WiscKey: Separating Keys from Values in SSD-Conscious Storage

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Key-Value Stores

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Key-value stores are important

- web indexing, e-commerce, social networks
- various key-value stores
  - hash table, b-tree
  - log-structured merge trees (LSM-trees)

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LSM-tree based key-value stores are popular

- optimize for write intensive workloads
- widely deployed
  - BigTable and LevelDB at Google
  - HBase, Cassandra and RocksDB at FaceBook

Why LSM-trees ?

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Good for hard drives

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- high sequential throughput
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- large write/read amplification
  - wastes device resources
- unique characteristics of SSDs
  - fast random reads
  - internal parallelism

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- ➡ decouple sorting and garbage collection

LSM-tree

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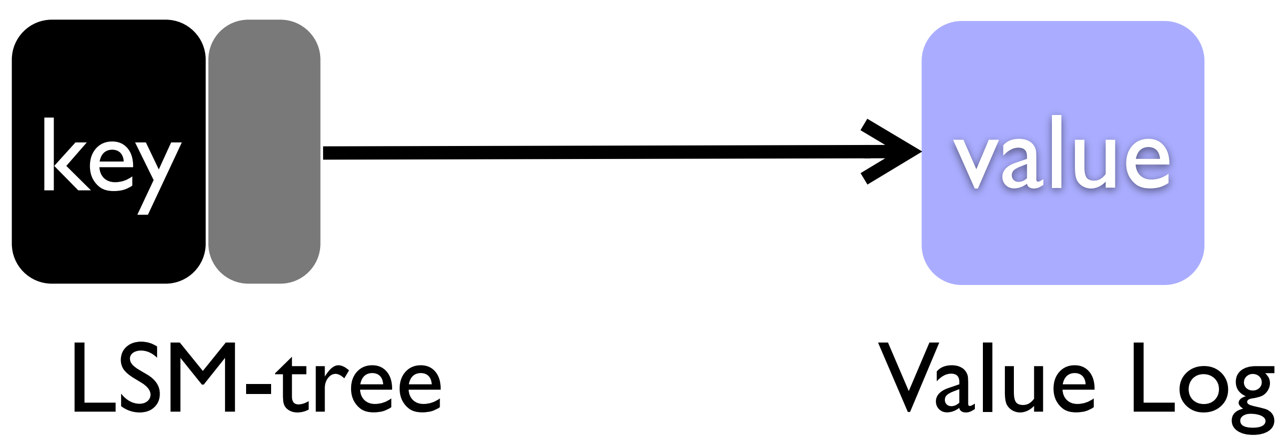

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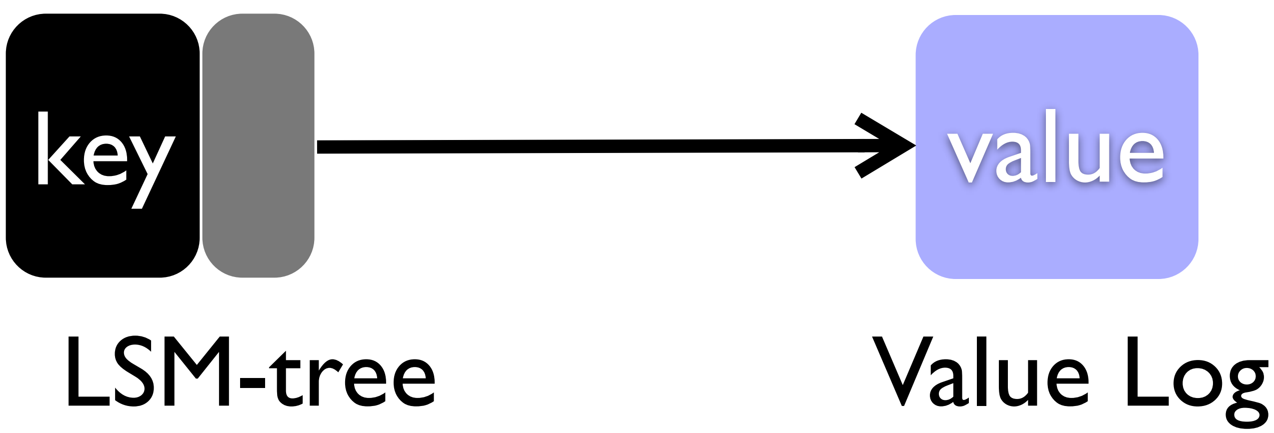

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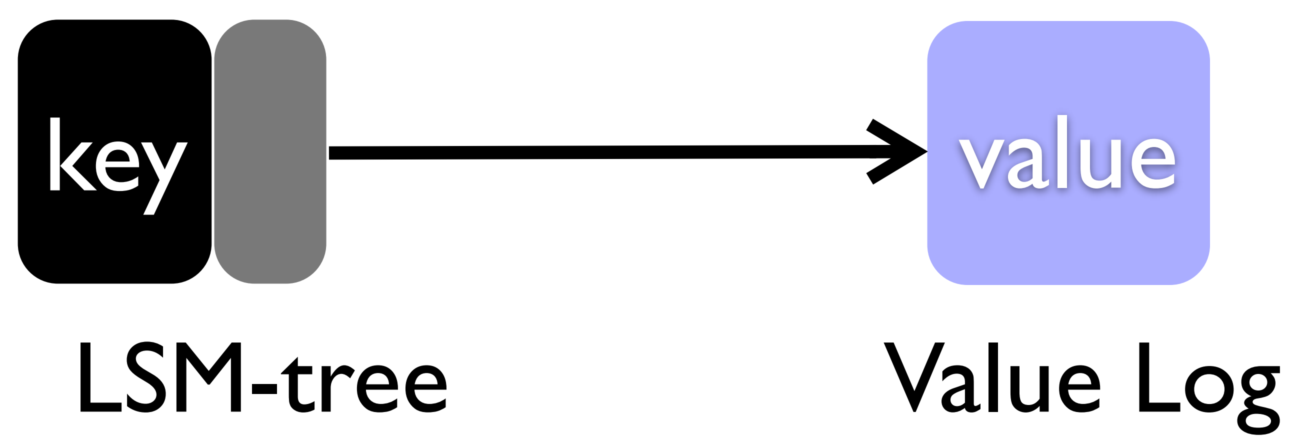

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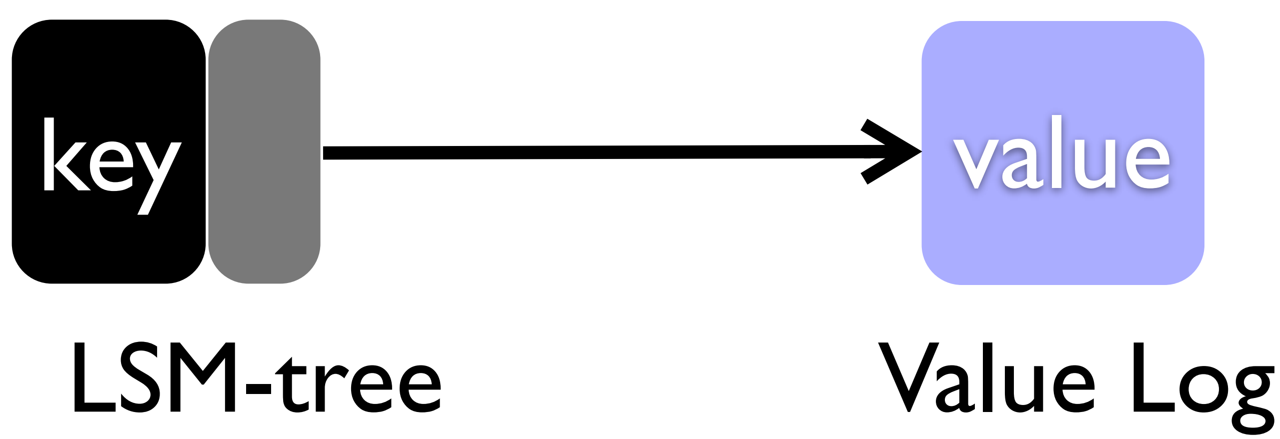

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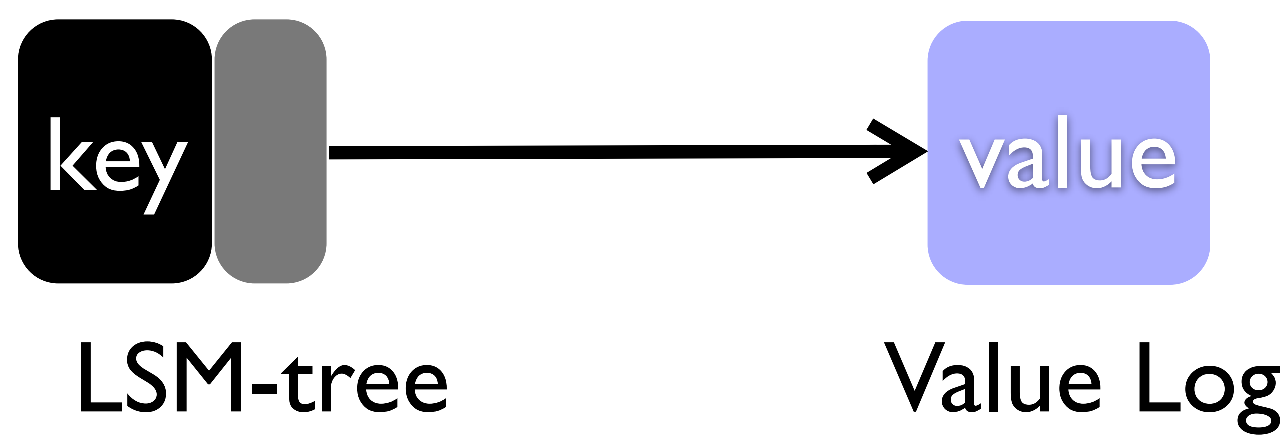


Performance of WiscKey

- 2.5x to 111x for loading, 1.6x to 14x for lookups

Background

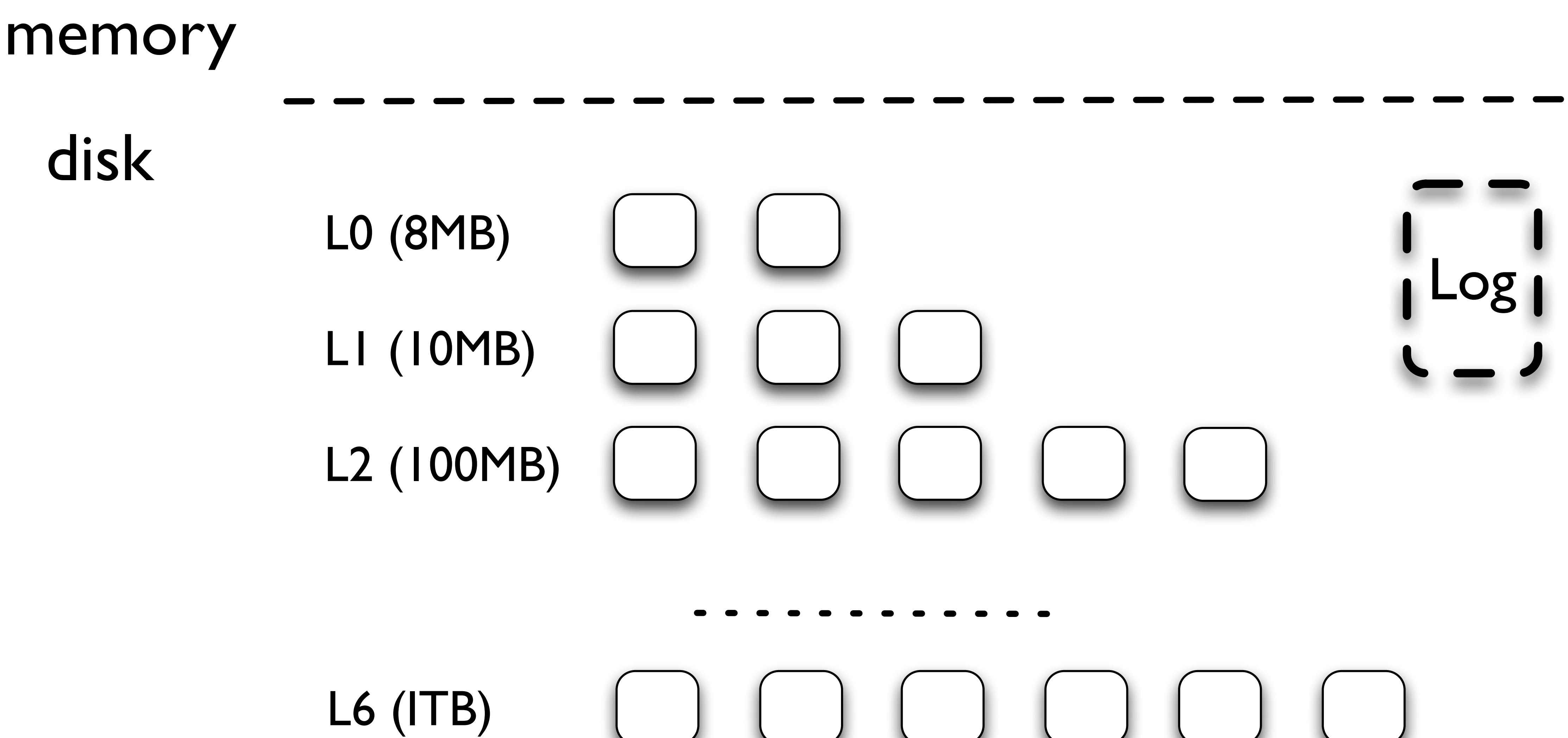
Key-Value Separation

Challenges and Optimizations

Evaluation

Conclusion

LSM-trees: Insertion



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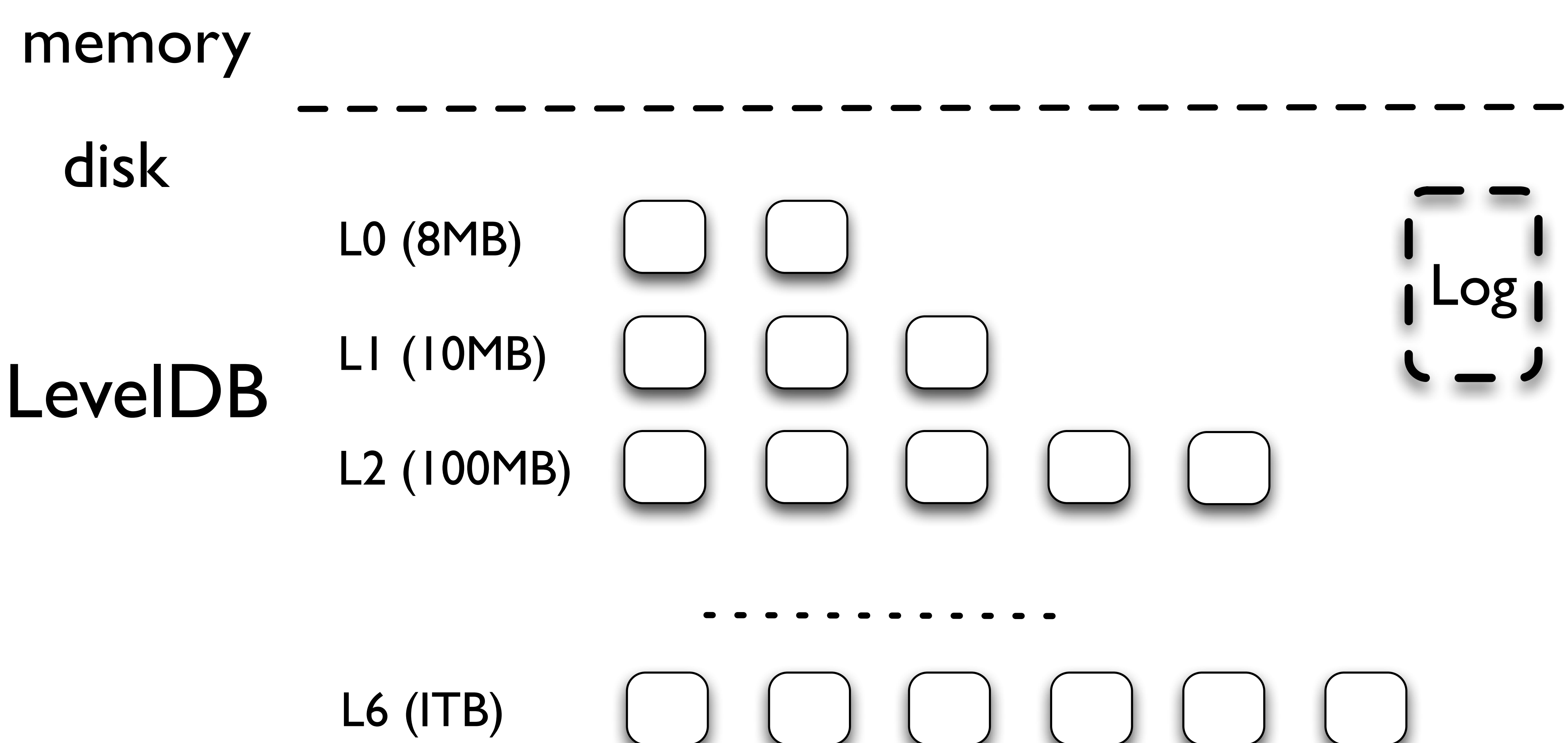

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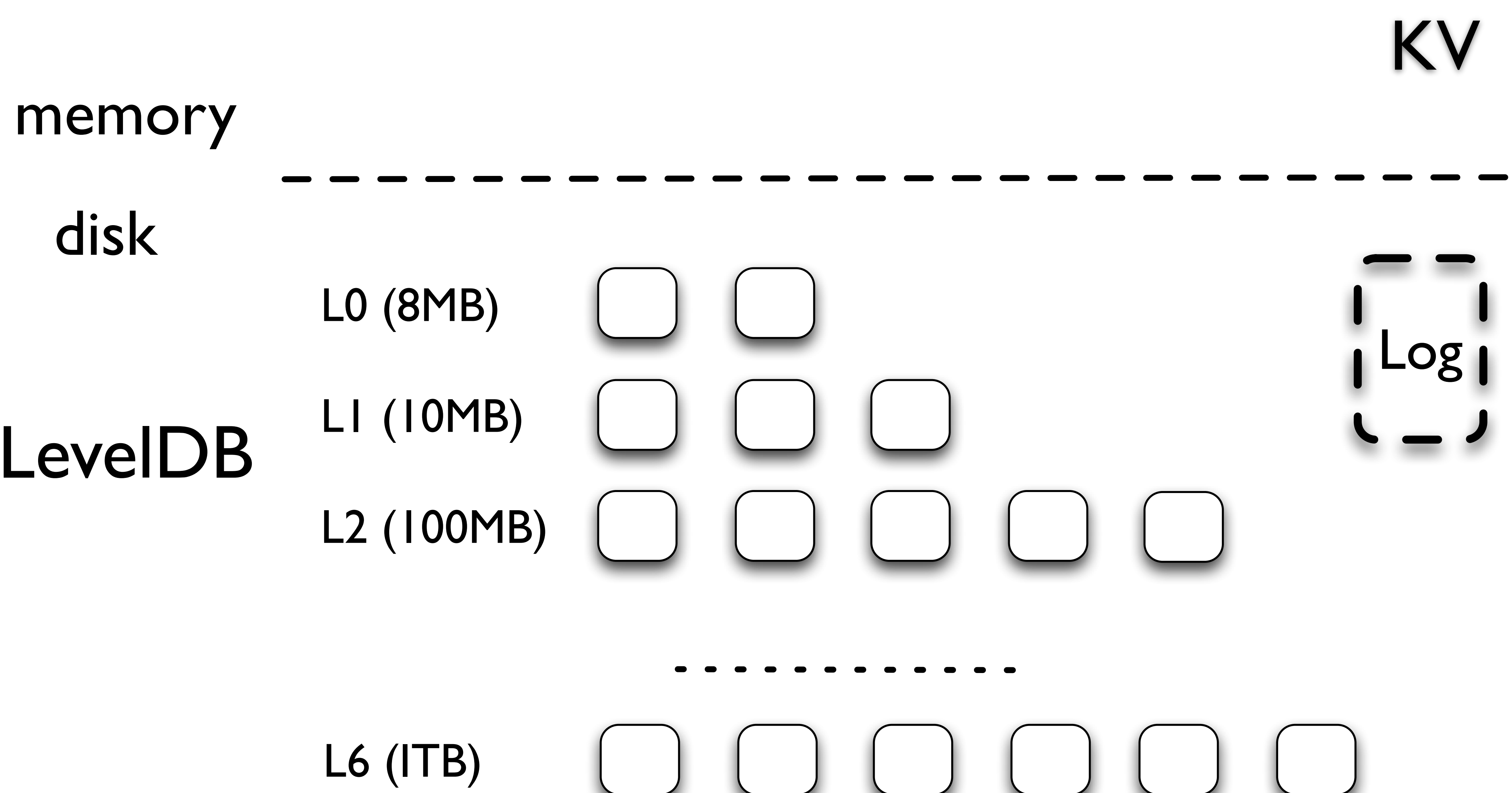

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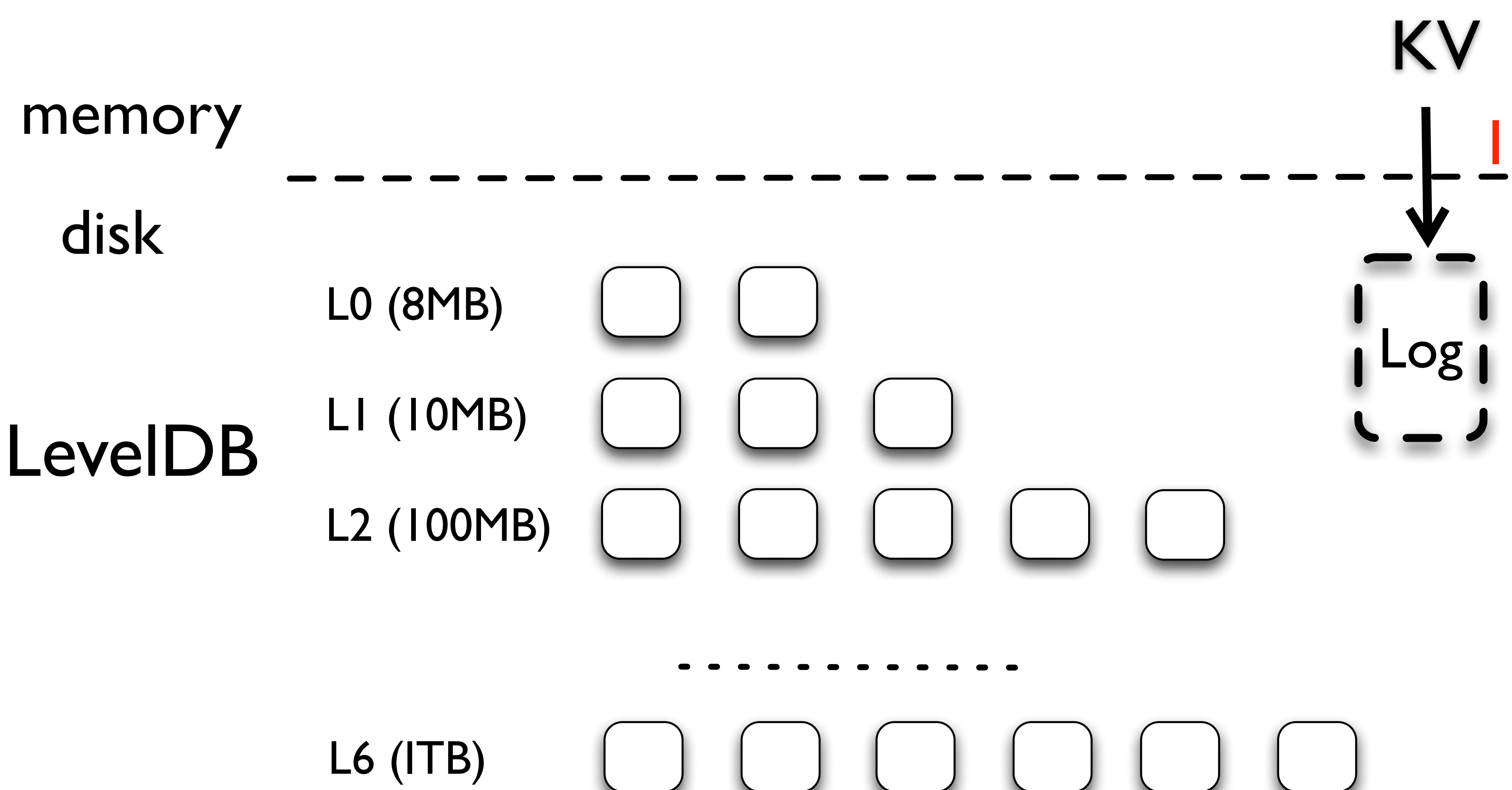

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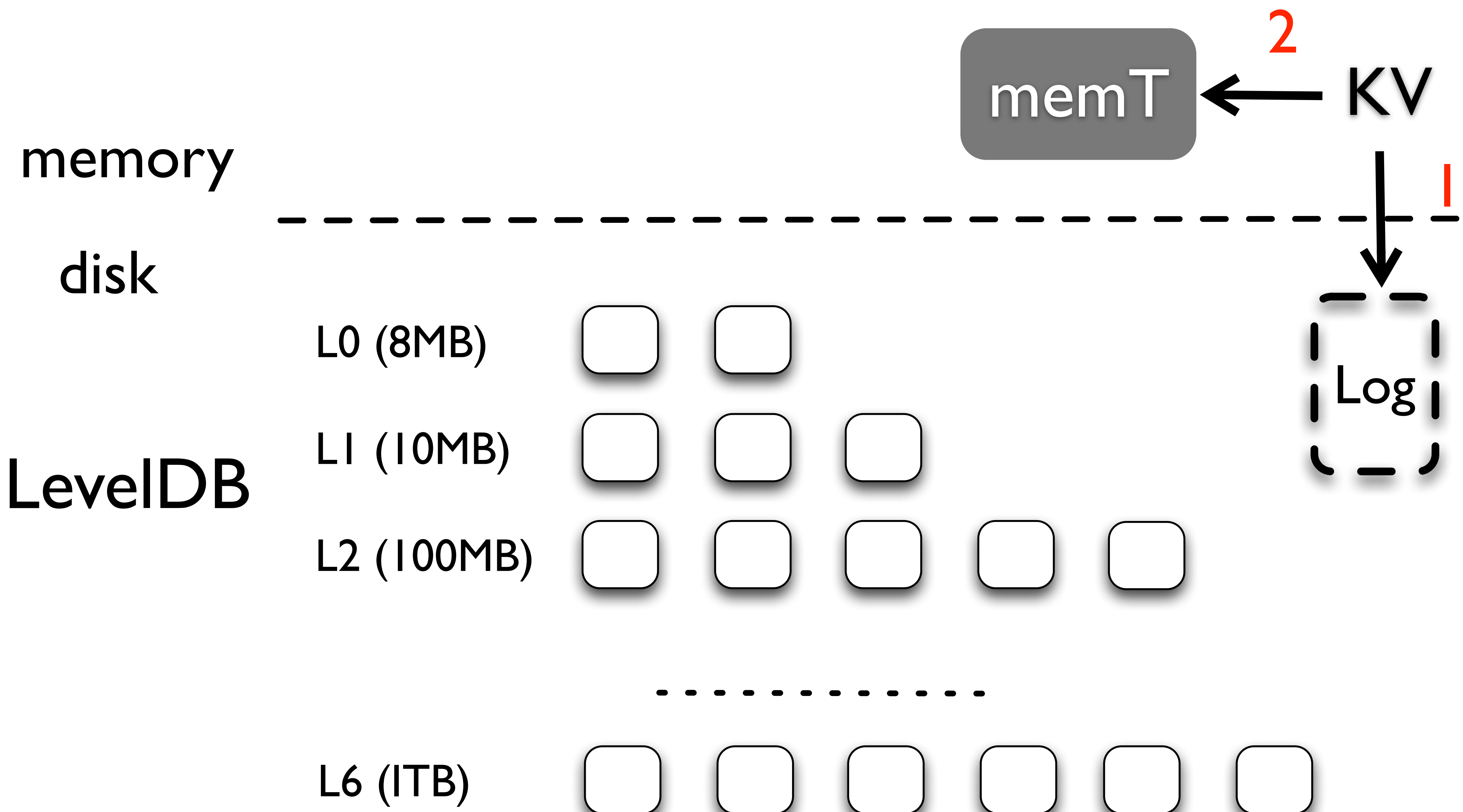

