Anatomy of LSM Memory Buffer: Insights & Implications

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Subhadeep Sarkar

Brandeis UNIVERSITY

Santiago, Chile, 2024

dbtest.io

LSM-tree

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Log Structured Merge-tree

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Log Structured Merge-tree

The Log-Structured Merge-Tree (LSM-Tree) 1996

Patrick O'Neil[1], Edward Cheng[2]
Dieter Gawlick[3], Elizabeth O'Neil[1]
To be published: Acta Informatica

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1996

LSM-tree

O'Neil et al.

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1996

LSM-tree

O'Neil et al.

2006

BigTable

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1996 — LSM-tree

O'Neil et al.

2006 — *BigTable*

2007 — APACHE HBASE

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1996 — LSM-tree

O'Neil et al.

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2010 — cassandra

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2011 — levelDB

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1996 — LSM-tree

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2006 — *BigTable*

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2011 — levelDB

2013 — RocksDB

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2011 — levelDB

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2024

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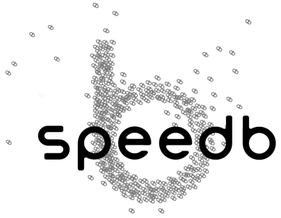
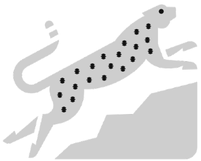
BigTable



LSM-tree



RocksDB

SCYLLA

DynamoDB

CockroachDB

influxdb

2024

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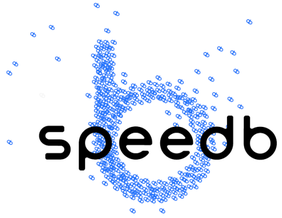
BigTable



LSM-tree

RocksDB

SCYLLA

DynamoDB

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influxdb

2024

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Why LSM ?

fast **writes**

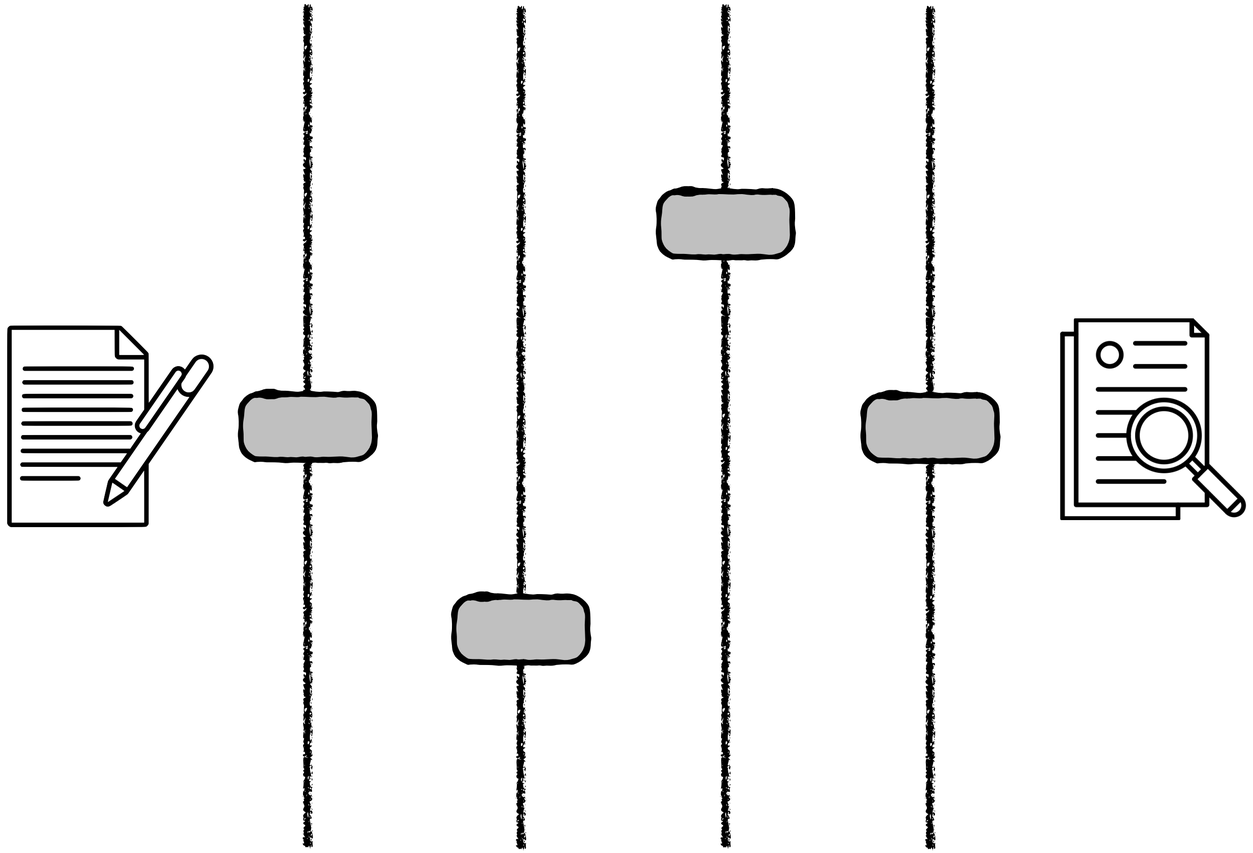
Why LSM ?

fast **writes**

competitive **reads**

Why LSM ?

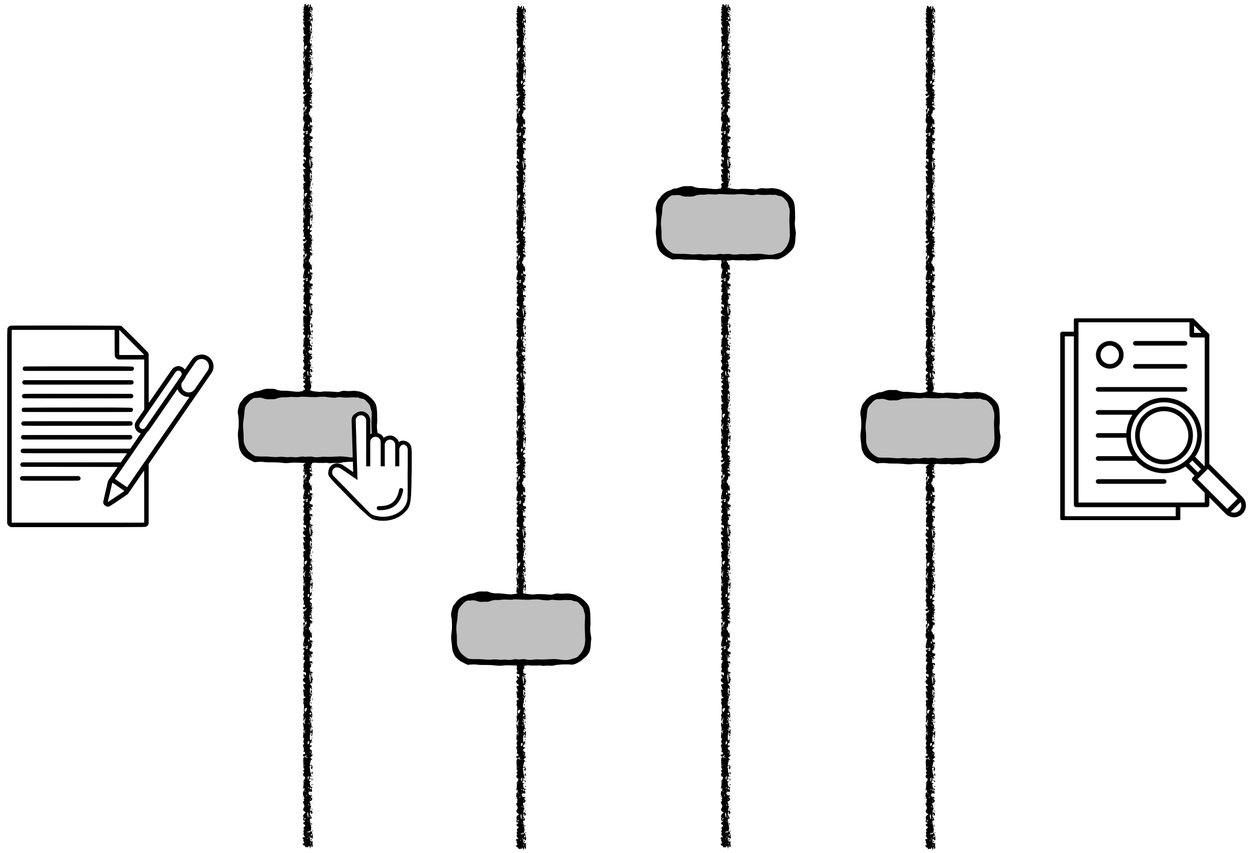
fast **writes**



competitive **reads**

Why LSM ?

fast **writes**



competitive **reads**

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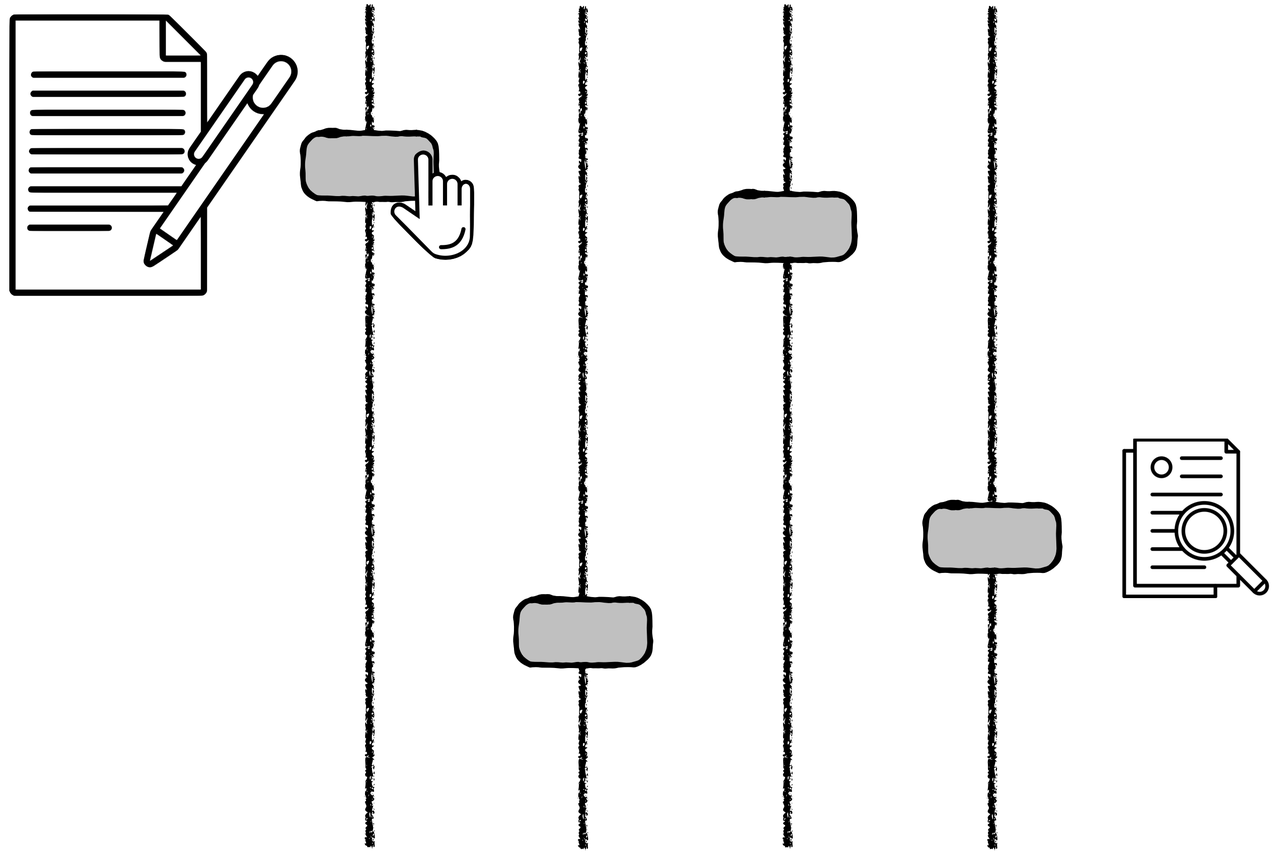

