FISHSTORE: FASTER INGESTION WITH SUBSET HASHING

BY BENJAMIN BORDEN

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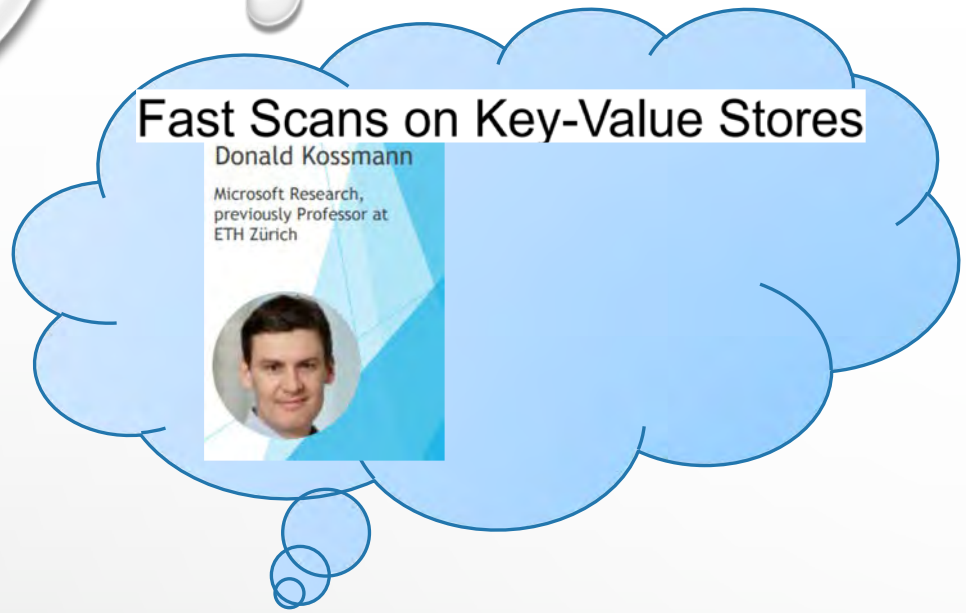

MEET THE AUTHORS

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Microsoft Research

Dong Xie
University of Utah

THE PROBLEM?

- Increased importance of cloud-edge architecture →
  - increased the amount of data being ingested by the cloud
- Previous Industry Goal:
  - Ingest information as fast as possible by dumping it into storage
- Current Industry Goal:
  - The data needs to be immediately ready for analytical queries

THE TYPE OF QUERIES WE CARE ABOUT

- Ad-hoc queries
  - Scan data over time ranges
- Recurring queries
  - Have identical predicates, but are repeated over different time ranges
- Point lookup queries
  - Based on various keys
- Streaming queries
  - Fed parts of the ingested data satisfying custom predicates and based on the query schema

TRADITIONAL APPROACHES

- Ingest the data in raw form
- Load data into warehouse in batch jobs

Why is this bad?

OR

- Parse data and load into database

or

- update secondary range index over every attribute during ingestion

Why is this bad?

TRADITIONAL APPROACHES

- Ingest the data in raw form
- Load data into warehouse in batch jobs

Why is this bad?
This is slow (low throughput)
Has high latency before the data is ready for queries

OR

- Parse data and load into database

or

- update secondary range index over every attribute during ingestion

Why is this bad?
Also very slow (low throughput)

INTRODUCING FASTER

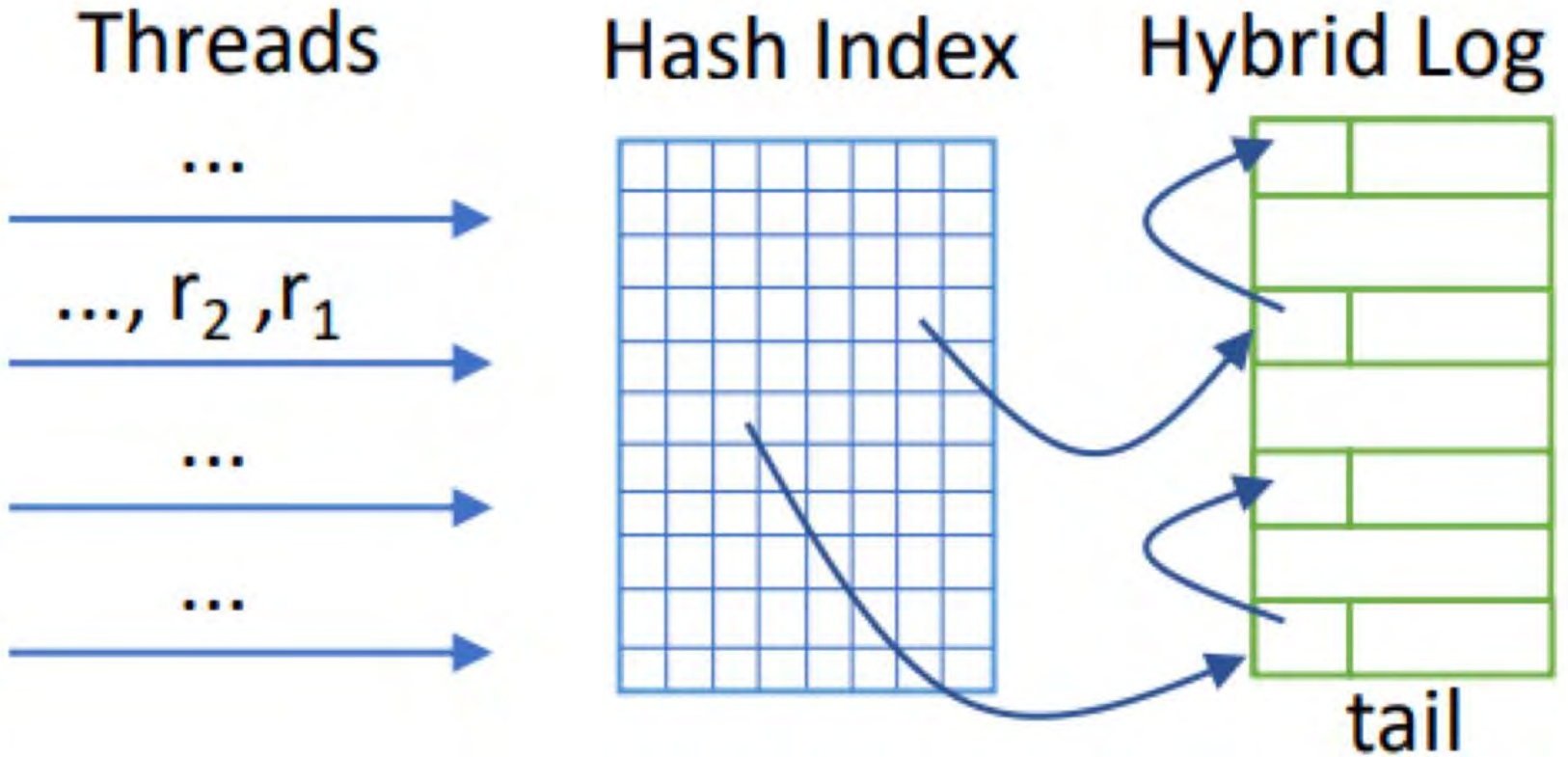
FASTER

- FASTER:
  - a **persistent key-value store**
  - consists of a:
    - lightweight
    - cache optimized
    - concurrent
  - hash index backed by a hybrid log ordered by data-arrival

- Benefits
  - Very low CPU cost
  - More than 150 millions operations per second

BACKGROUND ON FASTER

- FASTER: concurrent latch-free hash key value store with support for larger than memory data
- FASTER has two components:
  - a hash index
  - log structured record store



INTRODUCING FISHSTORE

INTRODUCING FISHSTORE

- Fishstore = [F]aster [I]ngestion with [S]ubset [H]ashing store:
  - a storage layer for flexible schema data
- Borrows some features from faster such as basic index design and epoch model
- Allows for the dynamic registration of predicated subset functions (PSF) →
  - allow for efficient retrieval of subsets of ingested data based on common criteria

- **PROS OF PSFs –**
- **CONS OF PSFs –**

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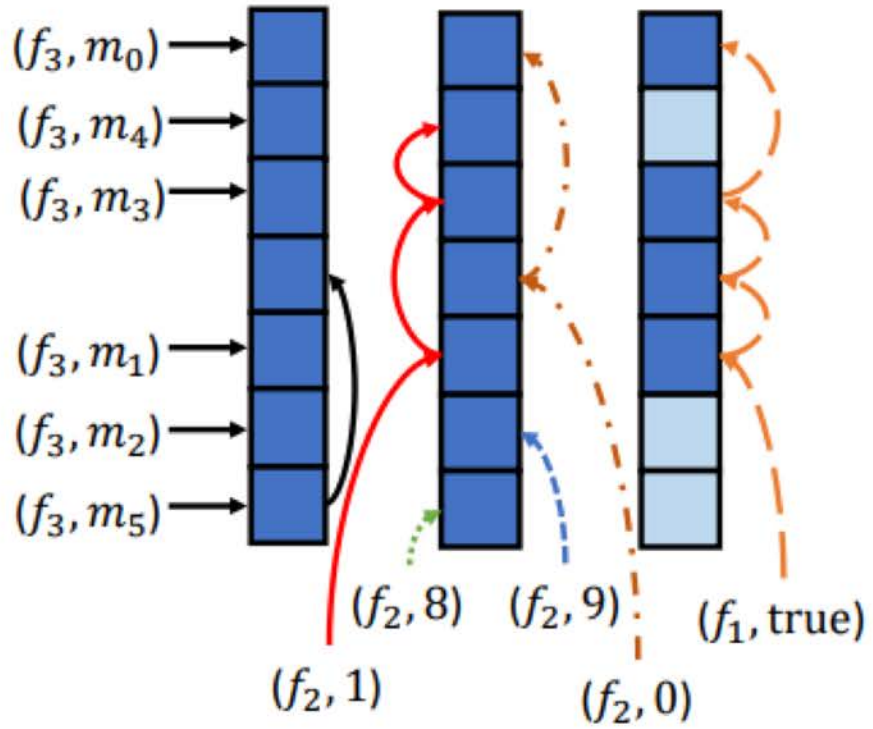
- **PROS OF PSFs – Allows for speedy and customizable retrieval of data**
- **CONS OF PSFs – A large number of PSF leads to throughput penalties**

PREDICATED SUBSET FUNCTION

- Predicated Subset Function (PSFs):
  - groups records with similar properties for later retrieval

- "Given a data source of records in R, a predicated subset function (PSF) is a function f : R → D which maps valid records in R, based on a set of fields of interest in R, to a specific value in domain D”

EXAMPLE: MACHINE TELEMETRY



Time	Machine	CPU	MEM
1:00pm	m_0	9.45%	83.52%
1:00pm	m_4	14.67%	57.44%
1:02pm	m_3	10.00%	92.50%
1:03pm	m_5	5.00%	75.32%
1:03pm	m_1	13.45%	90.45%
1:04pm	m_2	93.45%	84.56%
1:05pm	m_5	81.75%	65.03%

f_1: $\Pi_{\text{CPU}}(r) < 15\%$ & $\Pi_{\text{MEM}}(r) > 75\%$
f_2: $\Pi_{\text{CPU}}(r)$ / 10.0
f_3: $\Pi_{\text{Machine}}(r)$

Figure 1: Machine Telemetry PSF Example

- THE CHALLENGES OF THE FISHSTORE SYSTEM CONSISTS OF TWO MAJOR COMPONENTS:
  - INGESTION AND INDEXING
  - SUBSET RETRIEVAL