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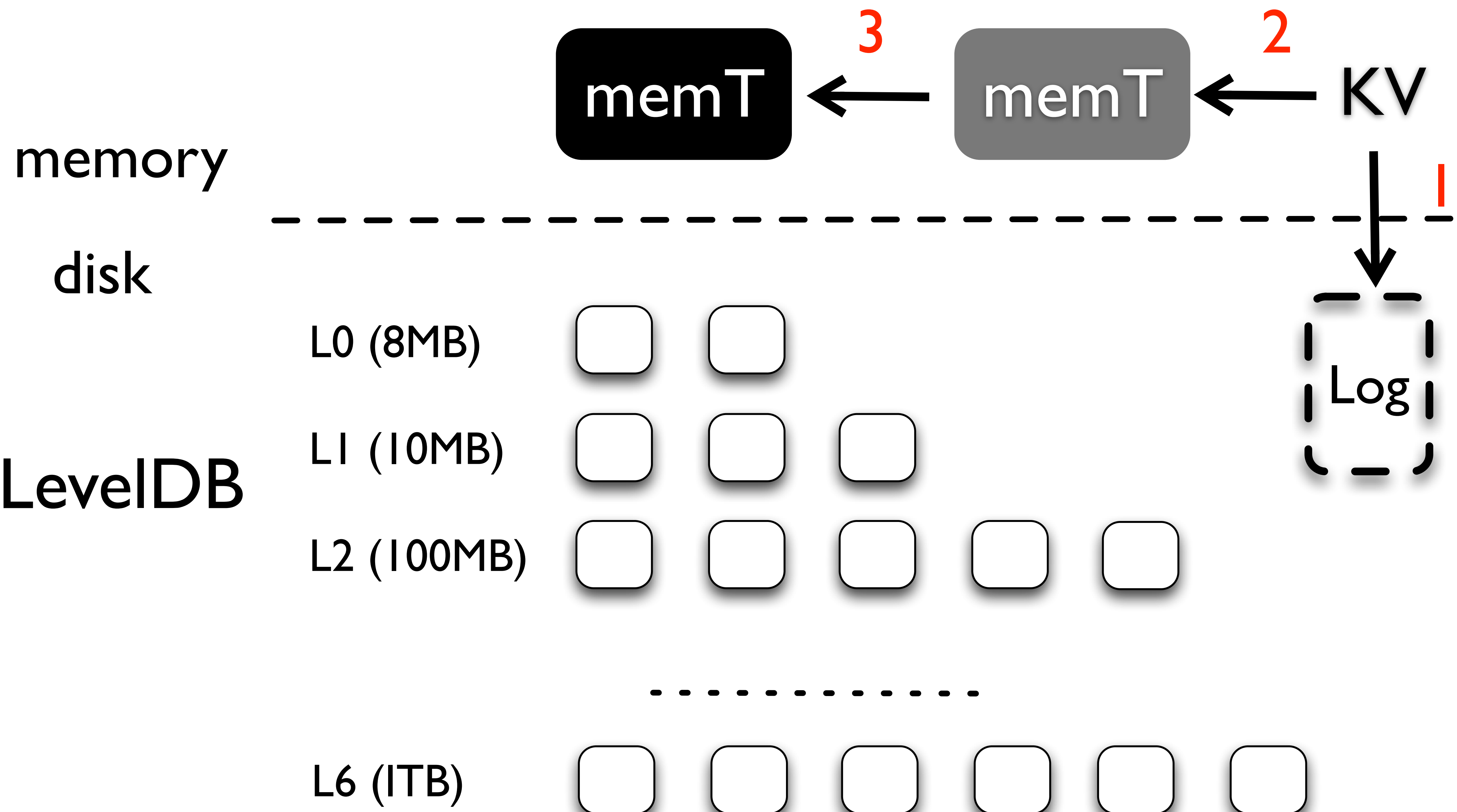

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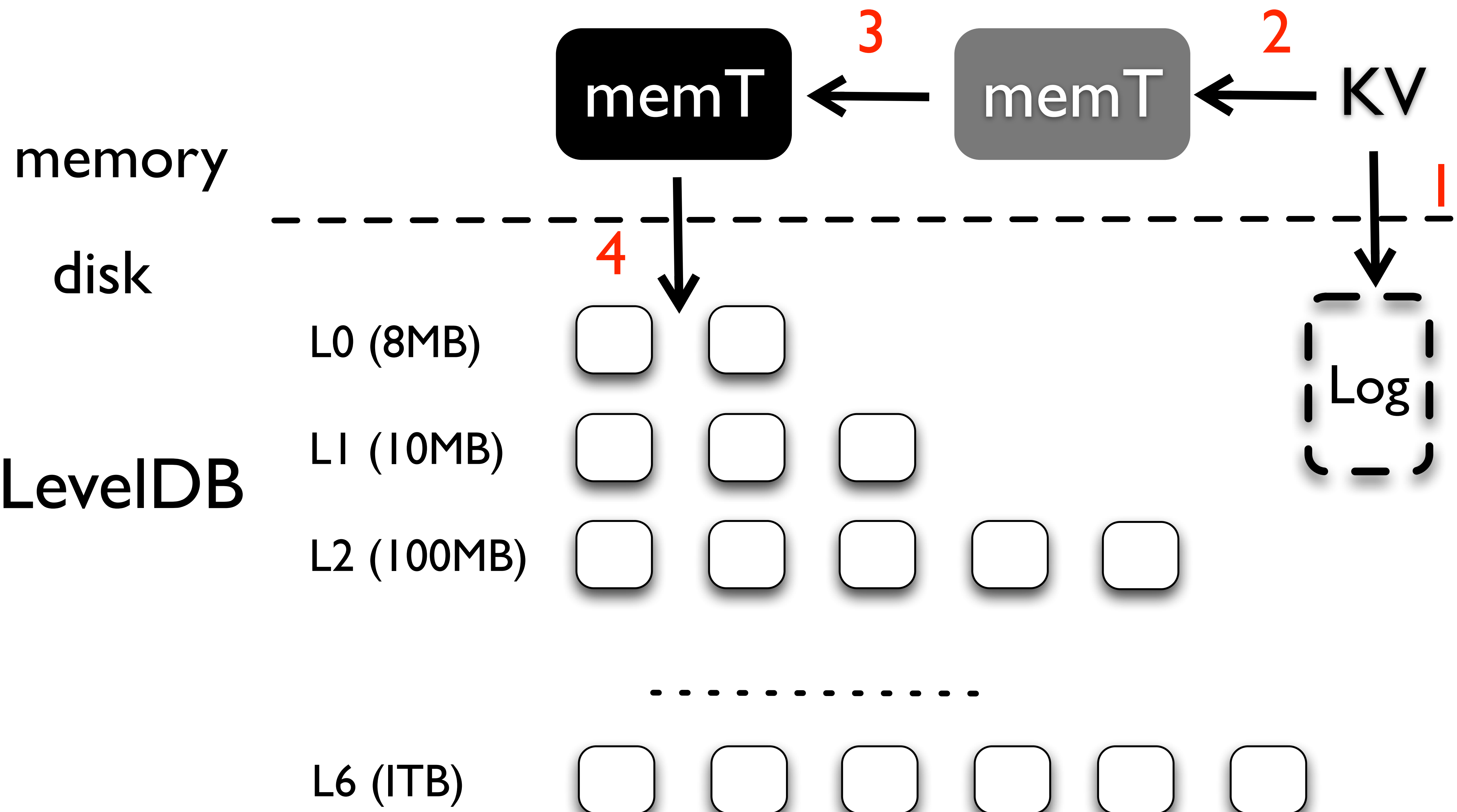

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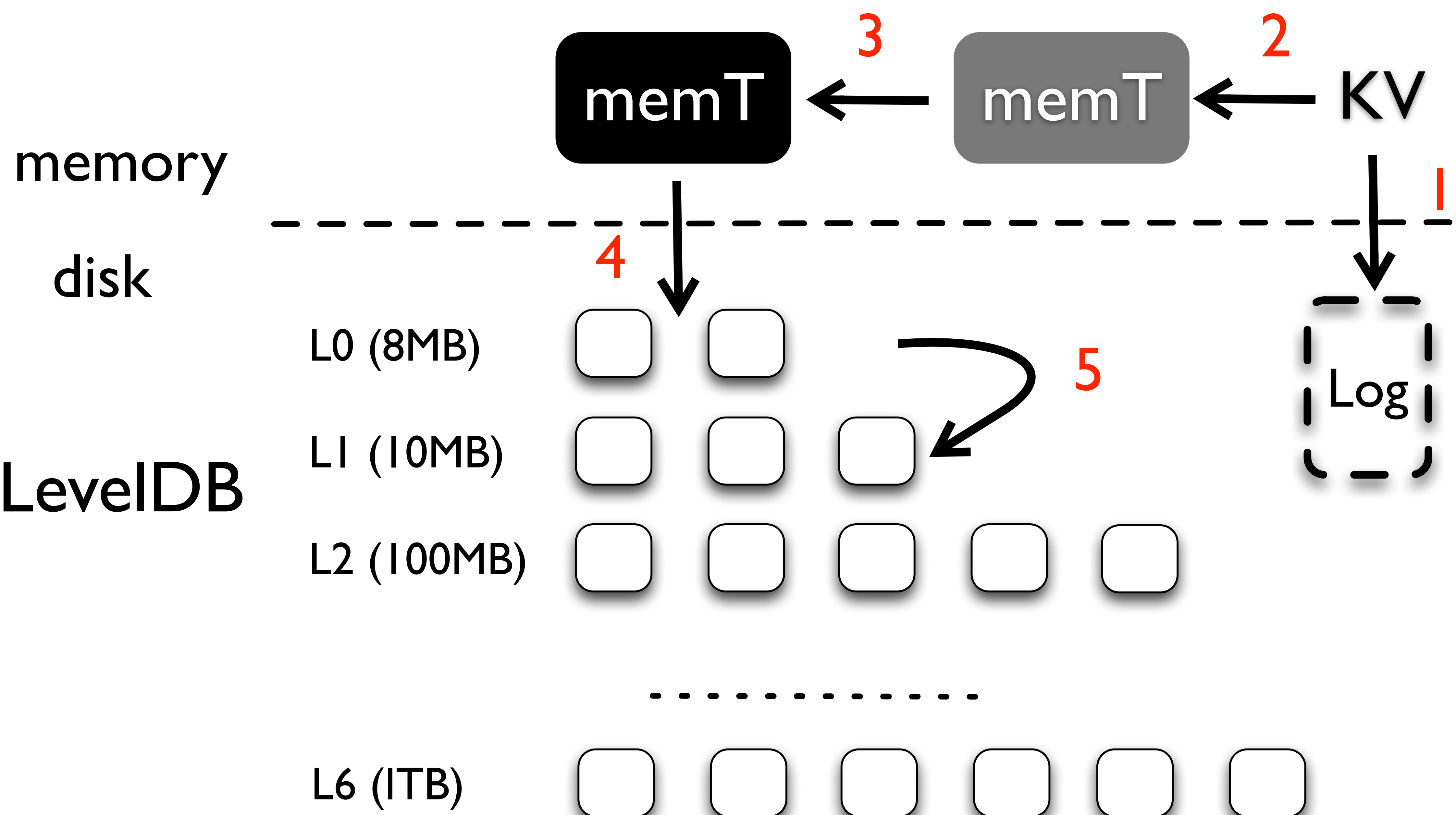
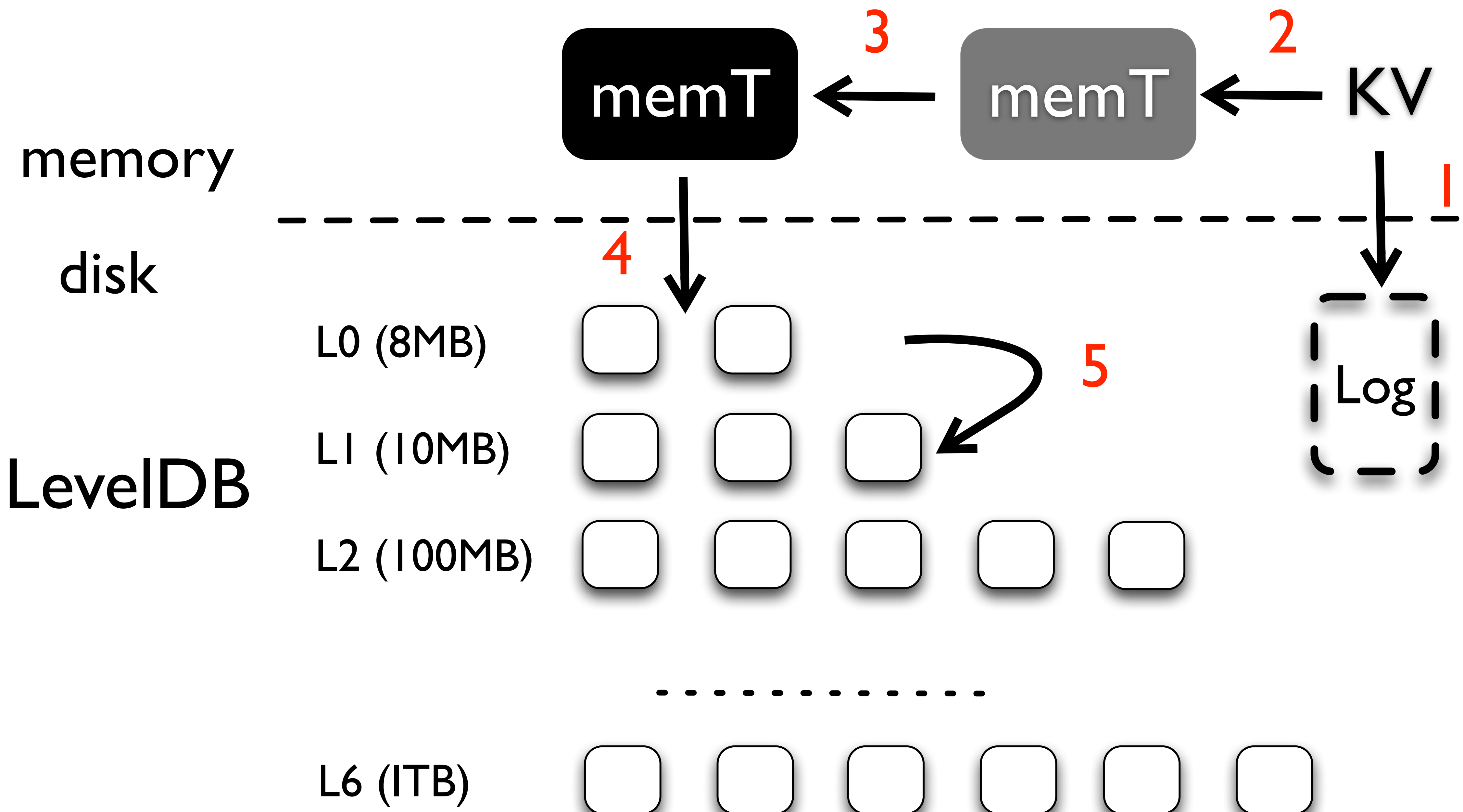


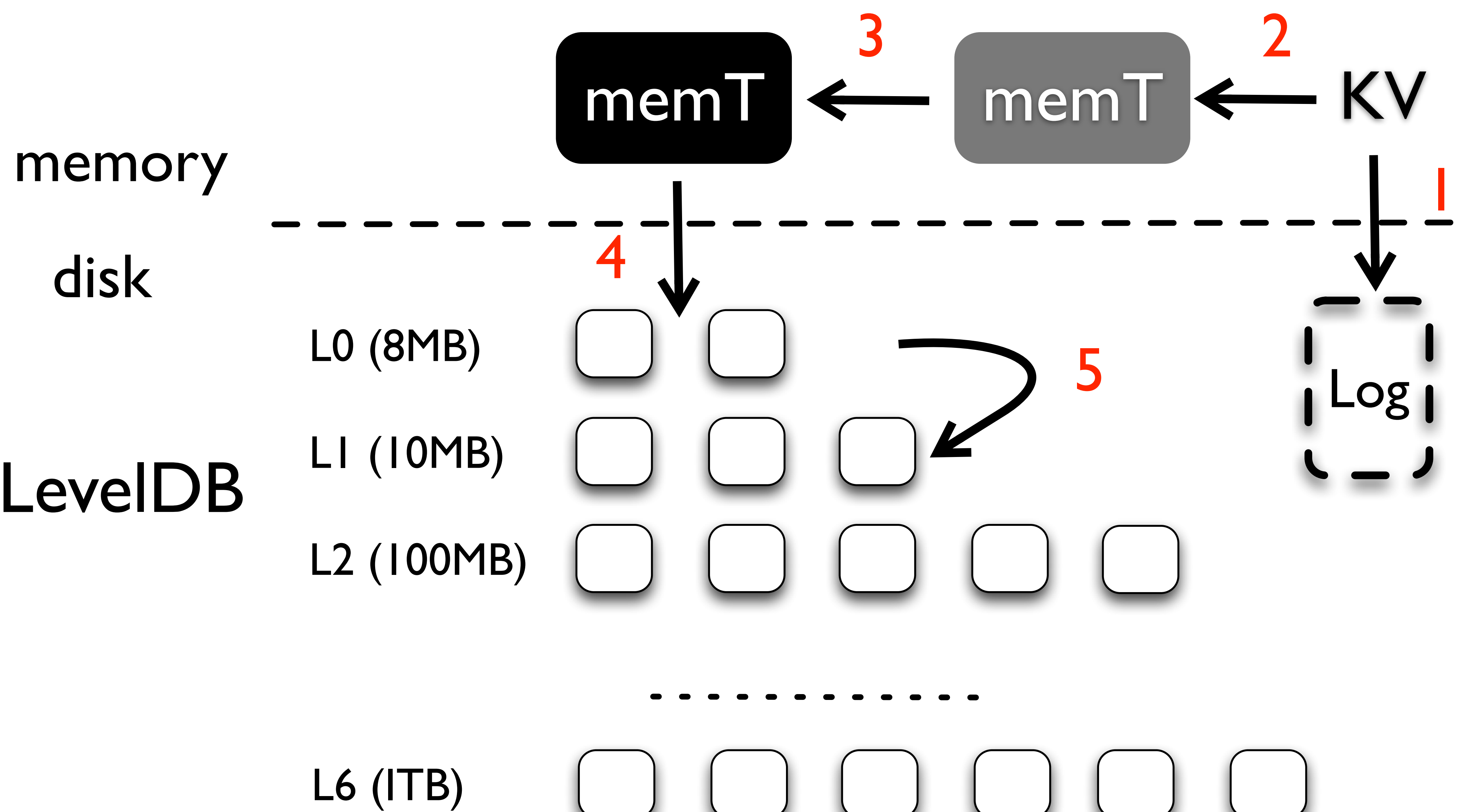
LSM-trees: Insertion

1. Write sequentially 2. Sort data for quick lookups



LSM-trees: Insertion

1. Write sequentially 2. Sort data for quick lookups
3. Sorting and garbage collection are coupled



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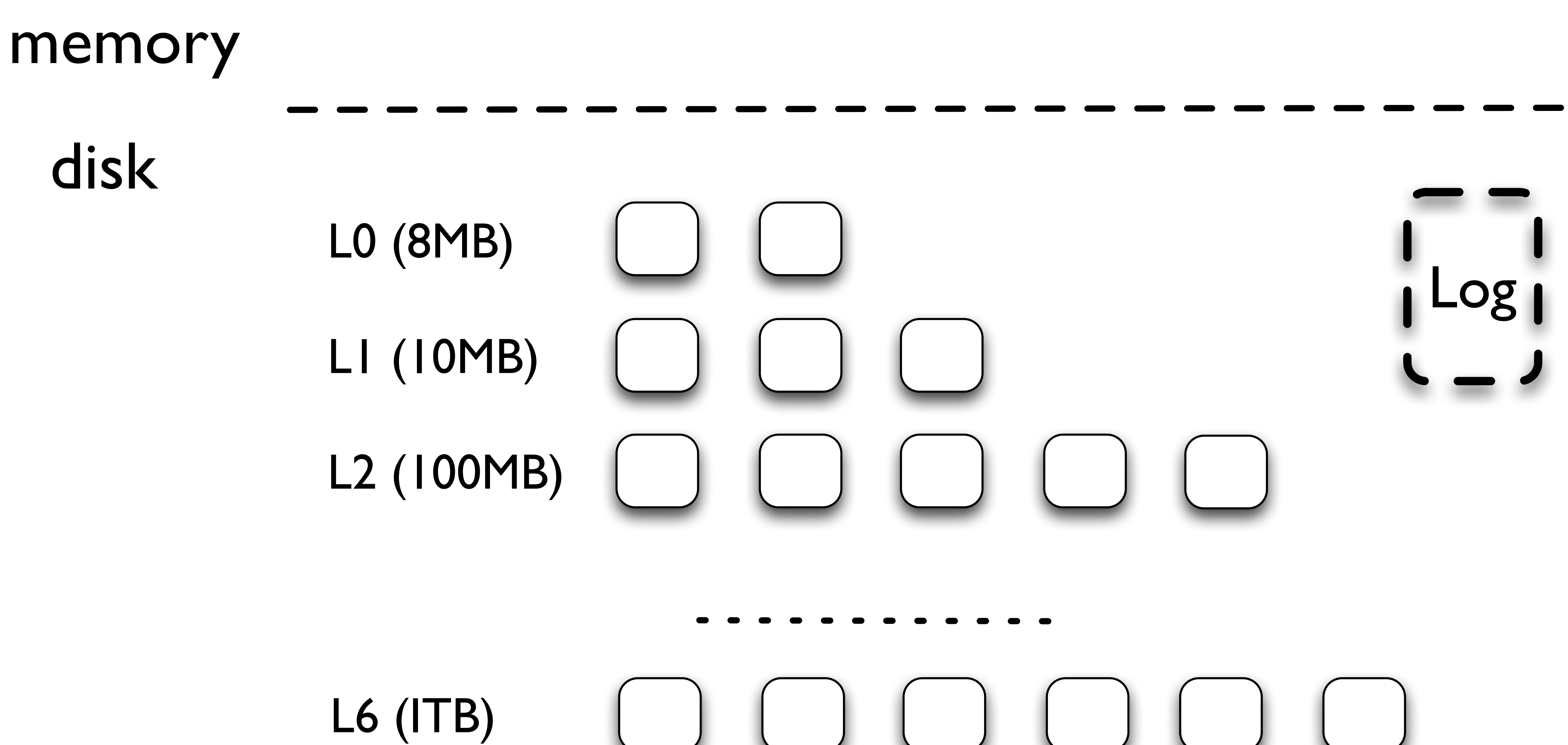

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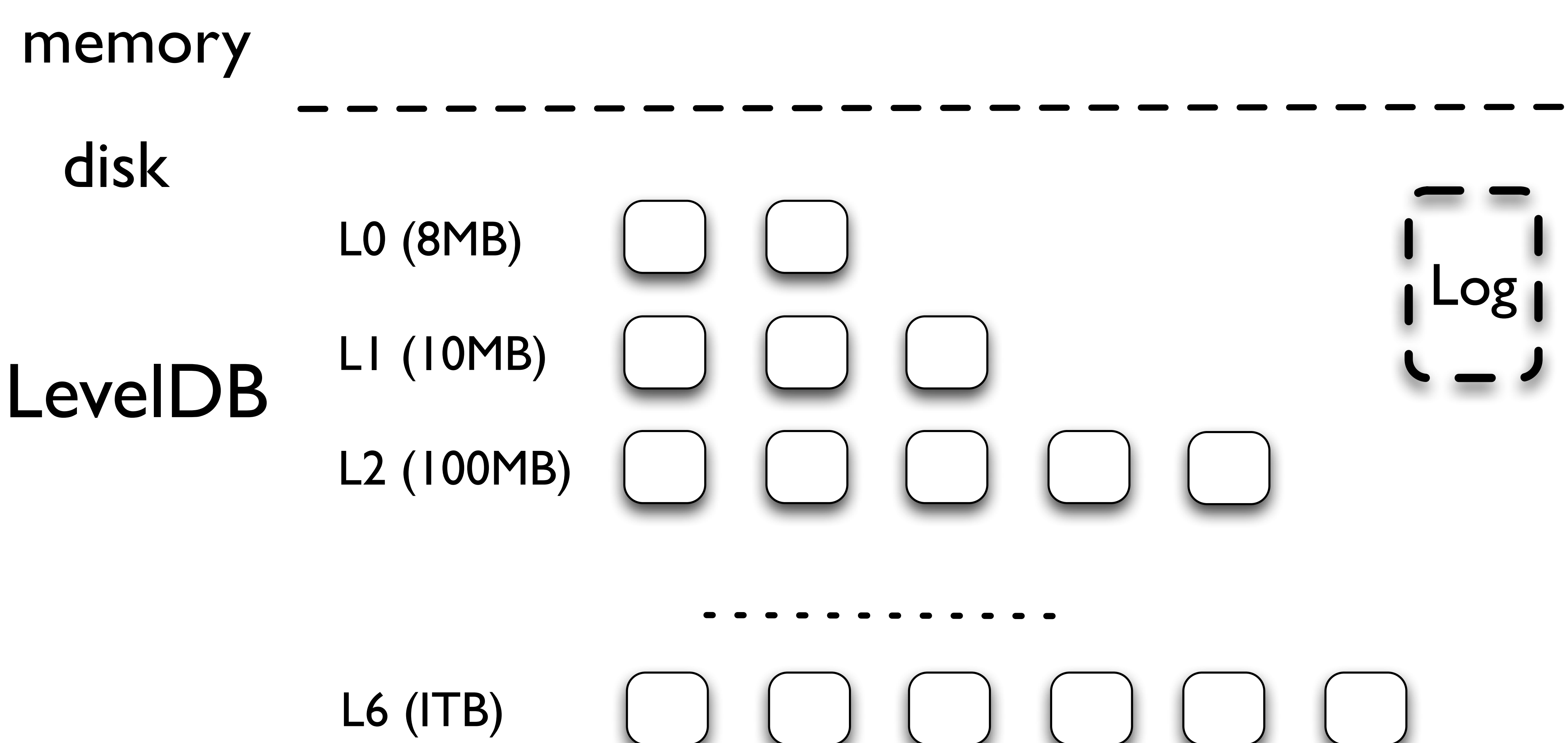

