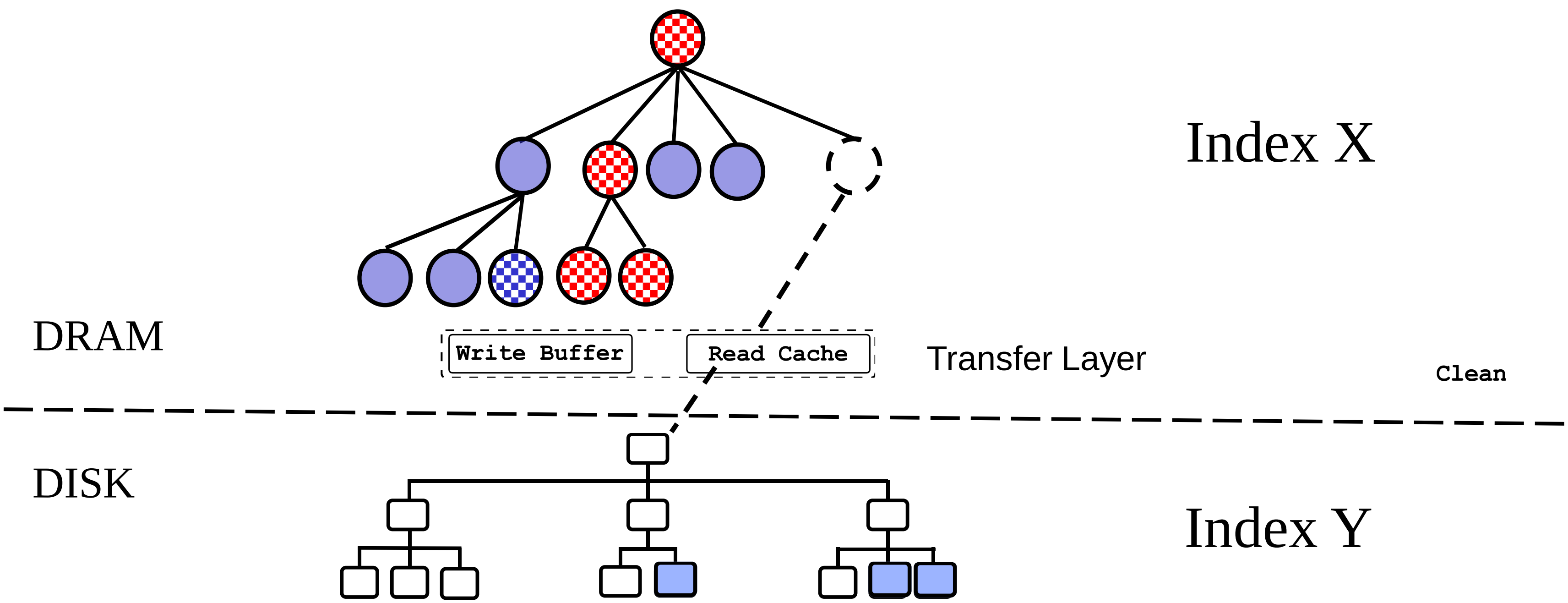
The Big Picture



Large and cold subtrees will be selected for release.

- space reclamation to keep the index size below its memory limit.

The Big Picture

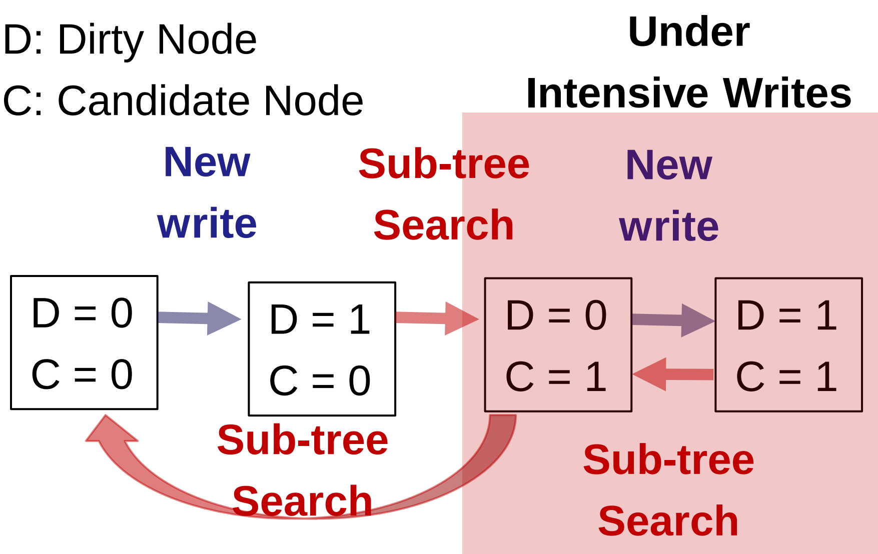


- New writes to Index X also go to a write-ahead-log for recovery.
- A thin transfer layer between Indexes X and Y is set up.
  - A write buffer to form sequences of disk writes
  - A read cache to act as a small block cache.