competitive
reads

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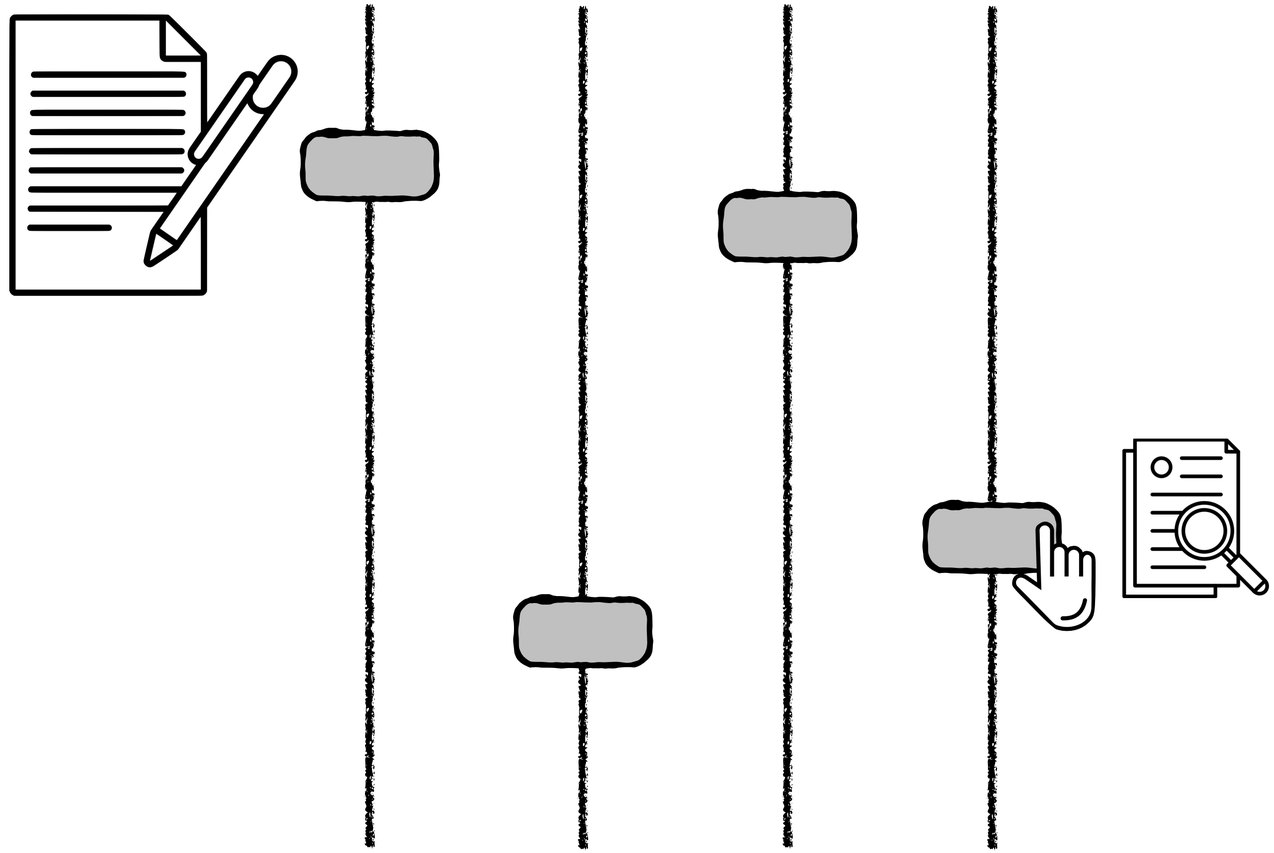

competitive
reads

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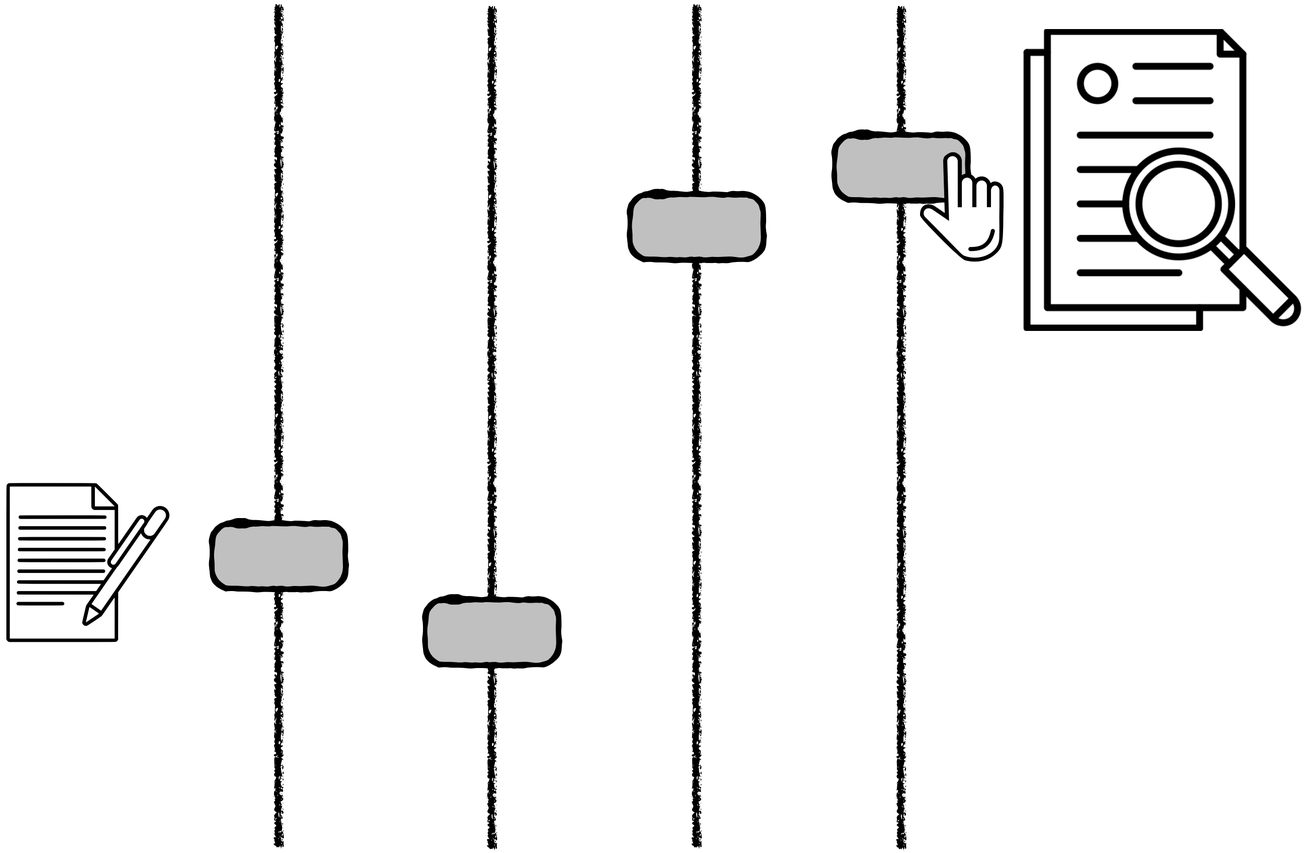
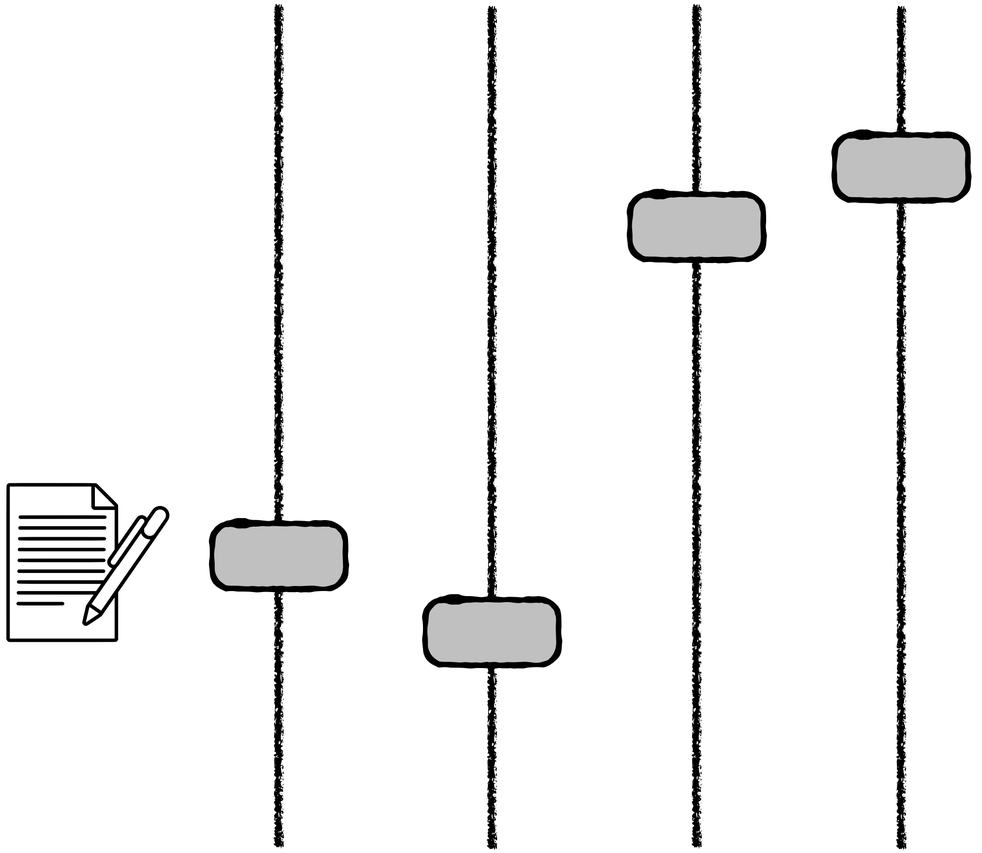


competitive **reads**

Why LSM ?

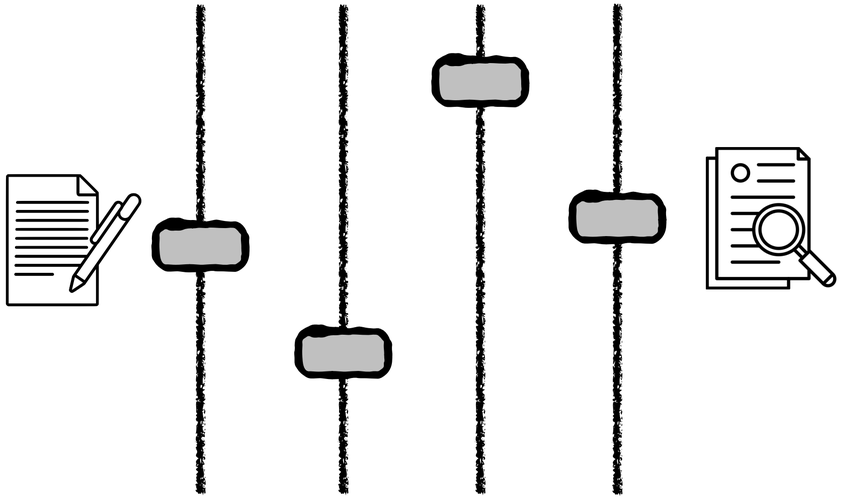
fast **writes**



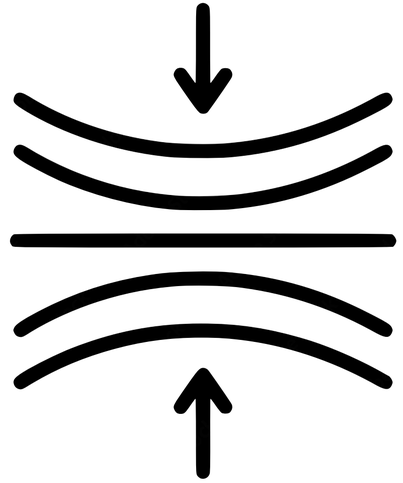
competitive **reads**

Why LSM ?