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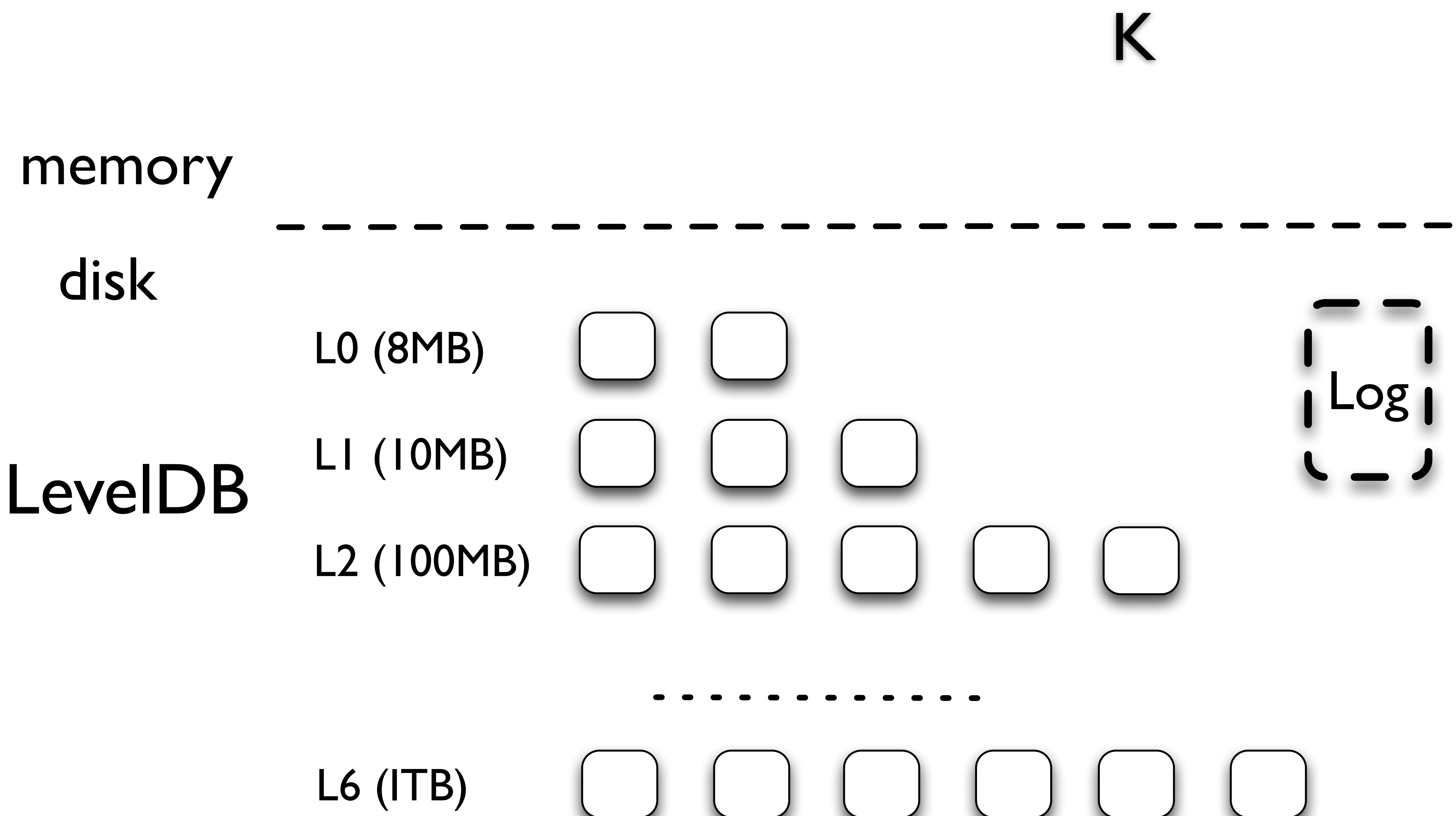

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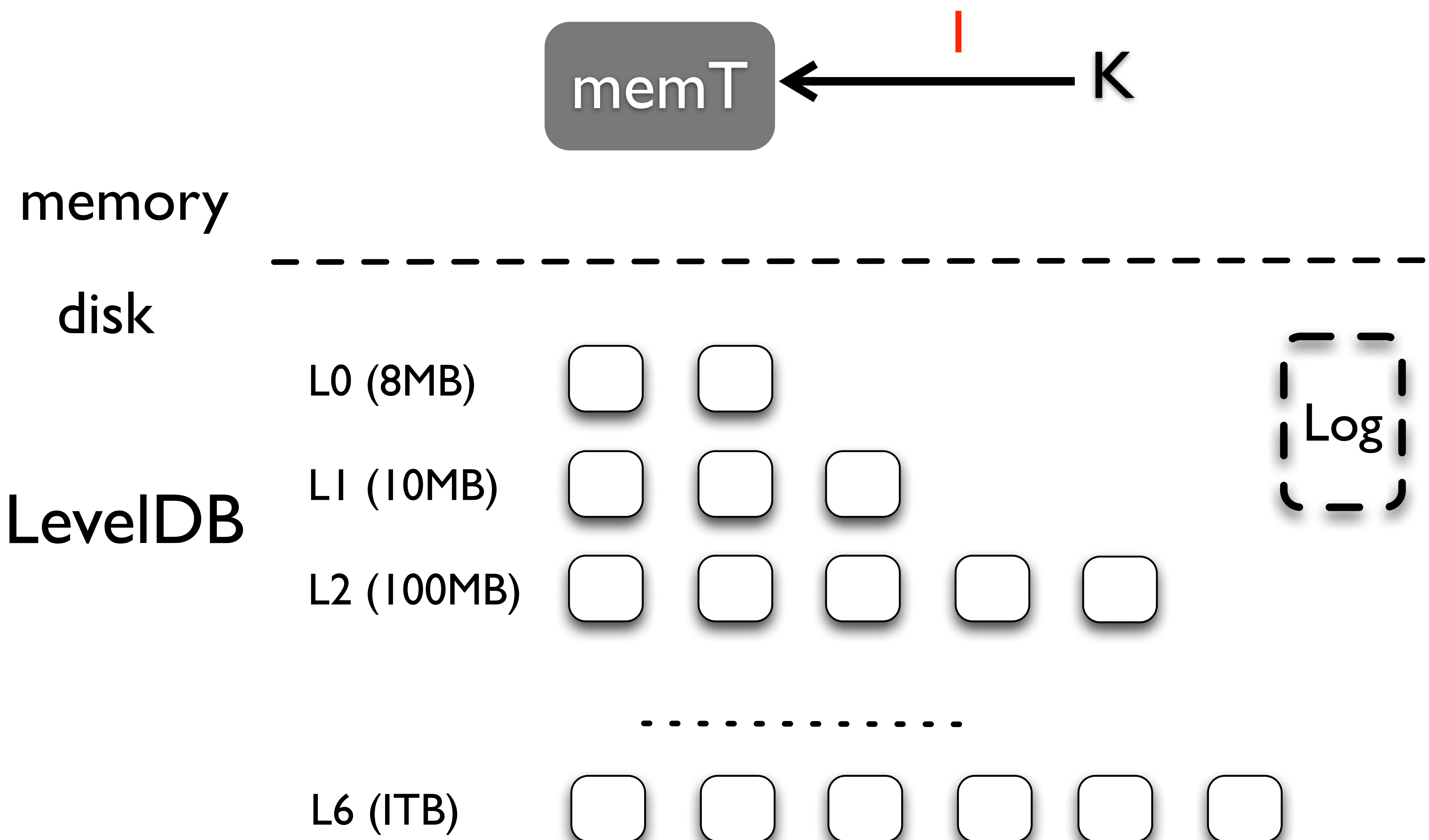

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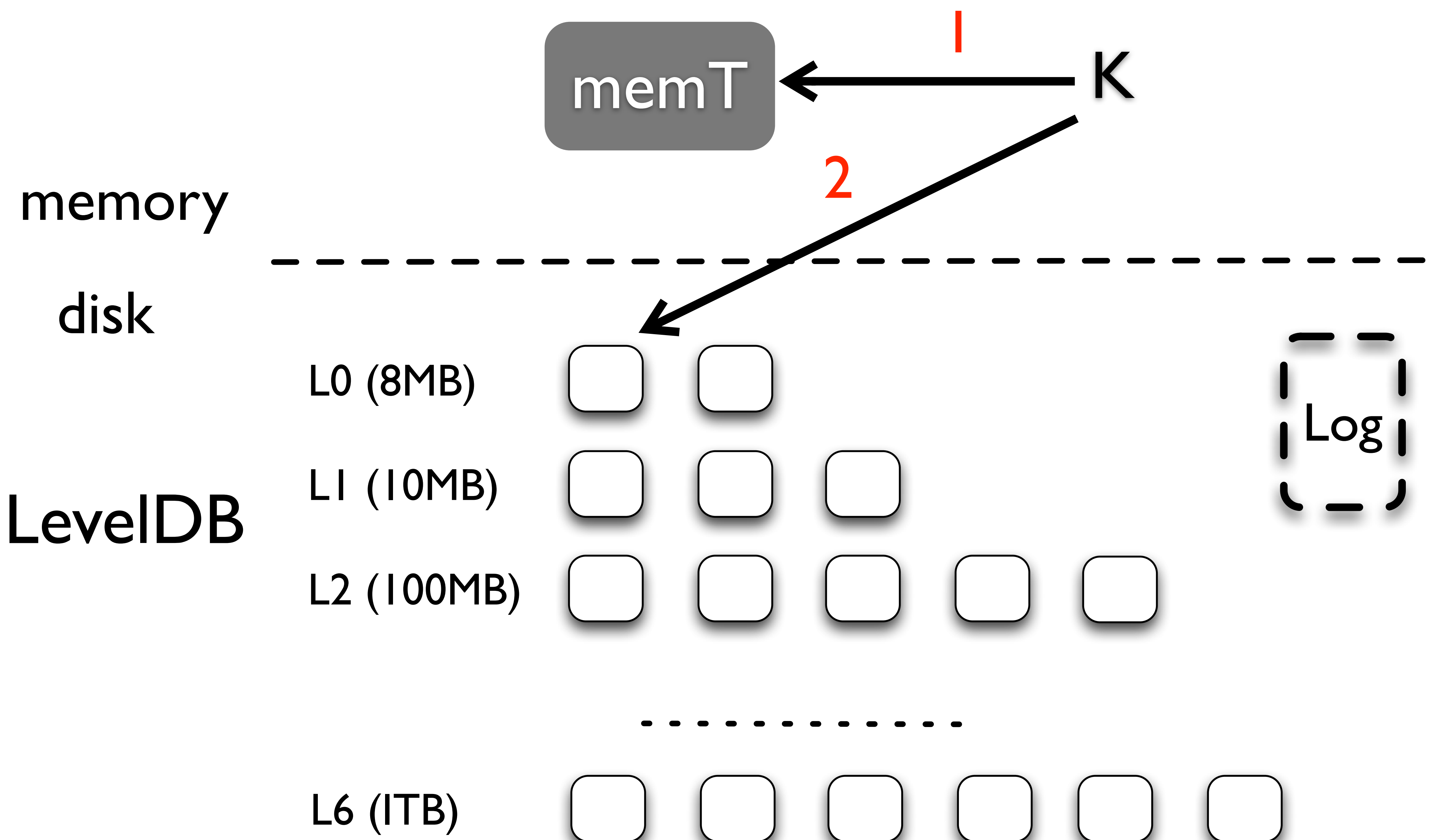

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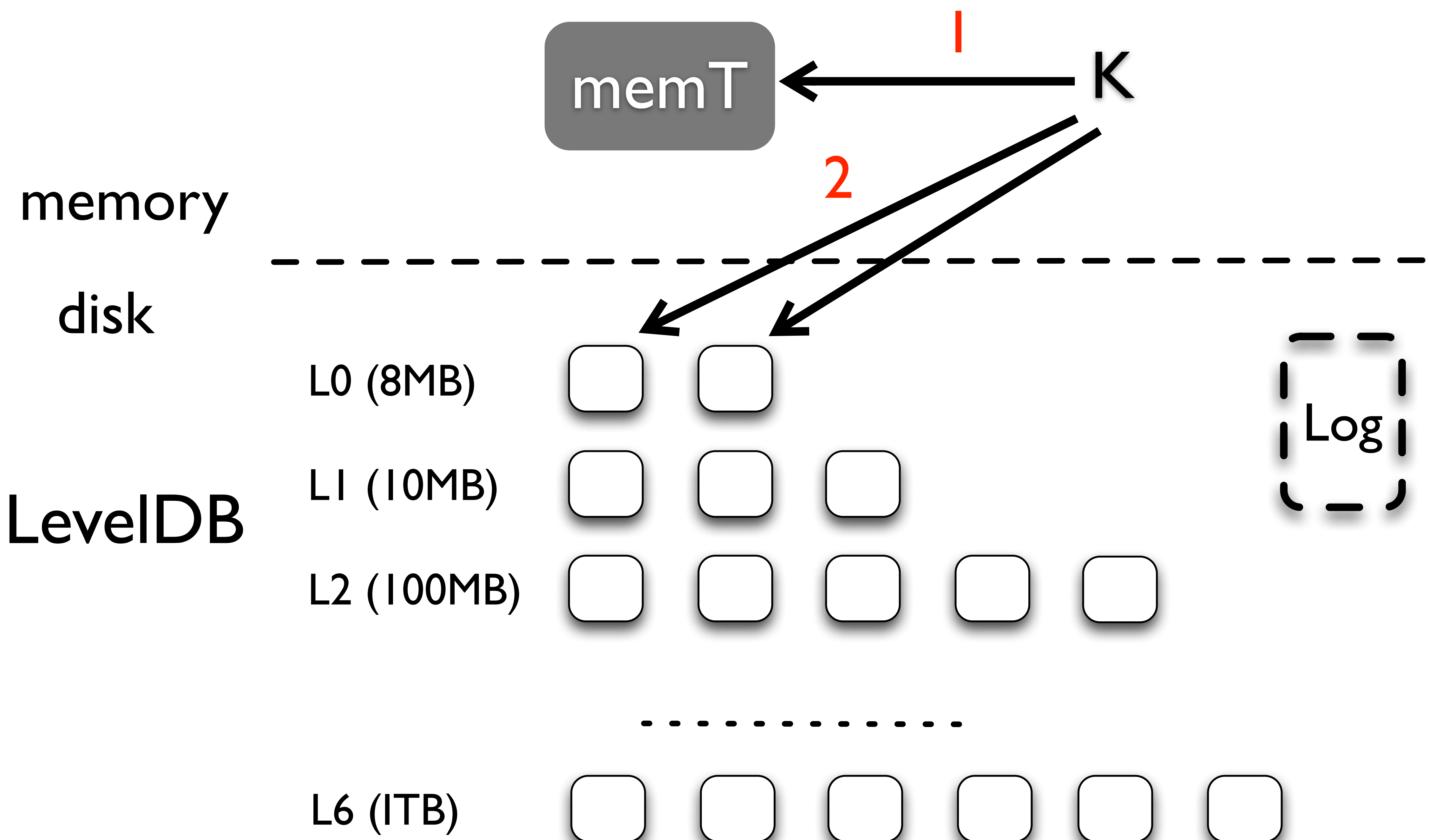

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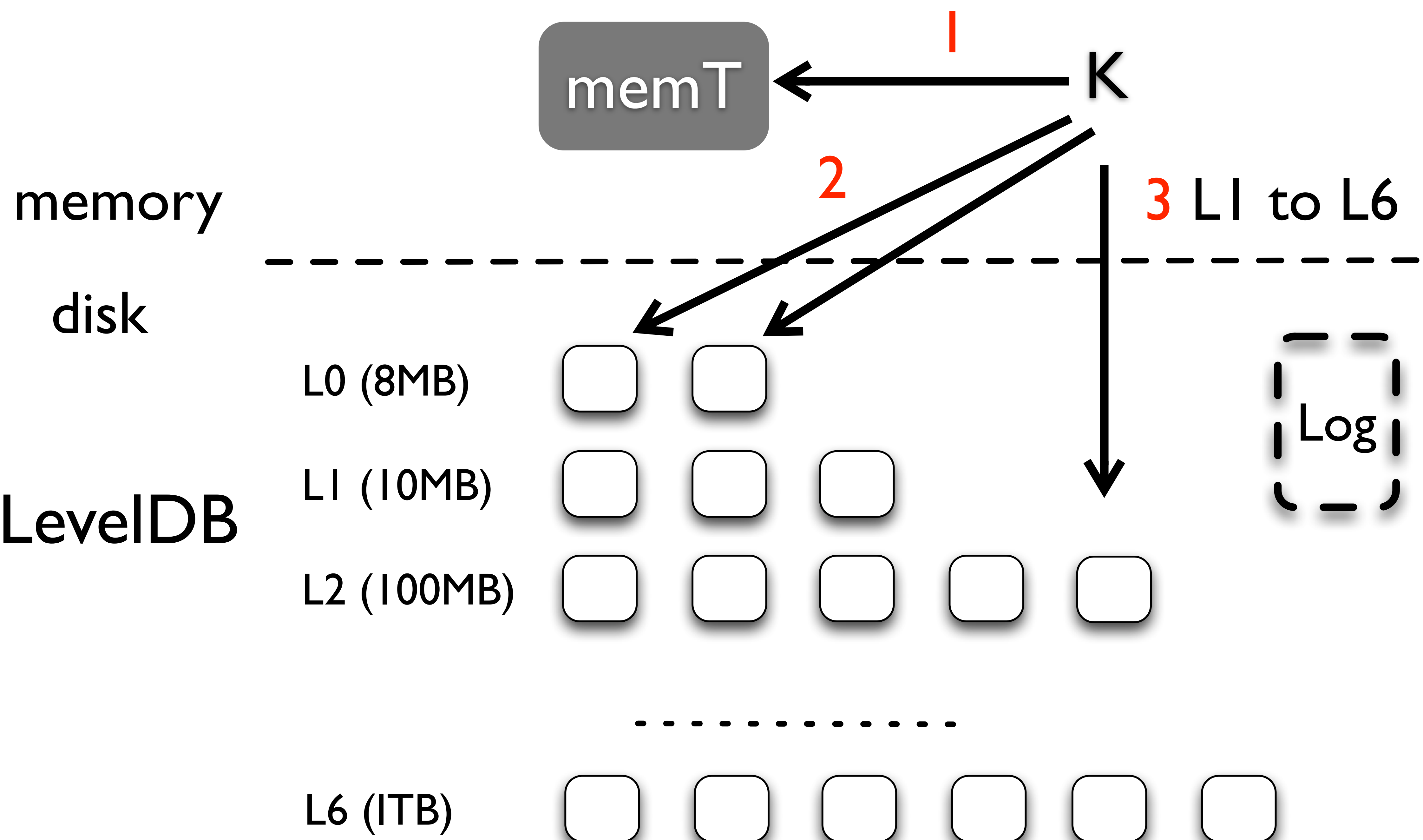
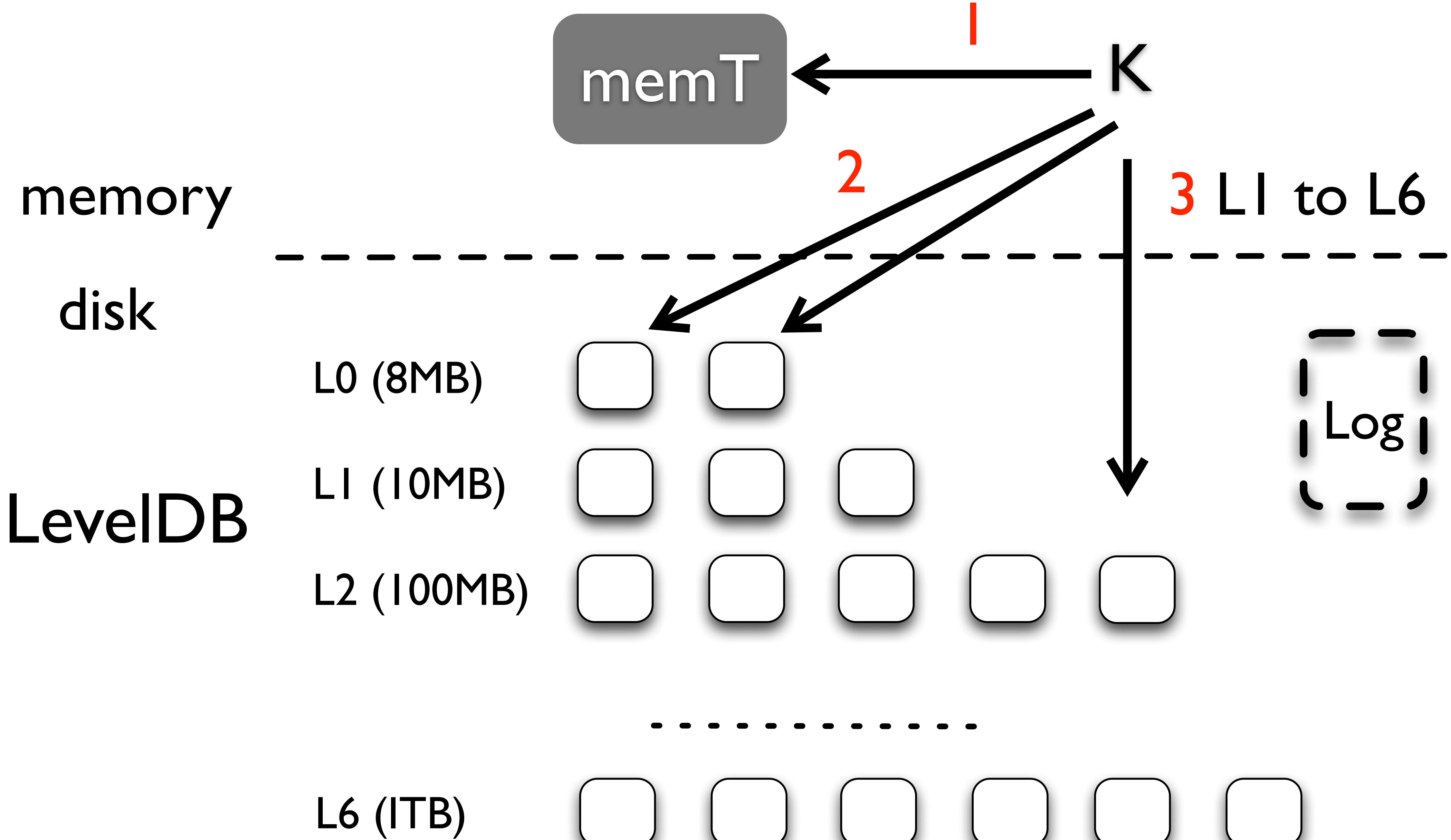


LSM-trees: Lookup

1. Random reads
2. Travel many levels for a large LSM-tree



I/O Amplification in LSM-trees

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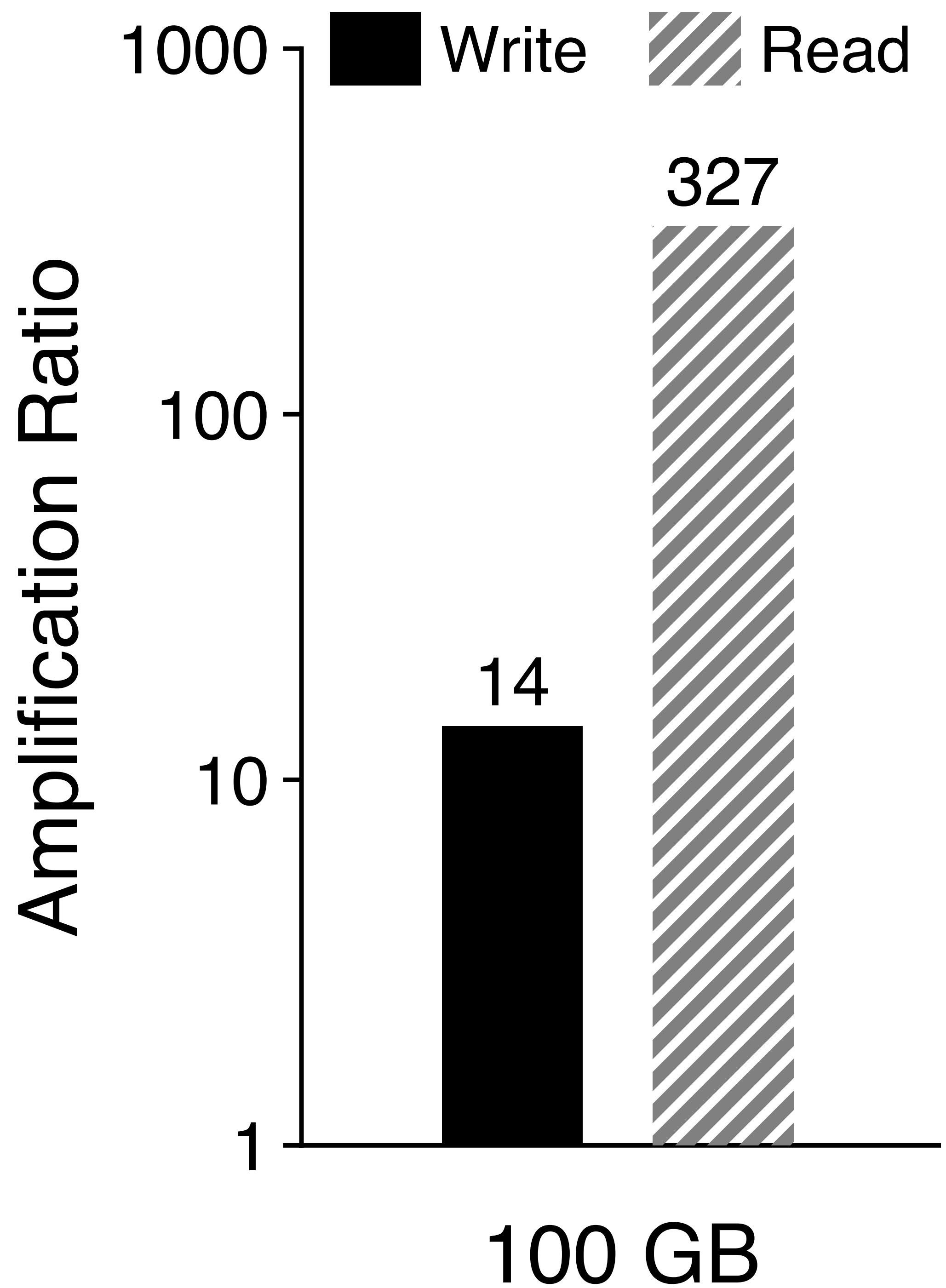