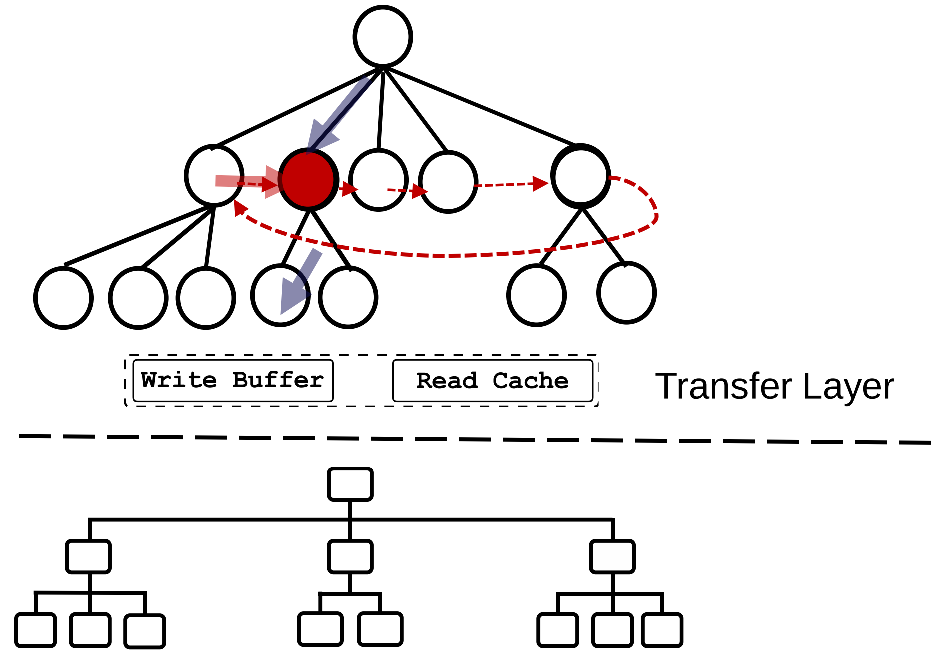
Pre-cleaning Sub-trees

D: Dirty Node

C: Candidate Node

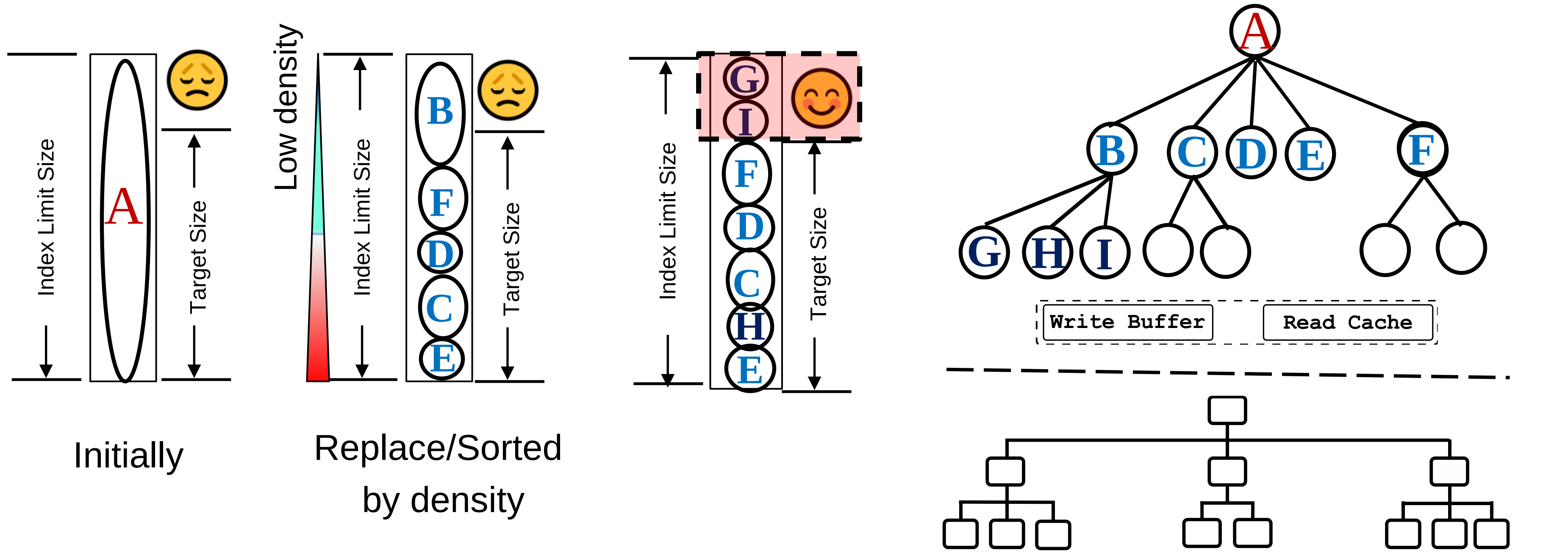


The subtree found!



- Search for a sub-tree for pre-cleaning on a linked list of inner nodes
- Use a two-bit algorithm to detect subtrees that:
  - have been written before
  - currently not under intensive writes.

Sub-tree Release



- When Index X size approaches its limit, memory release thread is triggered.