fast **writes**



tunable read-write performance

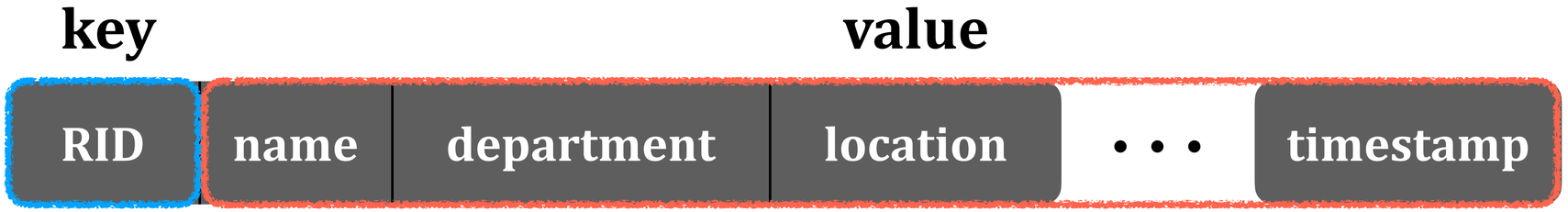


good **space** utilization

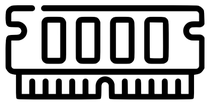
LSM Basics

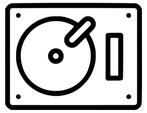
key-value pairs

LSM Basics



LSM Basics





buffer

L1

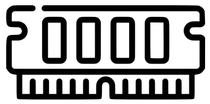
L2

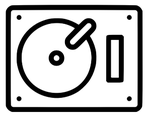
L3

L4

size ratio: T

LSM Ingestion





buffer

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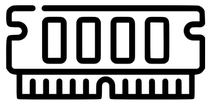
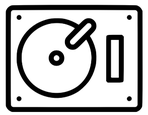
LSM Ingestion





buffer

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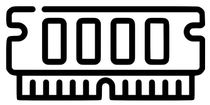

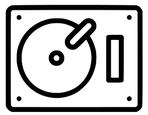

buffer

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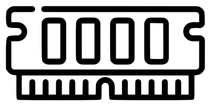

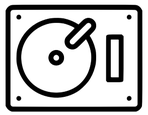

buffer 

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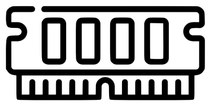
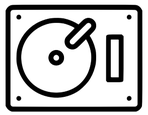


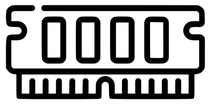


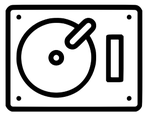
flush

buffer 

L1 

LSM Ingestion



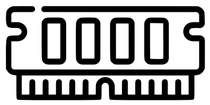


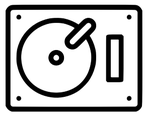
flush

buffer

L1

LSM Ingestion



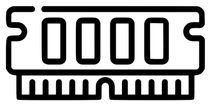


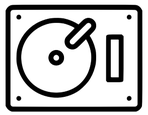
flush

buffer 

L1 

LSM Ingestion

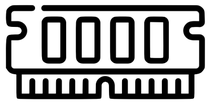


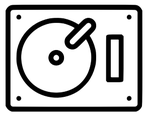


buffer 

L1 

LSM Ingestion

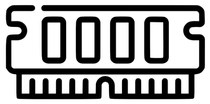


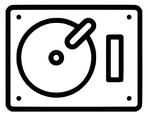


buffer 

L1 

LSM Compaction

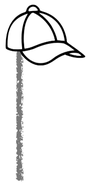




buffer

L1

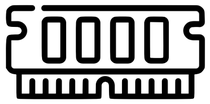
L2

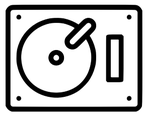


compaction

exponentially larger capacity

LSM Compaction





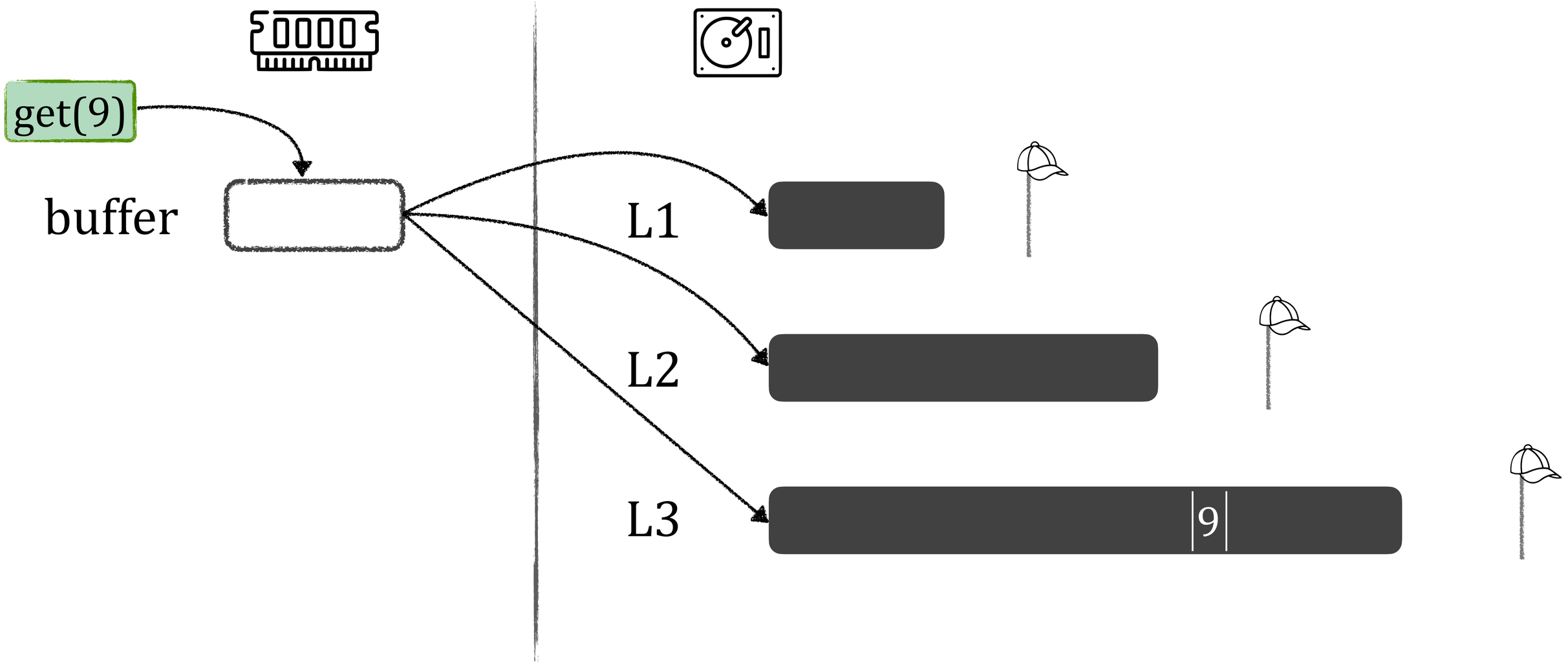
buffer

L1

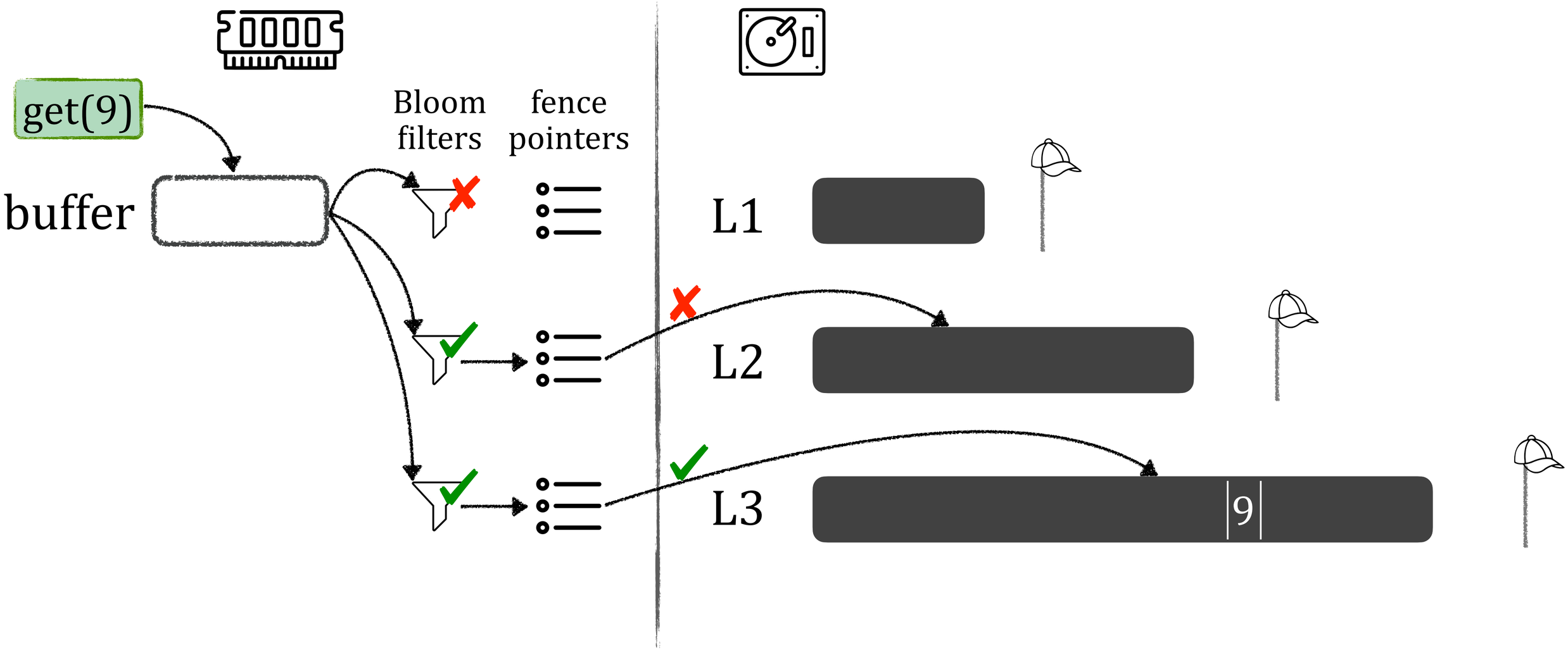
L2

L3

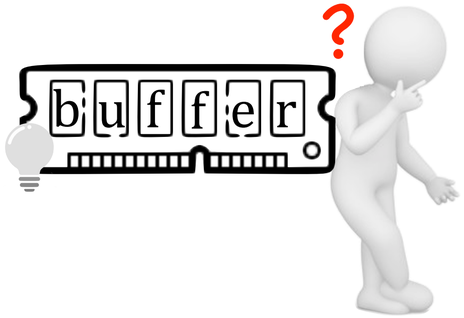
LSM Lookup



LSM Lookup



Research Trend



papers published*

200

100

50

0

2006

2011

2016

2022

* data from Google scholar

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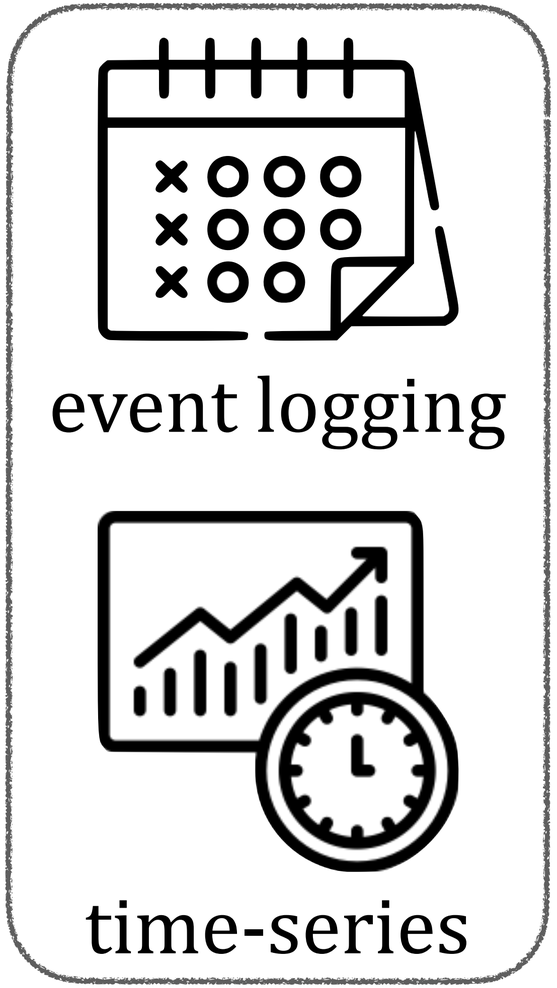
Motivation