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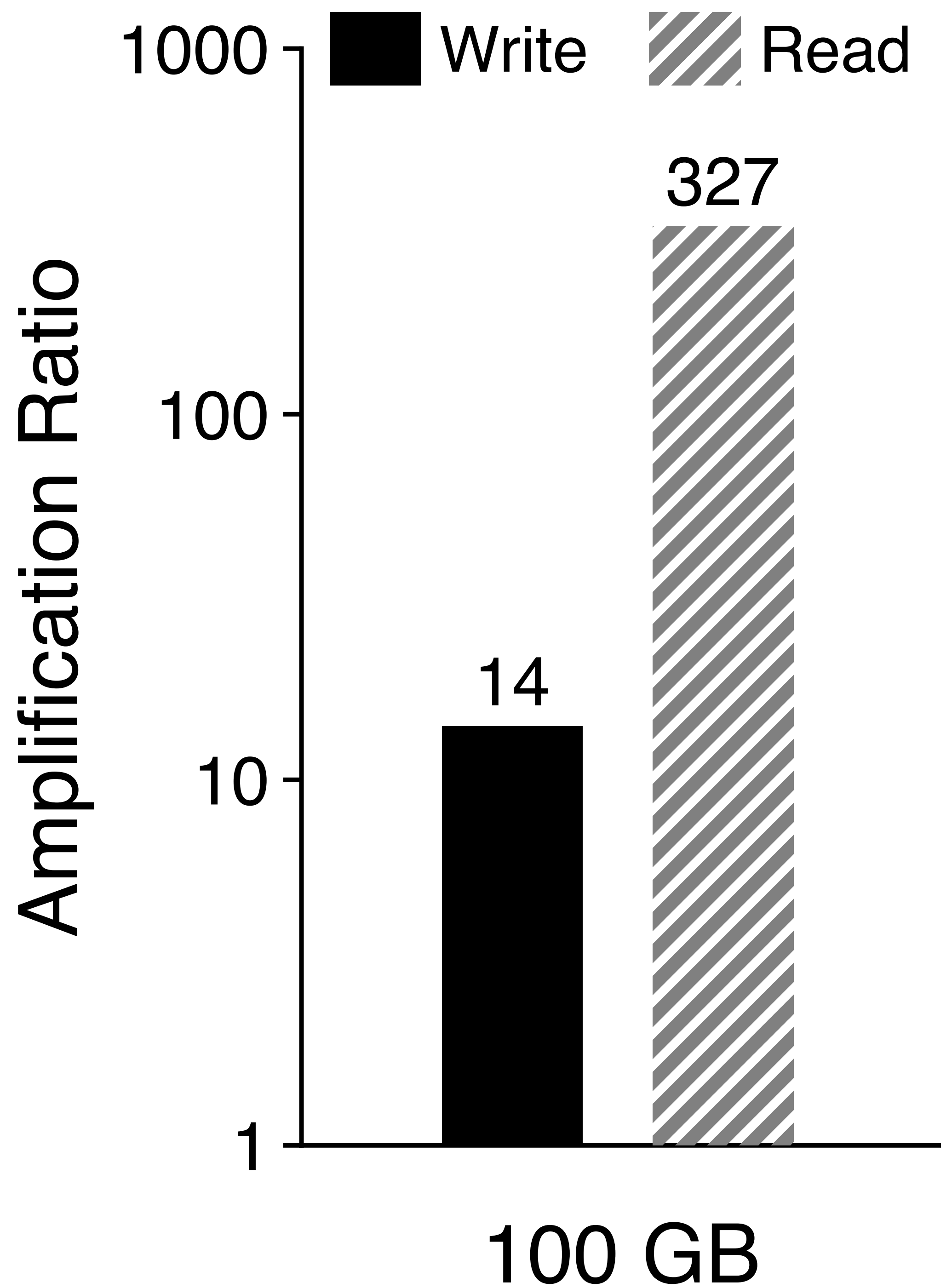

Random load:
a 100GB database

Random lookup:
100,000 lookups

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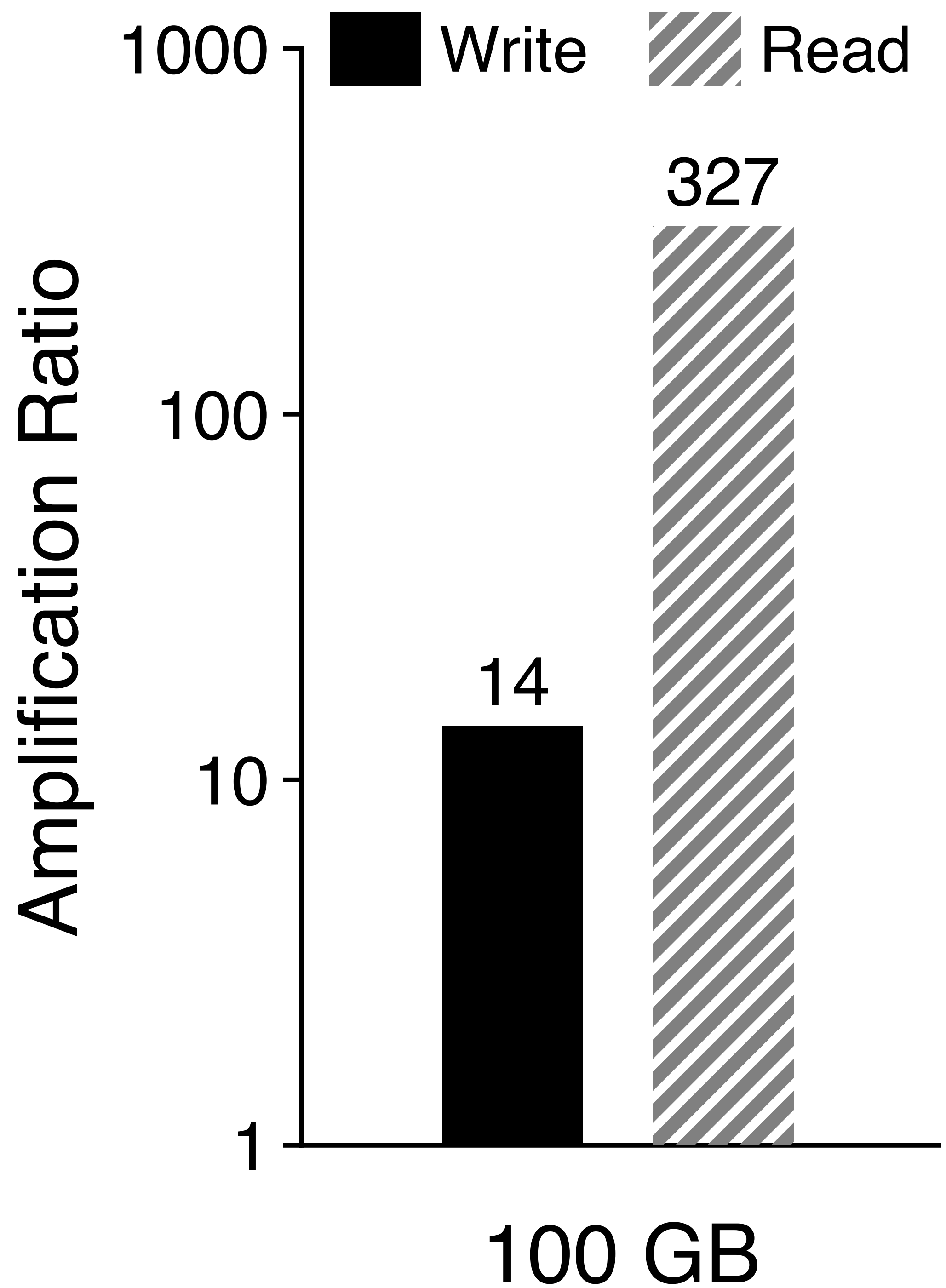

Random load:
a 100GB database

Random lookup:
100,000 lookups

Problems:

large write amplification

large read amplification

Background

Key-Value Separation

Challenges and Optimizations

Evaluation

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Main idea: only keys are required to be sorted

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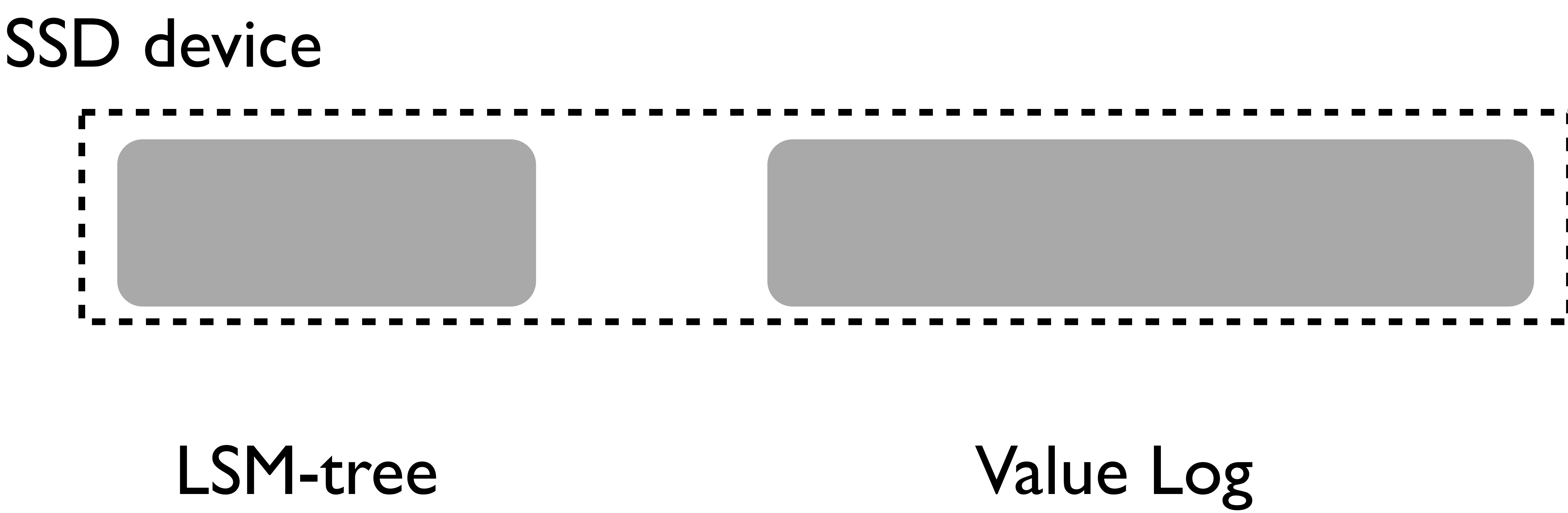

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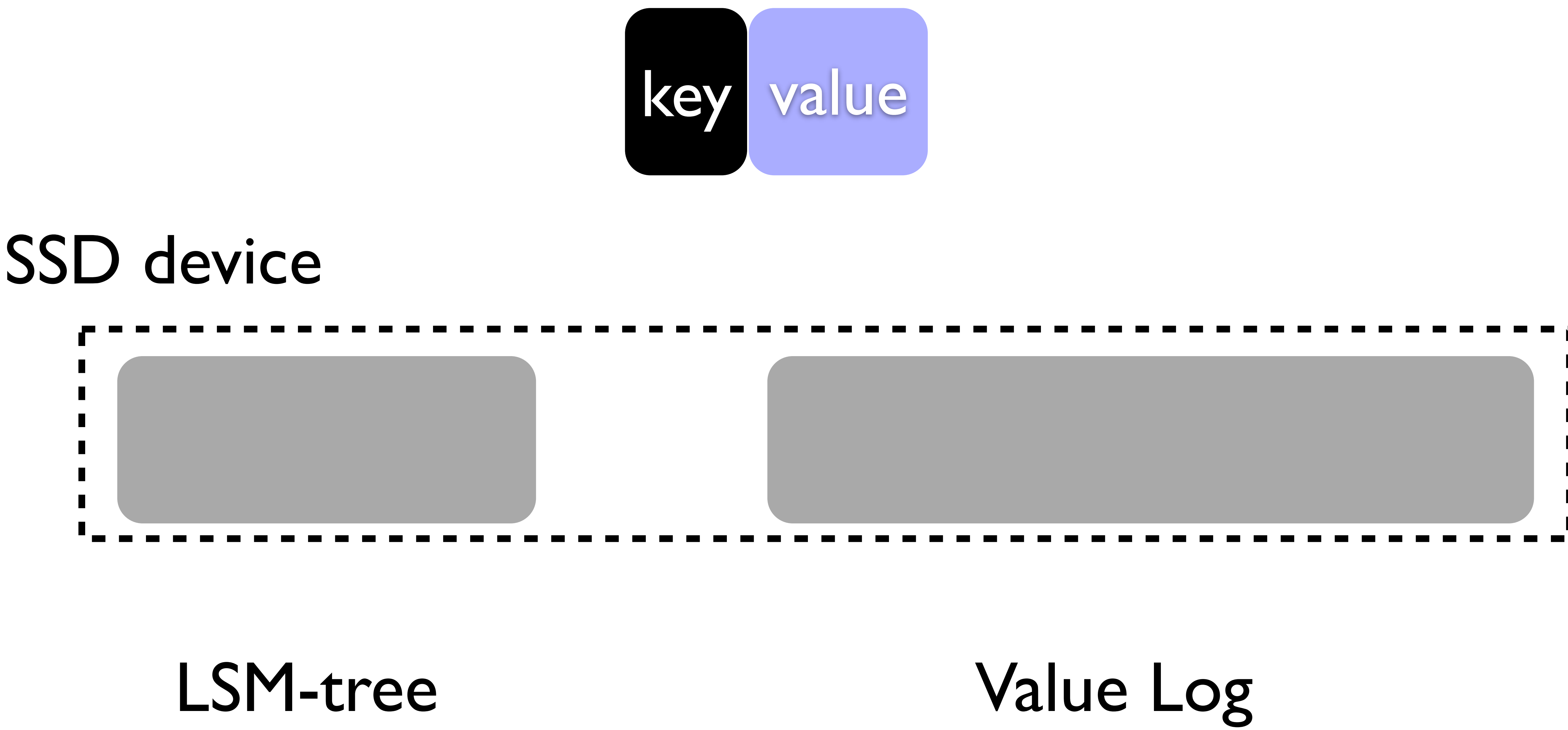

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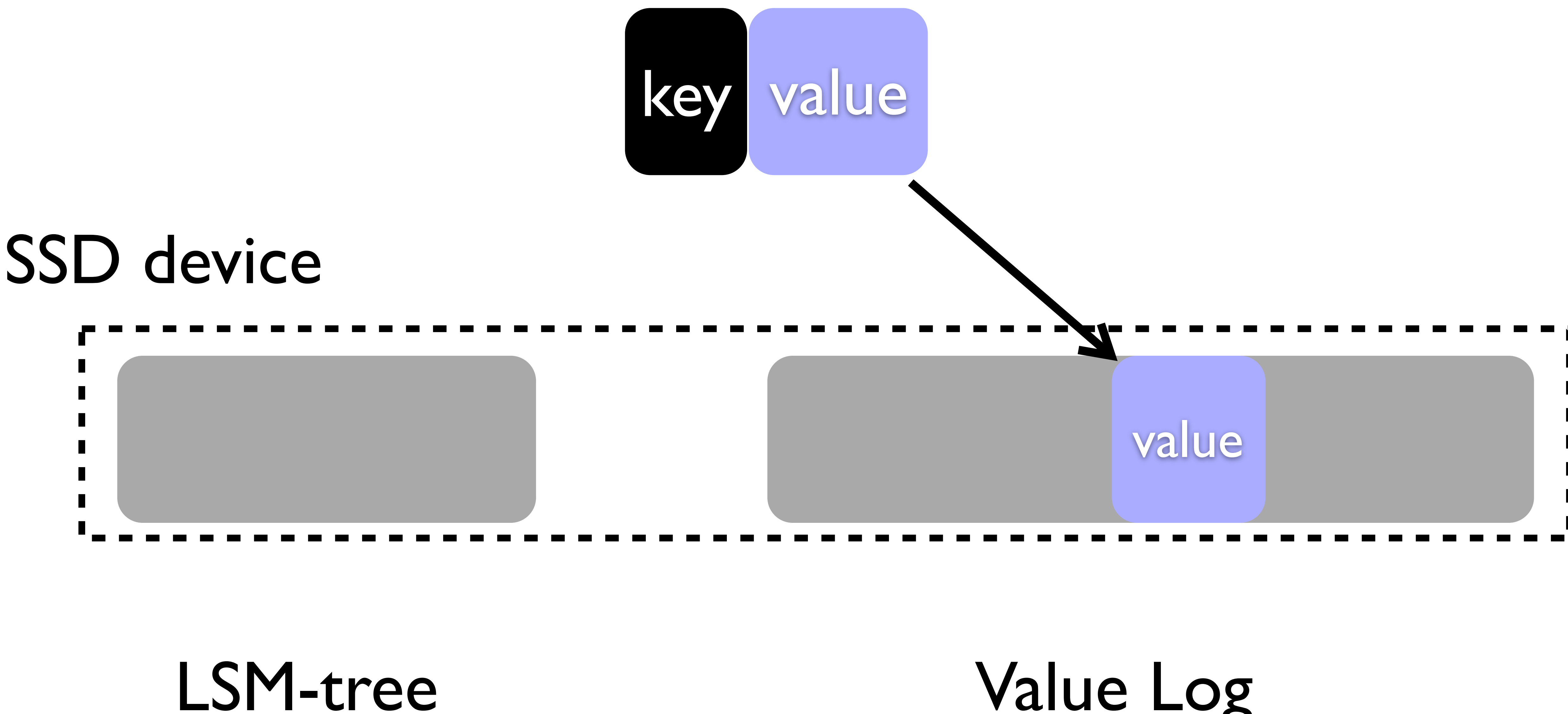

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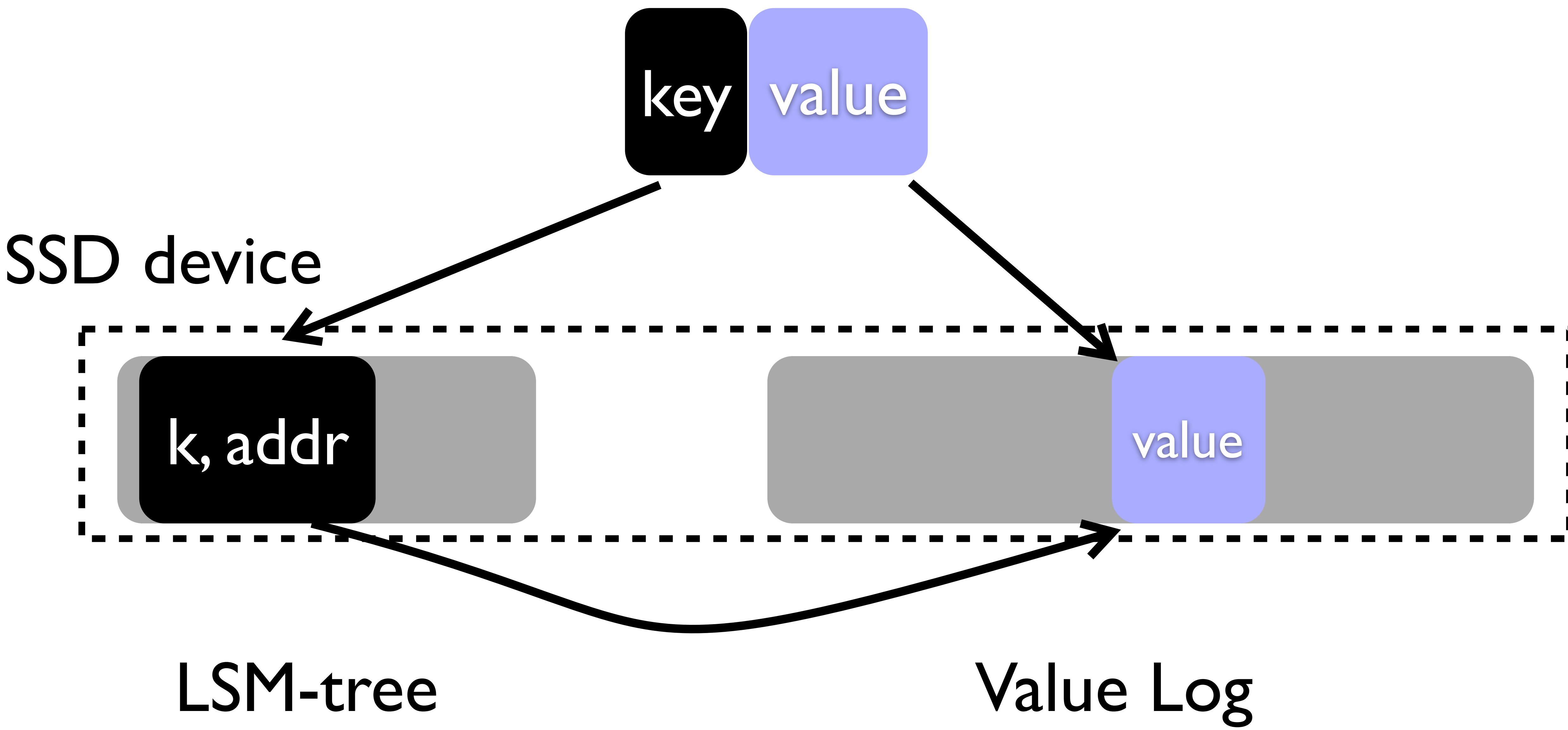

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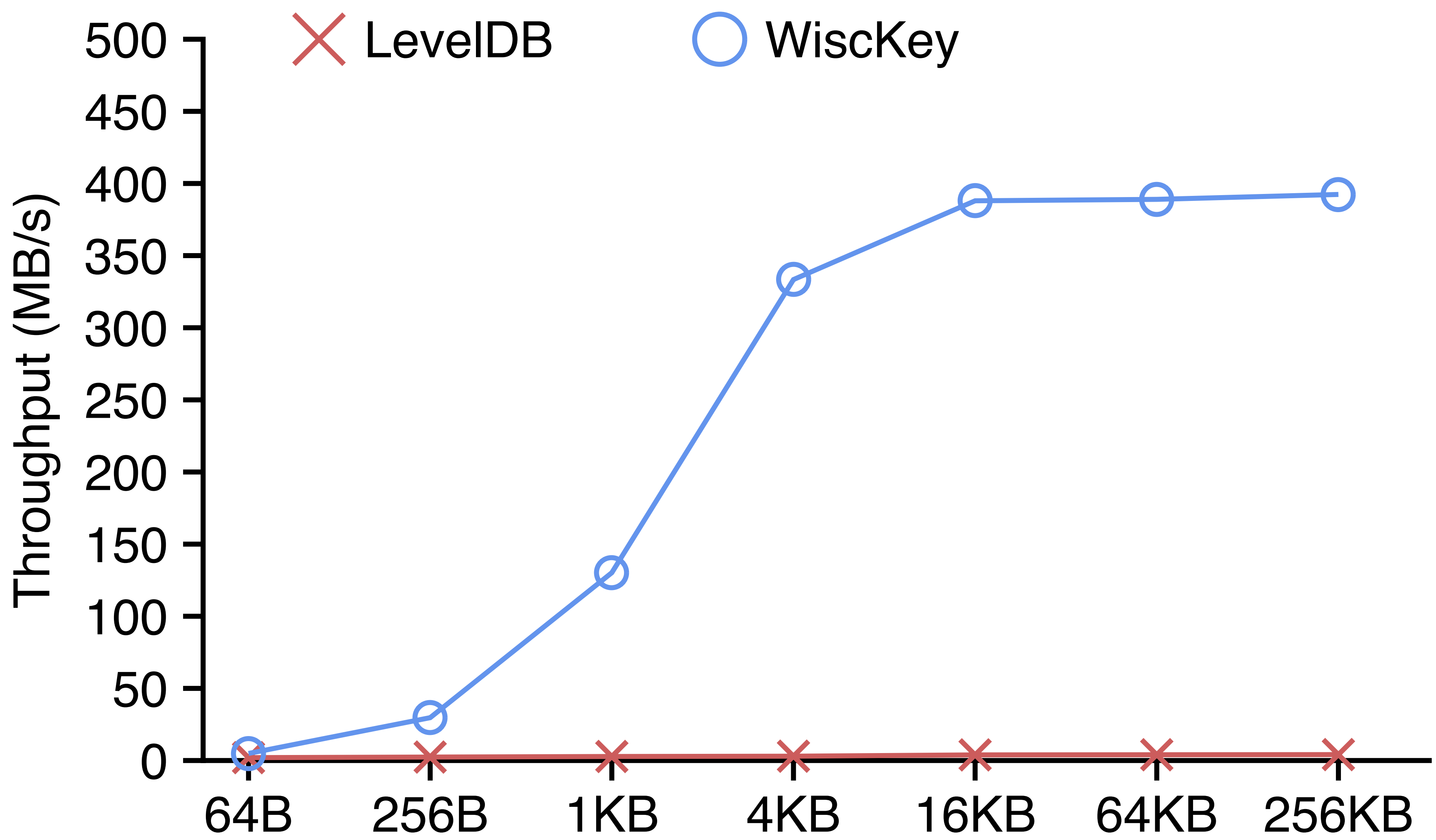
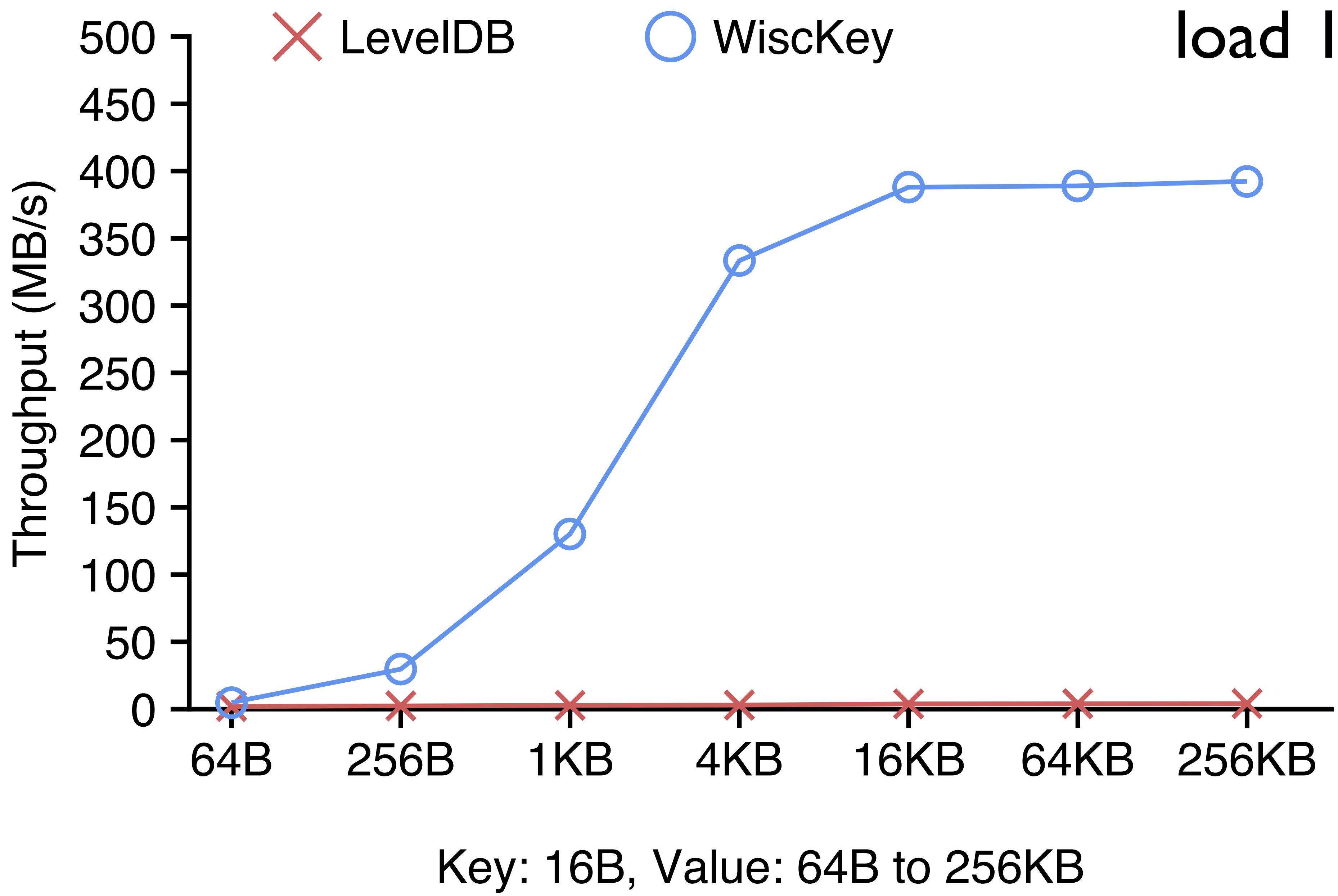