INGESTION & INDEXING

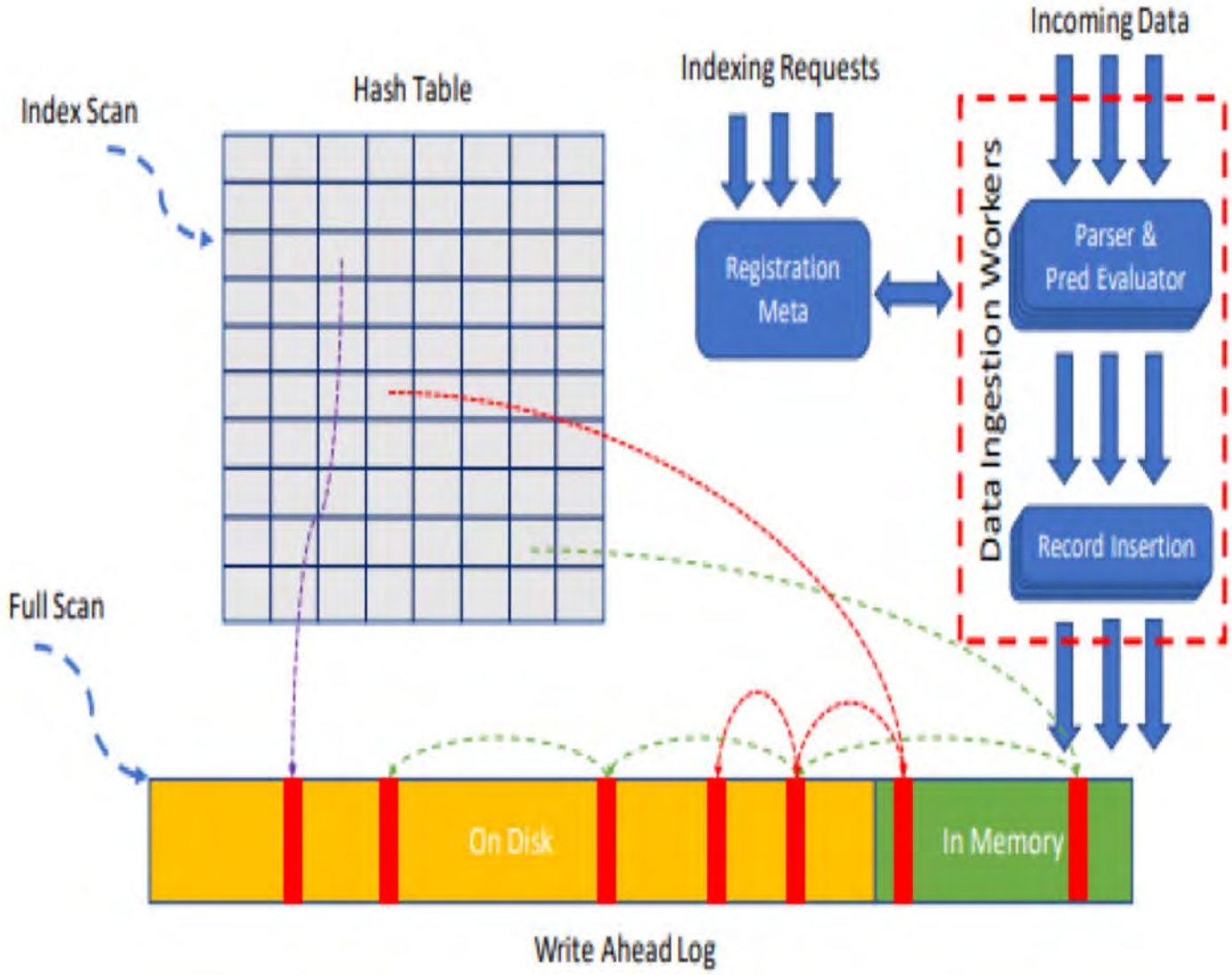
- FISHSTORE ingests data into an immutable log in ingestion order and with a hash index
  - For every PSF and value in the log there is a hash entry which links all matching values in a hash chain
  - Major difference between key-value store and PSF based hash chains:
    - A record can be part of more than one hash chain!

SUBSET RETRIEVAL

- The primary benefit of PSFs is scan optimization
  - If a subset needs to be retrieved which does not have a relevant PSF, a full scan of the data is required
  - Fishstore supports scans for records that match PSF values in which case it retrieves the relevant hash chain.
    - **However FISHSTORE does not recatagorize data which is older than the implementation of the PSF!**
  - When retrieving data that has a relevant PSF but the data is older than the PSF implementation:
    - a full scan must be done over the older data.

SYSTEM ARCHITECTURE OF FISHSTORE

- The architecture of FISHSTORE consists of:
  - A hybrid log for record allocation,
  - A hash index that holds pointers to records on the log,
  - A registration service
  - A set of ingestion workers



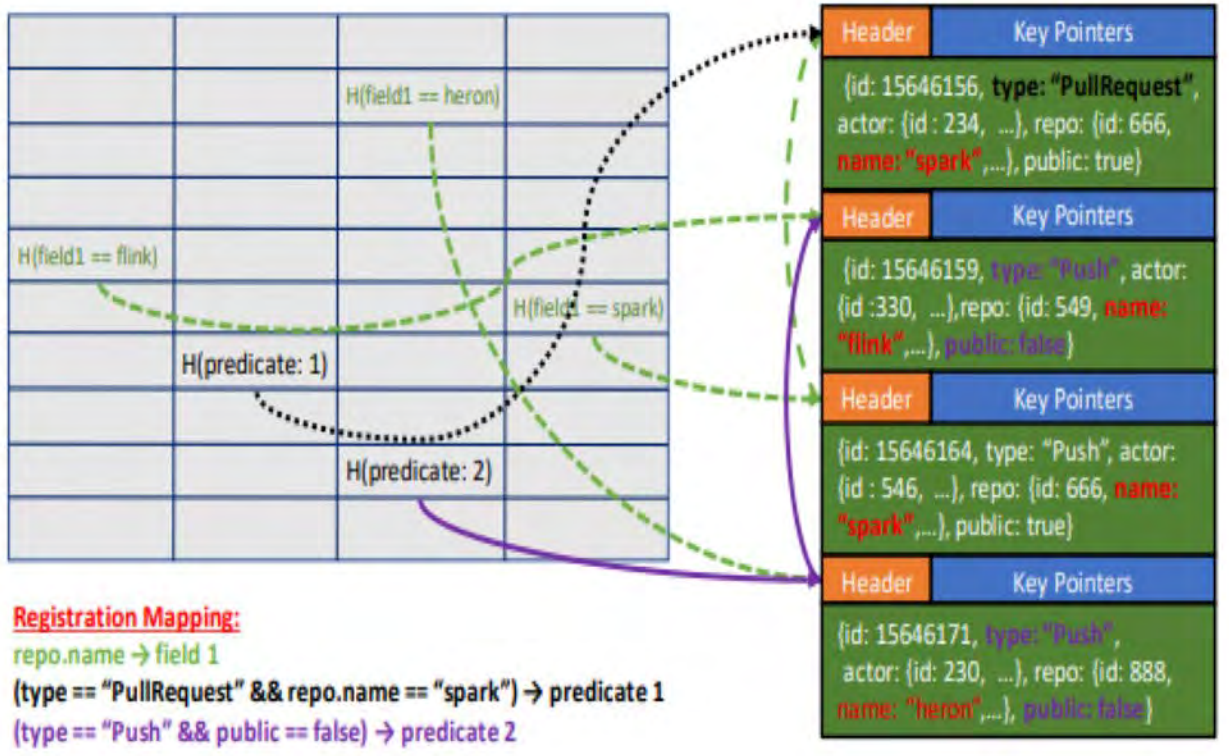
CHALLENGES/SOLUTIONS

- Problem: Designing a fast concurrent index which supports PSFs
  - Solution: Using a subset hash index combined with a carefully designed record layout
- Problem: Acquiring a safety boundary for on-demand indexing.
  - Solution: Utilizing epoch-based threading model to find safe boundaries
- Problem: Data ingestion should be latch-free in order to achieve high throughput
  - Solution: An unusual lock-free technique discussed later
- Problem: Scanning a hash chain imitates random I/Os which damages subset retrieval speeds
  - Solution: Utilizing an adaptive prefetching technique discussed in more detail later

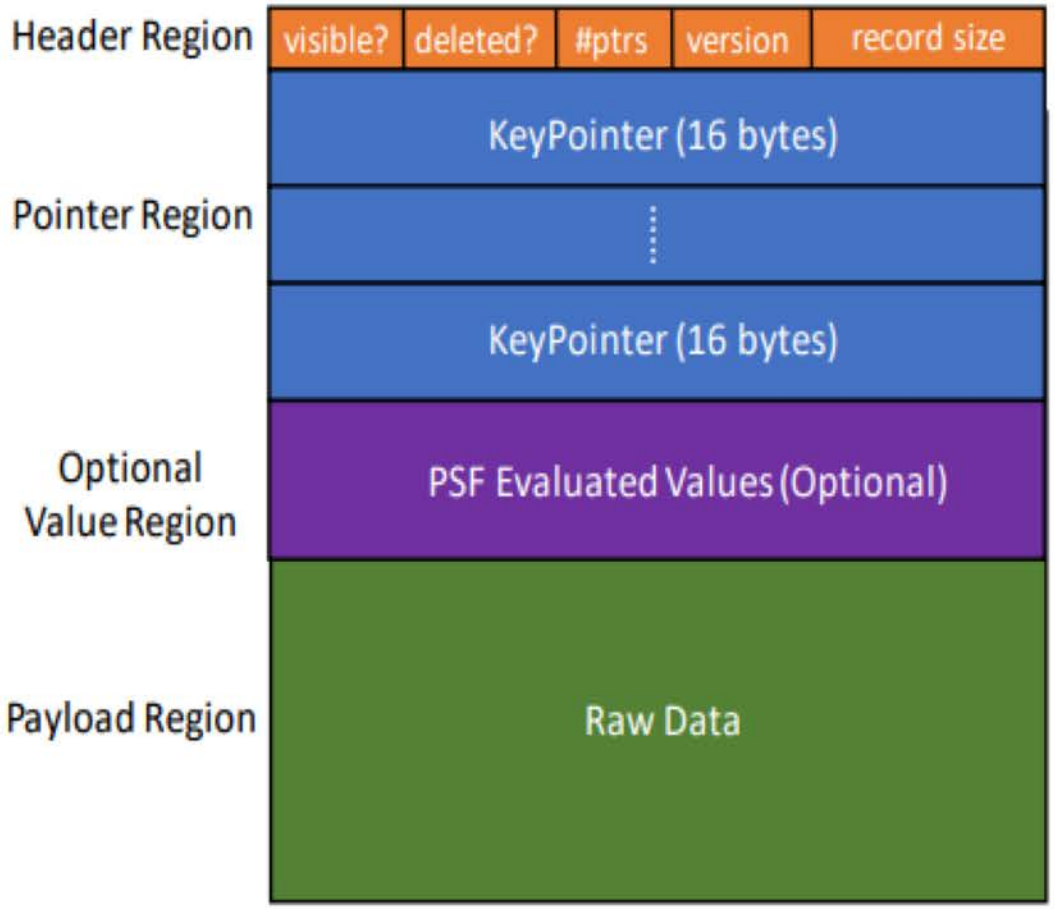
SUBSET HASH INDEX

SUBSET HASH INDEX

- FISHSTORE's fast index called subset hash index:
  - a hash table that indexes hash chains of records based on user defined PSFs
  - To retrieve records with a specific property:
    - calculates the hash signature of the property to locate the hash entry
    - follows the chain until it retrieves all matching entries



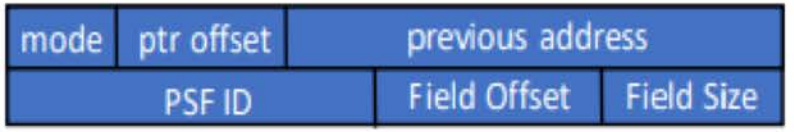
FISHSTORE RECORD LAYOUT



Sample KeyPointer Constructions:

Boolean Domain PSF Key Pointers

Field Projection PSF Key Pointers



General Key Pointers Referring to Value Region

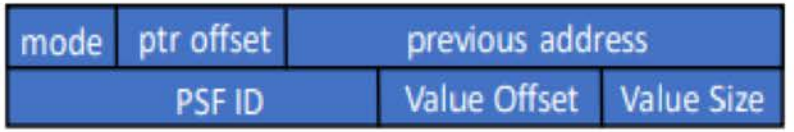


Figure 6: FishStore Record Layout

EPOCHS AND YOU

- Fishstore has an epoch framework where there is a global epoch e which may be incremented by any thread
- Each thread has a local epoch, which they refresh to keep up with the global epoch
- When all threads' epochs are at least at value c, then all threads are aware of all changes up to global epoch c

ON-DEMAND INDEXING

- FISHSTORE keeps two versions of all metadata
- **Rest** state:
  - when there are no index altering requests
- **Prepare** state:
  - when the user pushes an index altering request to the system
- Pending state:
  - Once the inactive metadata is updated, it becomes the active metadata and increments the global epoch to apply the changes.
- **Rest** state:
  - When the epoch becomes safe, FISHSTORE applies the changes to the old metadata

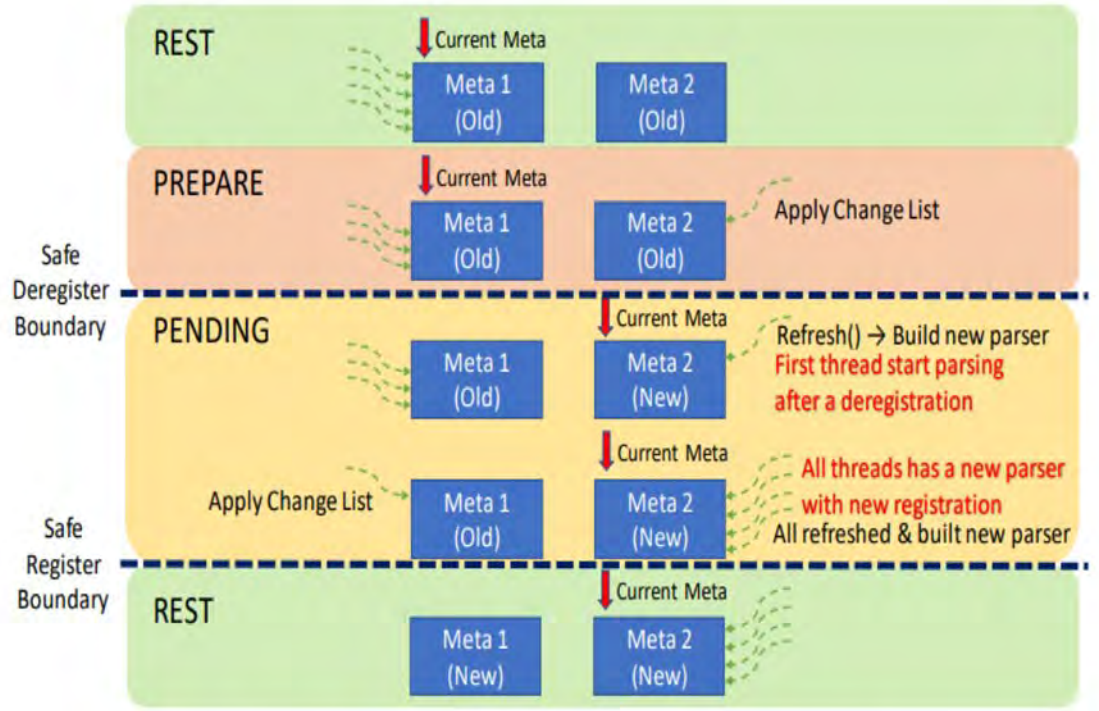


Figure 7: On Demand Indexing

DATA INGESTION IN FISHSTORE

DATA INGESTION

- Fishstore ingests data concurrently with each thread being referred to as an **ingestion worker**
- To complete ingestion, the incoming data moves through four phases:
  - Parsing and PSF evaluation
  - Record space allocation
  - Subset hash index update
  - Record visibility

PARSING AND PSF EVALUATION

- Ingestion worker uses whatever parser which was provided by the user to parse data fields in a batch.
- Whenever a worker detects changes:
  - it recalculates the minimum field set for index building and recreates its thread-local parser
- After parsing out essential fields:
  - the worker annotates the position of a field and evaluates all requested PSFs for each record.