Motivation

DEFAULT

skip-list



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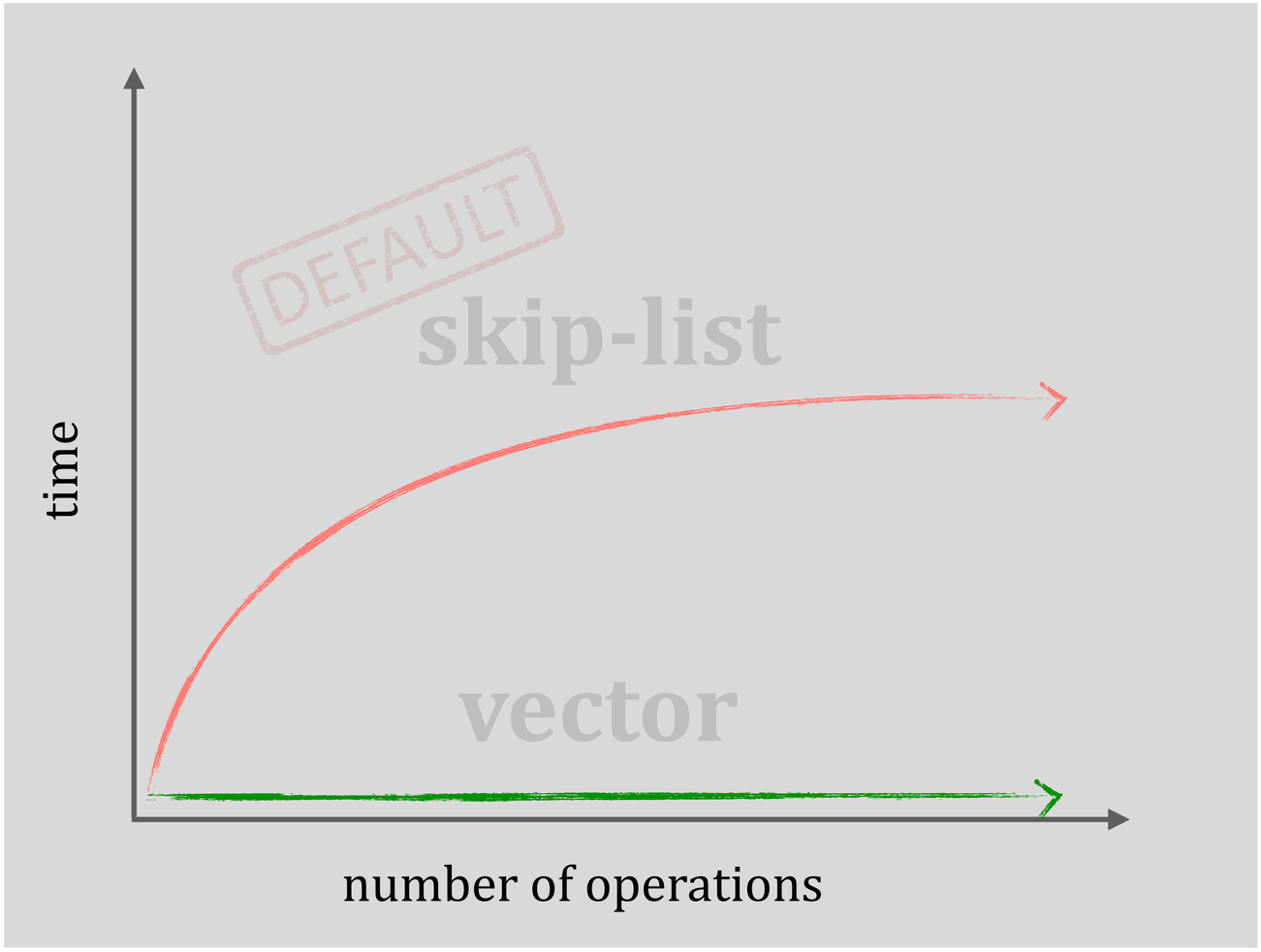
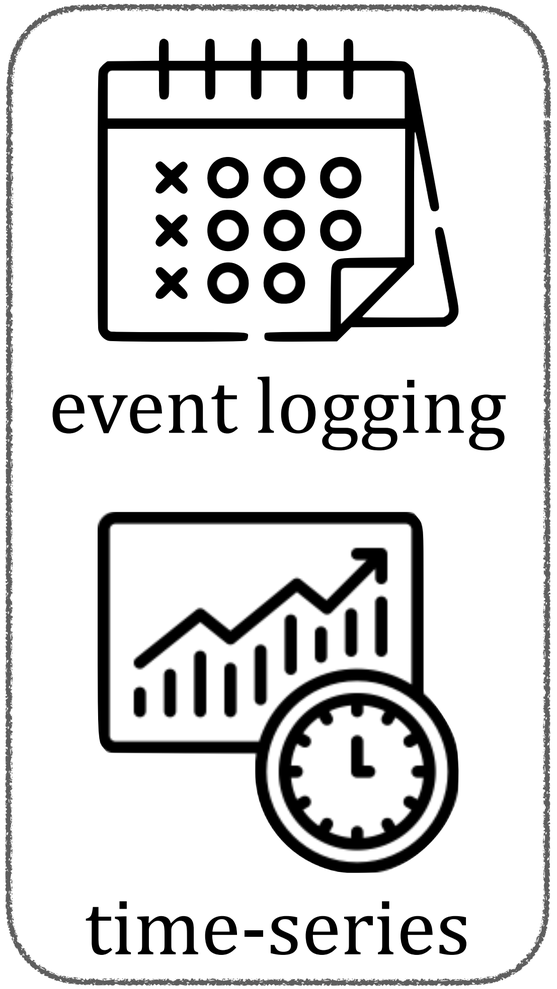
Motivation





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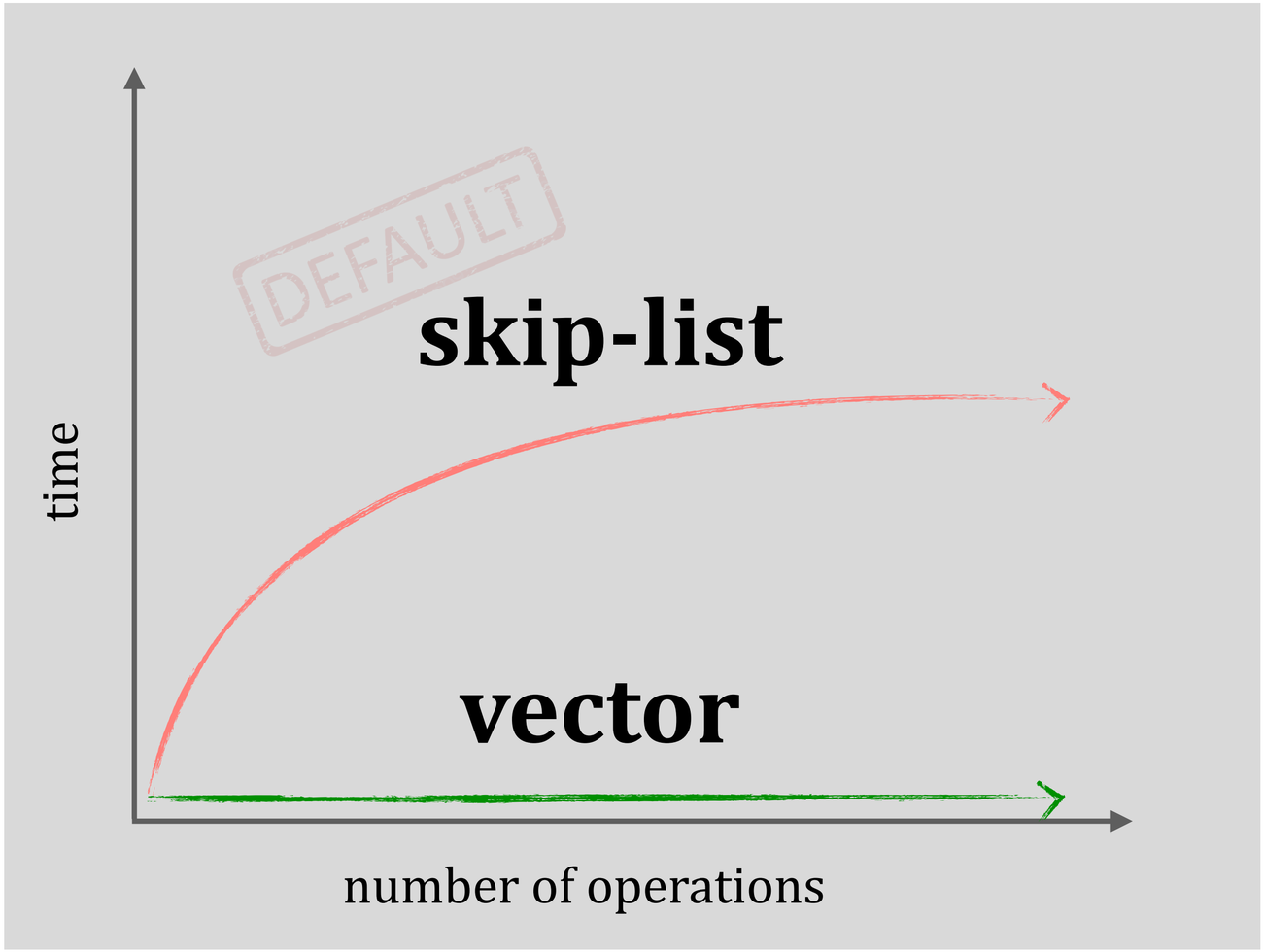
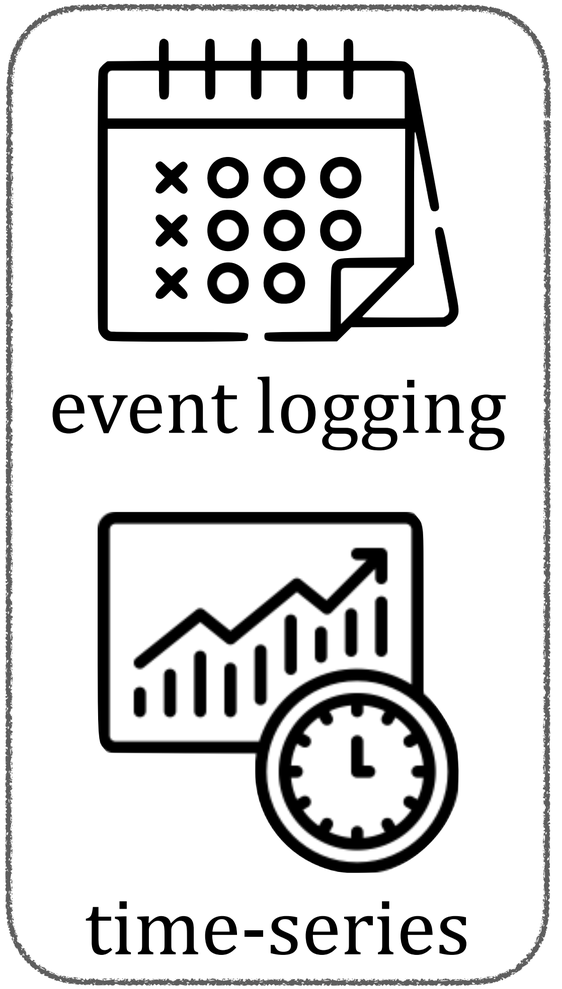
Motivation





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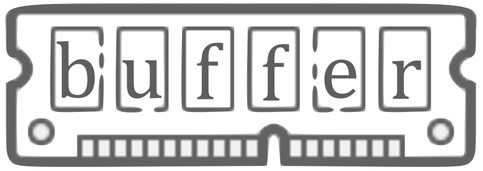
Contribution