- Access density of a **subtree** = # of accesses / the subtree size
- Efficiently track the density (see the paper)
- Density-based subtree ranking algorithm to find a subtree for release:
  - The subtree is not frequently accessed; and
  - The subtree is large.

Performance Evaluation

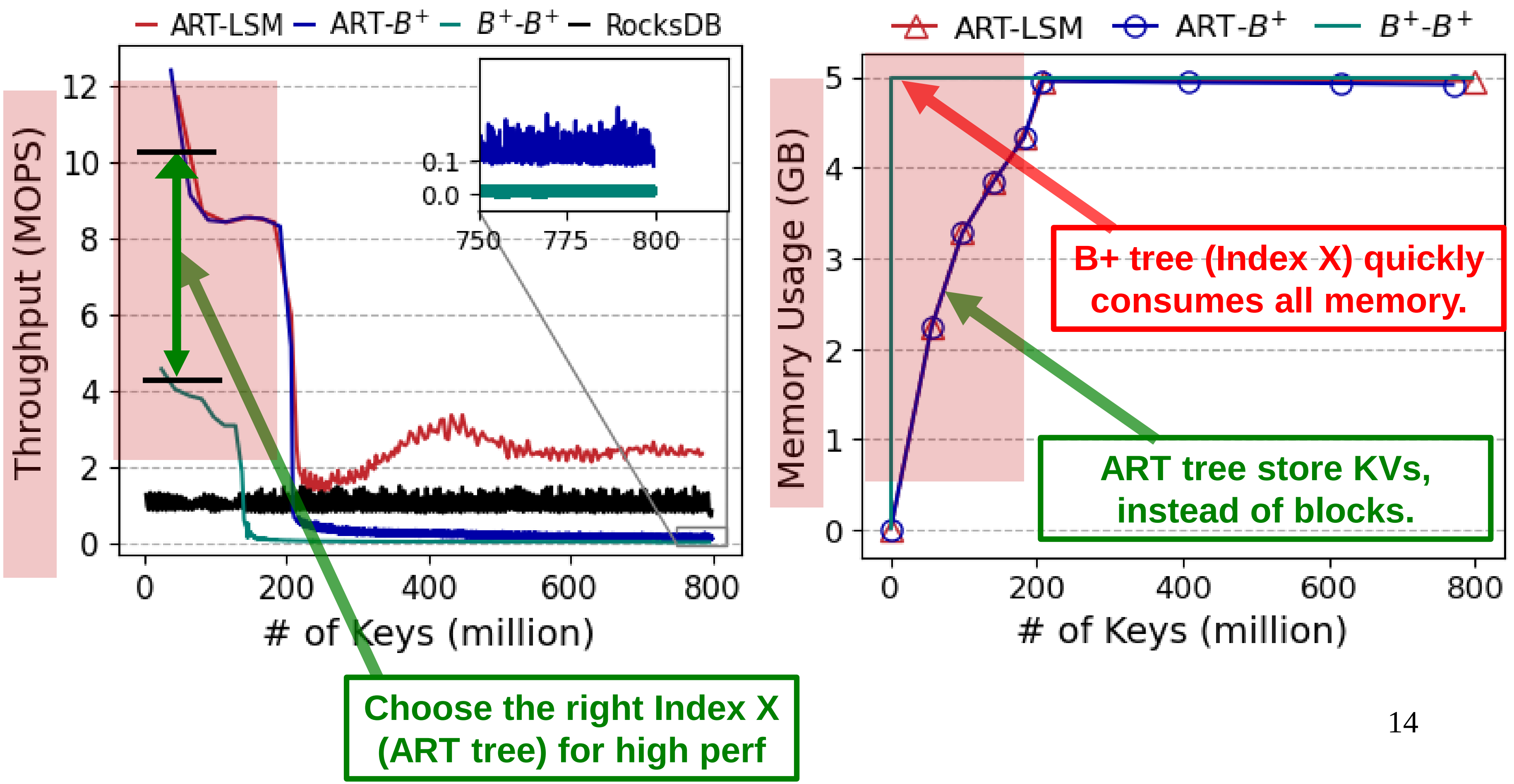
- The workloads
  - Micro-benchmarks
  - YCSB
  - TPC-C
- Experiment setup
  - Intel Xeon Platinum 8255C CPU processors
  - 128 GB DRAM, 512 GB SAMSUNG MZ7LH480 SSD
- The system