RECORD SPACE ALLOCATION

- After a worker is done parsing the received data →
  - it must determine how much space it requires in fishstore.
- Then the worker allocates space by shifting the tail of the log to accommodate more data.
- Lastly the data is copied over to the payload region and record headers are filled.
- Since we have yet to update the index, the record is inserted with its visibility bit set to false.
  - Any reader that touches an invisible record ignores it.
  - This guarantees the atomicity of record insertion.

INDEX UPDATE & RECORD VISIBILITY

- Once record space allocation is finished, the worker updates all the hash chains of which the record applies.
- To perform this update, we use a compare and swap
- IF THE compare-and-swap fails (which is usually):
  - mark the record as invalid, reallocate space on the log and try again.
- Finally, the record is made atomically visible to readers by setting the visibility bit in the header

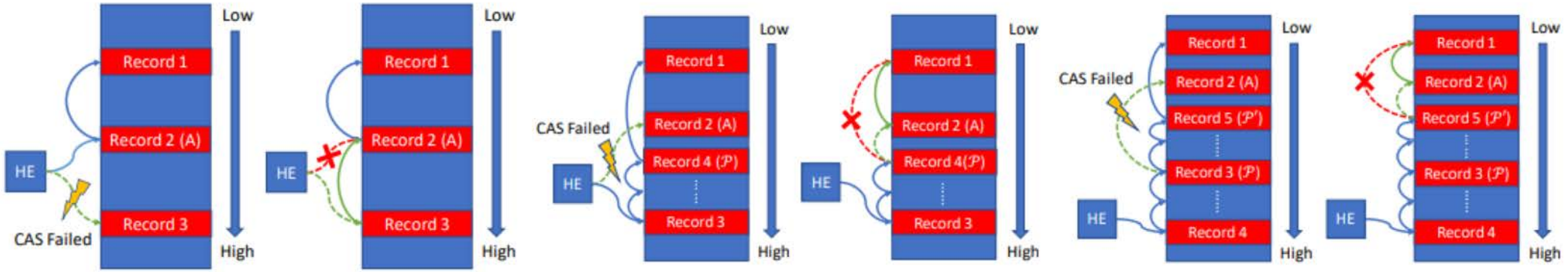


Figure 8: Handling CAS failure.

SUBSET RETRIEVAL IN FISHSTORE

SUBSET RETRIEVAL INTERFACE

- Fishstore retrieves all records satisfying a given property in a continuous range of the log
- However, just because a given property currently has a hash chain associated with it, does not mean all the records which satisfy that property have been indexed. Why?

SUBSET RETRIEVAL INTERFACE

- Fishstore retrieves all records satisfying a given property in a continuous range of the log
- However, just because a given property currently has a hash chain associated with it, does not mean all the records which satisfy that property have been indexed. Why? Because records could have been entered before the PSF was written!
  - Fishstore breaks the request into index scans + full scans based on safe registration and deregistration boundaries for all psfs.
  - Full scans have to parse and evaluate the request against each record encountered

ADAPTIVE PREFETCHING

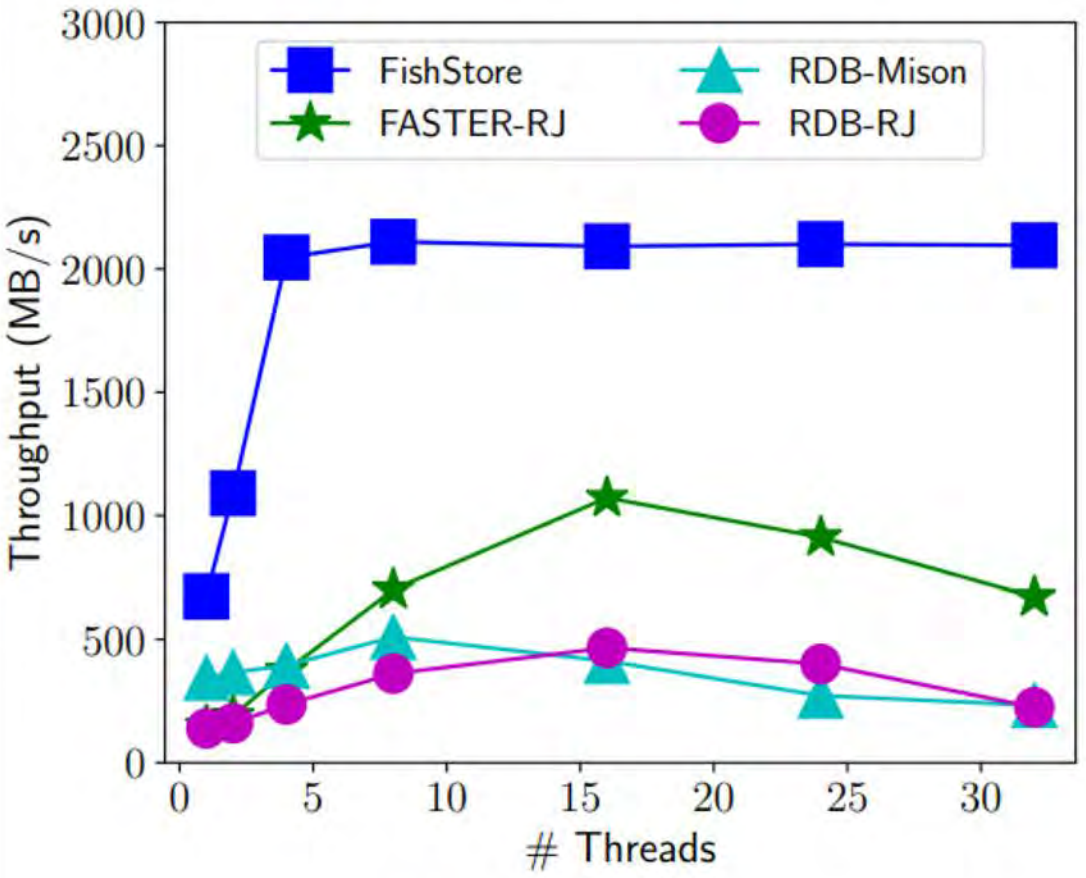
ADAPTIVE PREFETCHING

- When the log is totally in-memory, exploring the hash chain is not resource intensive.
- If the exploration lands on storage:
  - will issue random I/Os even when retrieved records may be continuously located on the log, hurting performance.
- In FISHSTORE, we use adaptive prefetching to detect locality on the hash chain and actively prefetch more data on the log to reduce random I/Os.

Figure 9: Adaptive Prefetching

EVALUATION OF FISHSTORE ON DATASETS

*HIGHER IS BETTER



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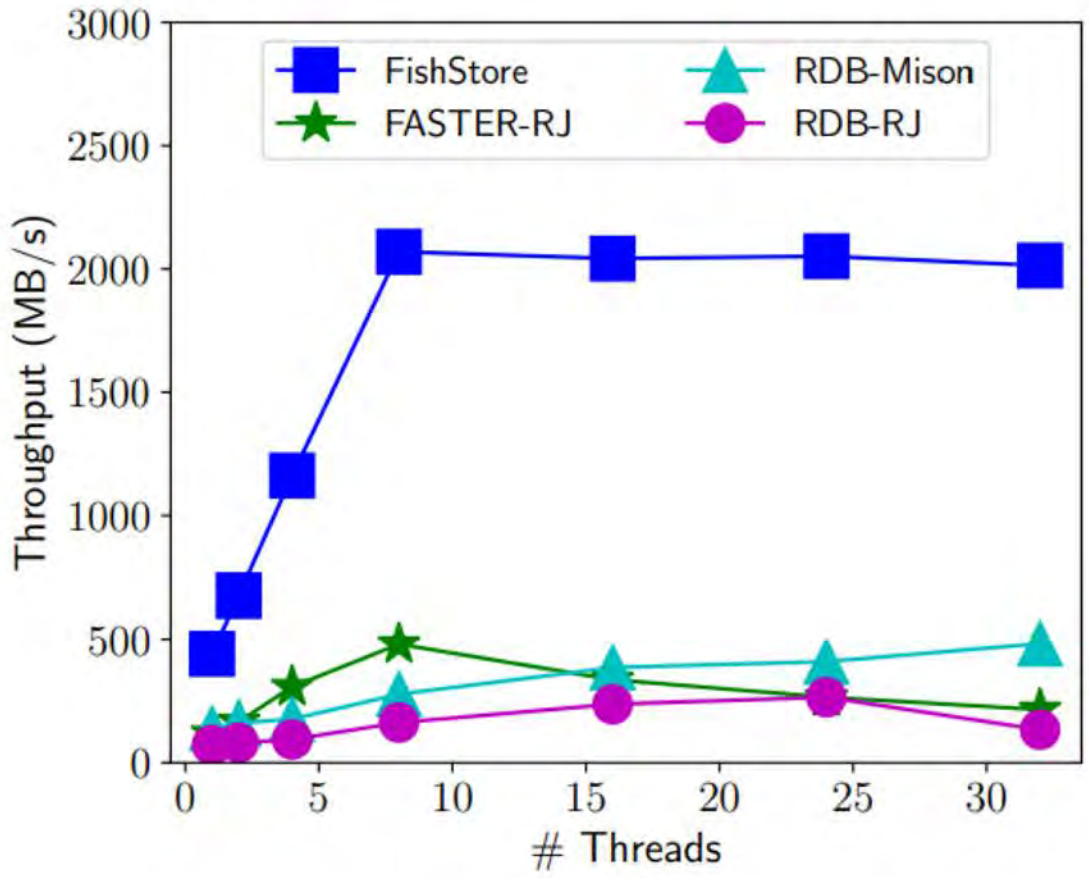
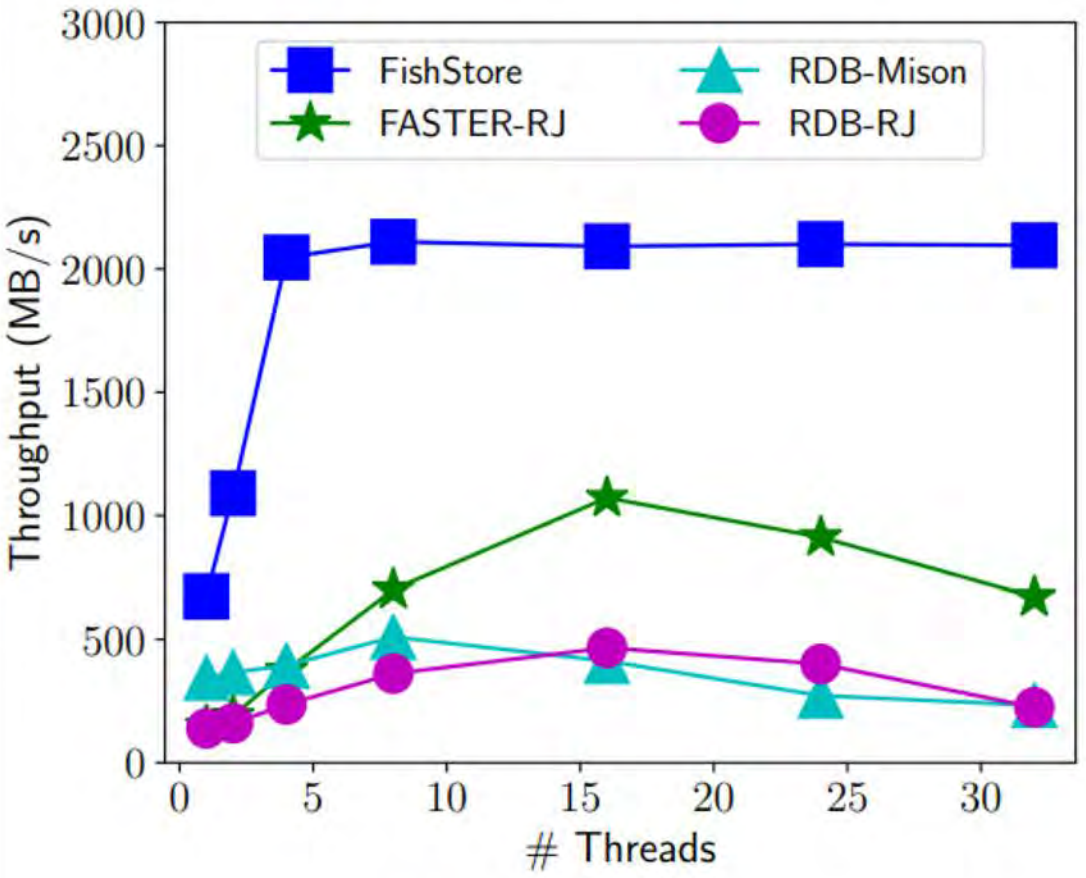


(b) Yelp

Figure 10: Comparison with Existing Solutions

*HIGHER IS BETTER

FISHSTORE Outperforms Due To Removal Of Indexing And Parsing Bottlebecks!