1 **vector** dynamic

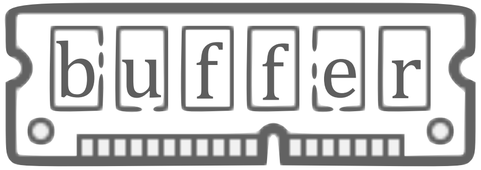
2 **vector** static

3 **skip-list**

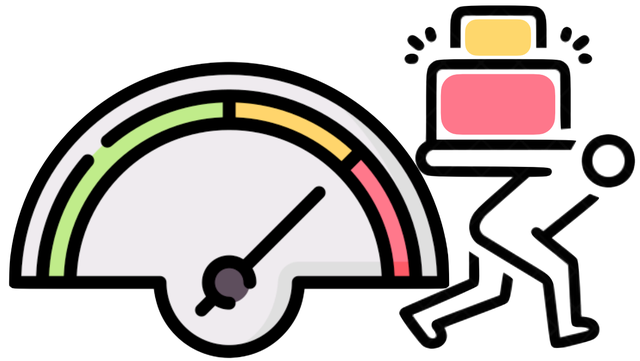
4 **hash** skip-list

5 **hash** linked-list

Contribution

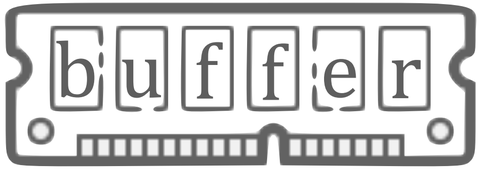


1. **vector** dynamic
2. **vector** static
3. **skip-list**
4. **hash** skip-list
5. **hash** linked-list



benchmark

Contribution



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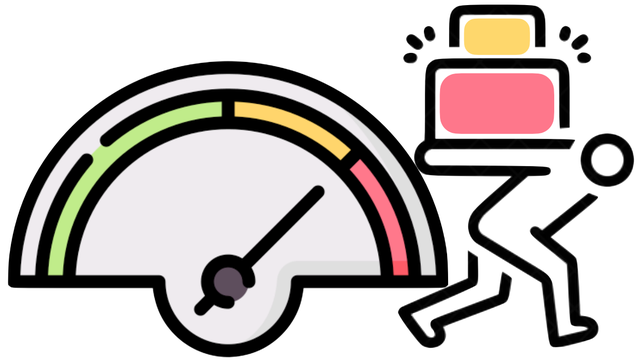

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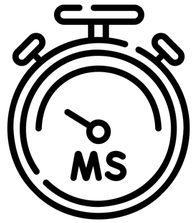
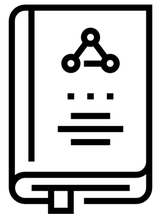


latency

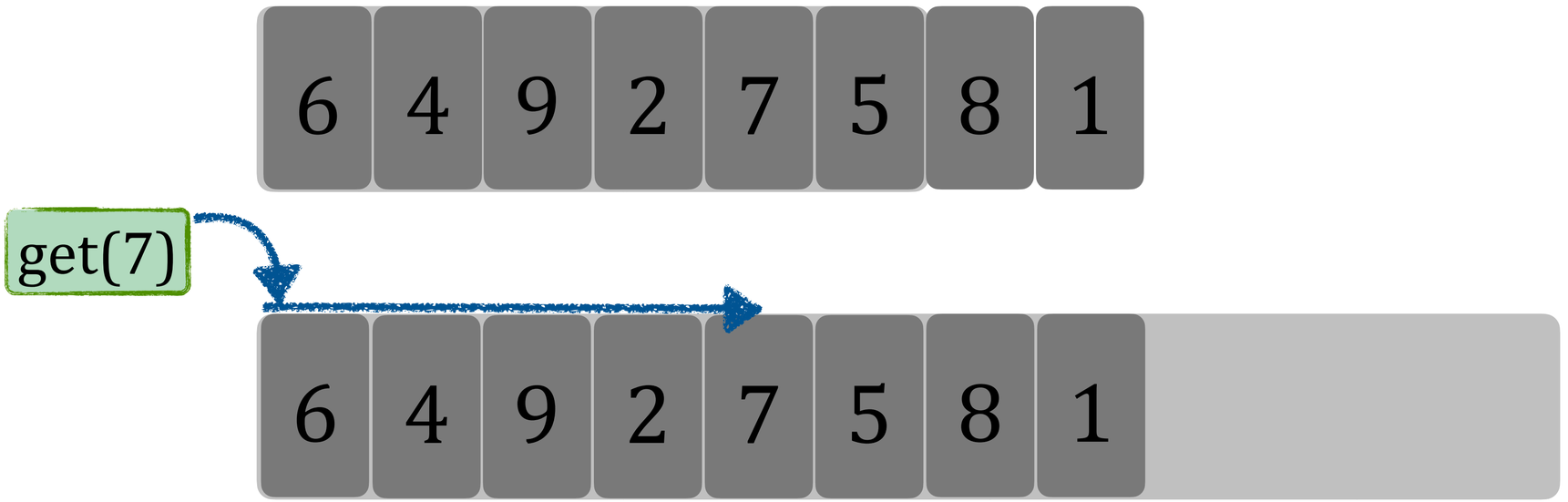
footprint



handbook

N : number of entries

Implementation: Vector



dynamic

static

- great for insert-heavy w/l
- no extra space needed
- expensive point queries

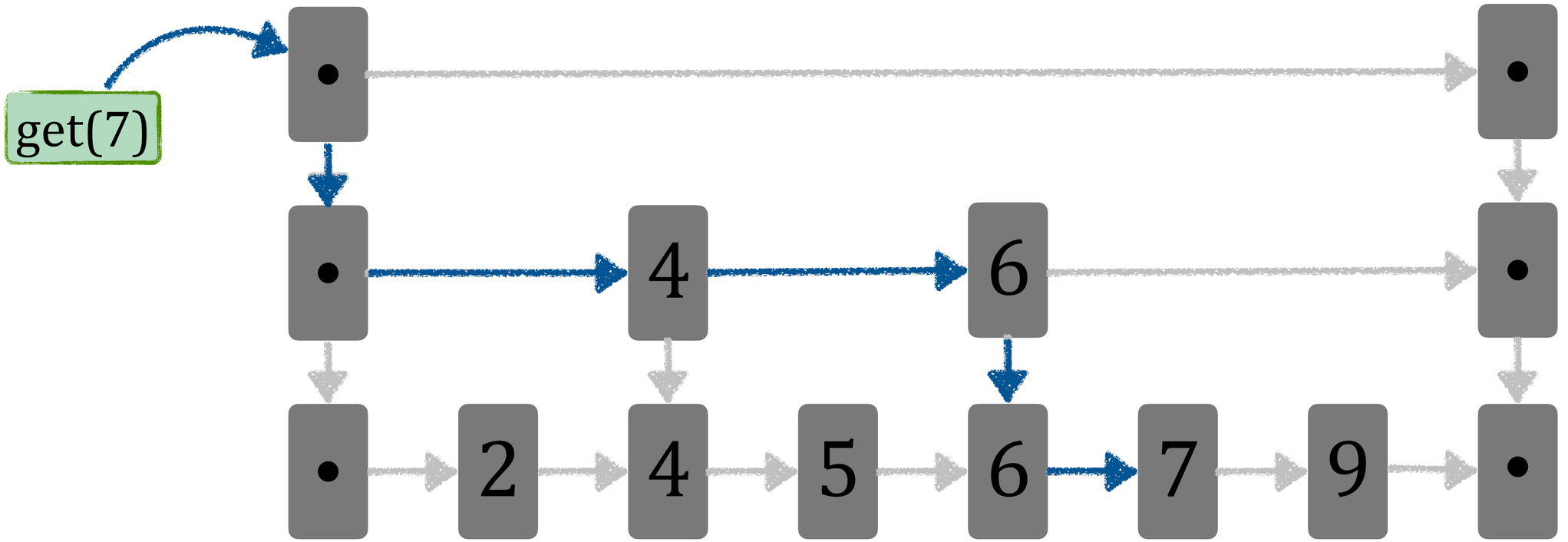
insert cost: $\mathcal{O}(1)$

space complexity: $\mathcal{O}(N)$

point query cost: $\mathcal{O}(N)$

N : number of entries
M : meta data

Implementation: Skip-list



- great for mixed w/l
- some extra space needed
- good for point queries

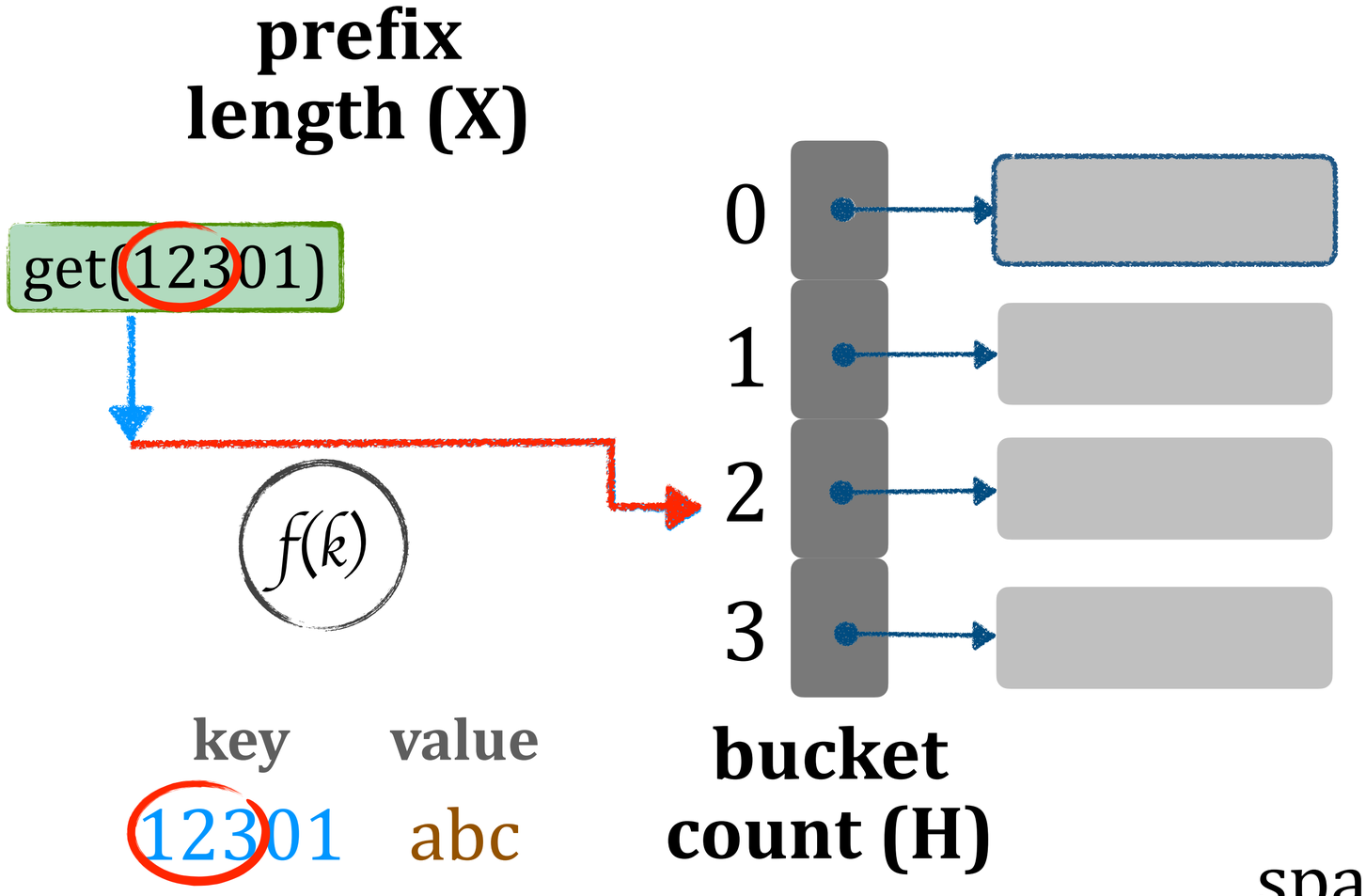
insert cost: $\mathcal{O}(\log N)$

space complexity: $\mathcal{O}(N + M)$

point query cost: $\mathcal{O}(\log N)$

N : number of entries
M : meta data

Implementation: Hash Hybrids

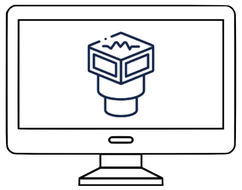


skip-list
linked-list

- great for mixed w/l
- more meta space needed
- good for point queries

insert cost: $\mathcal{O}(\log N/H)$
space complexity: $\mathcal{O}(N+M)$
point query cost: $\mathcal{O}(\log N/H)$