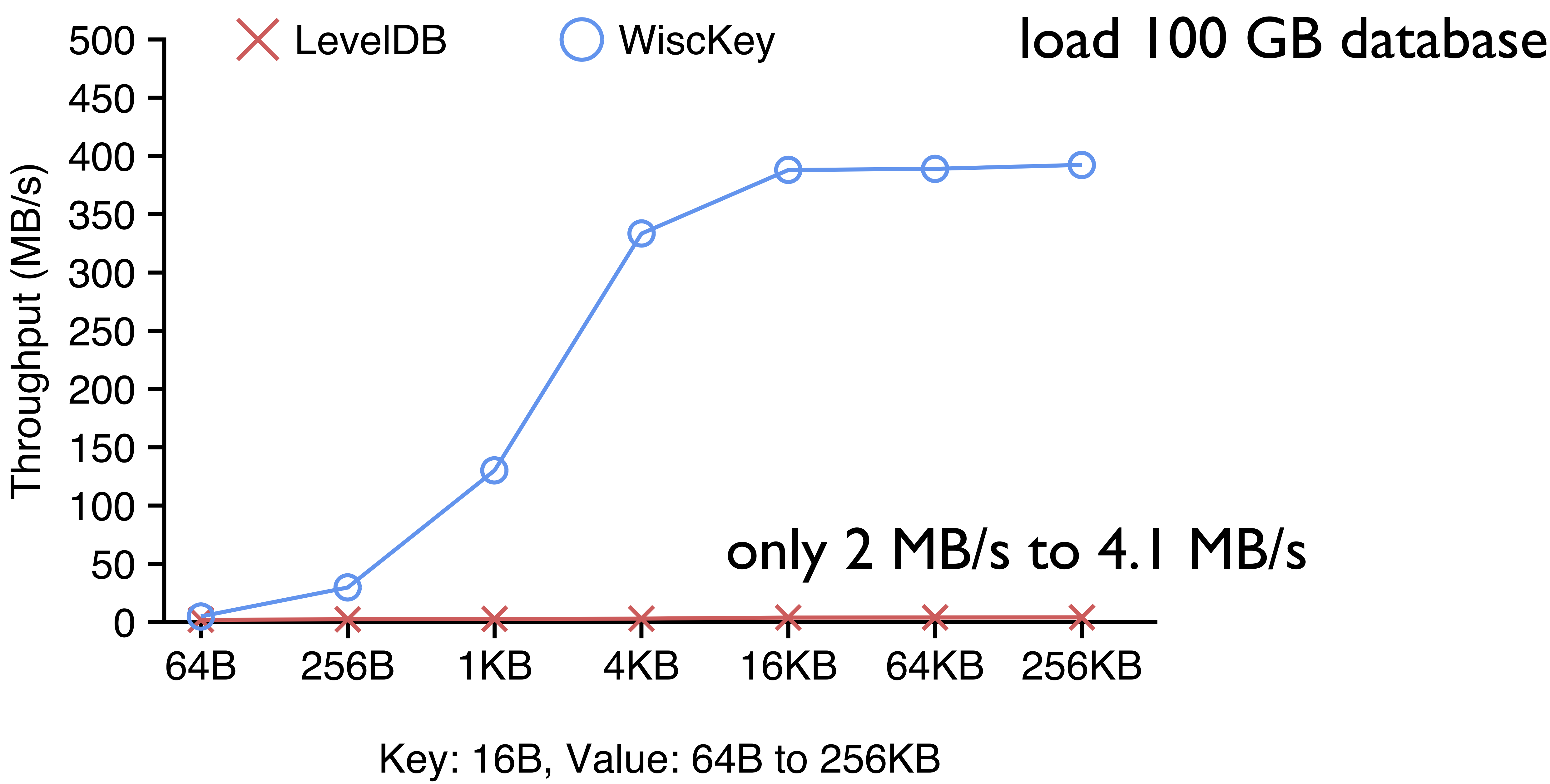
Key: 16B, Value: 64B to 256KB

Random Load



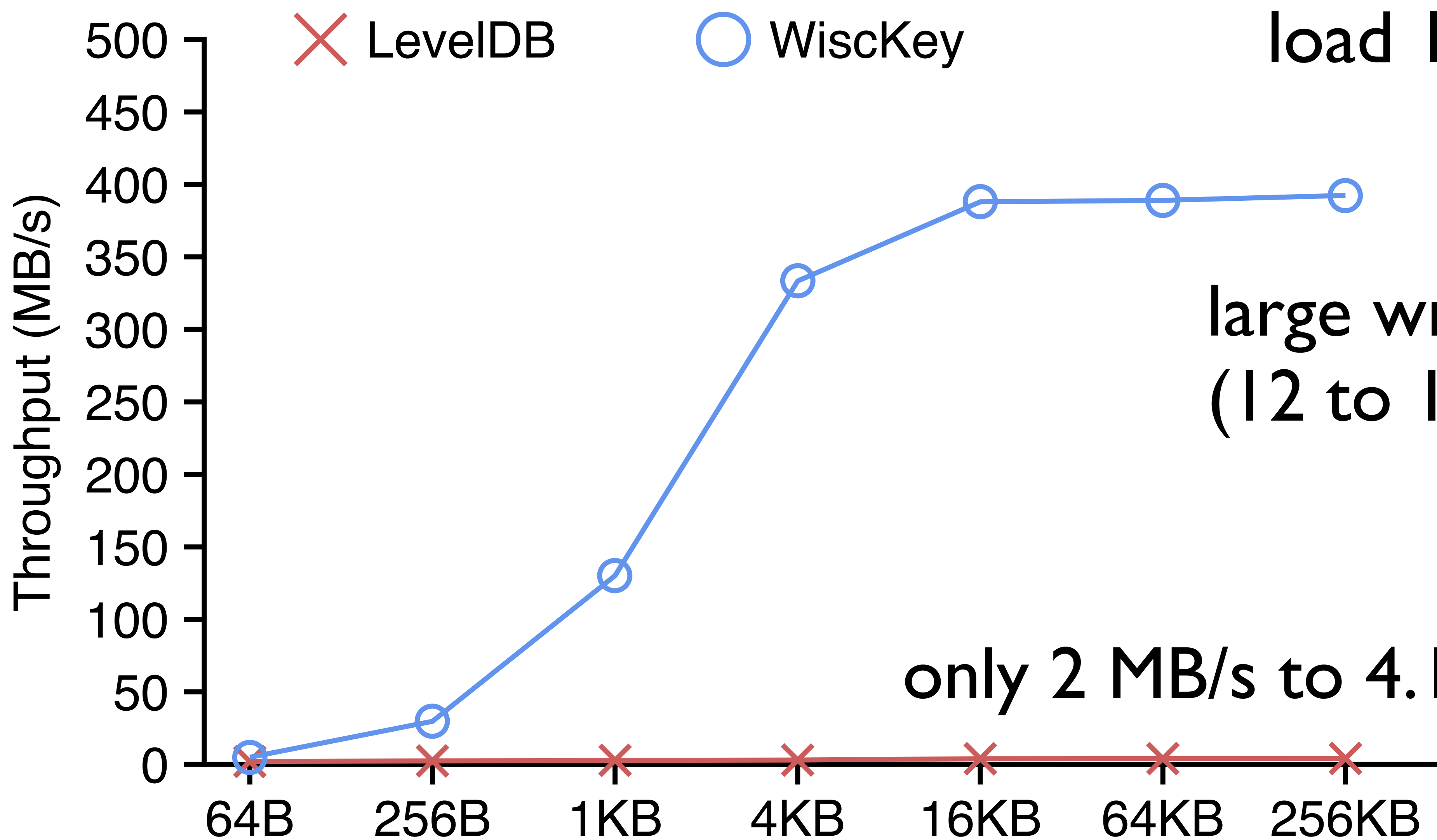
load 100 GB database

Random Load



LevelDB
WiscKey
load 100 GB database
Throughput (MB/s)
500
450
400
350
300
250
200
150
100
50
0
only 2 MB/s to 4.1 MB/s
64B
256B
1KB
4KB
16KB
64KB
256KB
Key: 16B, Value: 64B to 256KB

Random Load



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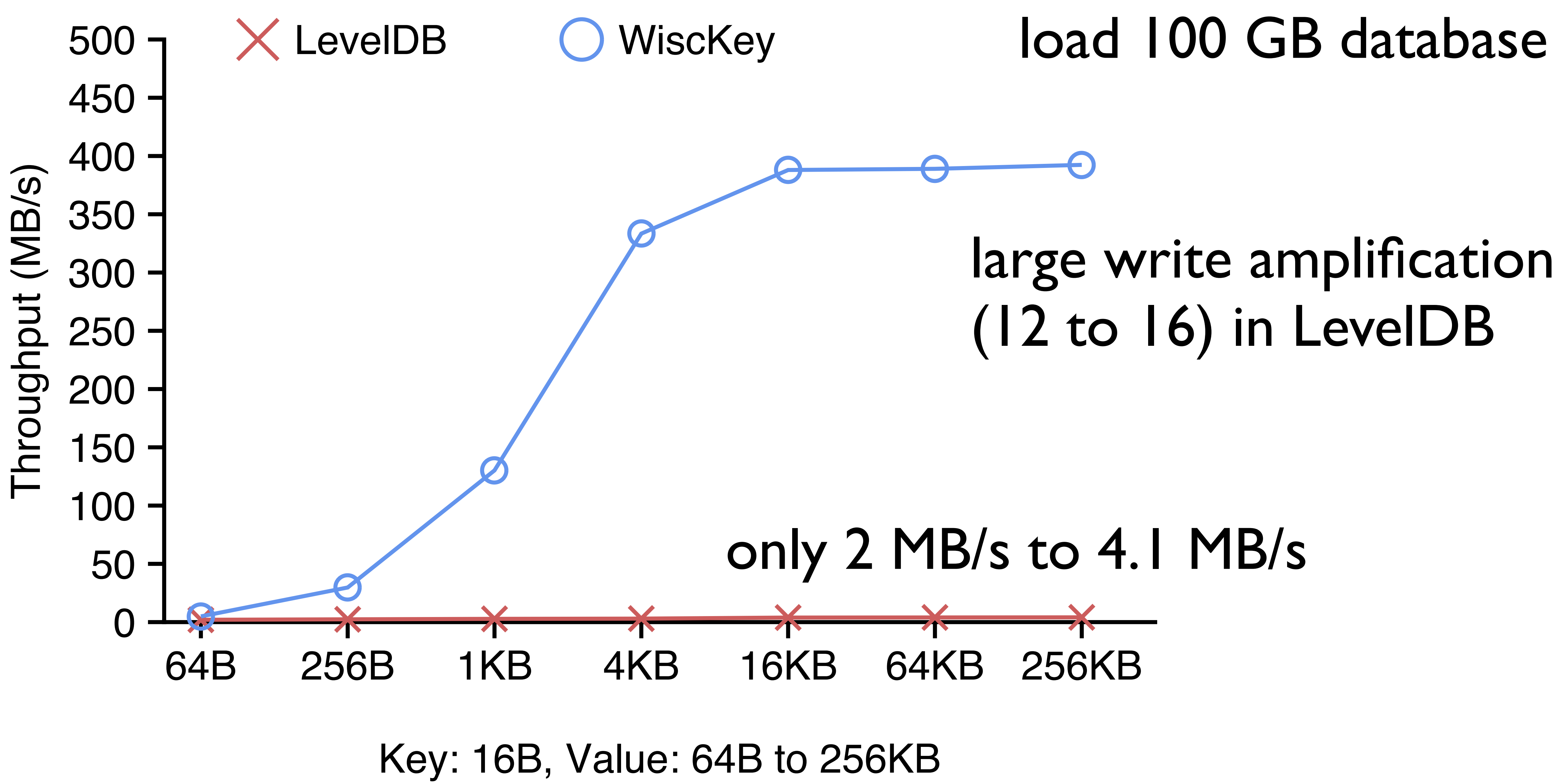
load 100 GB database

large write amplification (12 to 16) in LevelDB

only 2 MB/s to 4.1 MB/s

Random Load



Small write amplification in WiscKey due to key-value separation (up to 111x in throughput)

Random Load

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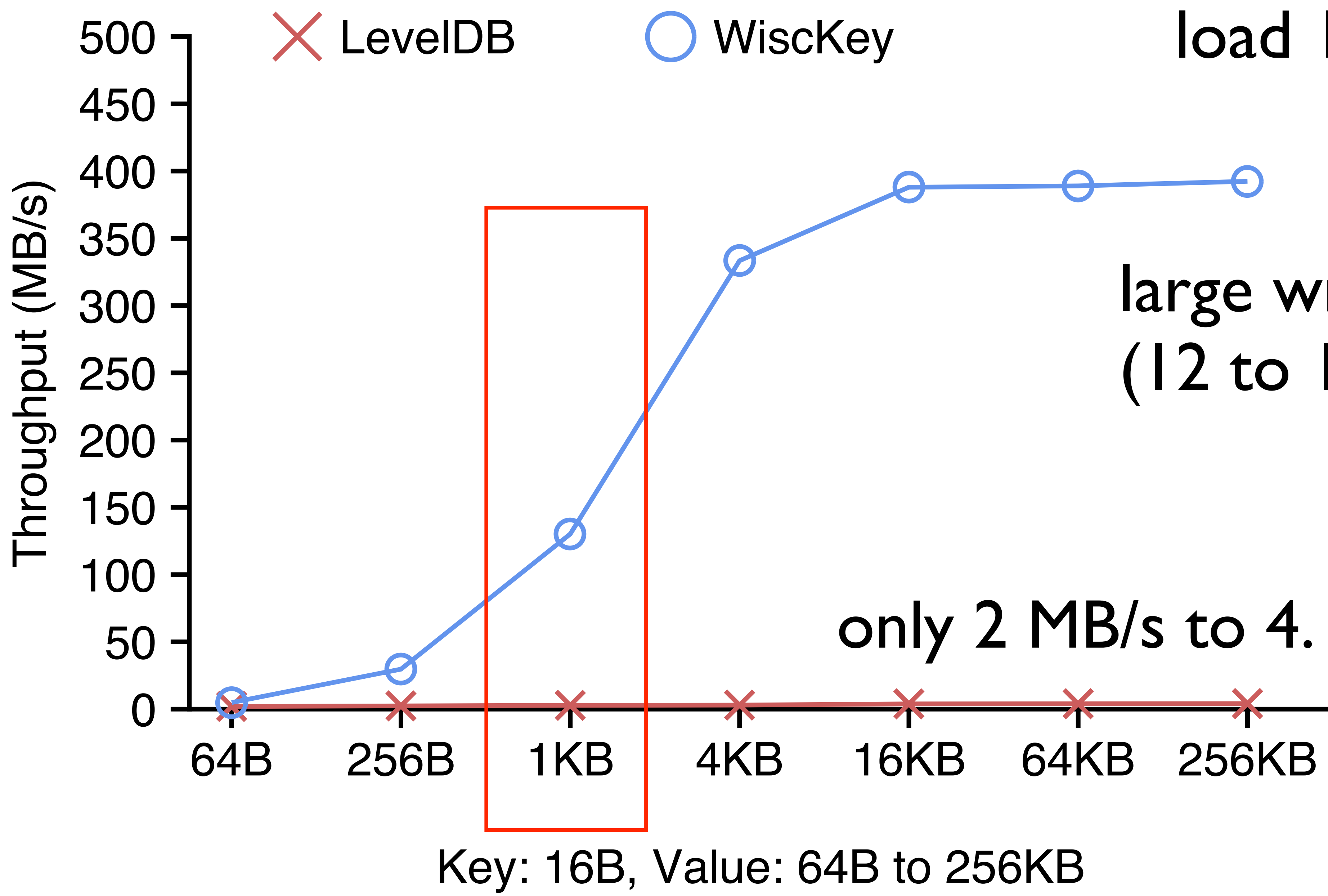

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LevelDB

limits of files	num of files
L0	9
L1 (5)	30
L2 (50)	365
L3 (500)	2184
L4 (5000)	15752
L5 (50000)	23733
L6 (500000)	0

LevelDB

limits of files	num of files
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Large LSM-tree:

Intensive compaction

➡ repeated reads/writes

➡ stall foreground I/Os

Many levels

➡ travel several levels for each lookup

	LevelDB	WiscKey
limits of files	**num of files**	**num of files**
L0	9	7
L1 (5)	30	11
L2 (50)	365	127
L3 (500)	2184	460
L4 (5000)	15752	0
L5 (50000)	23733	0
L6 (500000)	0	0

	LevelDB	WiscKey
limits of files	**num of files**	**num of files**
L0	9	7
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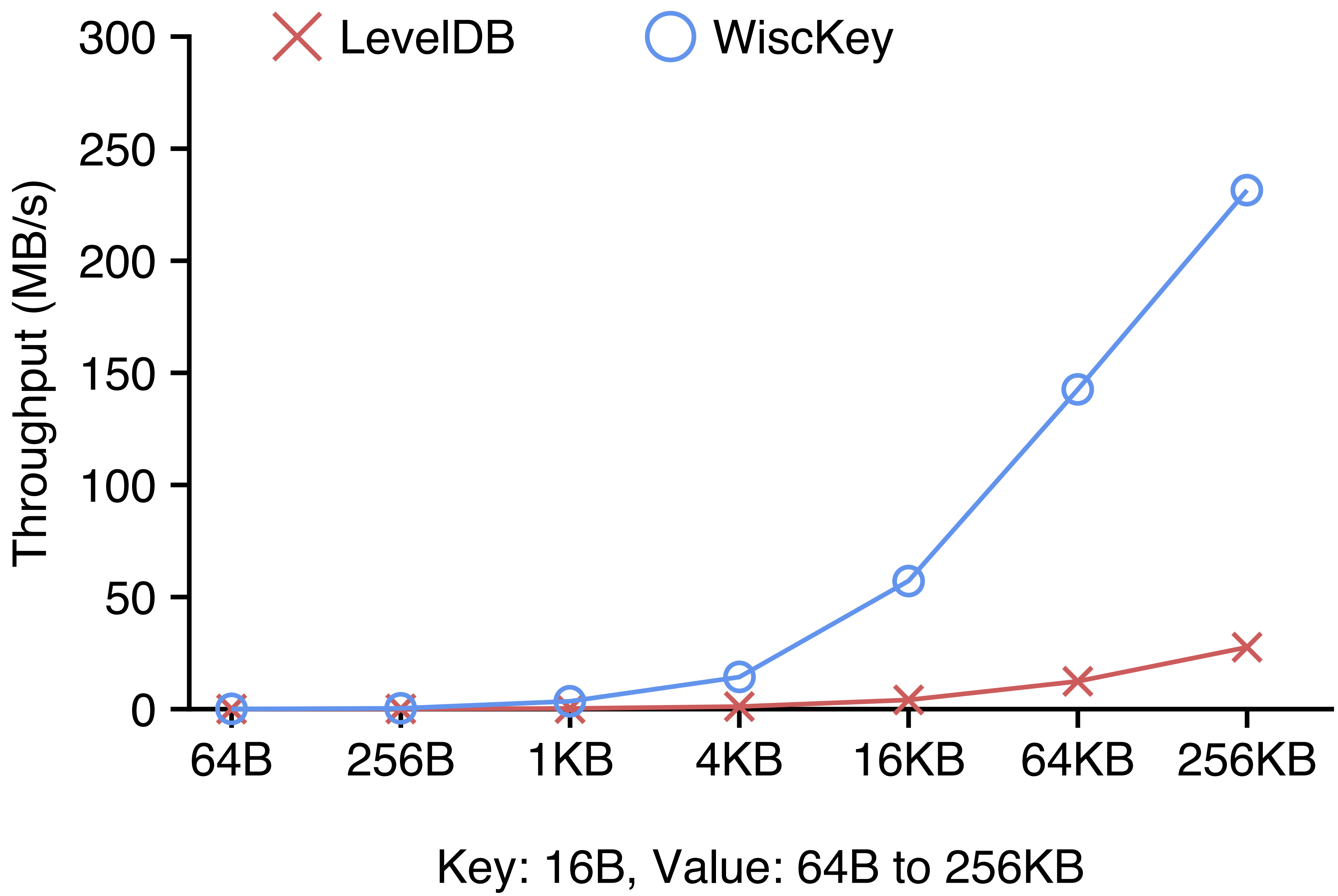
Small LSM-tree: less compaction, fewer levels to search, and better caching

Random Lookup



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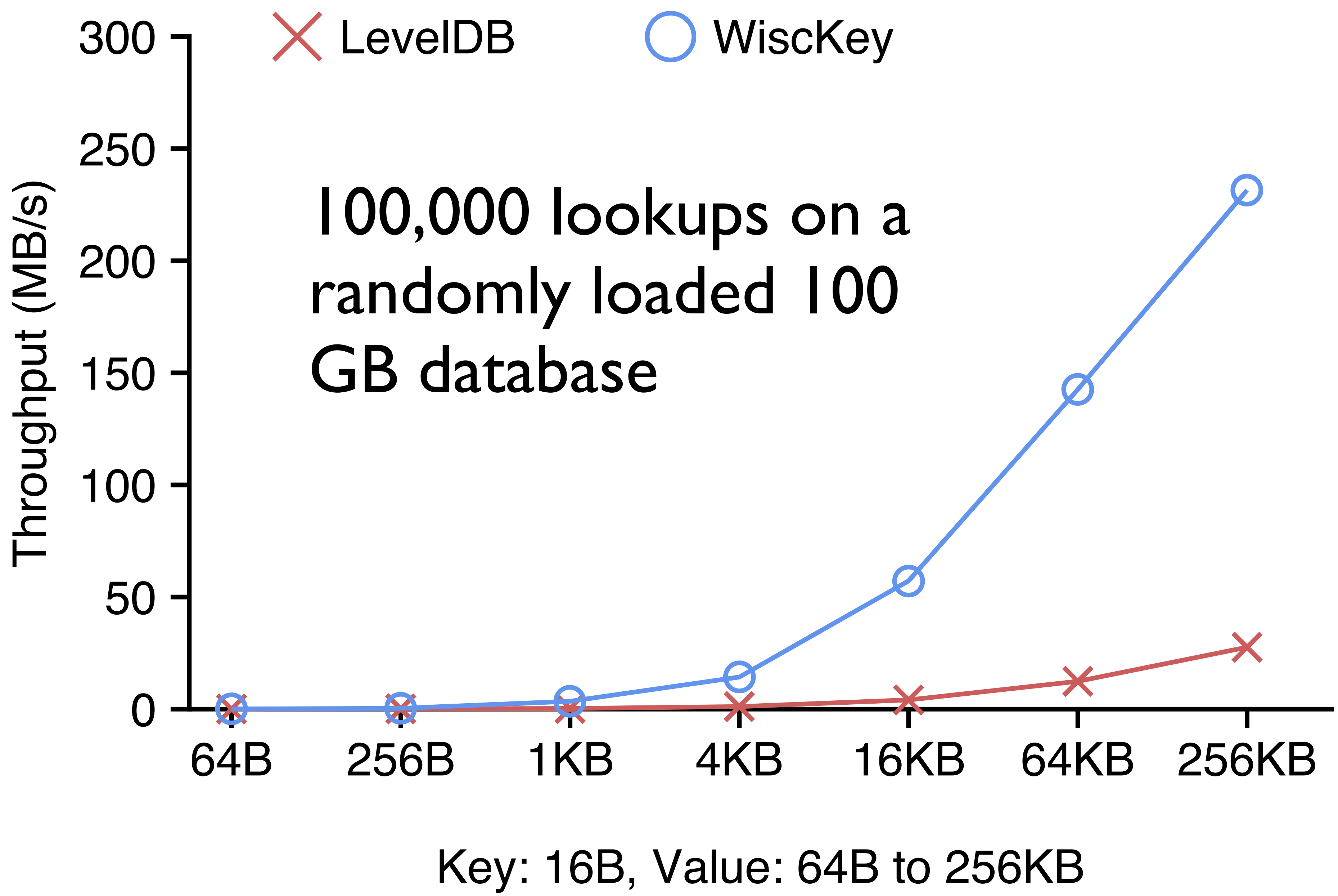