Systems	Index X	Index Y
B+ – B+	B+ Index	B+ Index
ART – B+	ART Index	B+ Index
ART – LSM	ART Index	LSM-tree Index
RocksDB	RocksDB buffer	LSM-tree Index

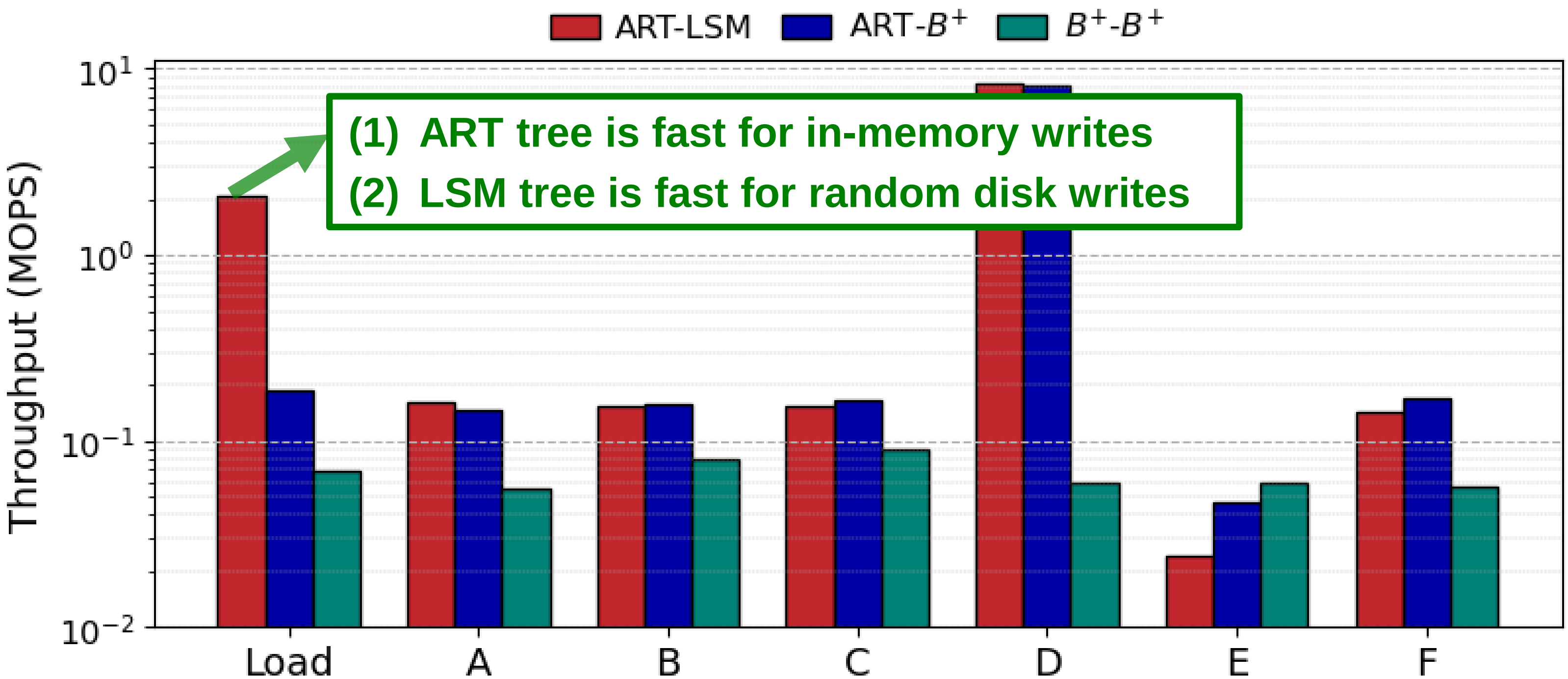
* Use LeanStore as a representative of B+ tree design

Write Performance (memory limit = 5GB)

Insert 800 million unique random key-value 16B pairs (12GB working set).