Experiments



2 Intel Gold 6126 vCPUs
192 GB RAM
240 GB SSD
Ubuntu 20.04 LTS

RocksDB v9.0.0

size ratio	4
buffer size	16MB
page size	4KB
entry size	64B
key size	10

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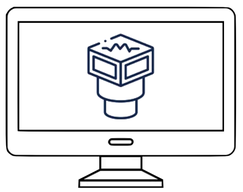
Experiments



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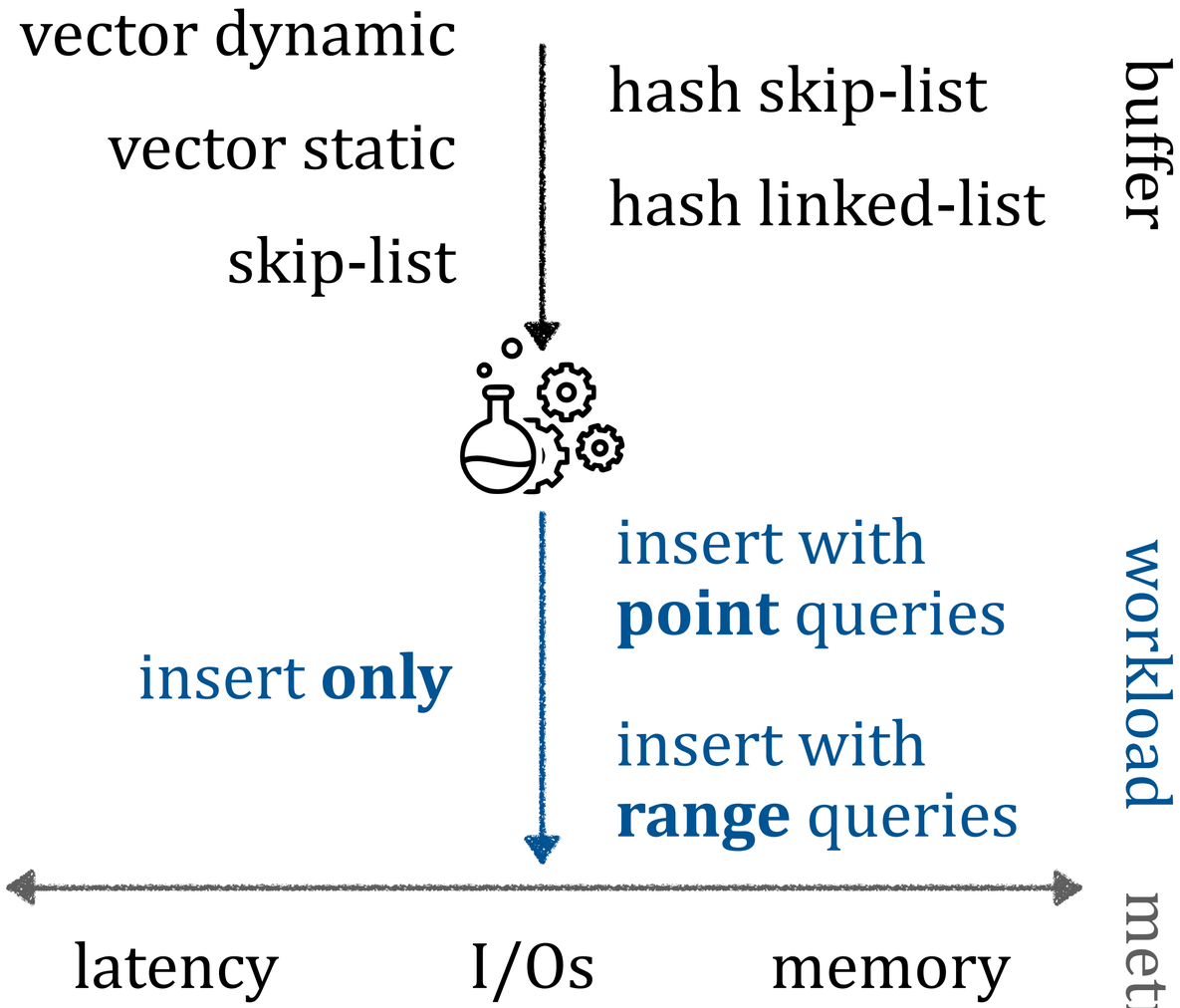
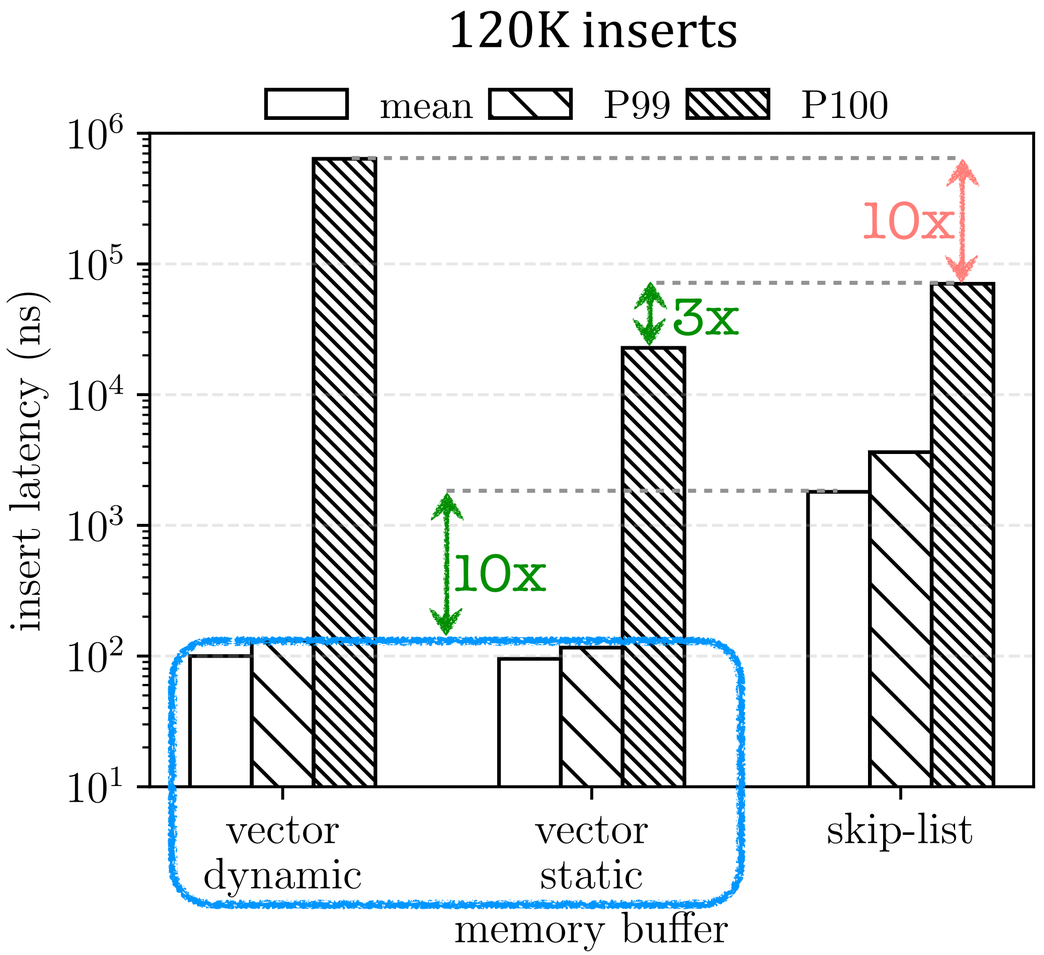


Evaluation

vector is 10x faster than skip-list for an *insert only* w/l



insert only

Evaluation

vector is 10x faster than
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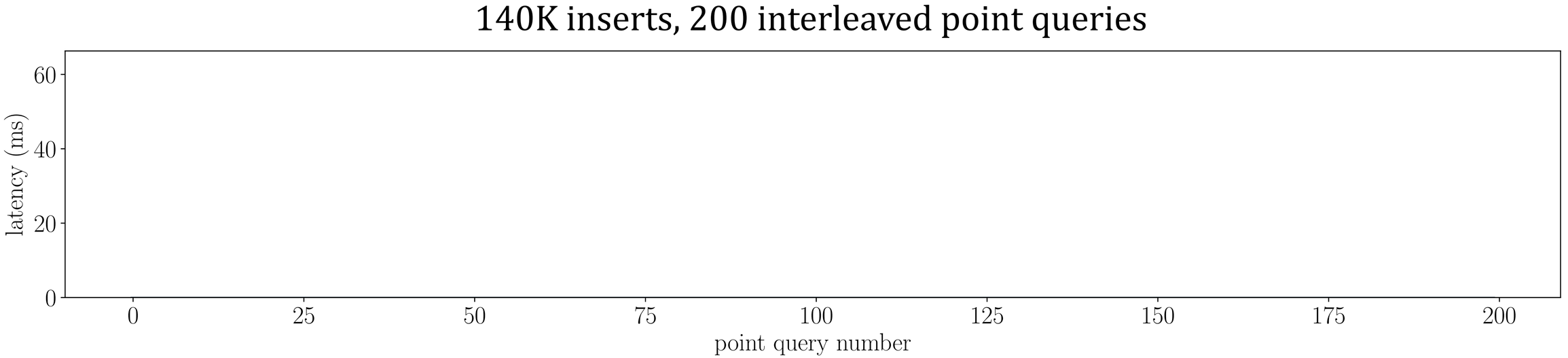
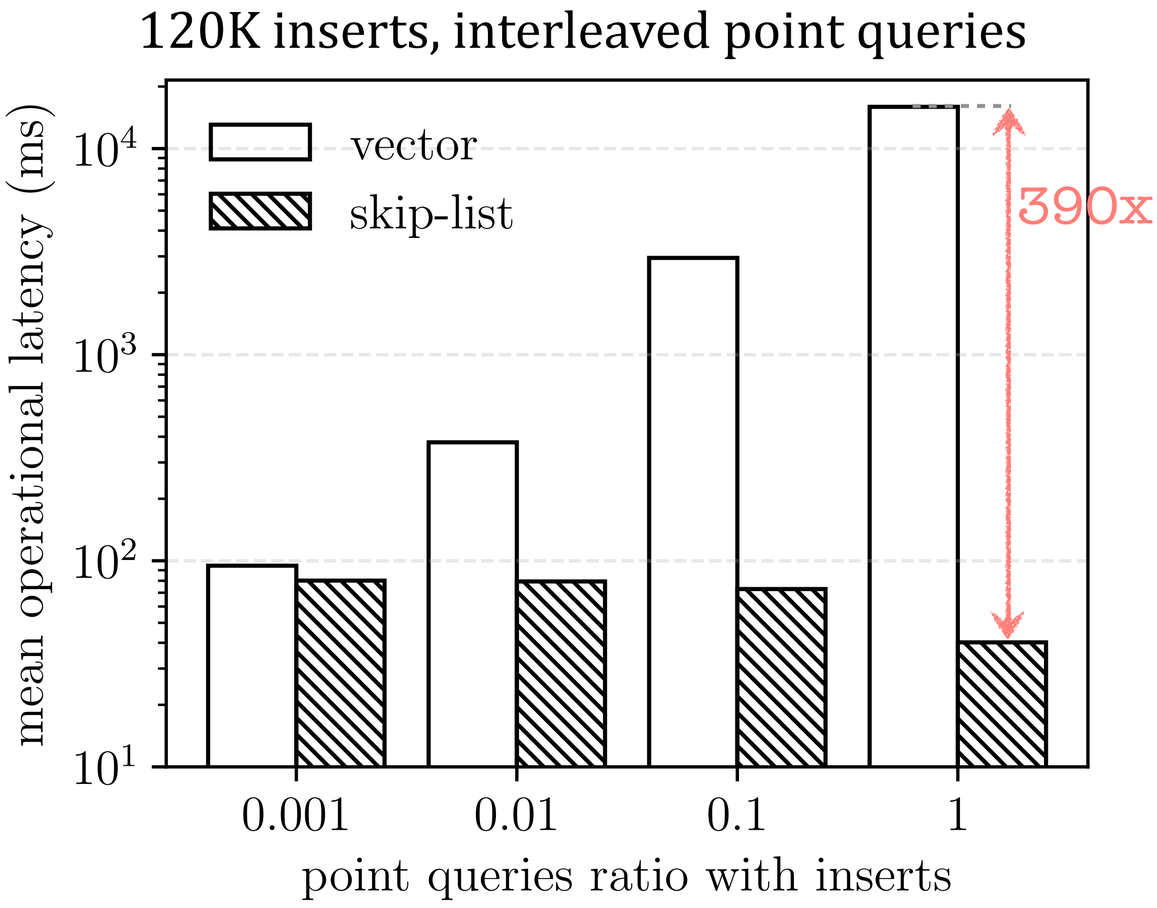