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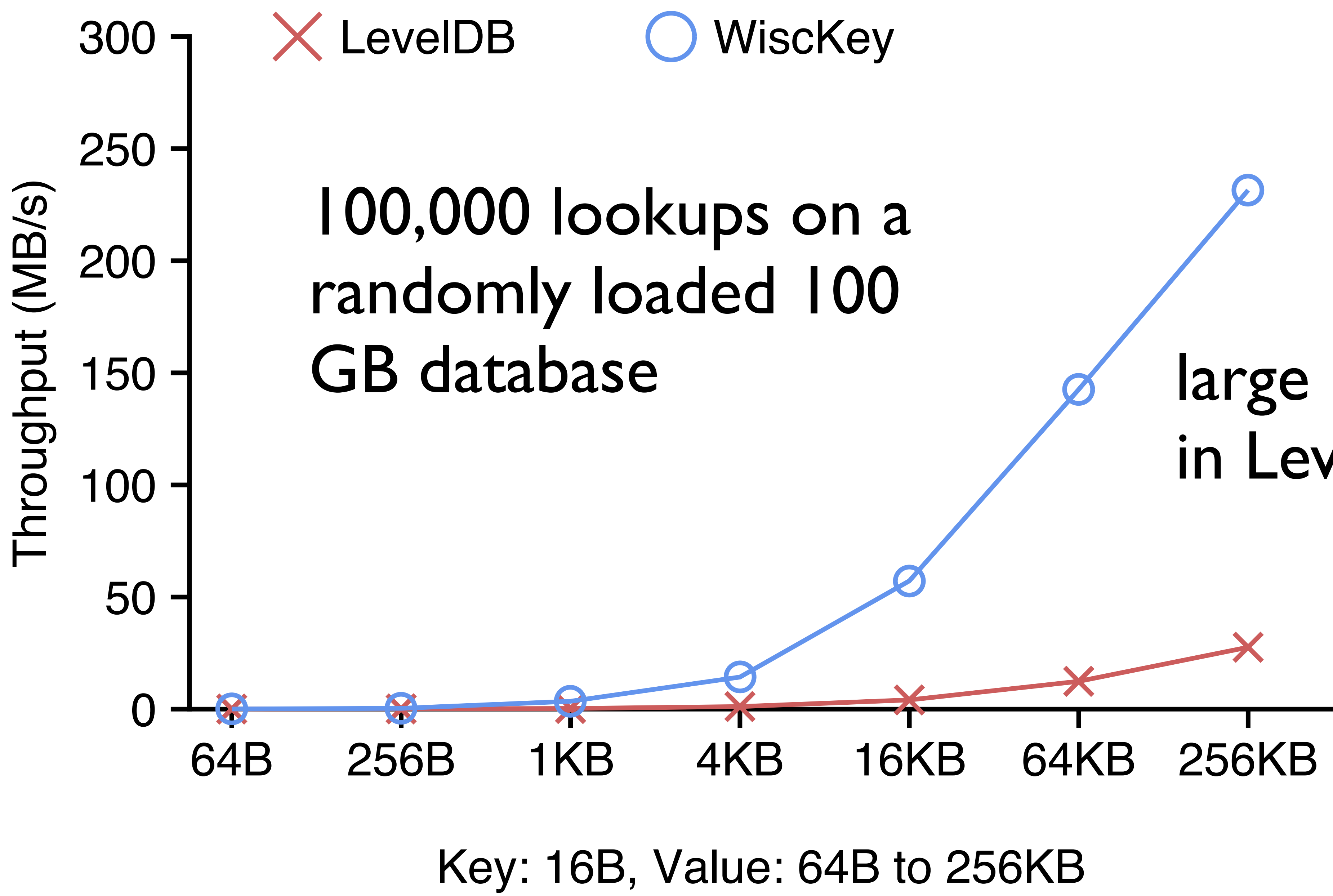
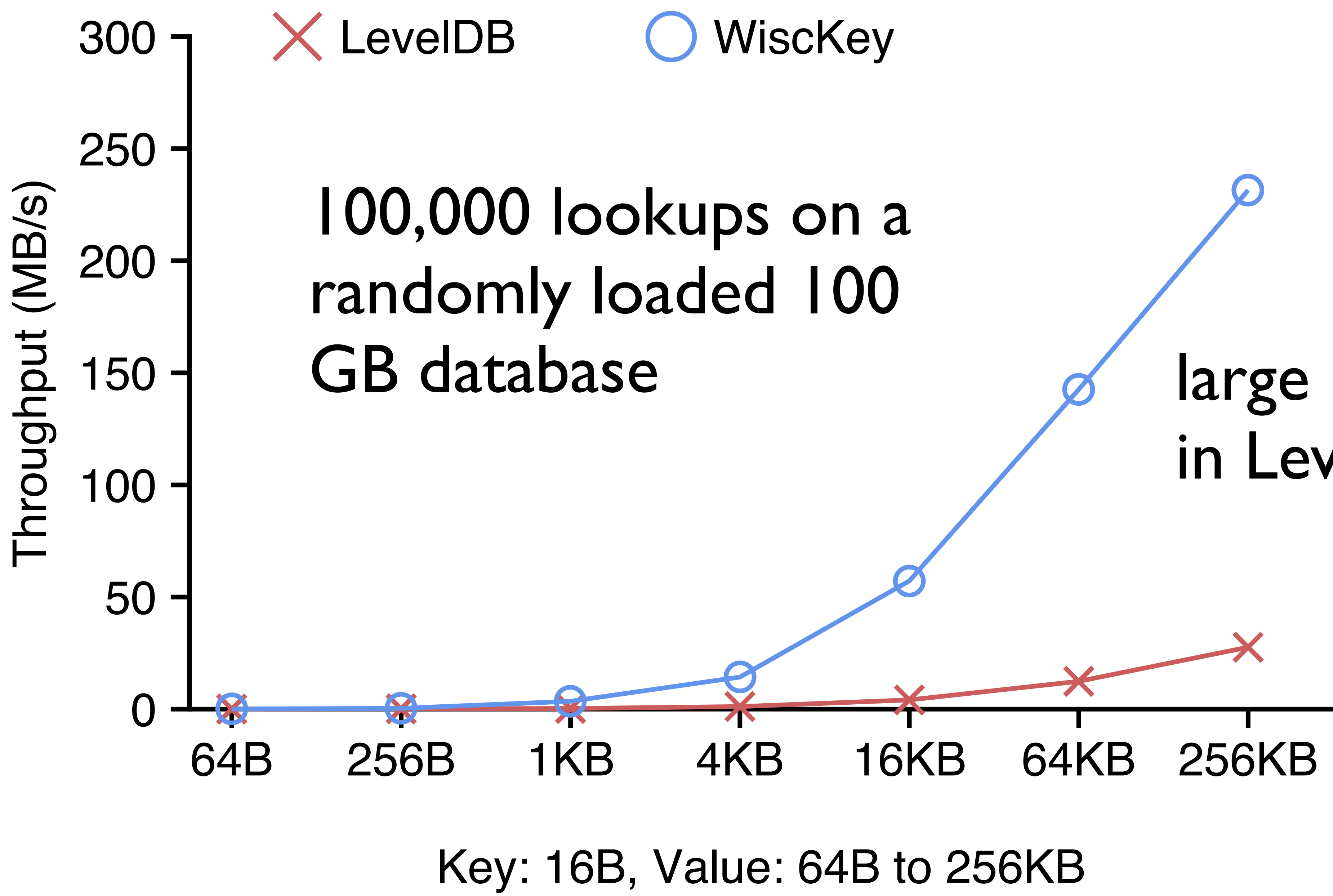


100,000 lookups on a randomly loaded 100 GB database

large read amplification in LevelDB

Random Lookup



large read amplification in LevelDB

Smaller LSM-tree in WiscKey leads to better lookup performance (1.6x - 14x)

Background

Key-Value Separation

Challenges and Optimizations

- Parallel range query
- Garbage collection
- LSM-log

Evaluation

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Parallel Range Query

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SSD read performance

- sequential, random, parallel

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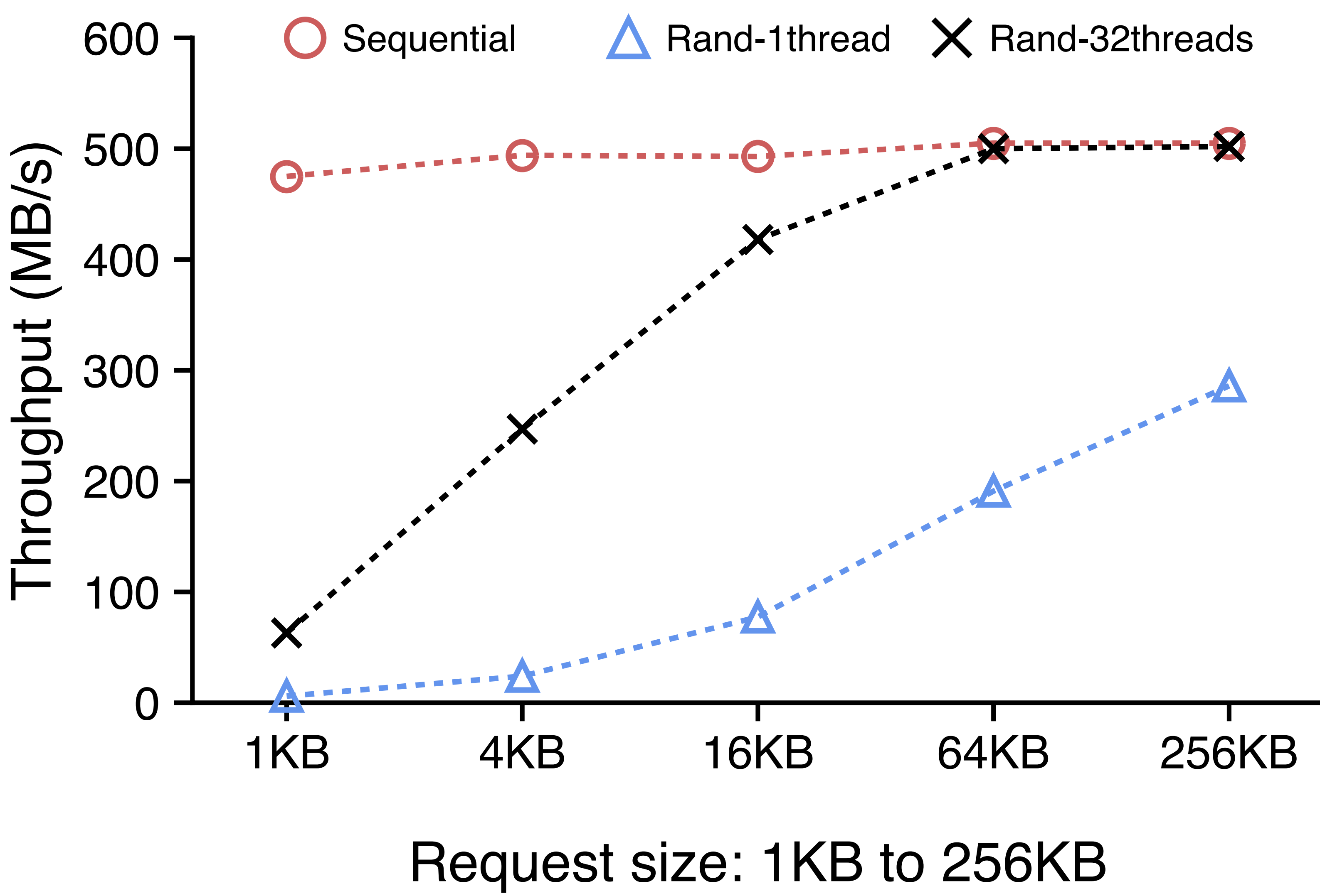

SSD: Samsung 840 EVO 500GB

Reads on a 100GB file on ext4

Parallel Range Query

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Challenge

- sequential reads in LevelDB
- read keys and values separately in WiscKey

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Parallel range query

- leverage parallel random reads of SSDs

Parallel Range Query

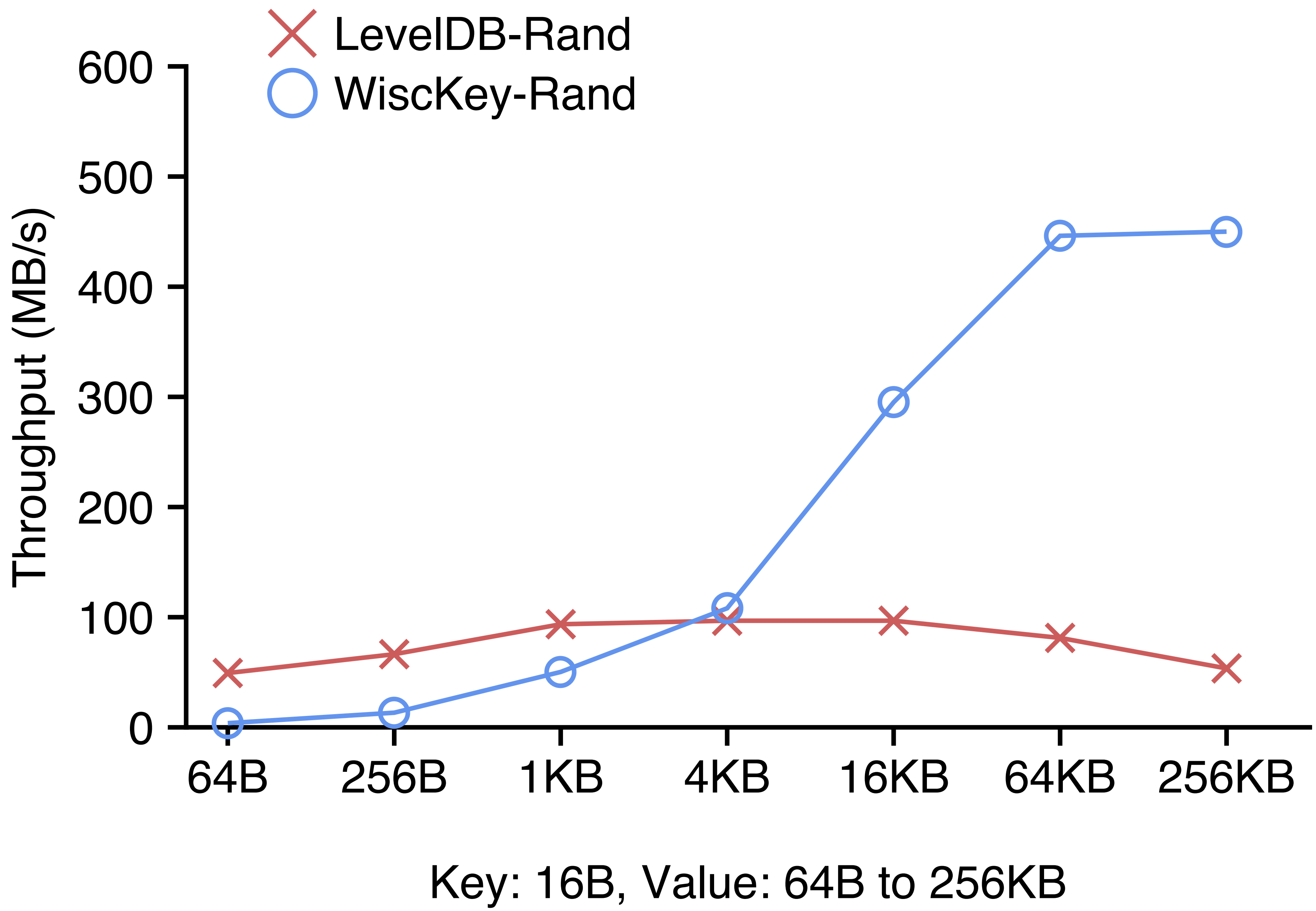
Challenge

- sequential reads in LevelDB
- read keys and values separately in WiscKey

Parallel range query

- leverage parallel random reads of SSDs
- prefetch key-value pairs in advance
  - range query interface: seek(), next(), prev()
  - detect a sequential pattern
  - prefetch concurrently in background

Range Query



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WiscKey-Rand
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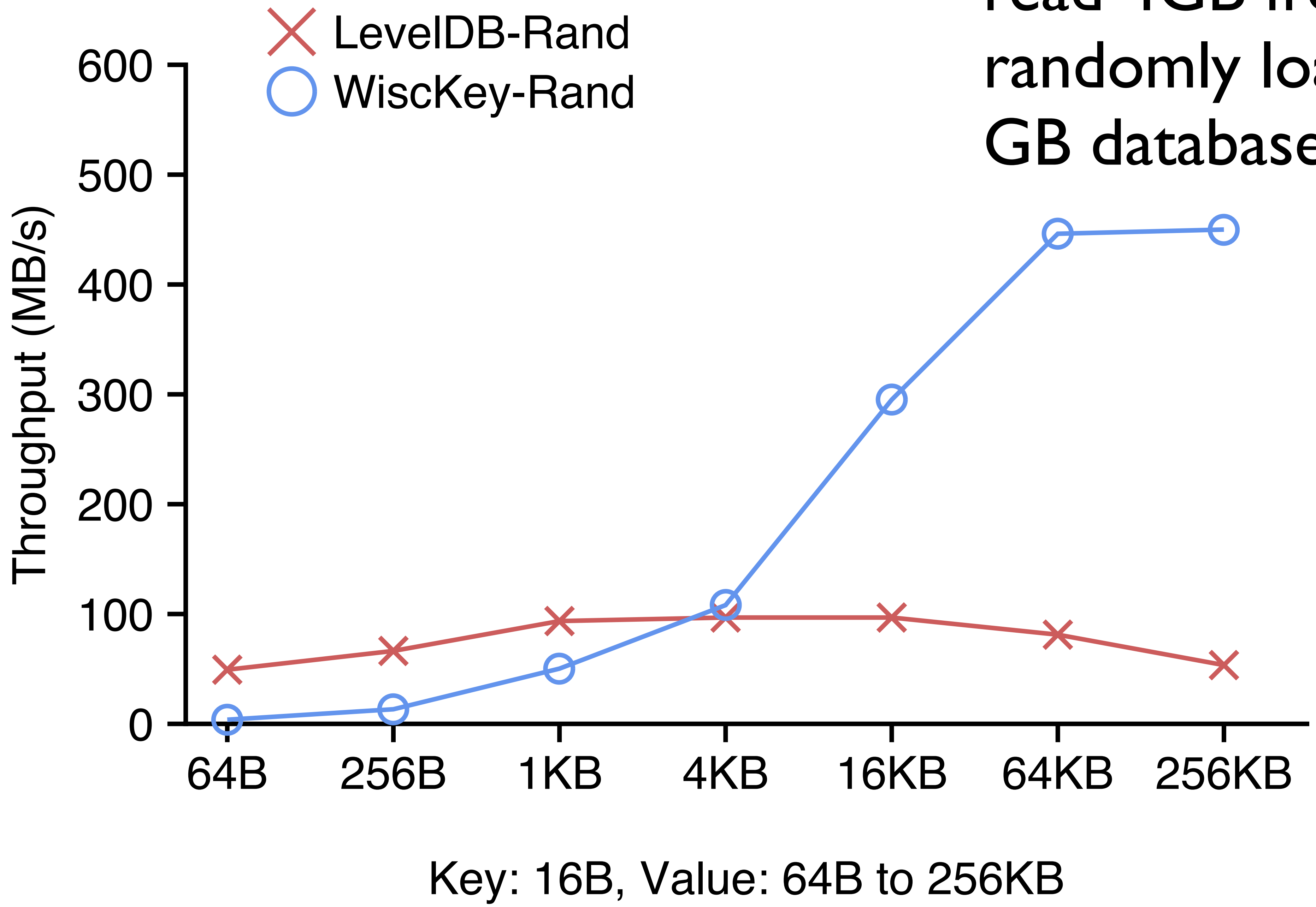
Range Query

read 4GB from a randomly loaded 100 GB database



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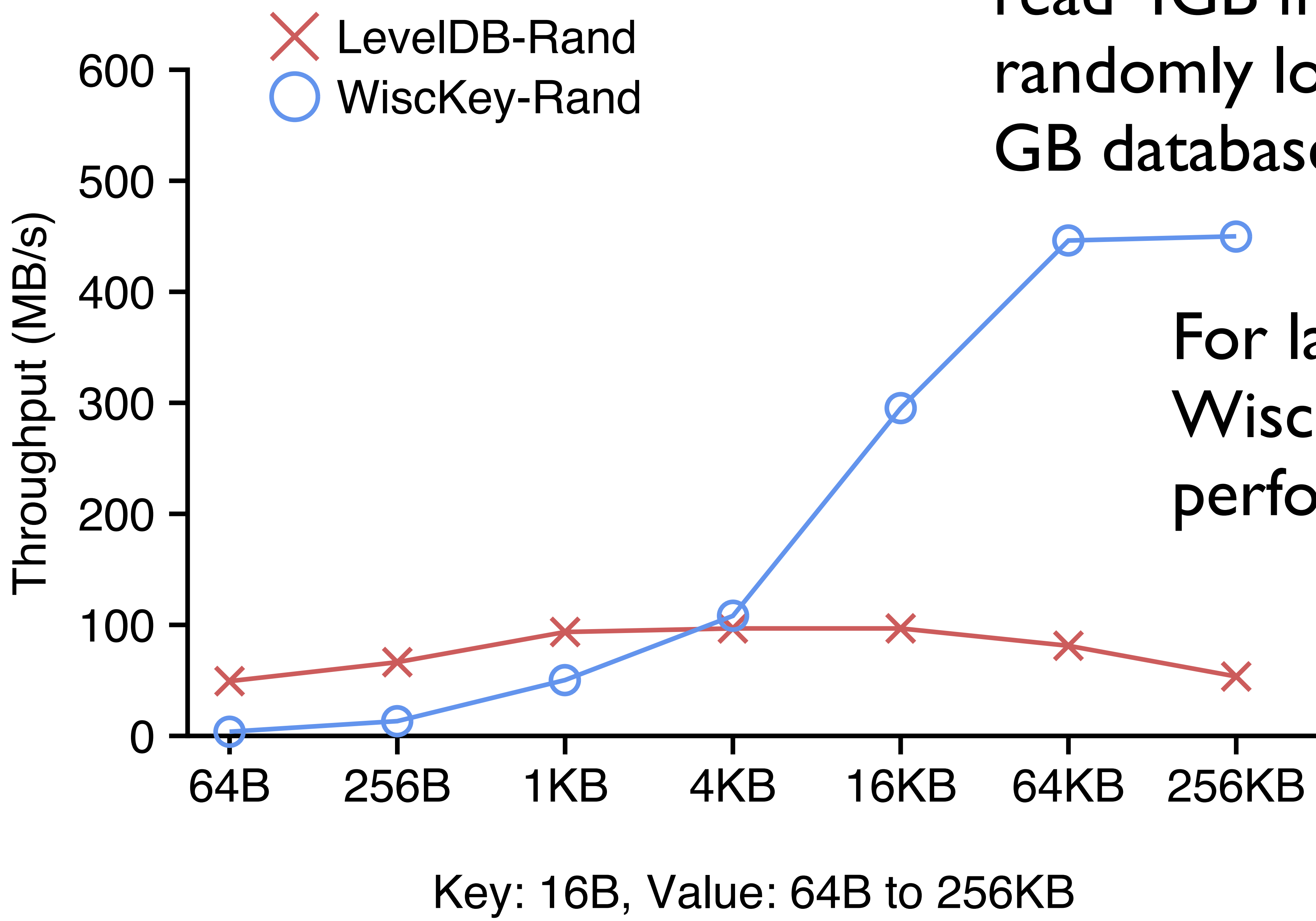

read 4GB from a randomly loaded 100 GB database

For large kv pairs, WiscKey can perform better

Range Query

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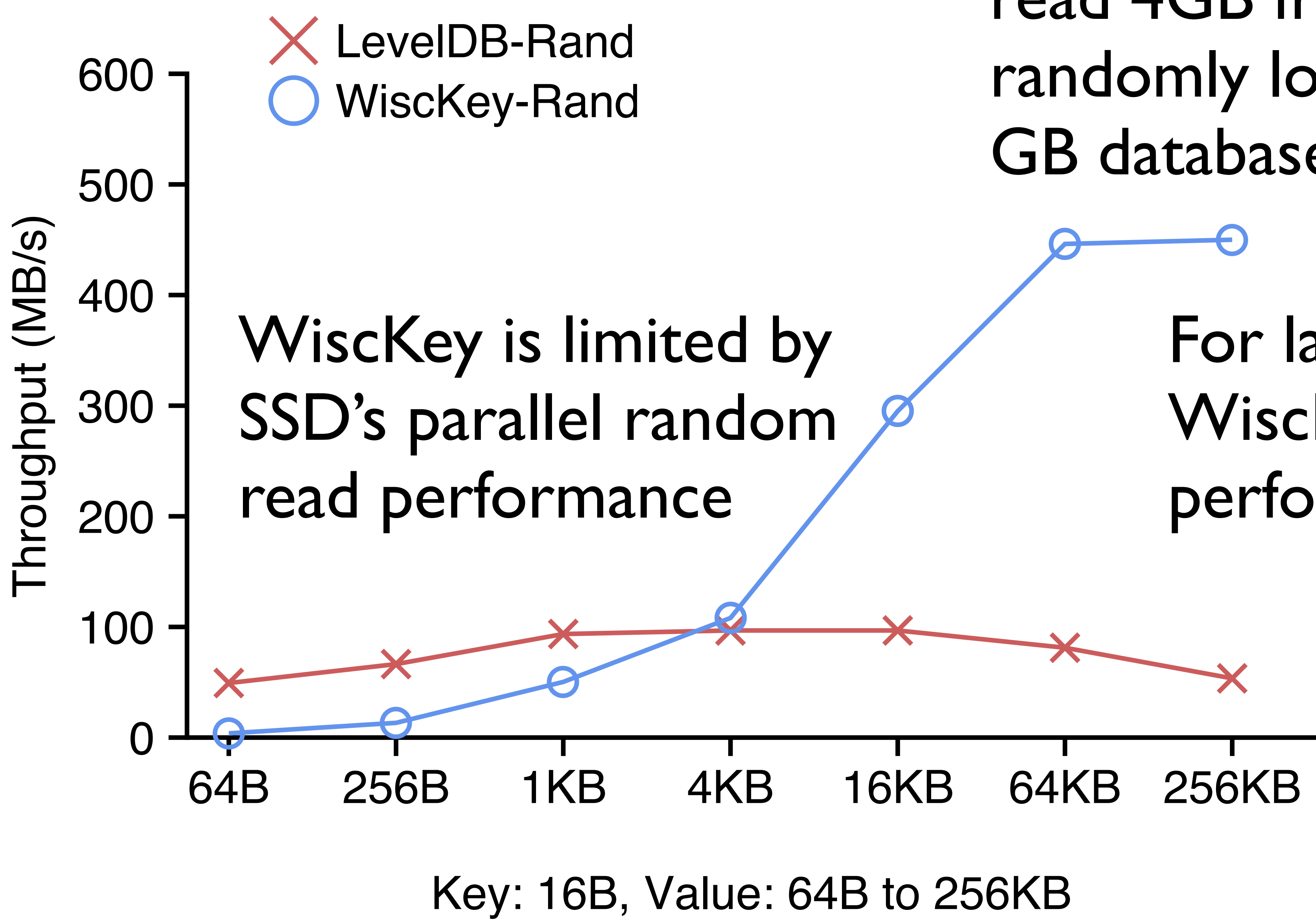

WiscKey is limited by SSD's parallel random read performance

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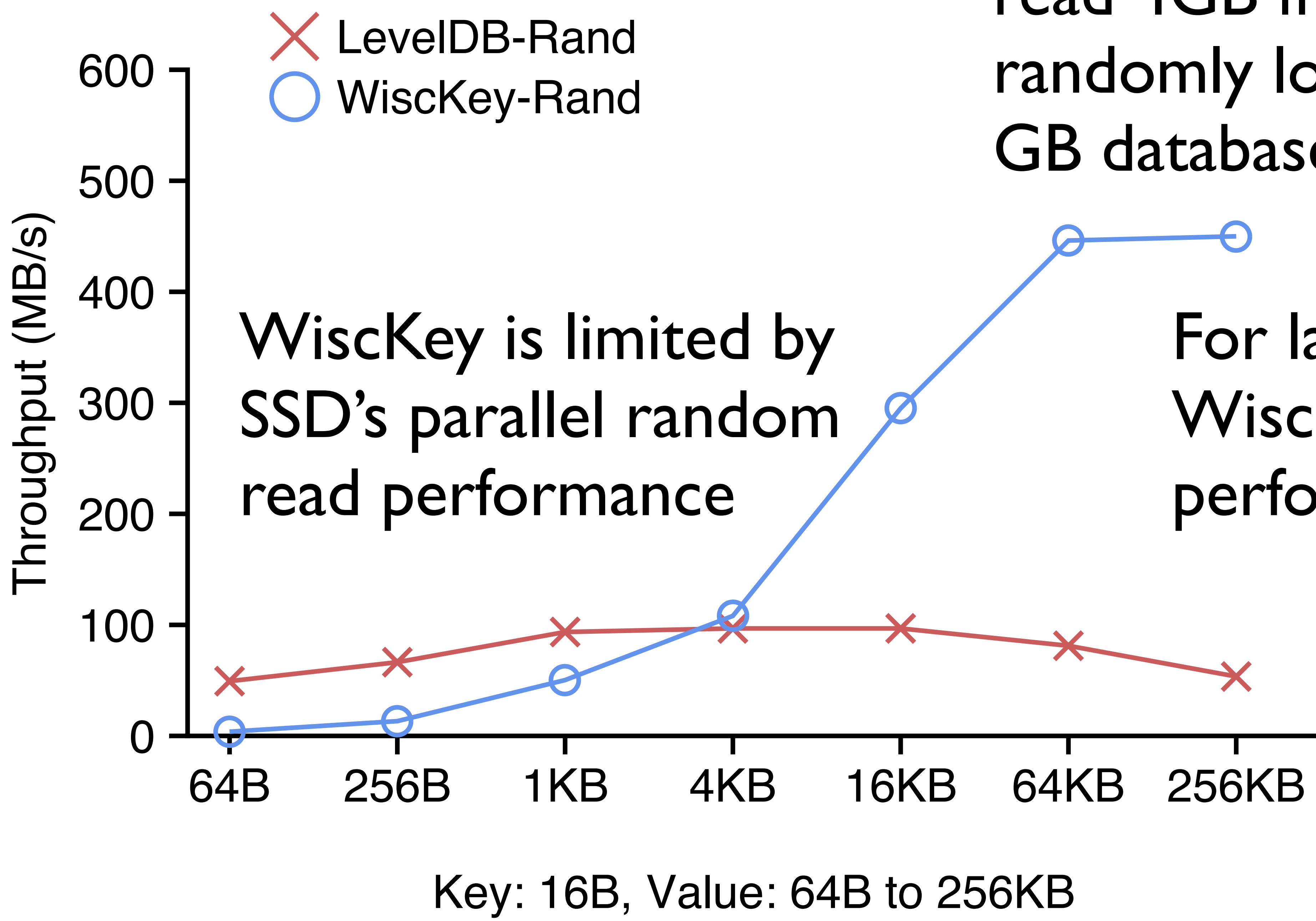