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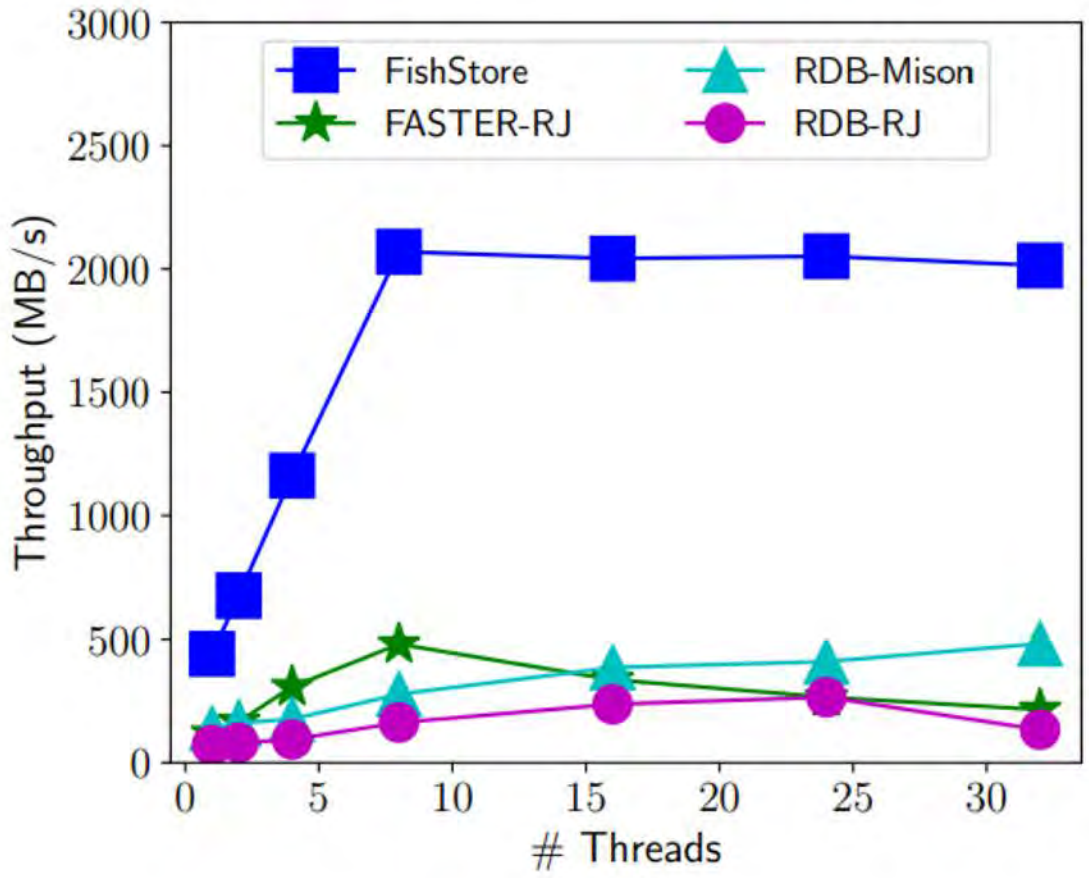

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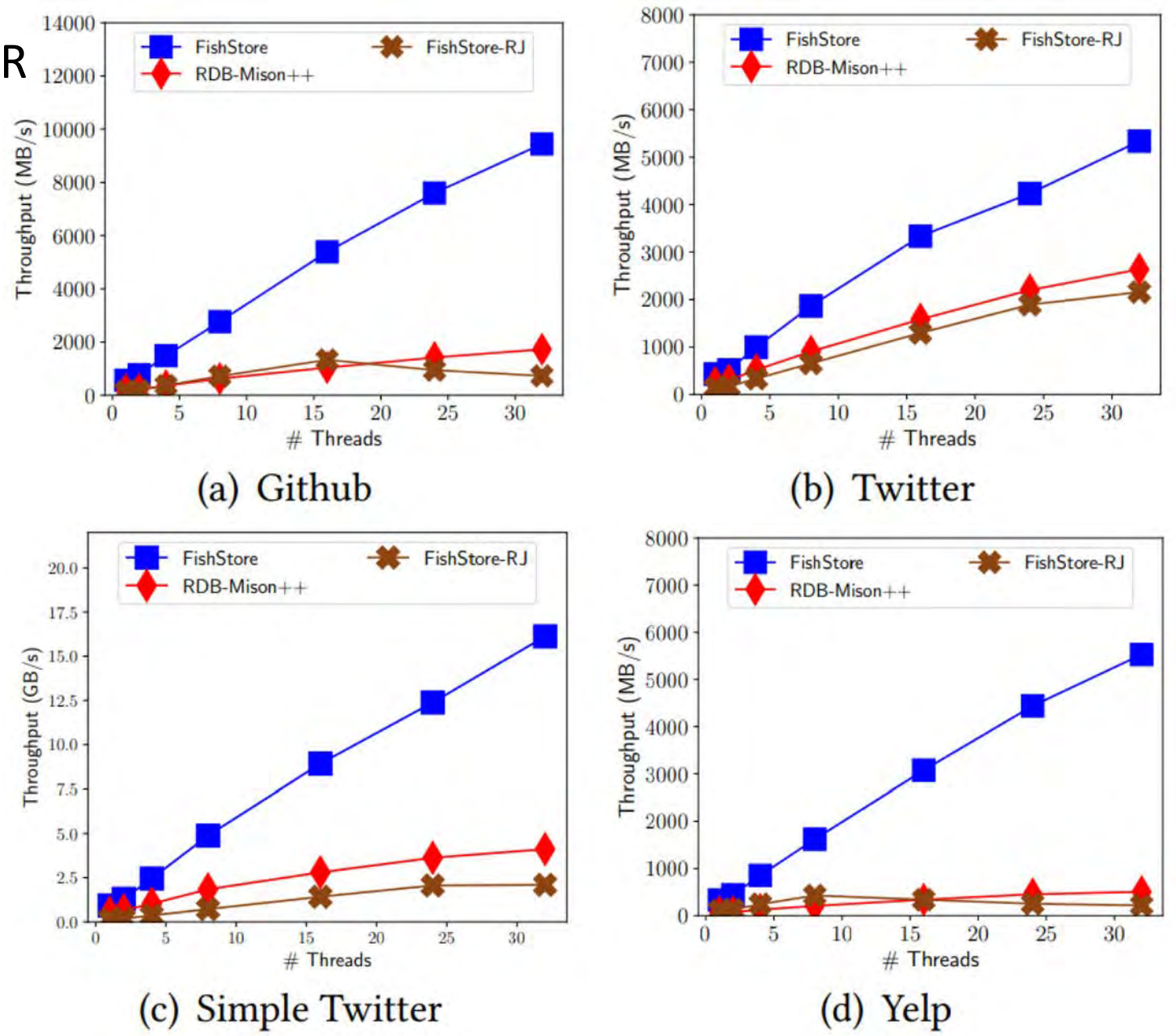
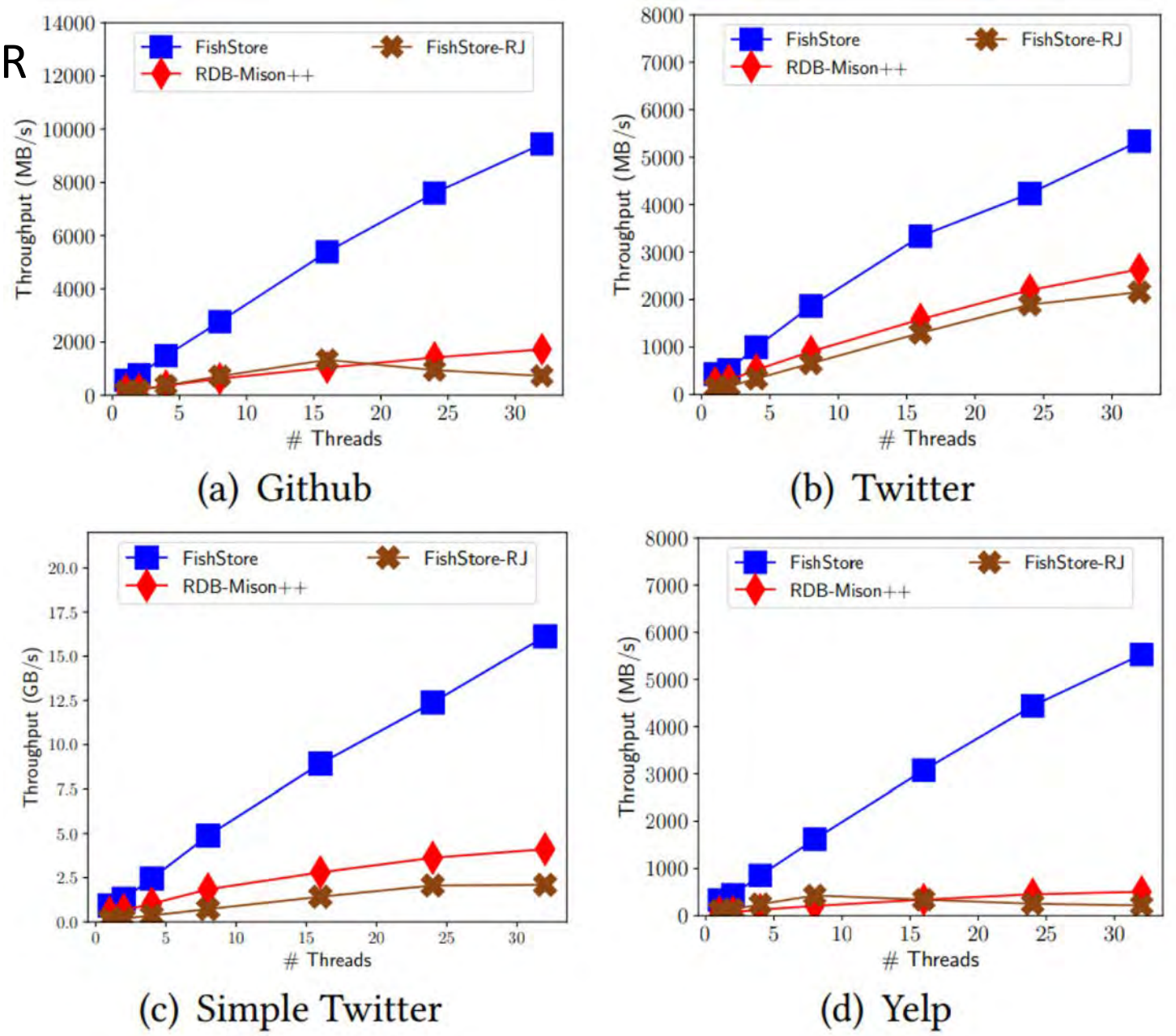


Figure 11: Ingestion Throughput in Main Memory

*HIGHER IS BETTER

FISHSTORE: Throughput ↑ as # of workers ↑!