insert with point queries

Evaluation

vector is 10x faster than skip-list for an *insert only* w/l

vector is worst choice for w/ls with point queries



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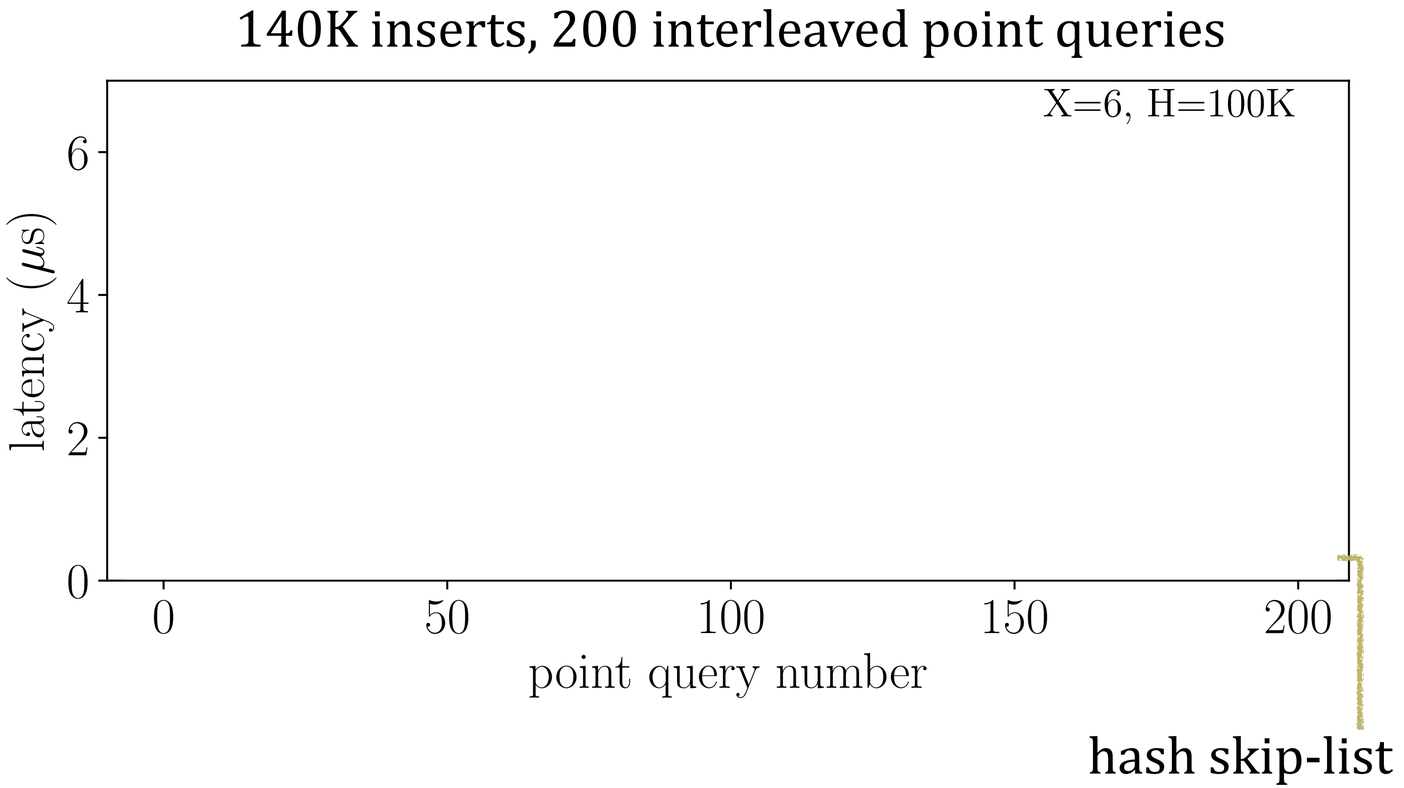

insert with point queries

Evaluation

vector is 10x faster than skip-list for an *insert only* w/l

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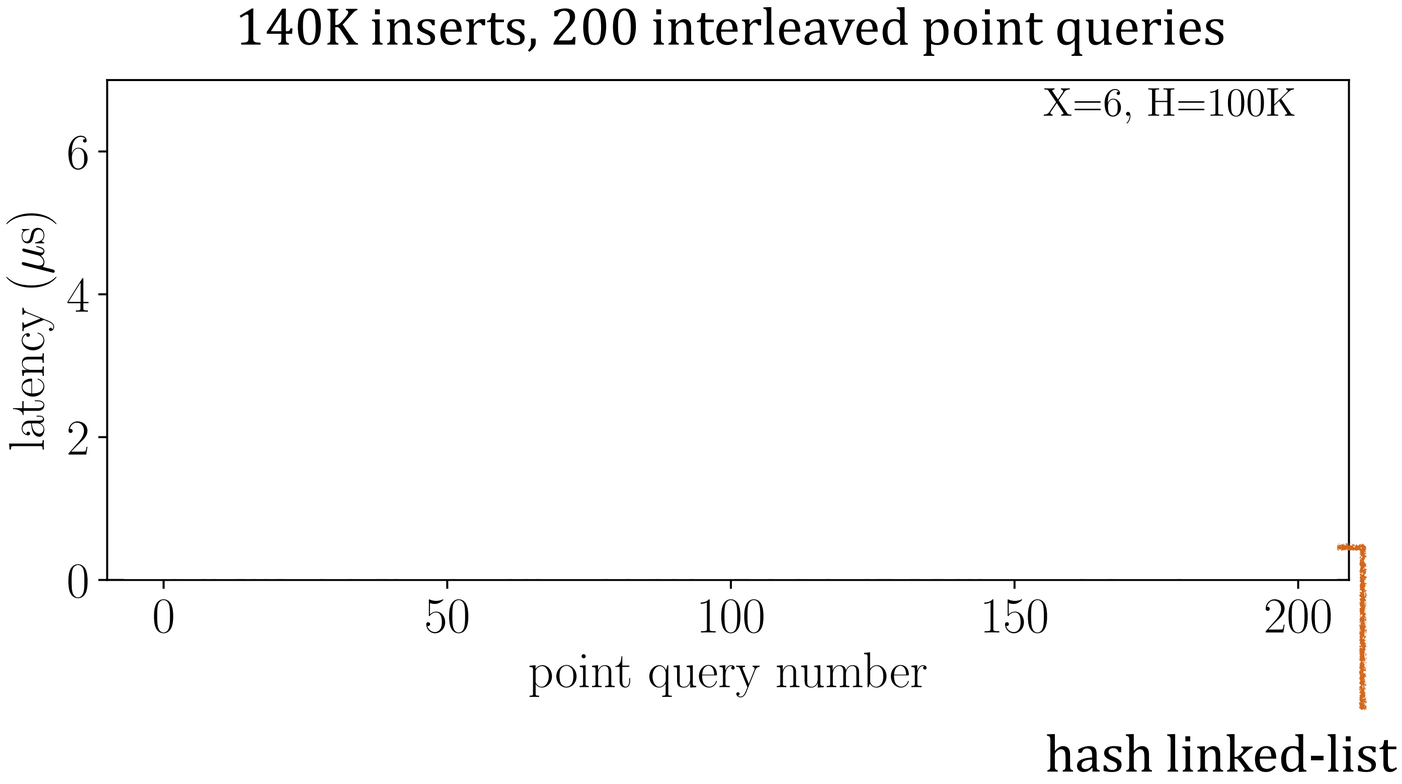
hash buffers are 2-3x faster than skip-list for point queries w/ls



insert with point queries

Evaluation

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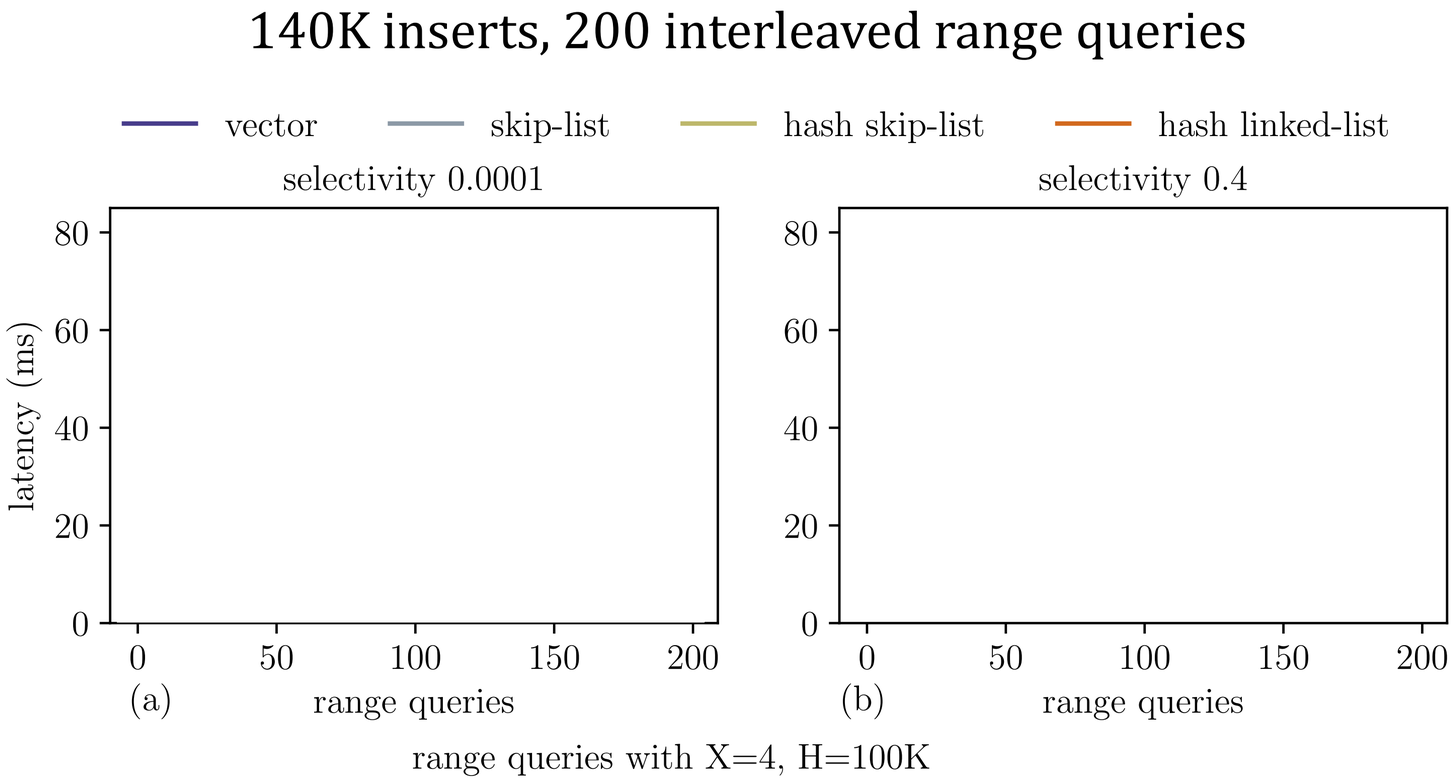
vector is worst choice for w/ls with point queries