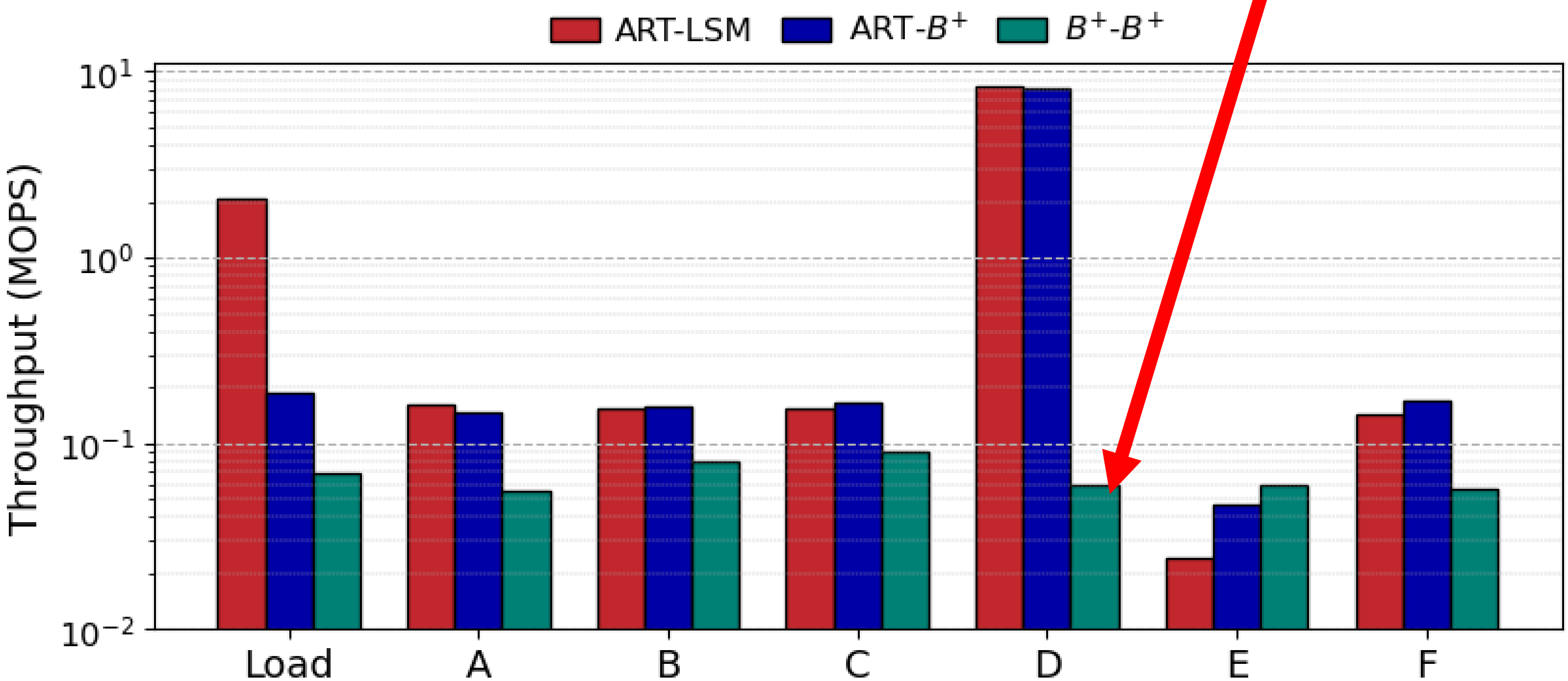
The YCSB Benchmark (memory limit = 30 GB)



Workloads	Description
Load	100% Random write
A	50% Read, 50% Update
B	95% Read, 5% Update
C	100% Read
D	95% Read Latest, 5% Update
E	95% Scan (average scan length 50, maximum 100), 5% Update
F	50% Read-Modify-Write, 50% Read

The YCSB Benchmark (memory limit = 30 GB)