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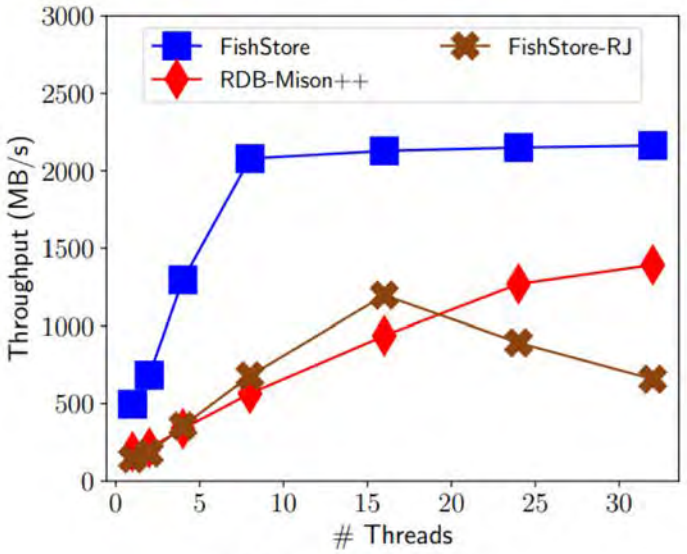

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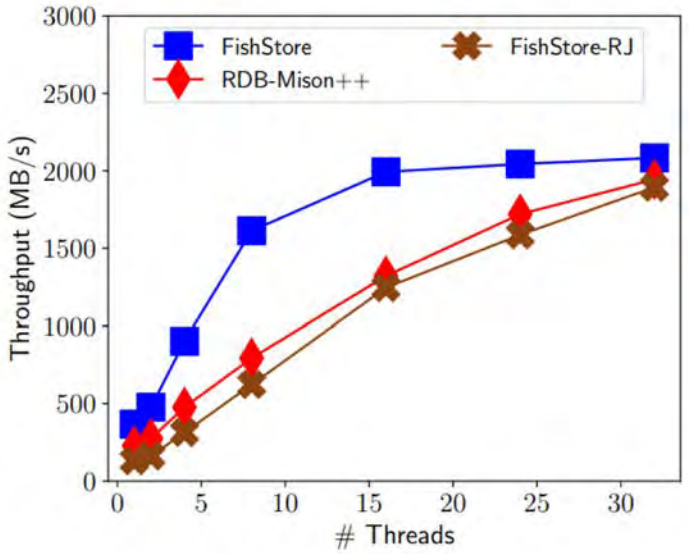
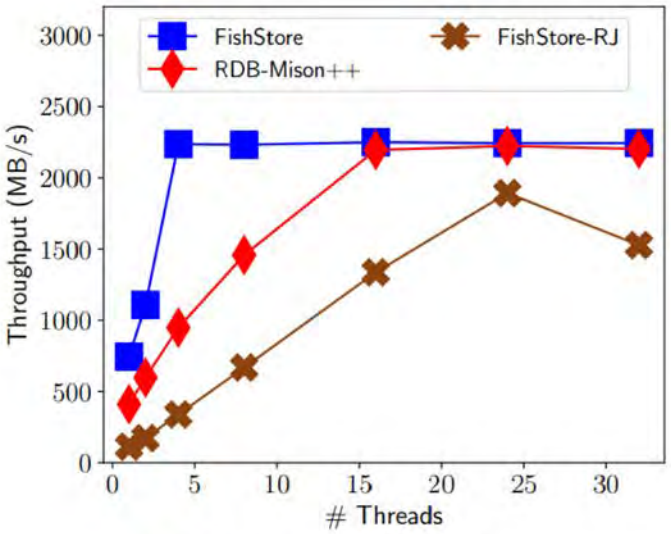
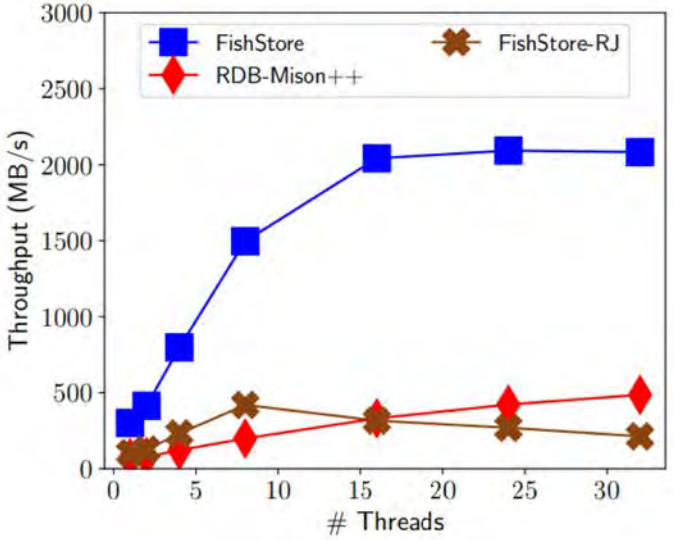


(b) Twitter



(c) Twitter Simple

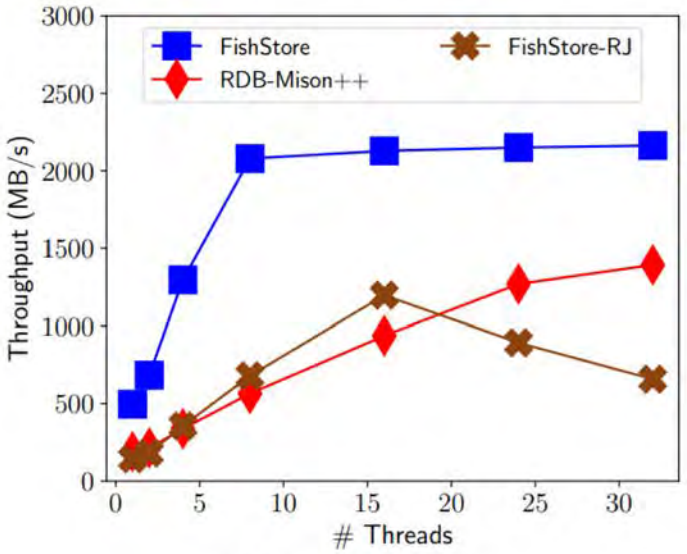


(d) Yelp

Figure 12: Ingestion Throughput on Disk

*HIGHER IS BETTER

FISHSTORE scales better than other solutions!



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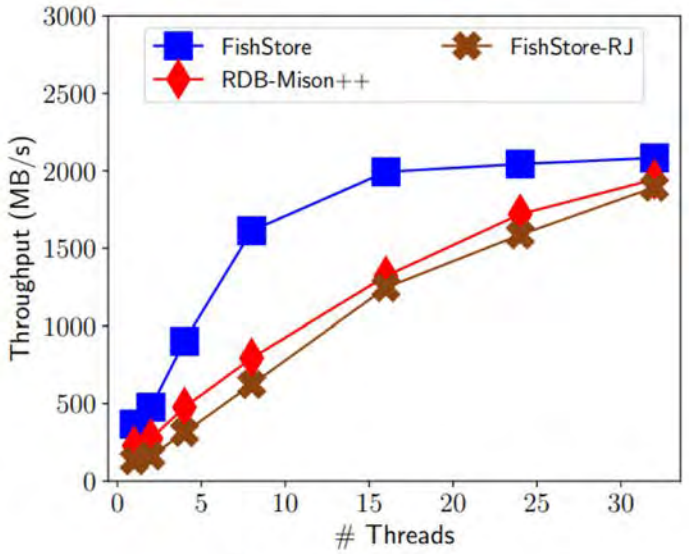

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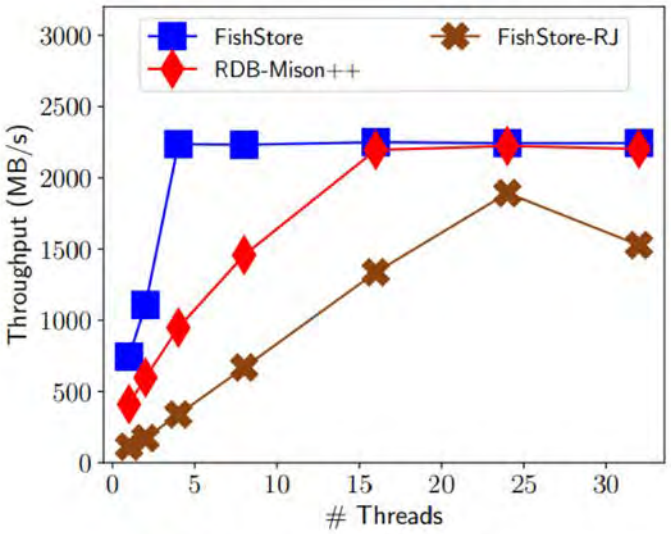

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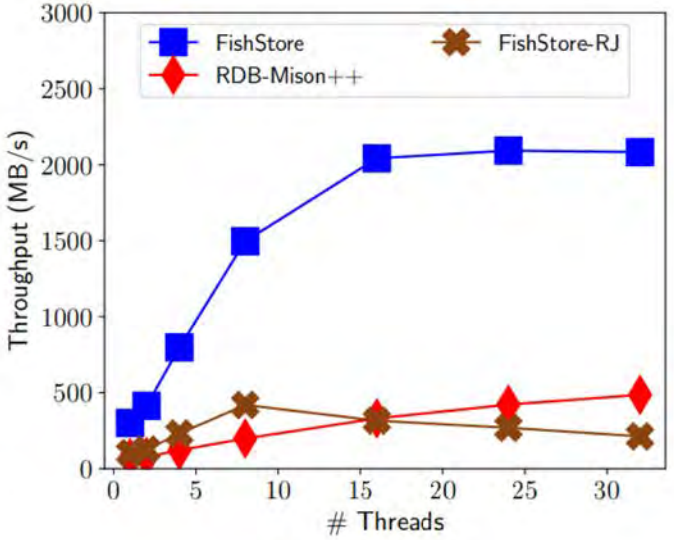

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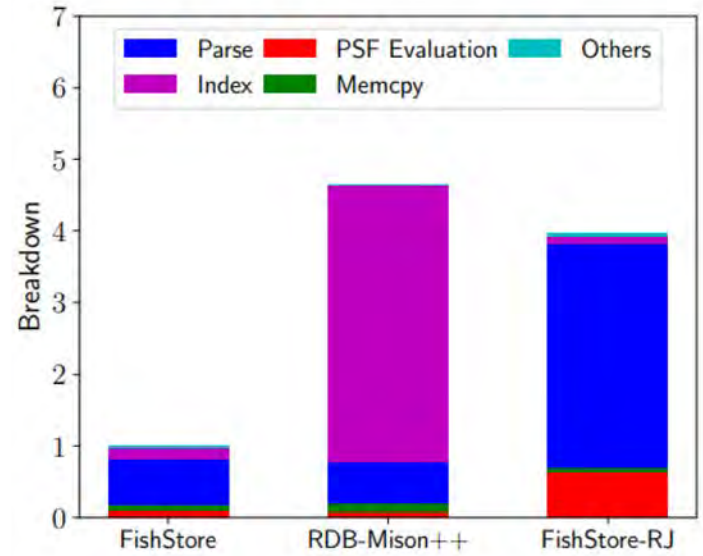

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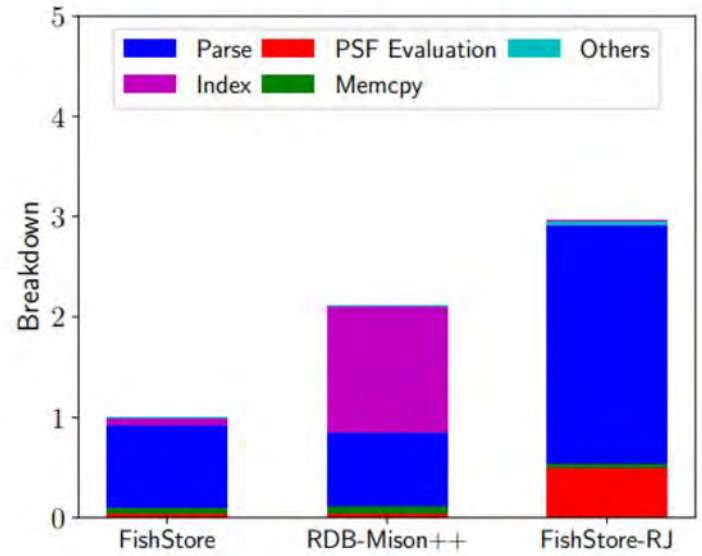

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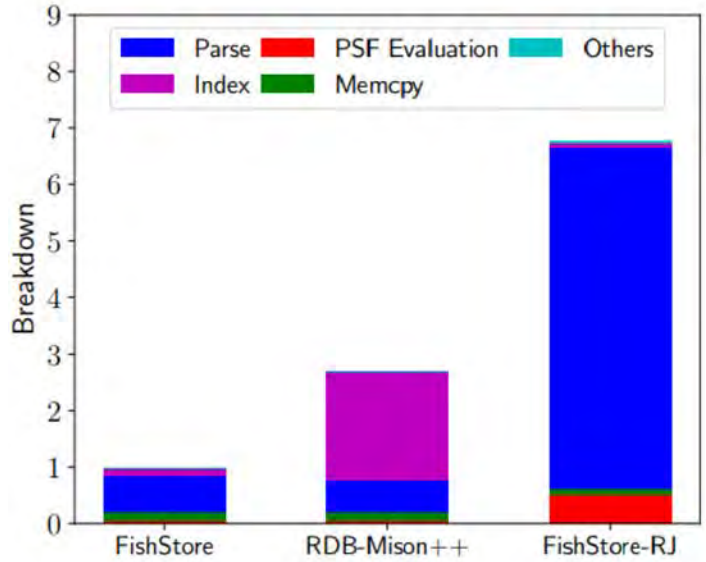

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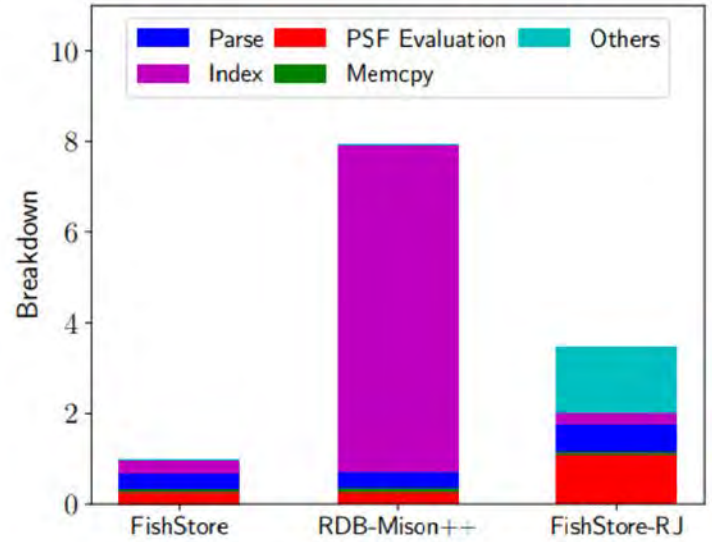