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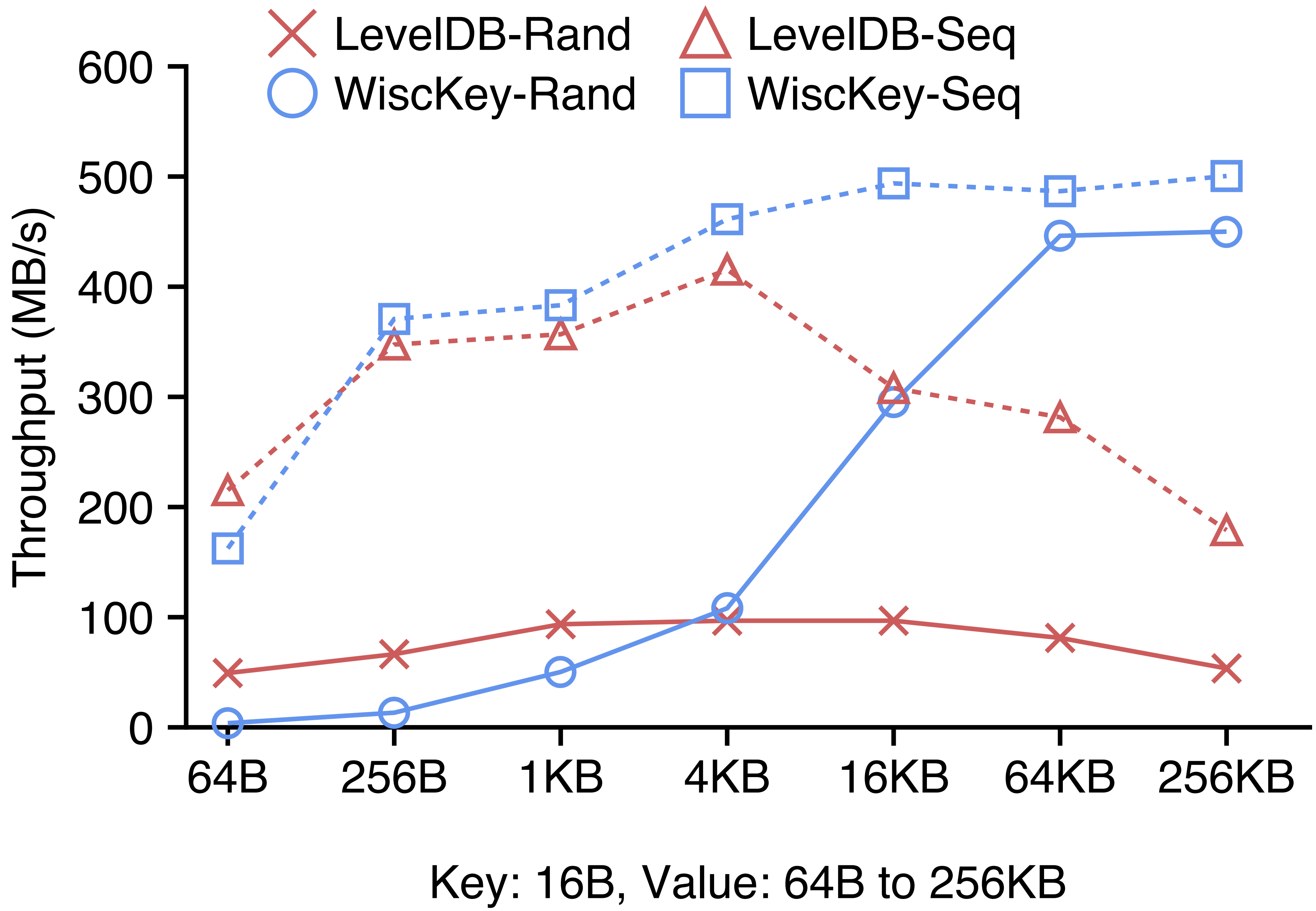
WiscKey is limited by SSD's parallel random read performance

For large kv pairs, WiscKey can perform better

Better for large kv pairs, but worse for small kv pairs on an unsorted database

Range Query



LevelDB-Rand
LevelDB-Seq
WiscKey-Rand
WiscKey-Seq
Throughput (MB/s)
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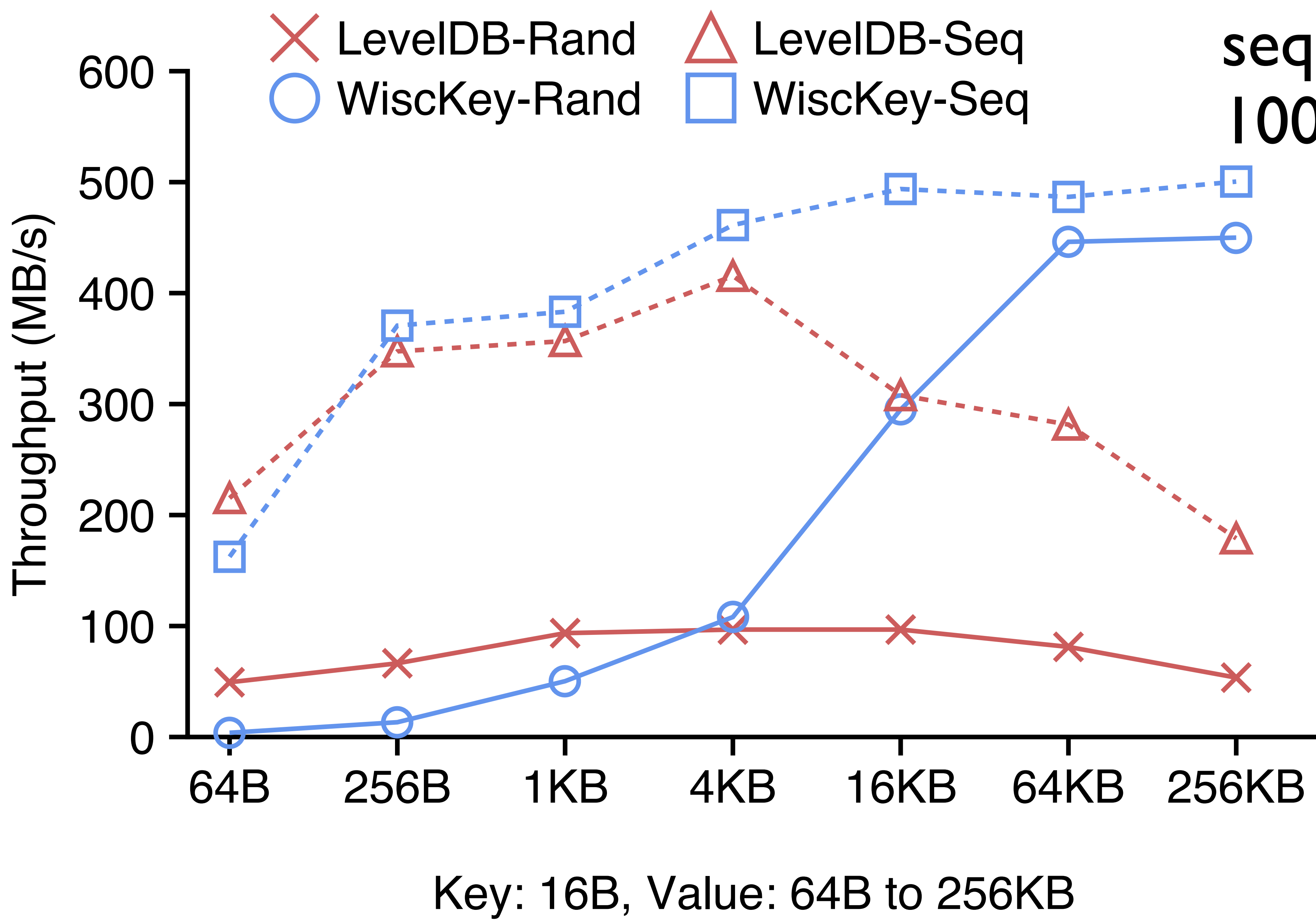
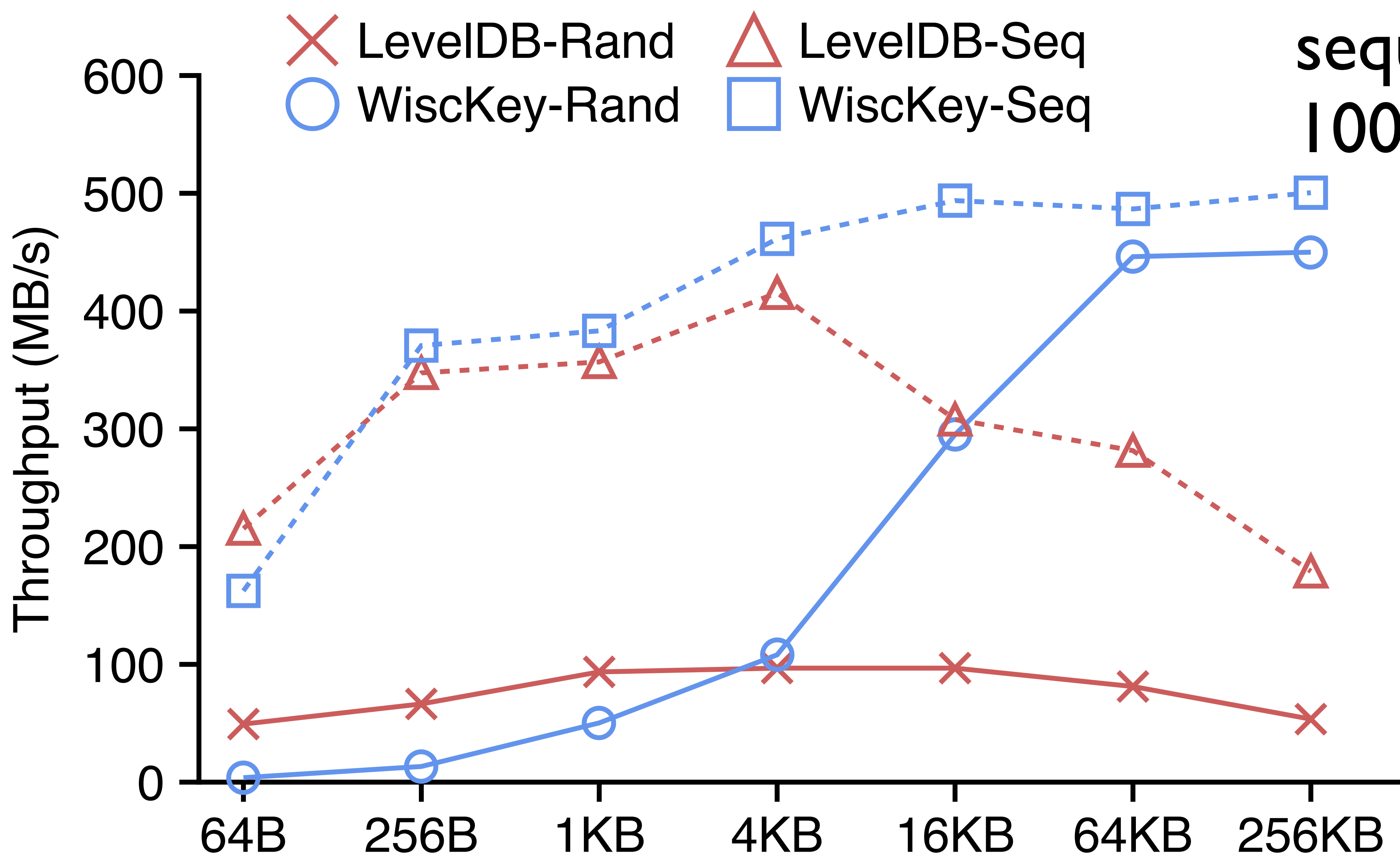


read 4GB from a sequentially loaded 100 GB database

Range Query

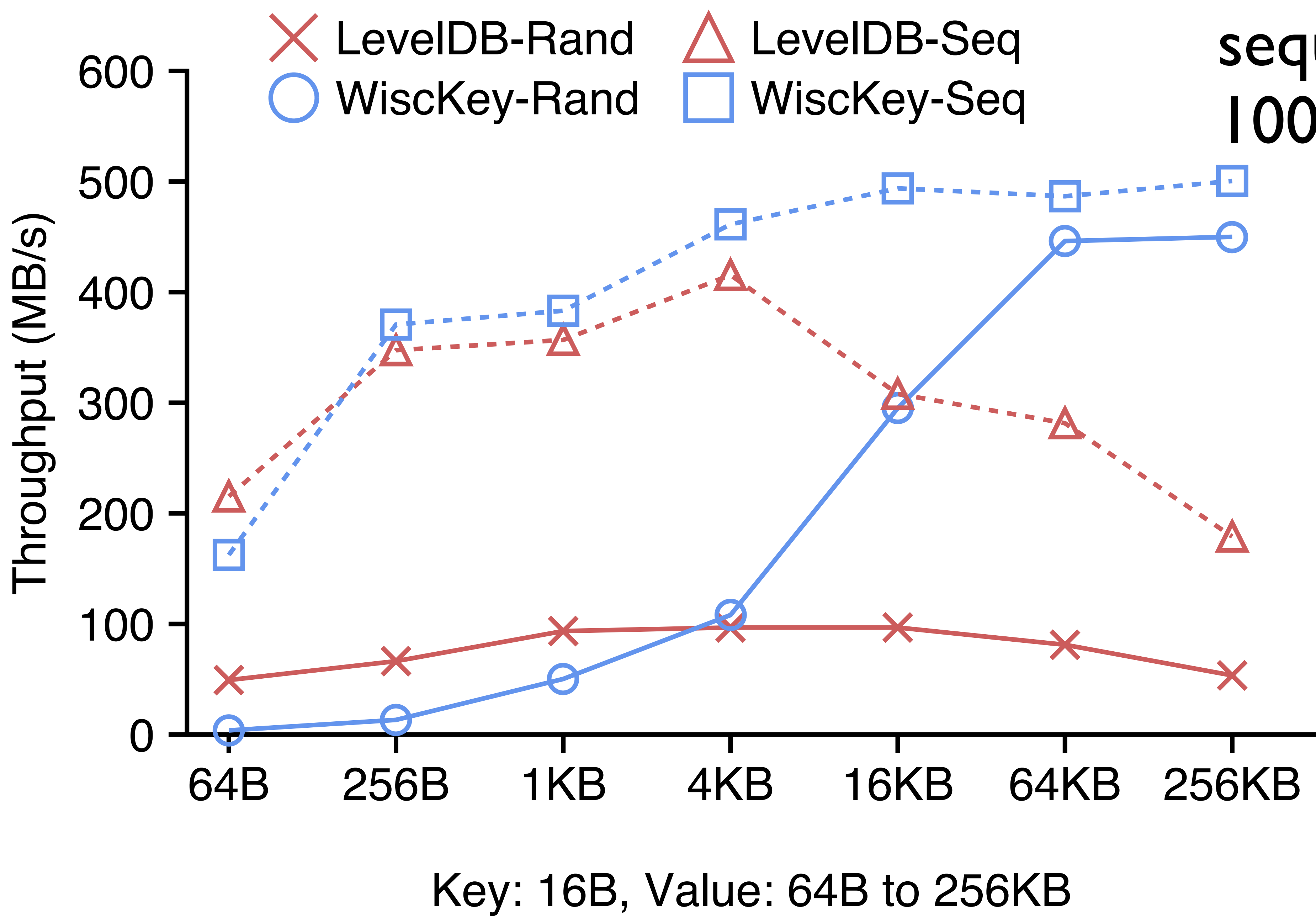


Key: 16B, Value: 64B to 256KB

read 4GB from a sequentially loaded 100 GB database

Both WiscKey and LevelDB read sequentially

Range Query



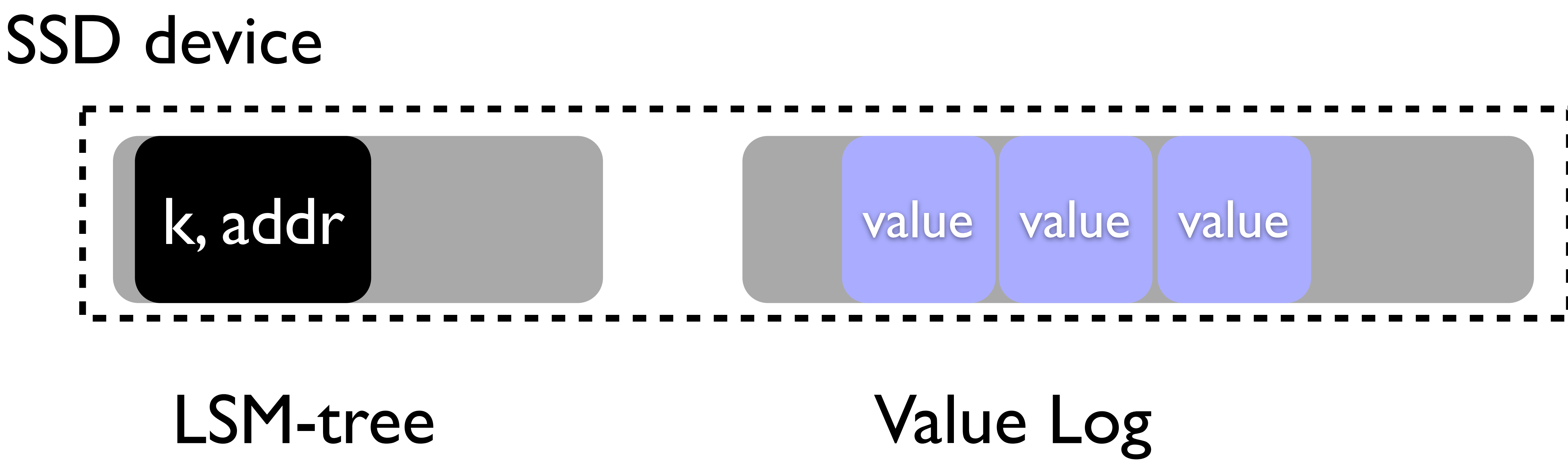
read 4GB from a sequentially loaded 100 GB database

Both WiscKey and LevelDB read sequentially

Sorted databases help WiscKey's range query

Optimizations

Optimizations

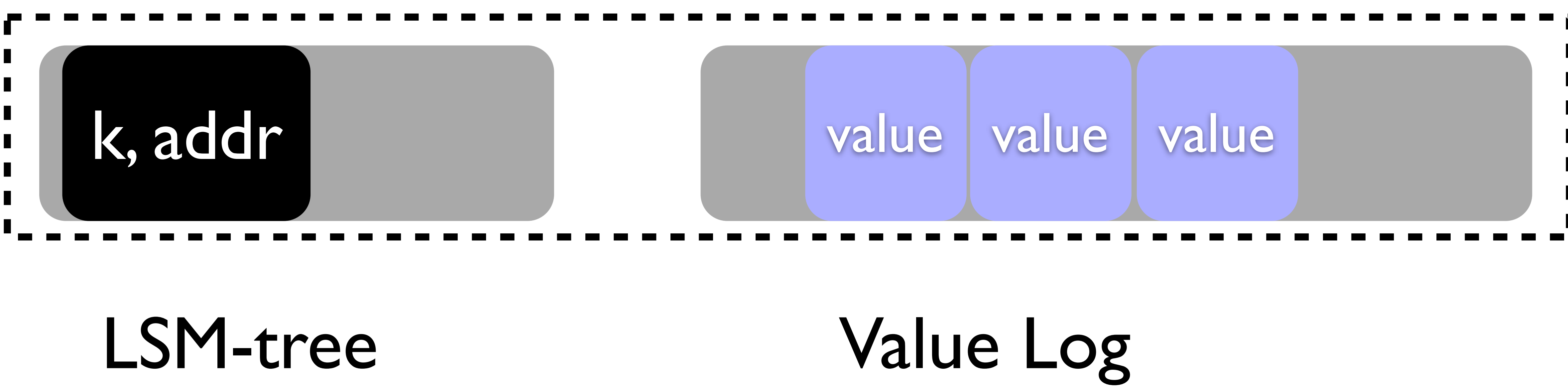


Optimizations

Online and light-weight garbage collection

- append (ksize, vsize, key, value) in value log

SSD device



Optimizations

Online and light-weight garbage collection

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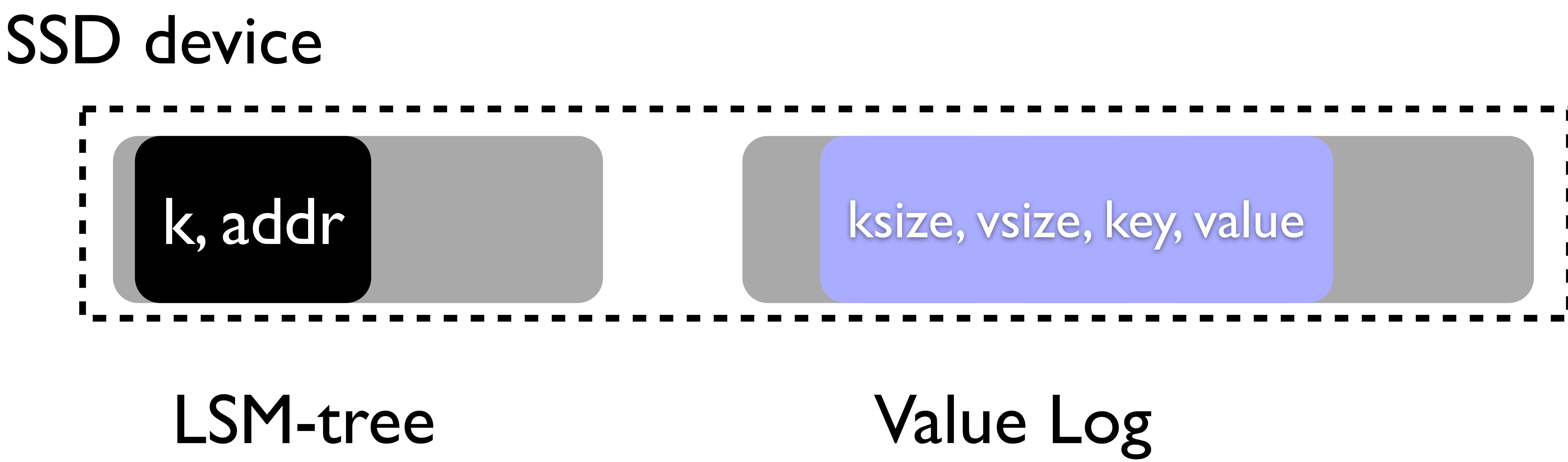

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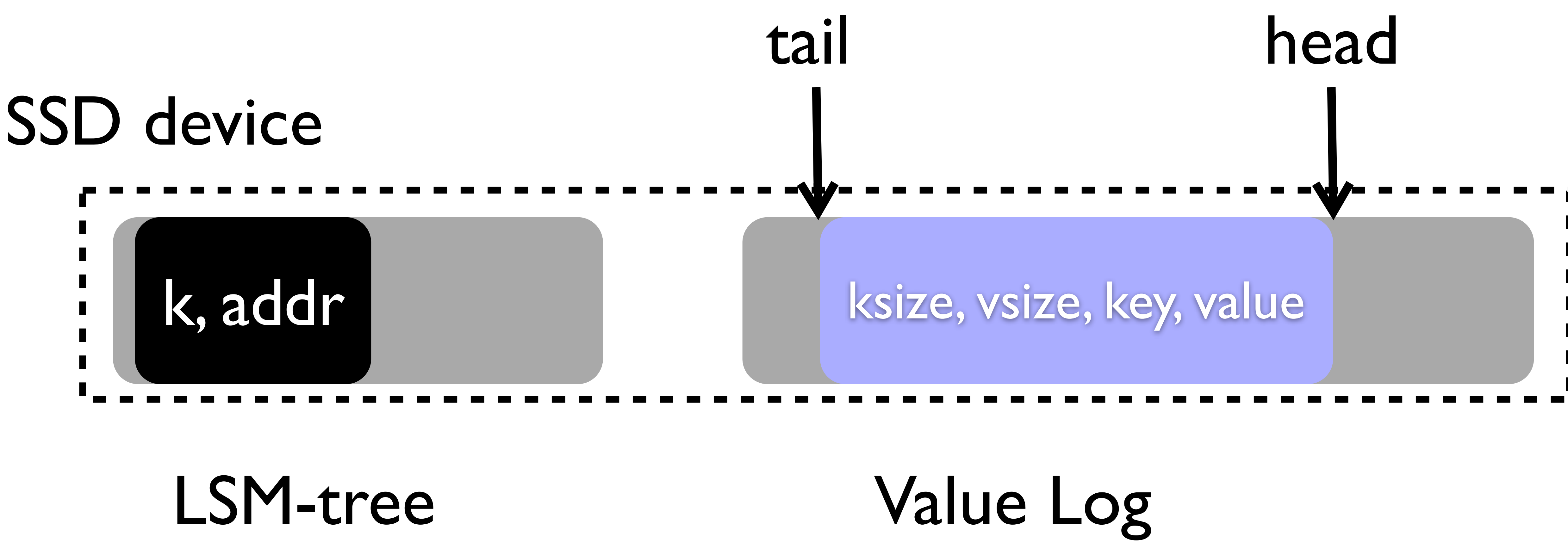

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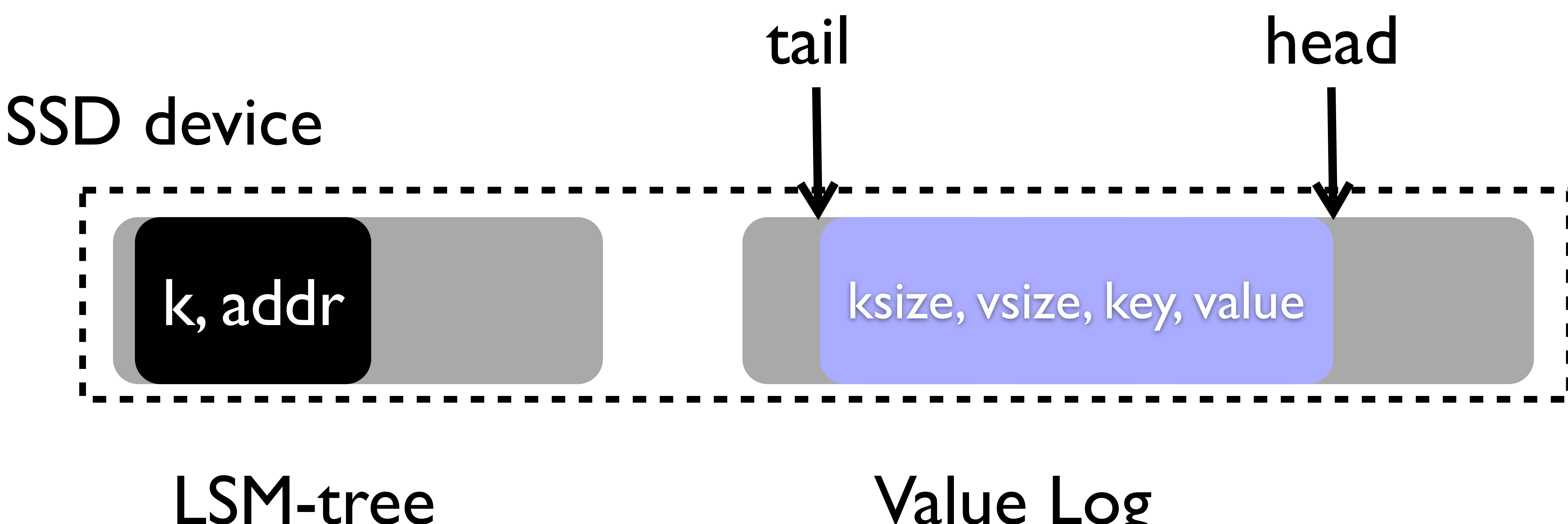
Remove LSM-tree log in WiscKey