B+-B+ doesn't use right index for each index



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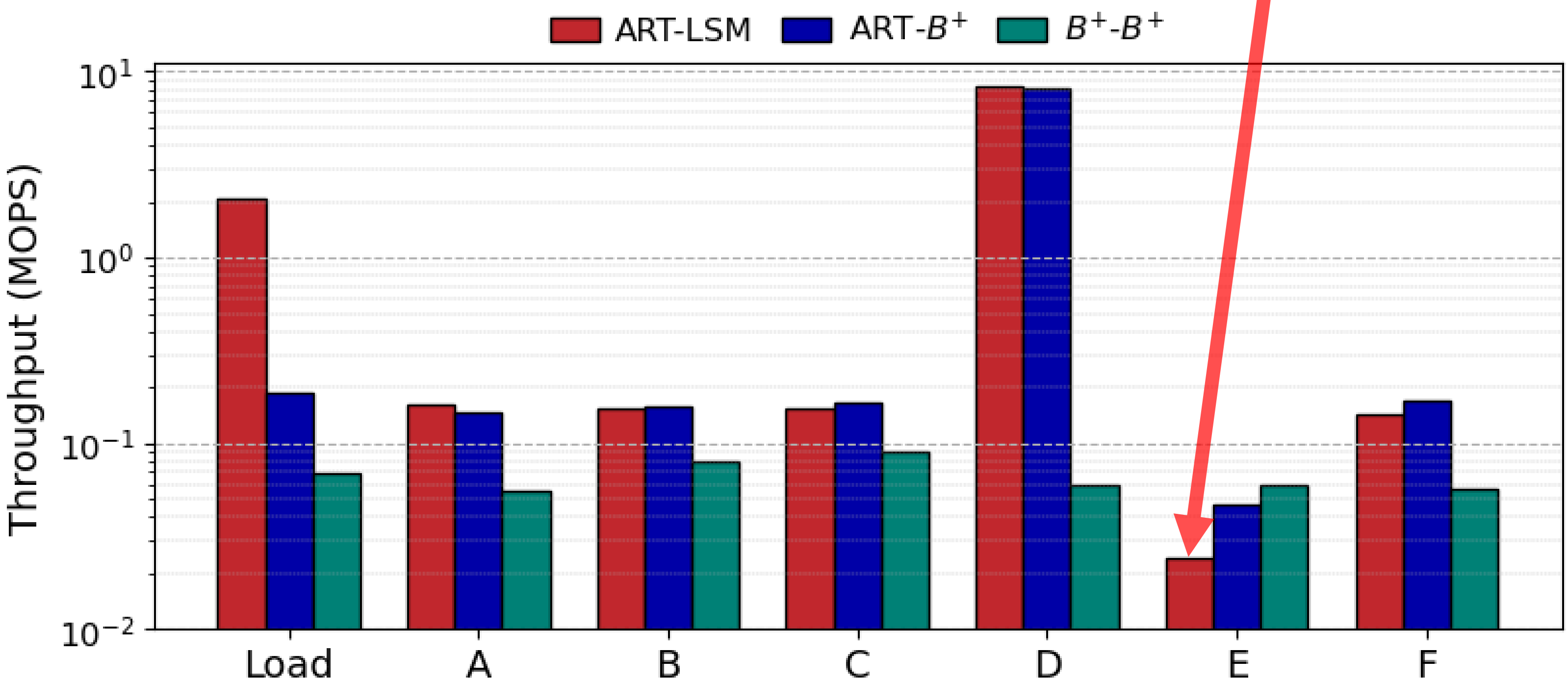
The YCSB Benchmark (memory limit = 30 GB)

LSM tree is not a right choice of Index Y for scans



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A Summary

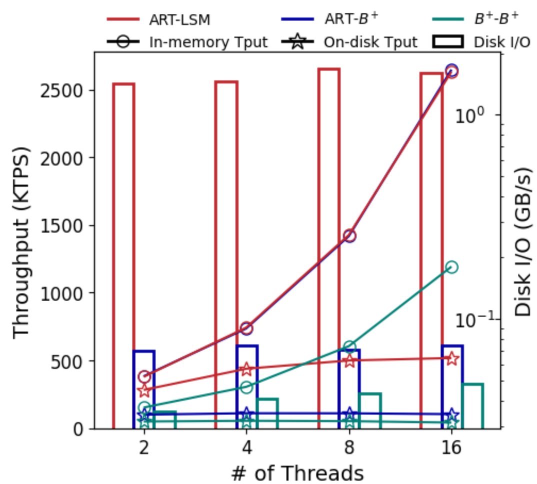
- IndeXY is a framework for a decoupled deployment of indexes in the memory and on the disk.
- IndeXY provides highly efficient supports for migrating index subsets between memory and disk.
- With the ease of selection and integration of two indexes, IndeXY makes quick development of high-performance extensible indexes possible.