(d) Yelp

Figure 13: Ingestion in Main Memory: CPU Breakdown

FISHSTORE increases speed with faster parsing and indexing

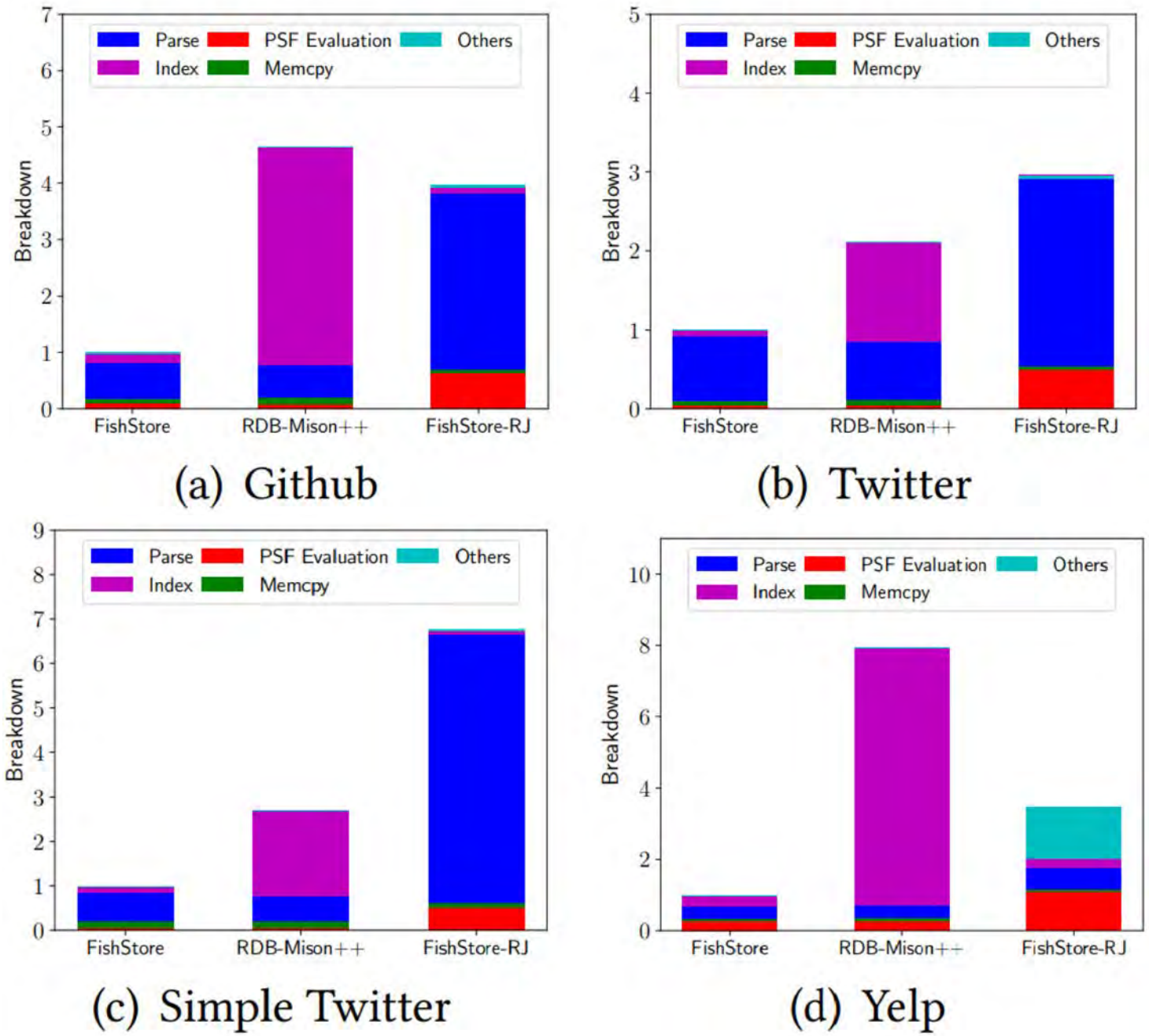
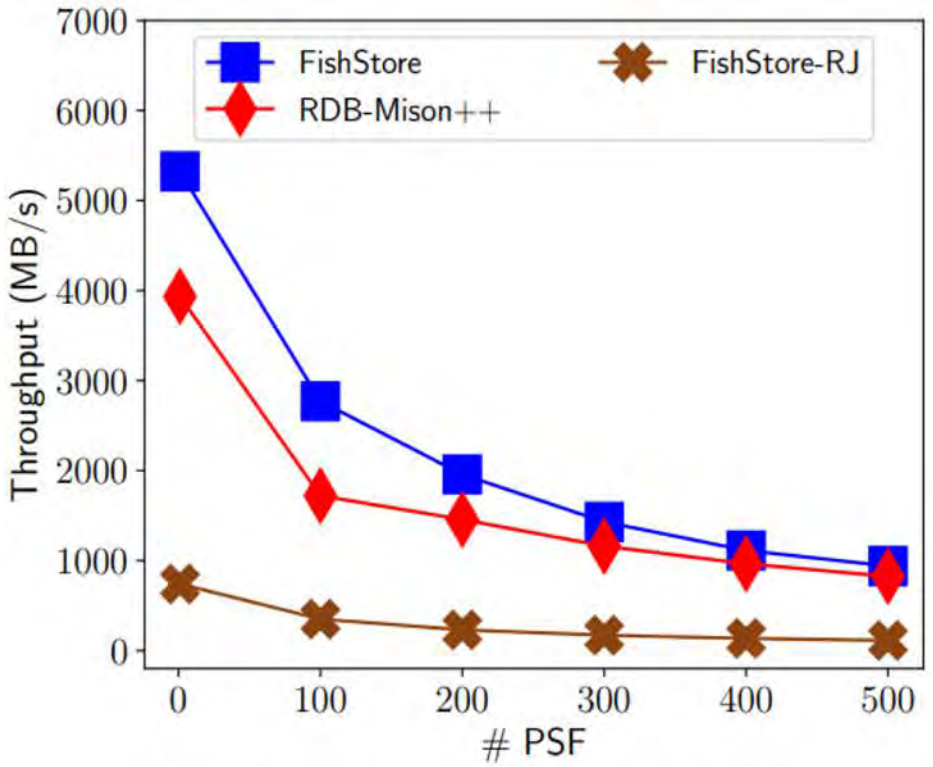
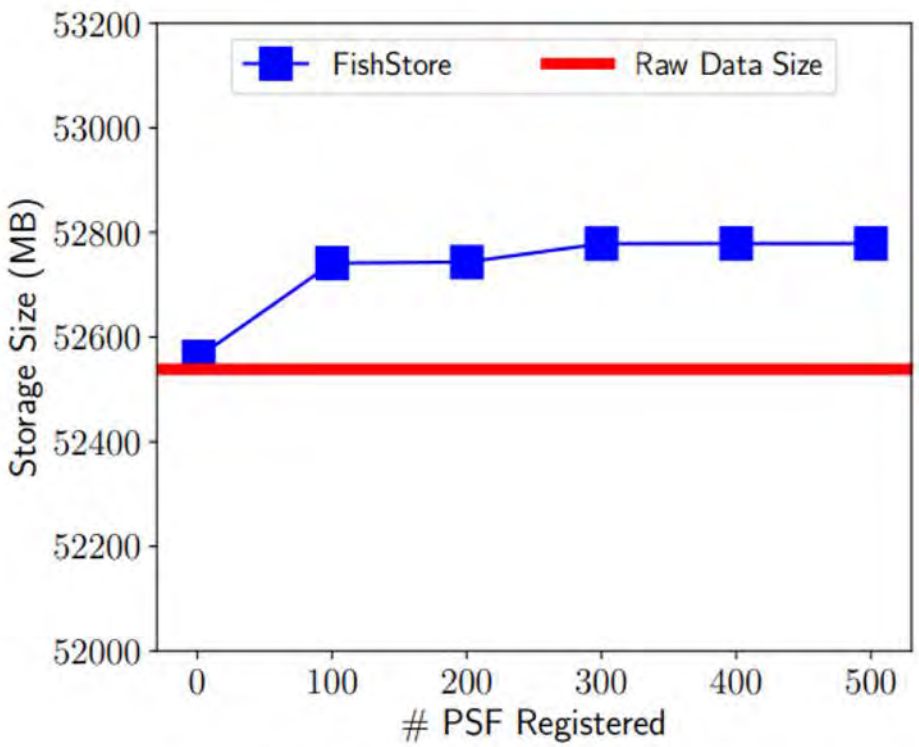


Figure 13: Ingestion in Main Memory: CPU Breakdown

*HIGHER IS BETTER



(a) Ingestion Throughput

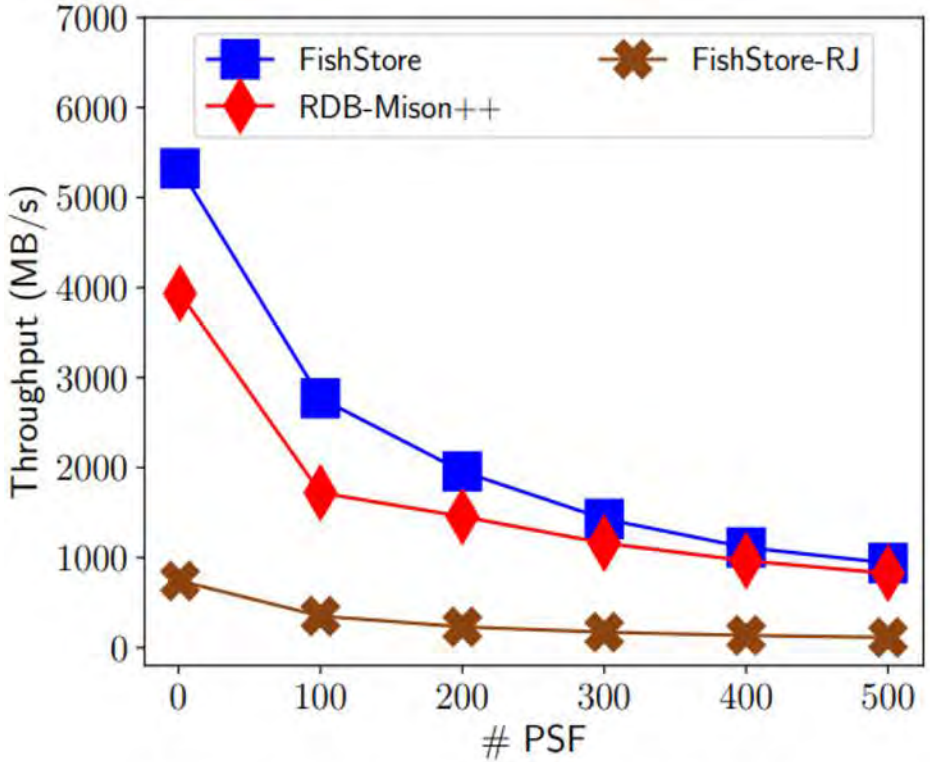


(b) Storage Cost

Figure 15: Predicate based PSF Scalability

*HIGHER IS BETTER

Ingestion speed goes ↓ as the # of PSFs ↑!