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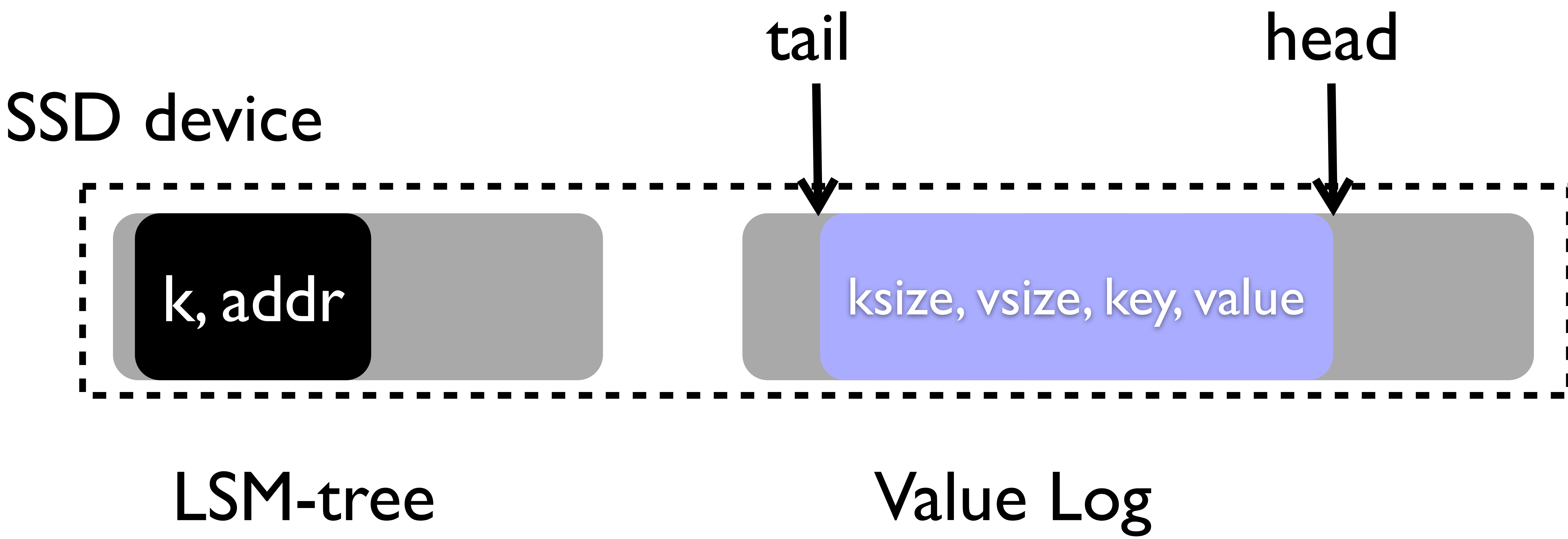

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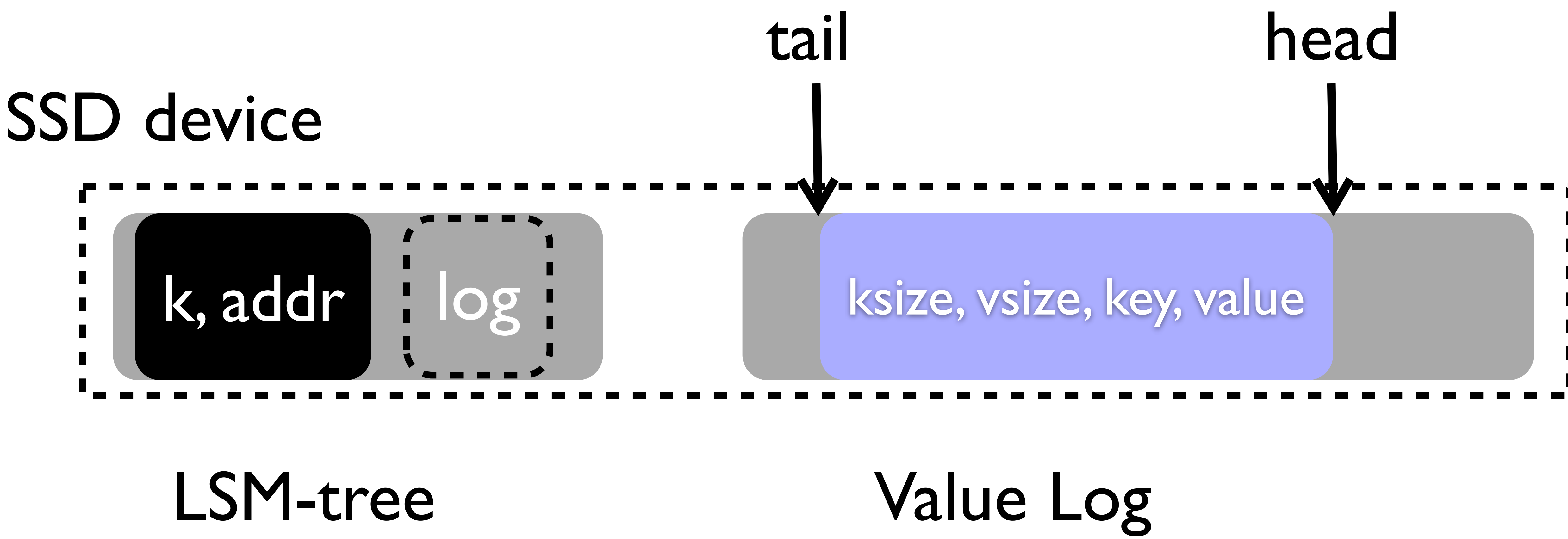

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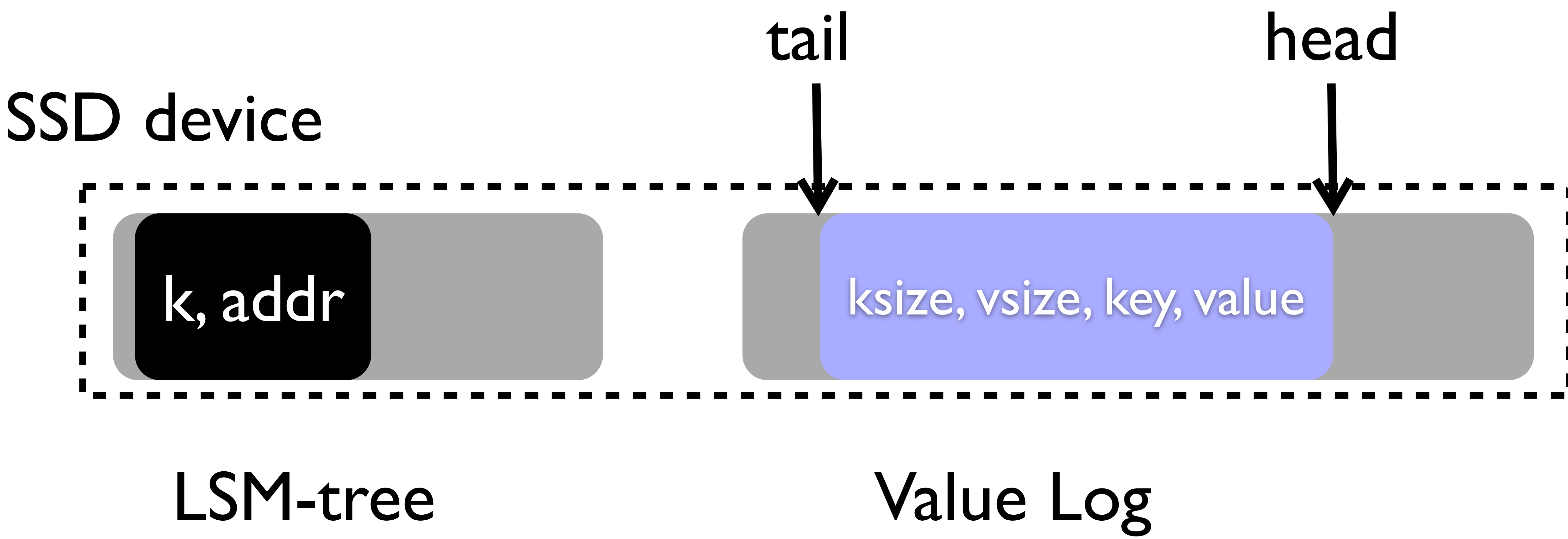

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- ➡ a separate vLog file for values
- ➡ modify I/O paths to separate keys and values
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File-system support

- fadvise to predeclare access patterns
- hole-punching to free space

Background

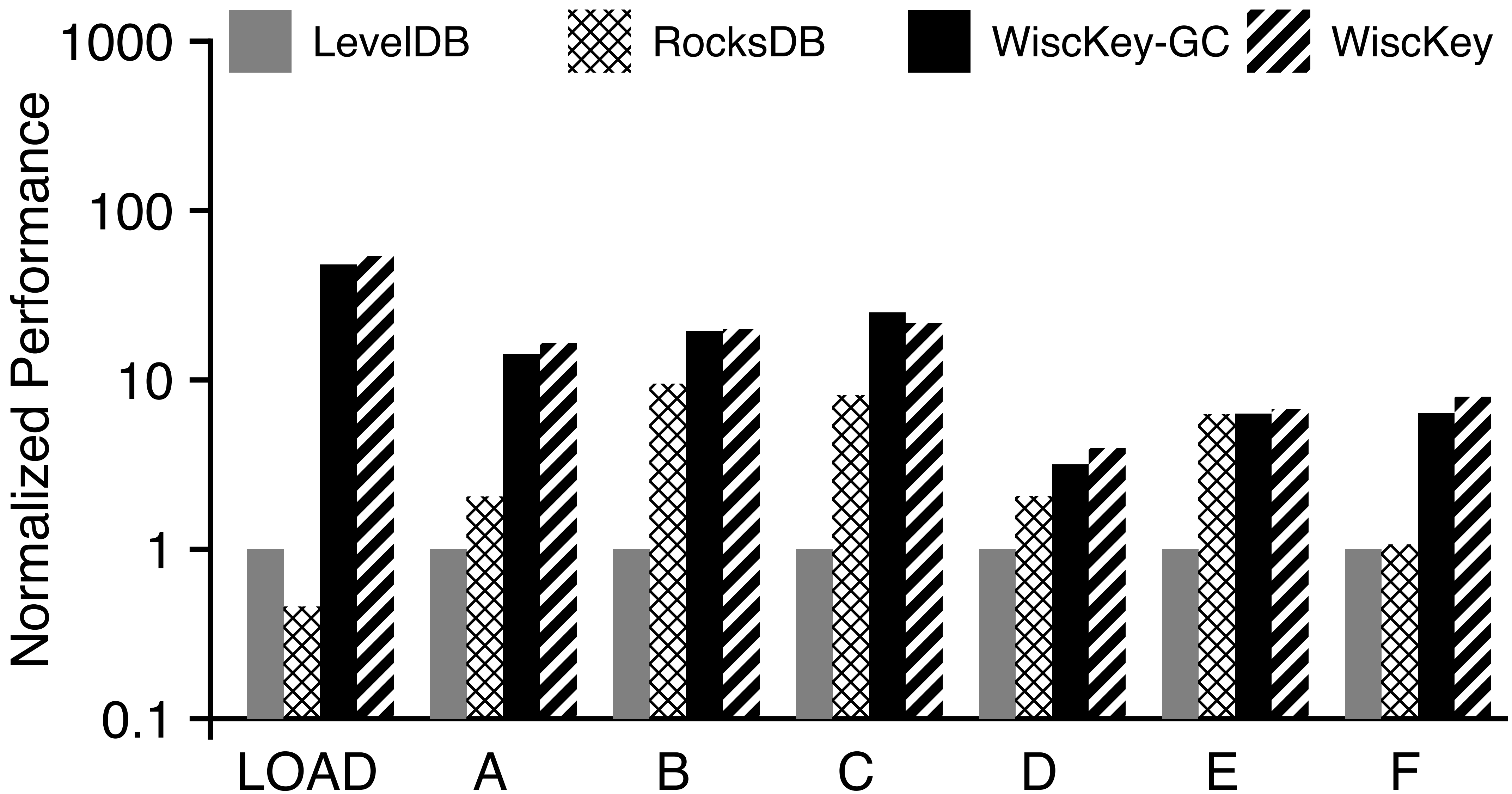
Key-Value Separation

Challenges and Optimizations

Evaluation

Conclusion

YCSB Benchmarks



A	B	C	D	E	F
50% R 50% U	95% R 5% U	100% R	95% R 5% I	95% S 5% I	50% R 50% RMW

Key size: 16B, Value size: 1KB

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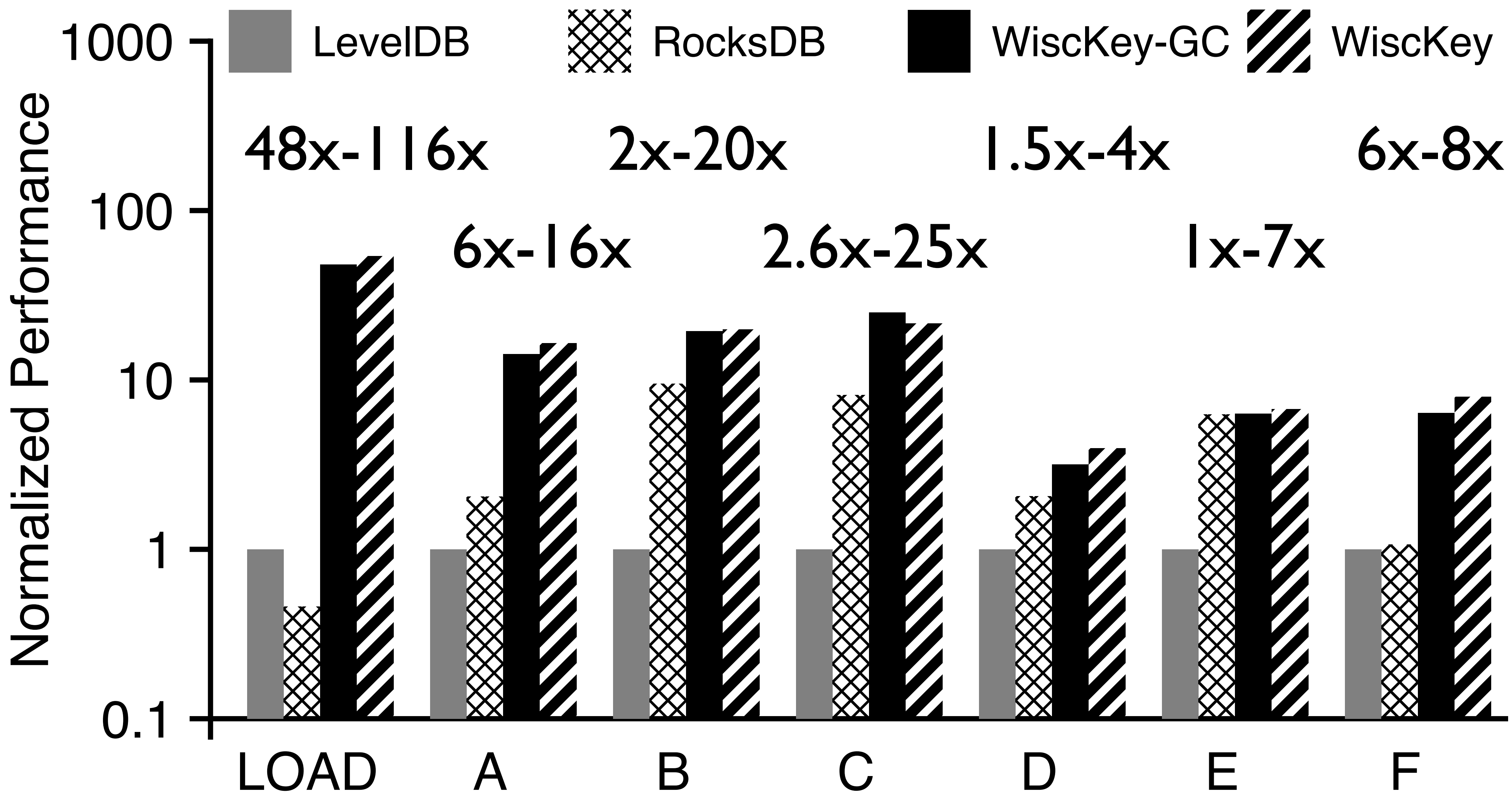

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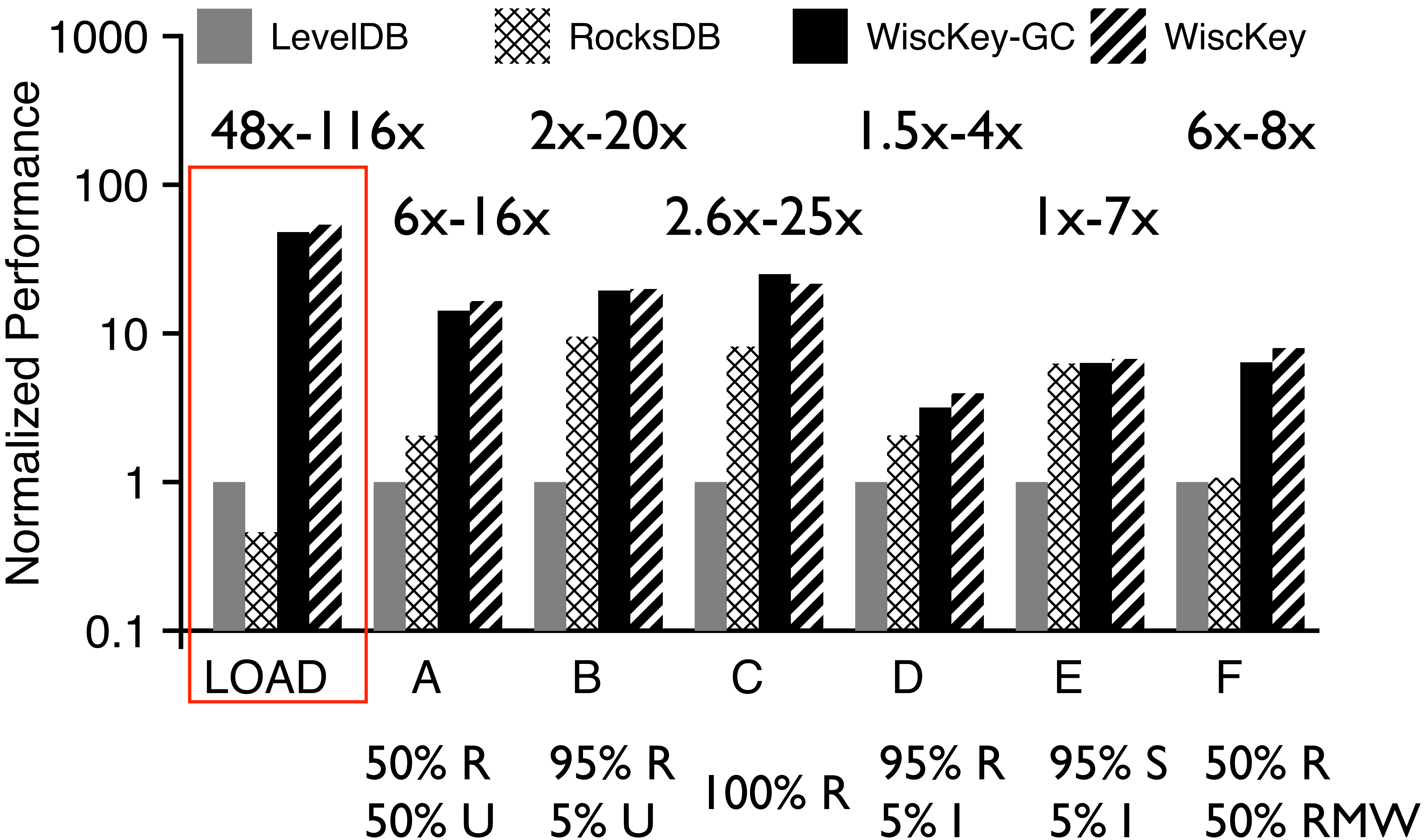

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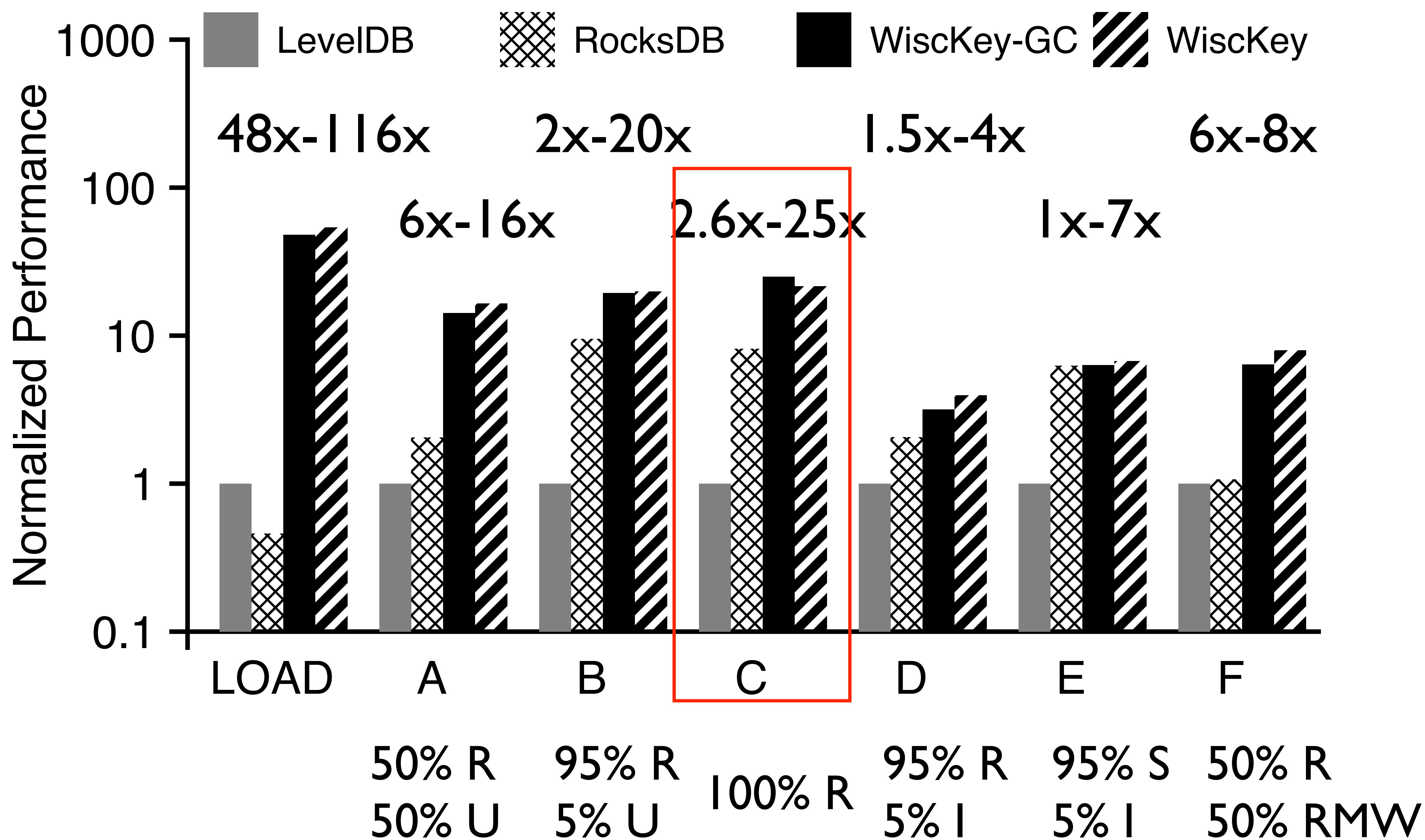

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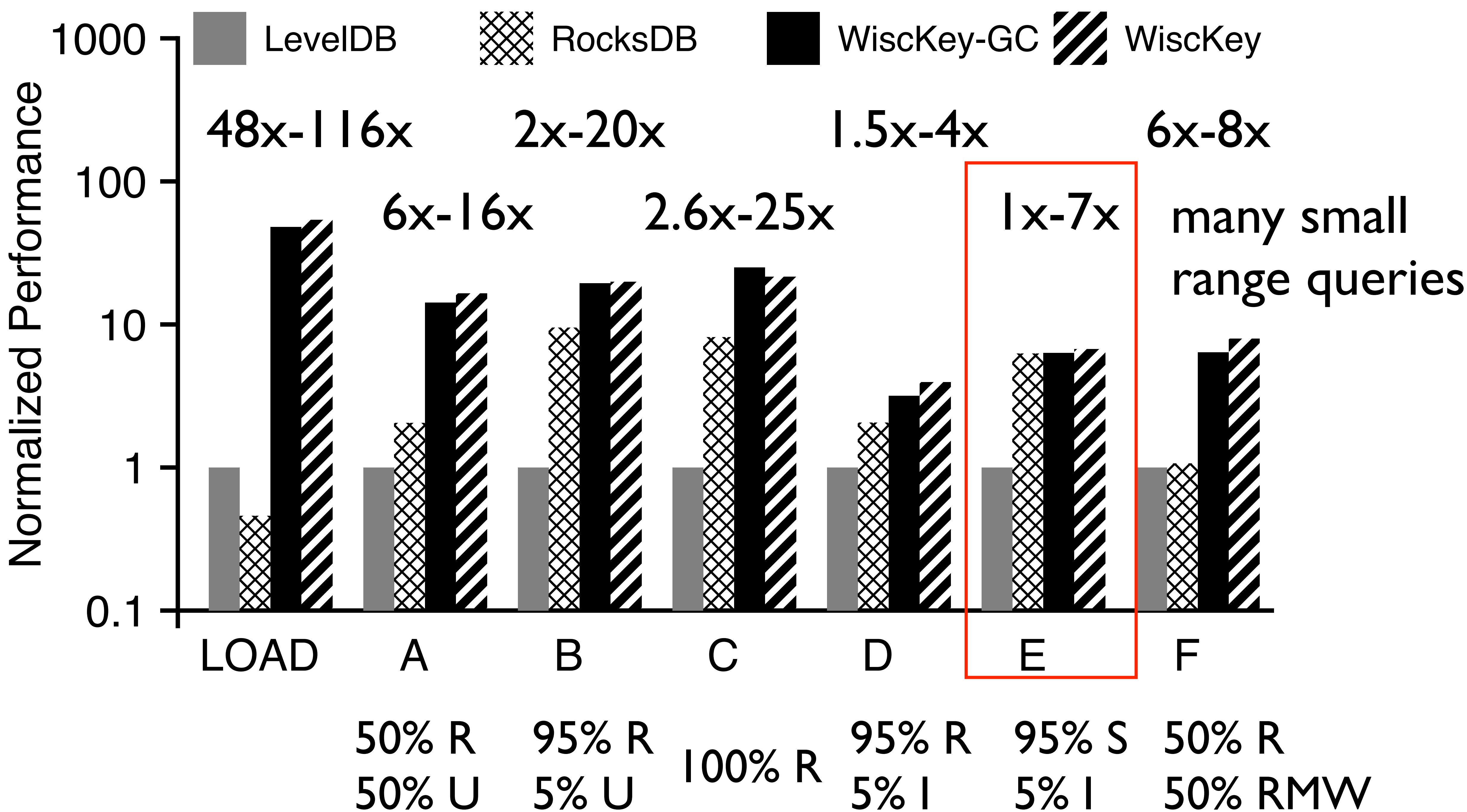

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Transition to new storage hardware

- understand and leverage existing software
- explore new designs to utilize the new hardware
- get the best of two worlds