hash buffers are 2-3x faster than skip-list for point queries w/ls

skip-list outperforms for w/ls with range queries



insert with range queries

Evaluation

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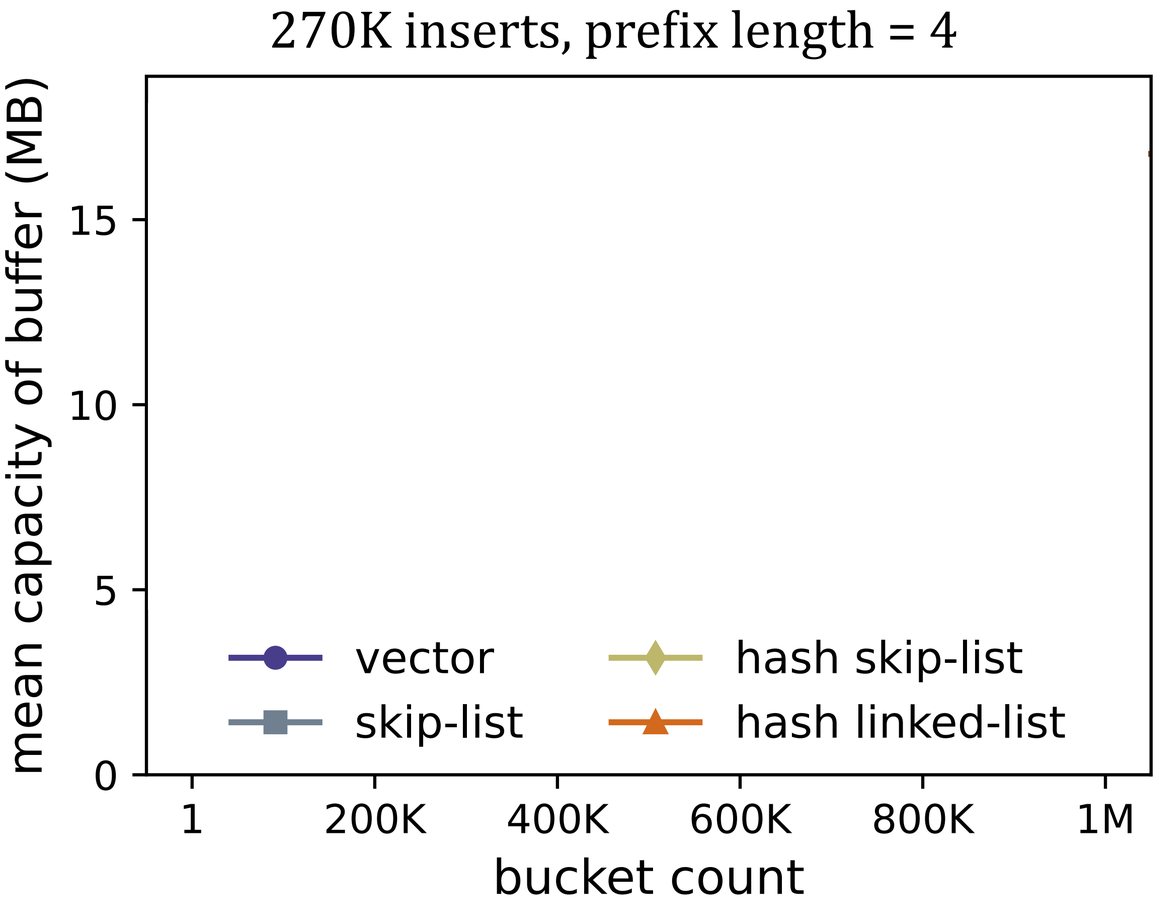
vector is worst choice for w/ls with point queries

hash buffers are 2-3x faster than skip-list for point queries w/ls

skip-list outperforms for w/ls with range queries



memory footprint

Evaluation

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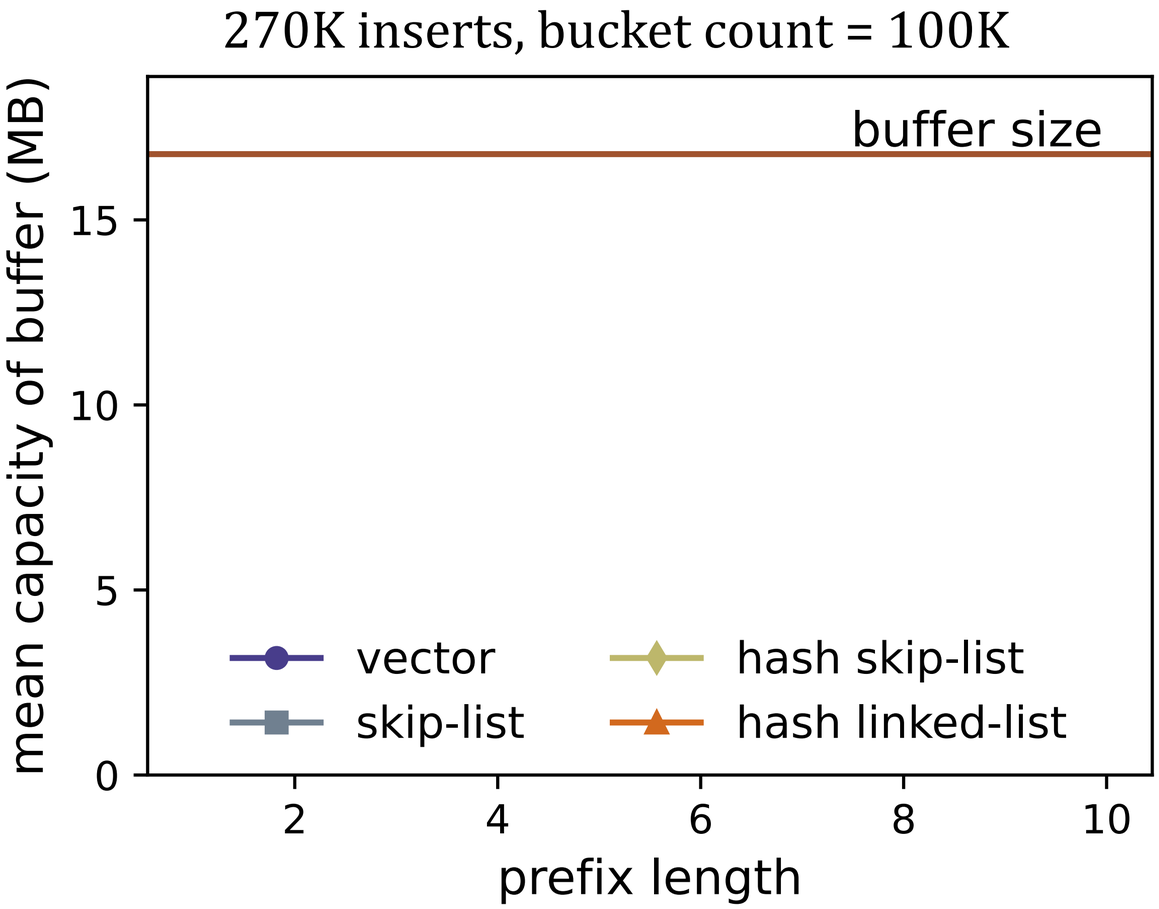

memory footprint

Evaluation

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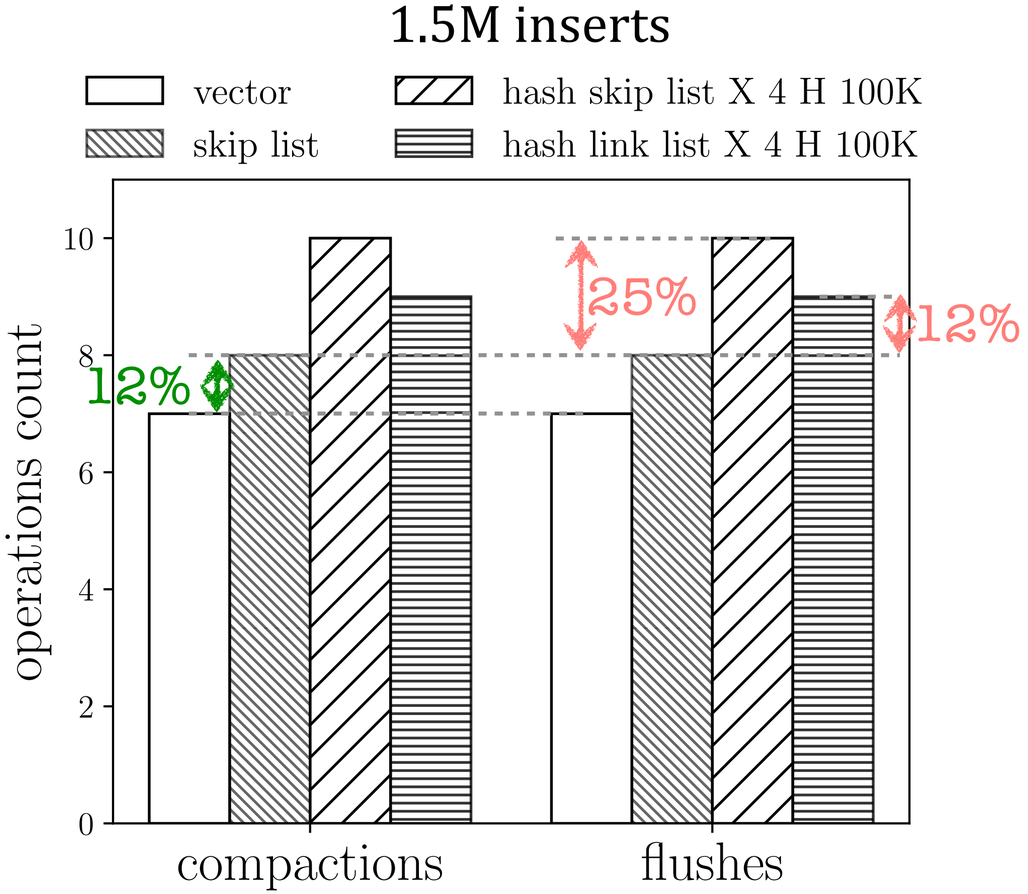
vector is worst choice for w/ls with point queries

hash buffers are 2-3x faster than skip-list for point queries w/ls

skip-list outperforms for w/ls with range queries

vector perform 12% less flushes; more I/Os in hash based buffers



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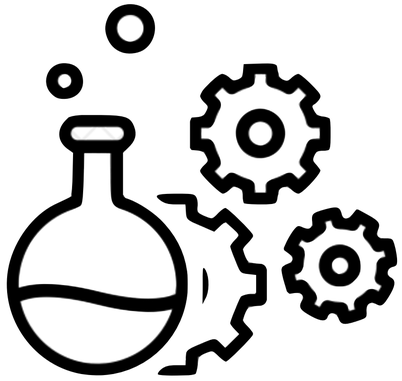
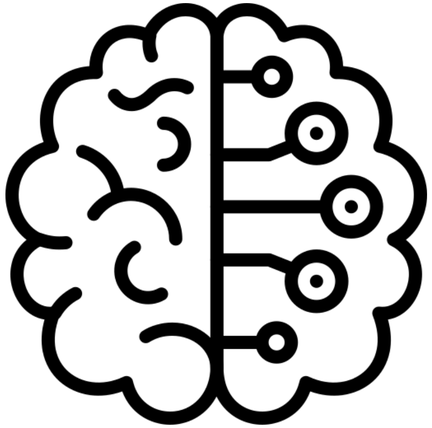
Future Work



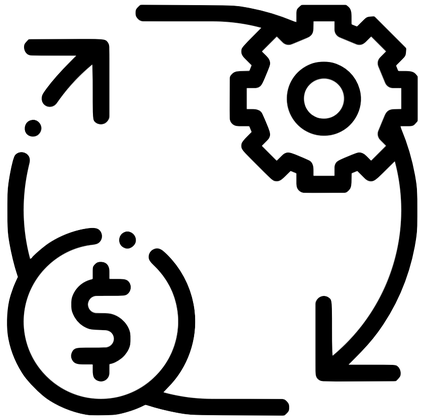
explore other implementations

tree, trie, heap



finding best buffer

using machine learning



switching buffer

on the fly when w/l changes

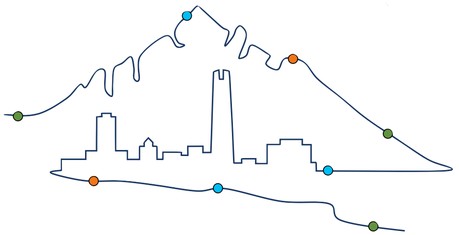
Anatomy of LSM Memory Buffer: Insights & Implications

Thank You!

Questions?

Shubham Kaushik

Subhadeep Sarkar



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Santiago, Chile, 2024

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