(a) Ingestion Throughput

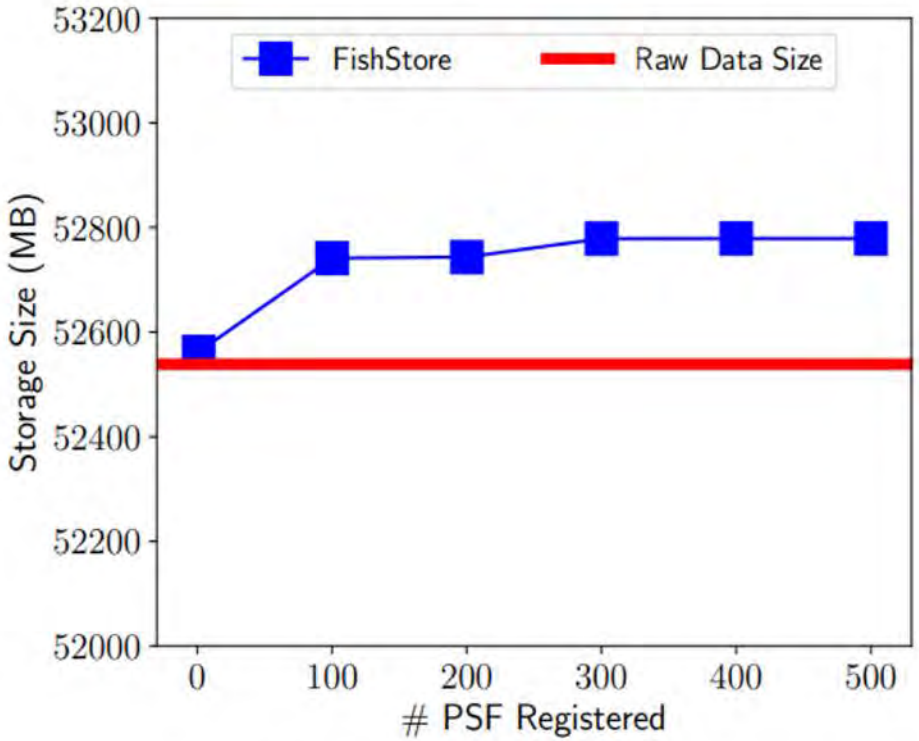


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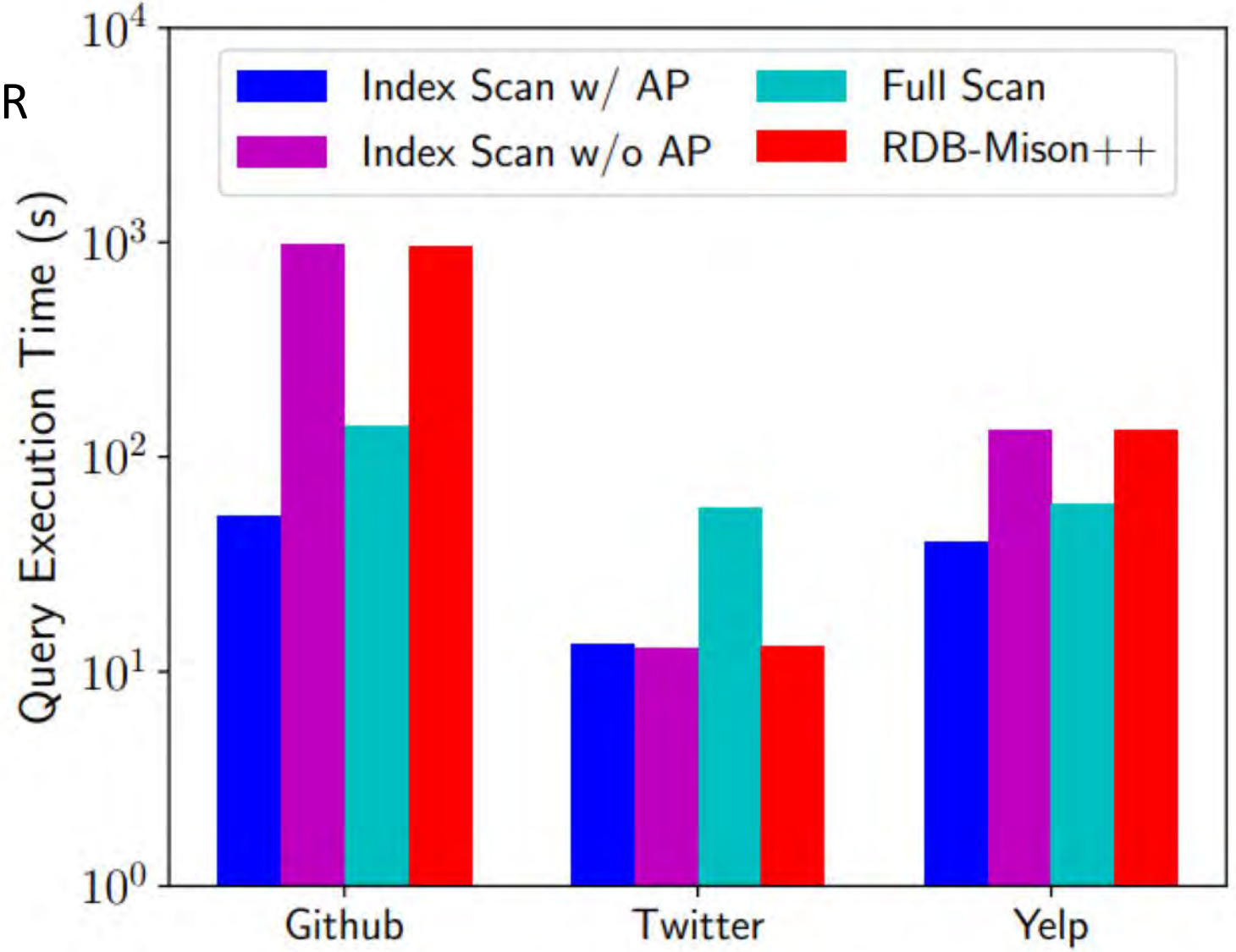
Figure 15: Predicate based PSF Scalability

FISHSTORE SUBSET RETRIEVAL PERFORMANCE

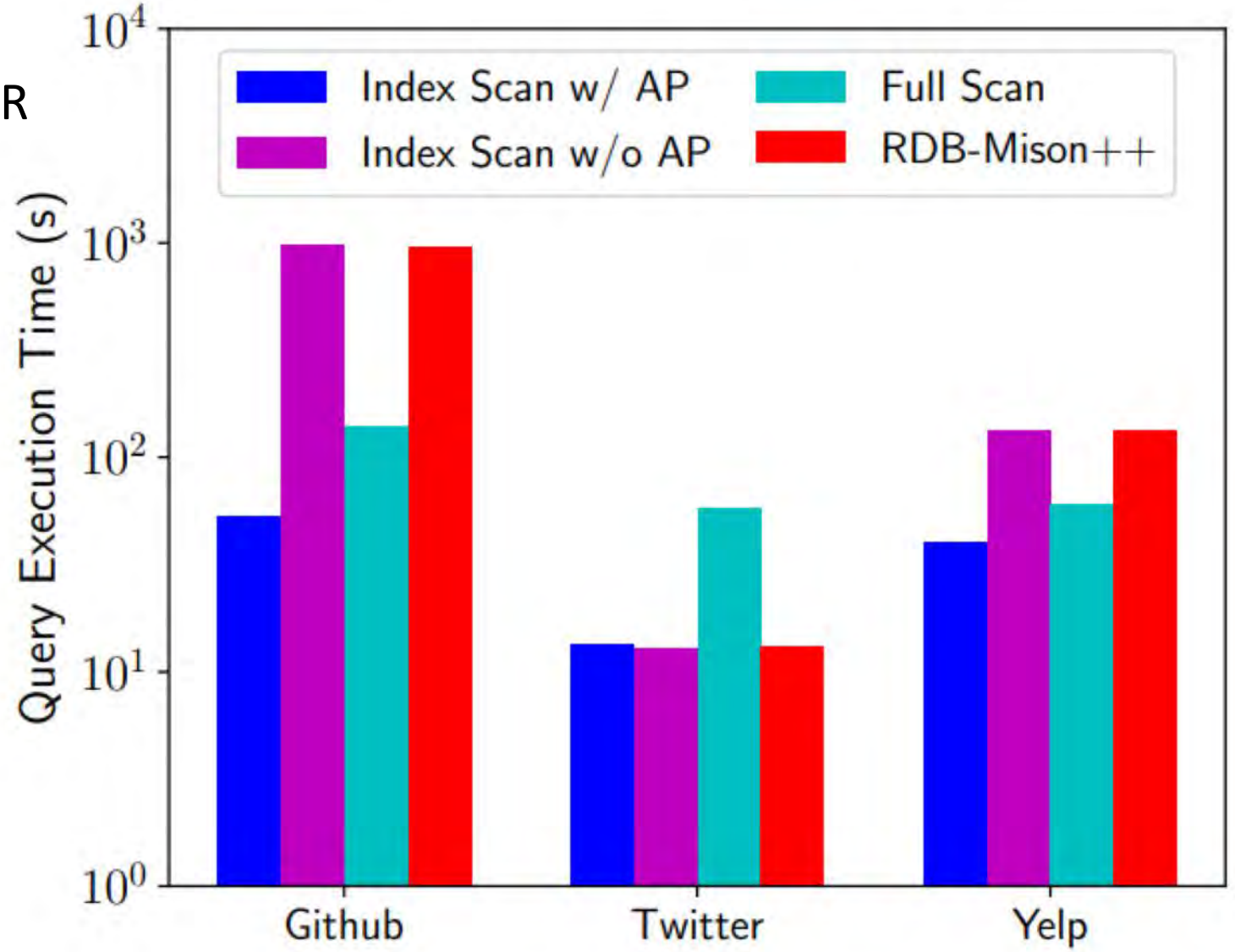
*LOWER IS BETTER



(a) Execution Time Summary

*LOWER IS BETTER

Prefetching good: issue random I/Os for selective queries and okay performance on non-selective ones!



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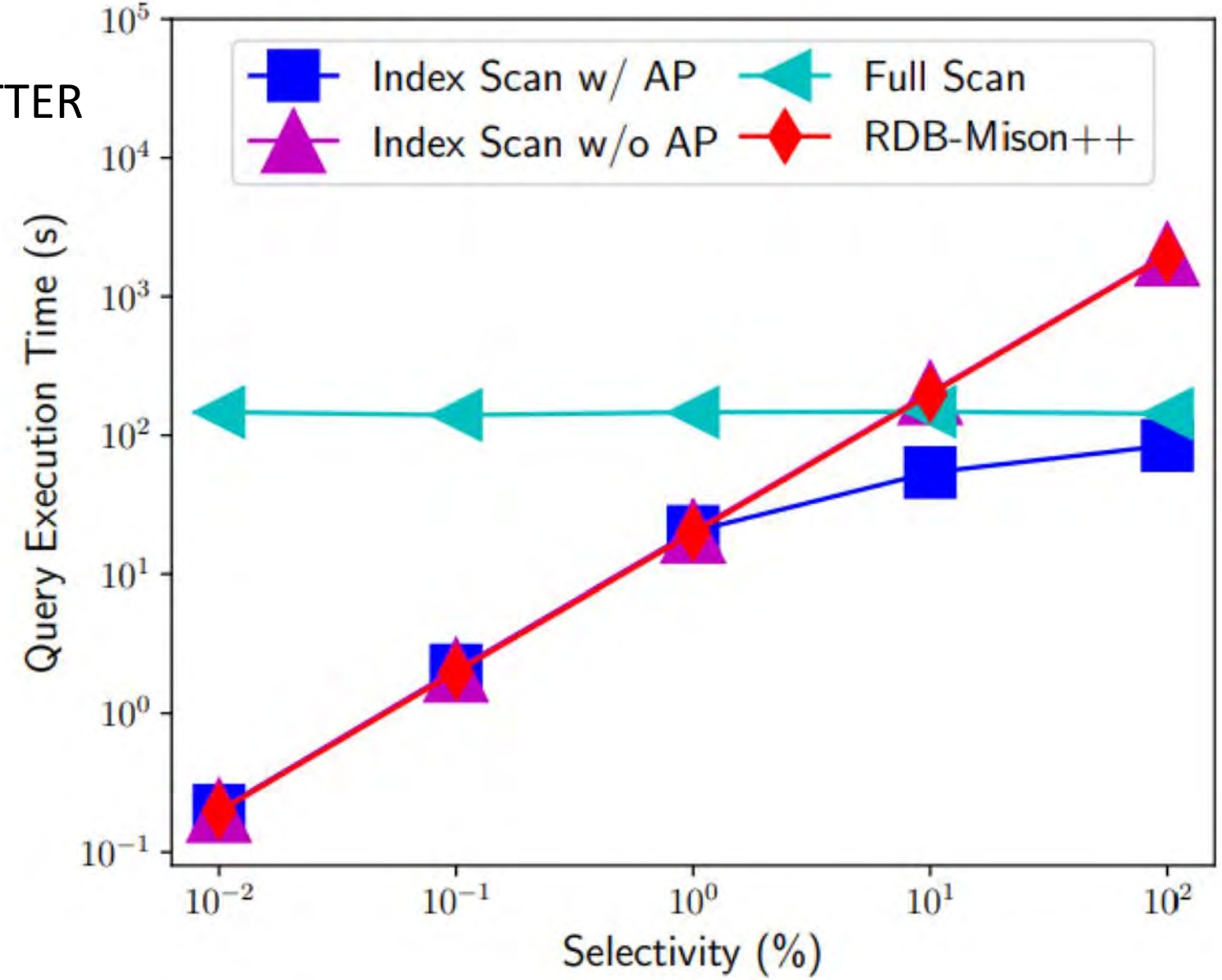
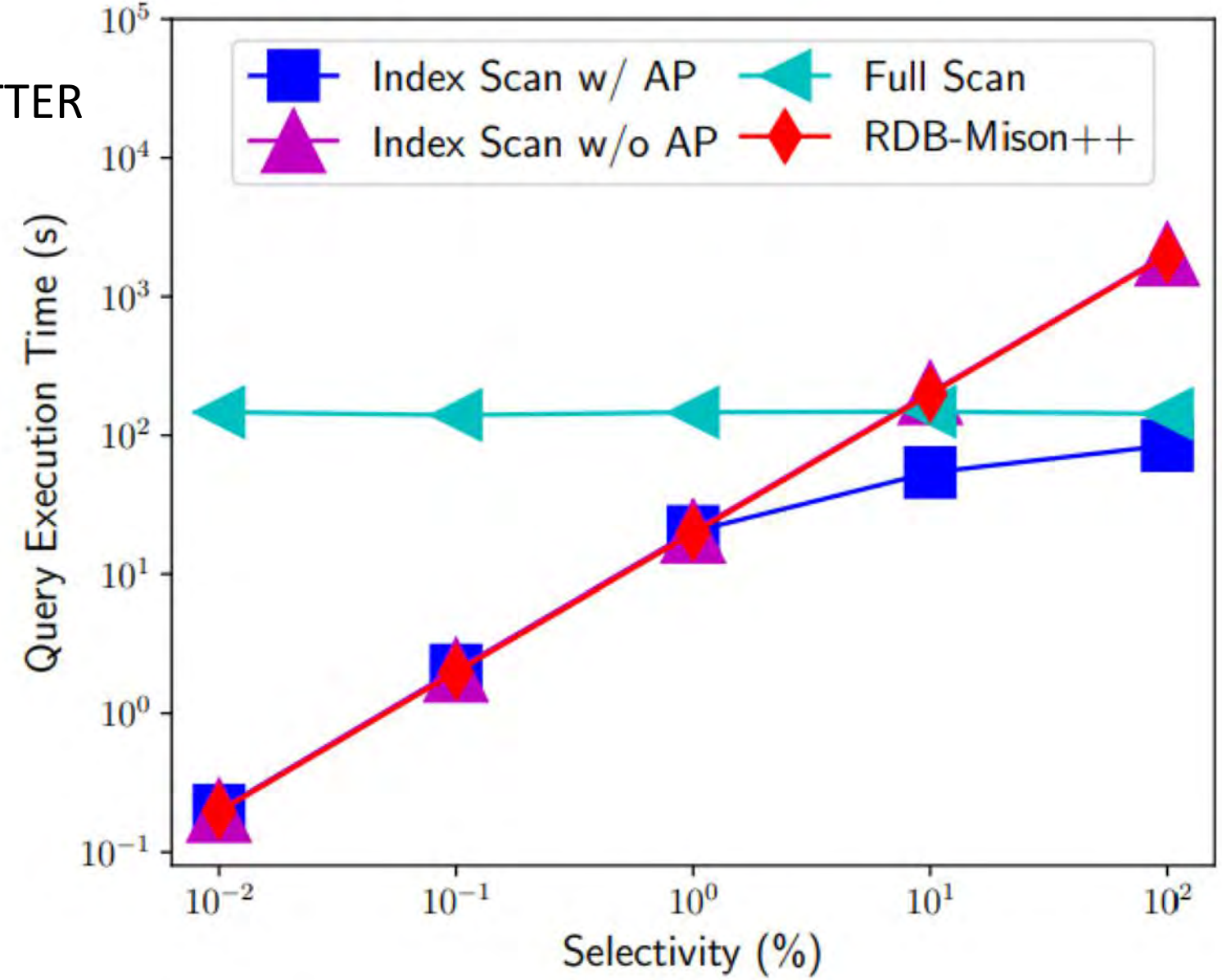