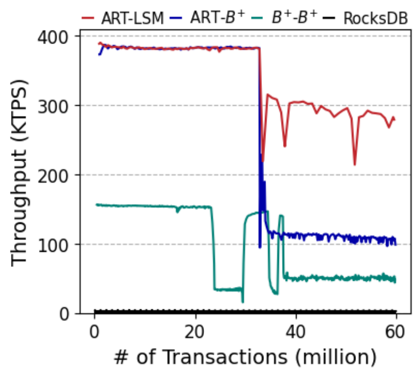
Backup Slides

TPC-C benchmark

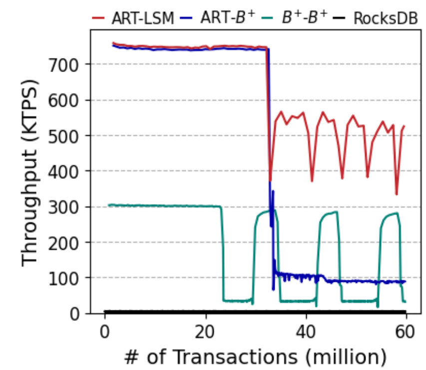
100 warehouse (~ 10GB)

New Order and Payment transactions are enabled (90%)

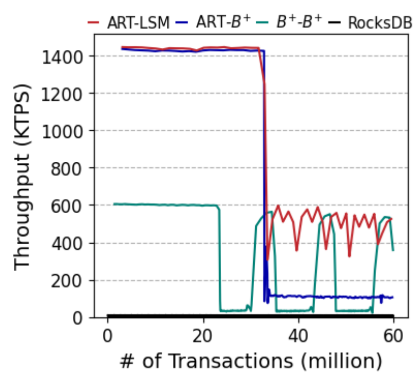




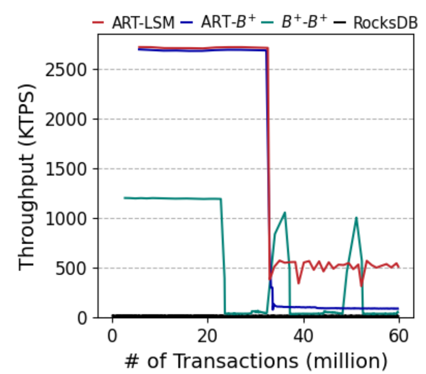
2 thread



4 thread

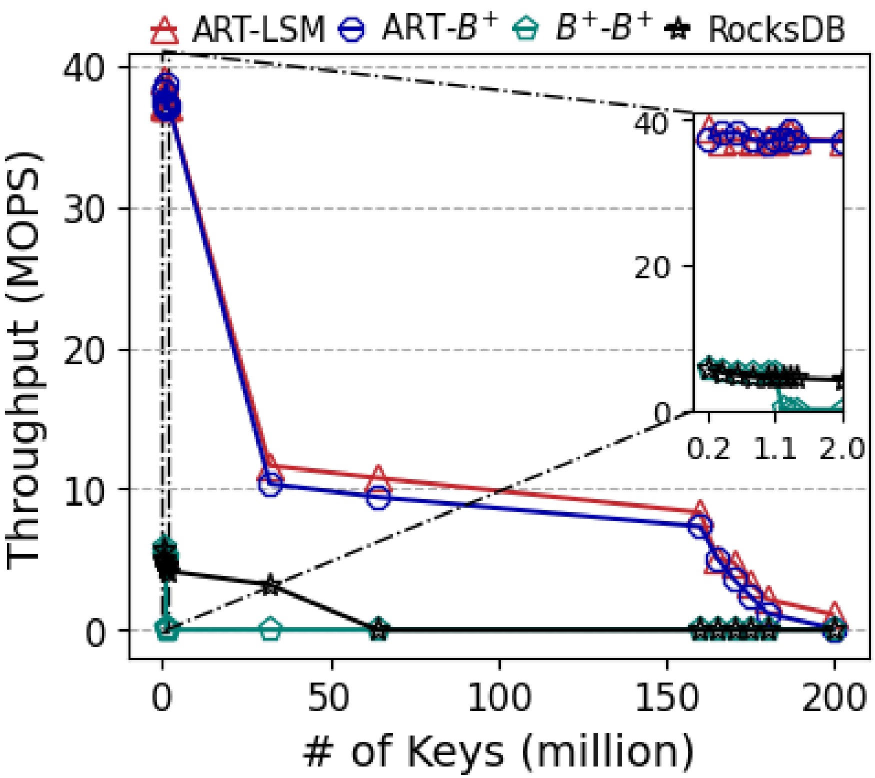


8 thread

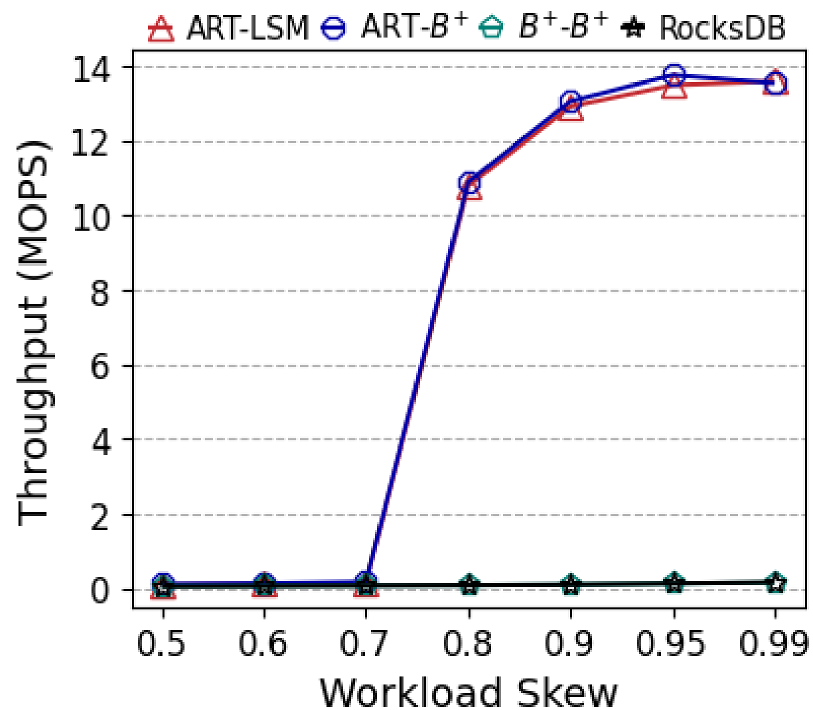


16 thread

Read Performance (Micro-benchmark)



Read throughput with
different working set sizes



Read throughput with
Various Zipfian distributions

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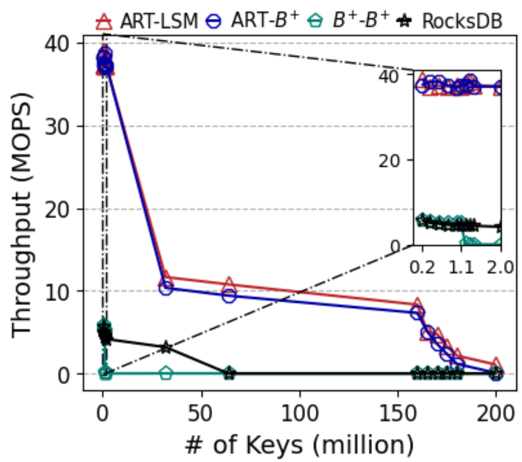

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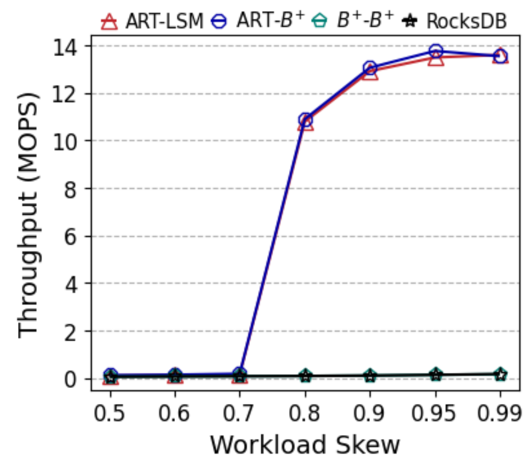

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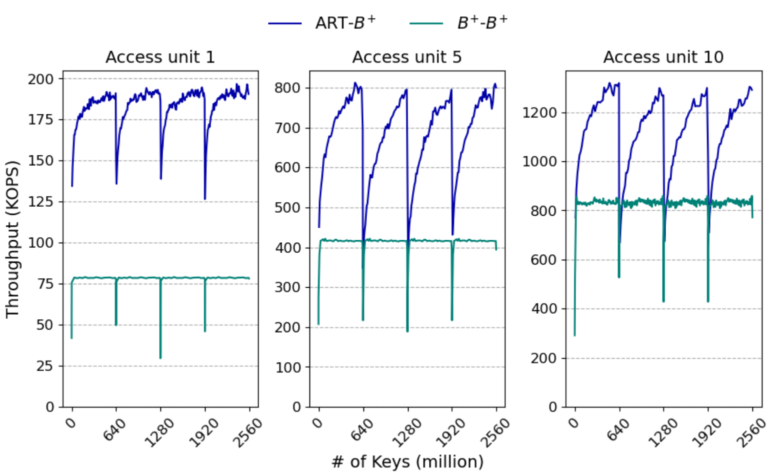

Lookup performance with shifting workload