(b) Effect of Selectivity

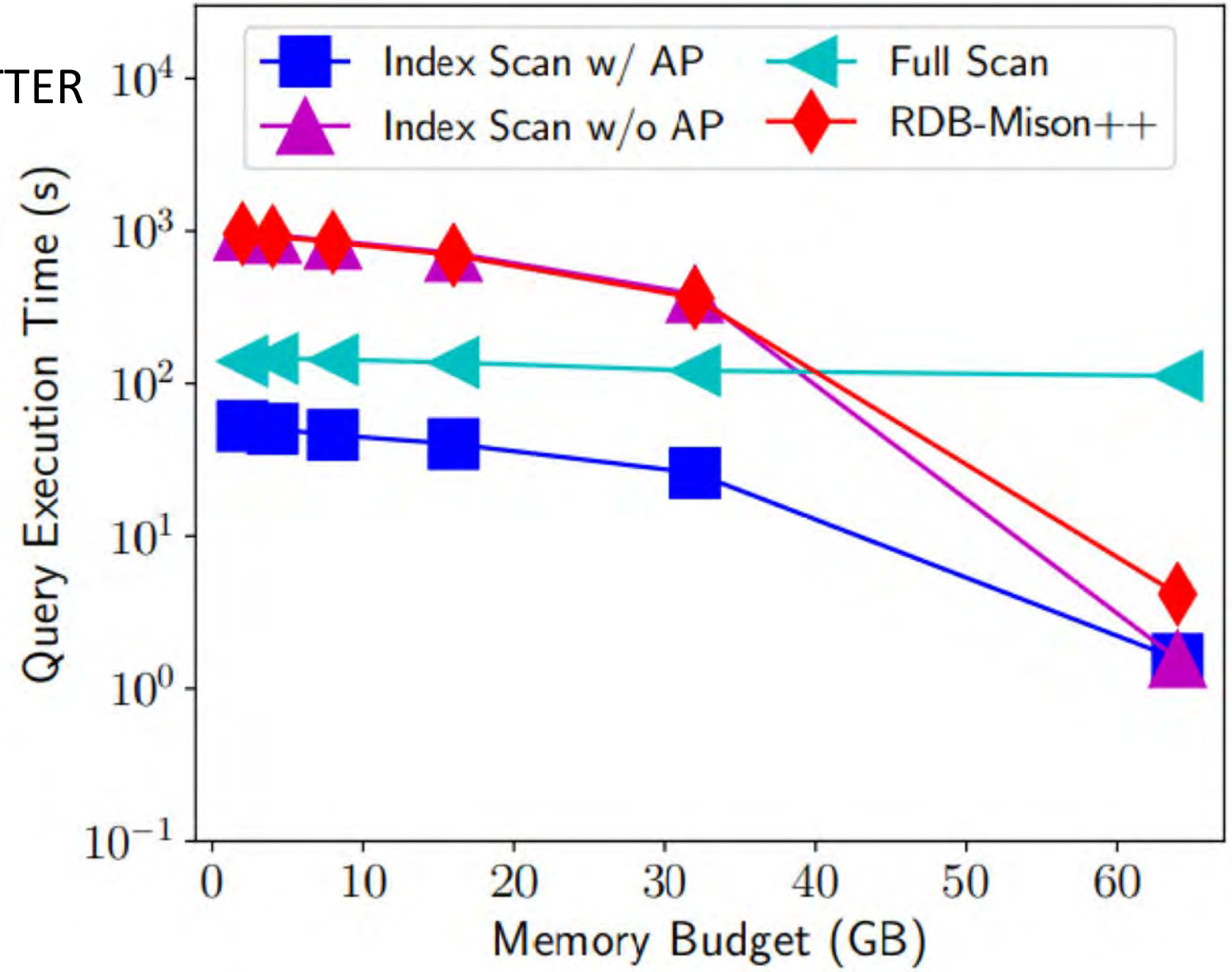
*LOWER IS BETTER

Due to adaptive prefetching, index scan does not become as slow as full scan!



(b) Effect of Selectivity

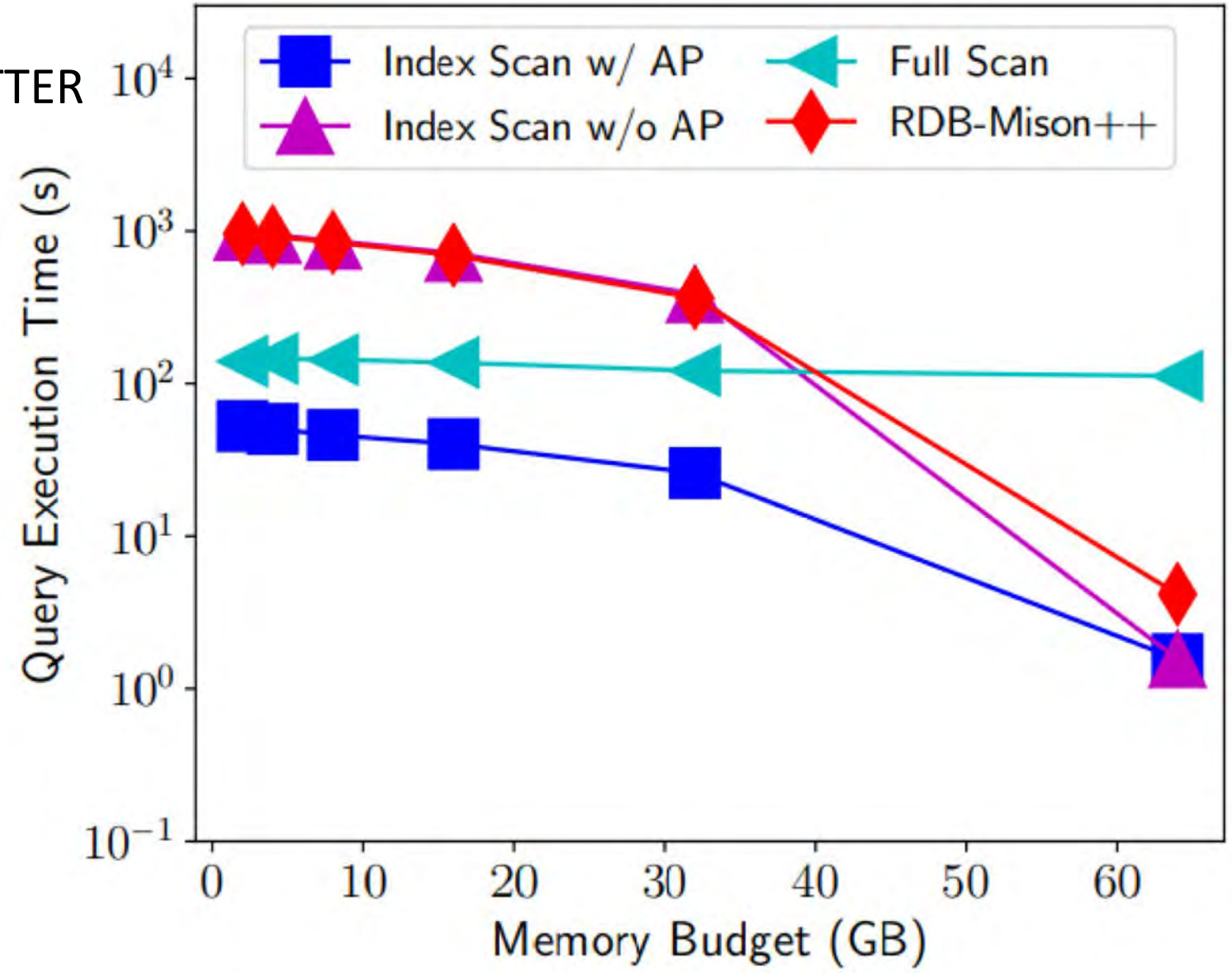
*LOWER IS BETTER



(c) Effect of Memory Budget

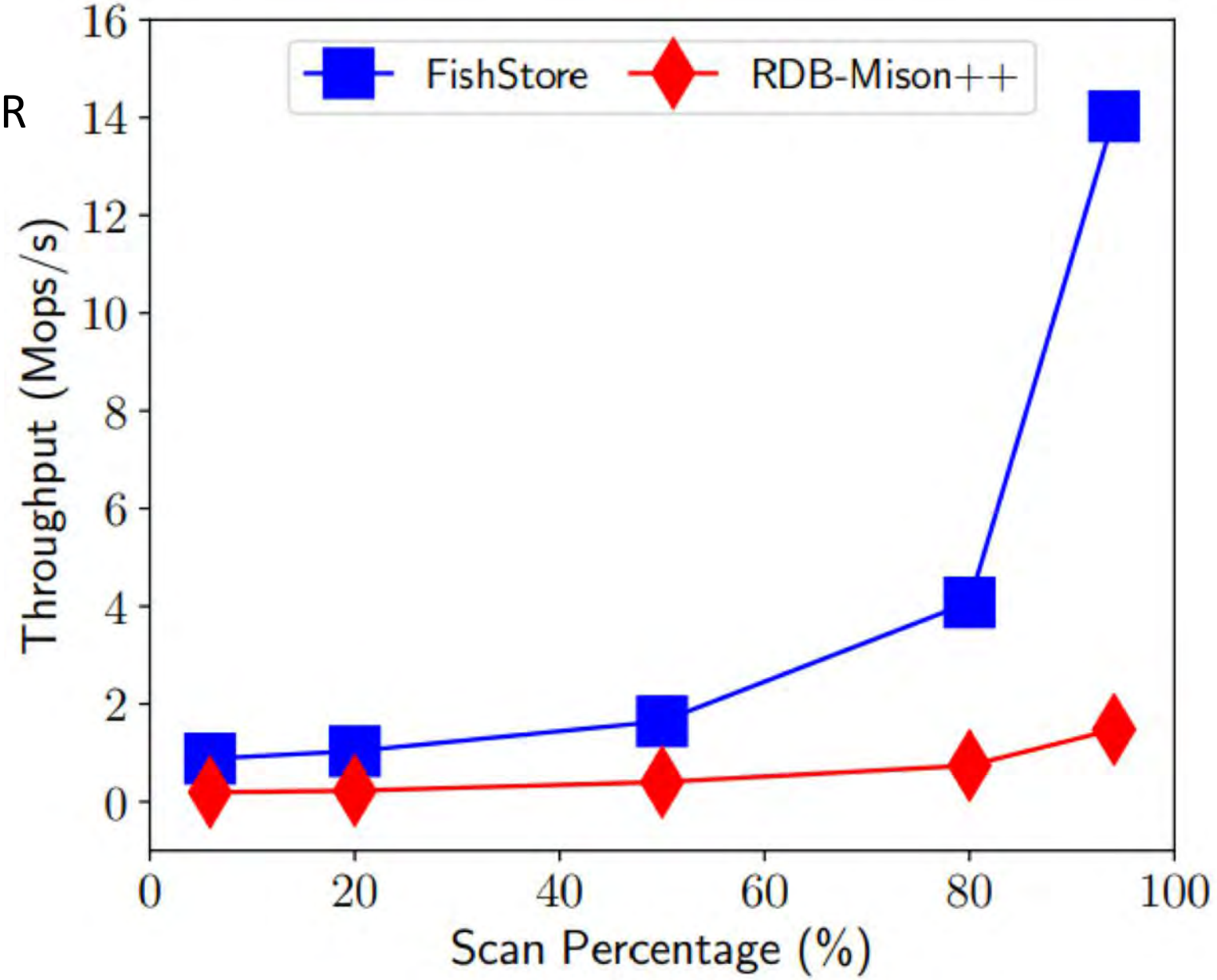
*LOWER IS BETTER

Index scan with and without adaptive prefetching benefit from having more memory!



(c) Effect of Memory Budget

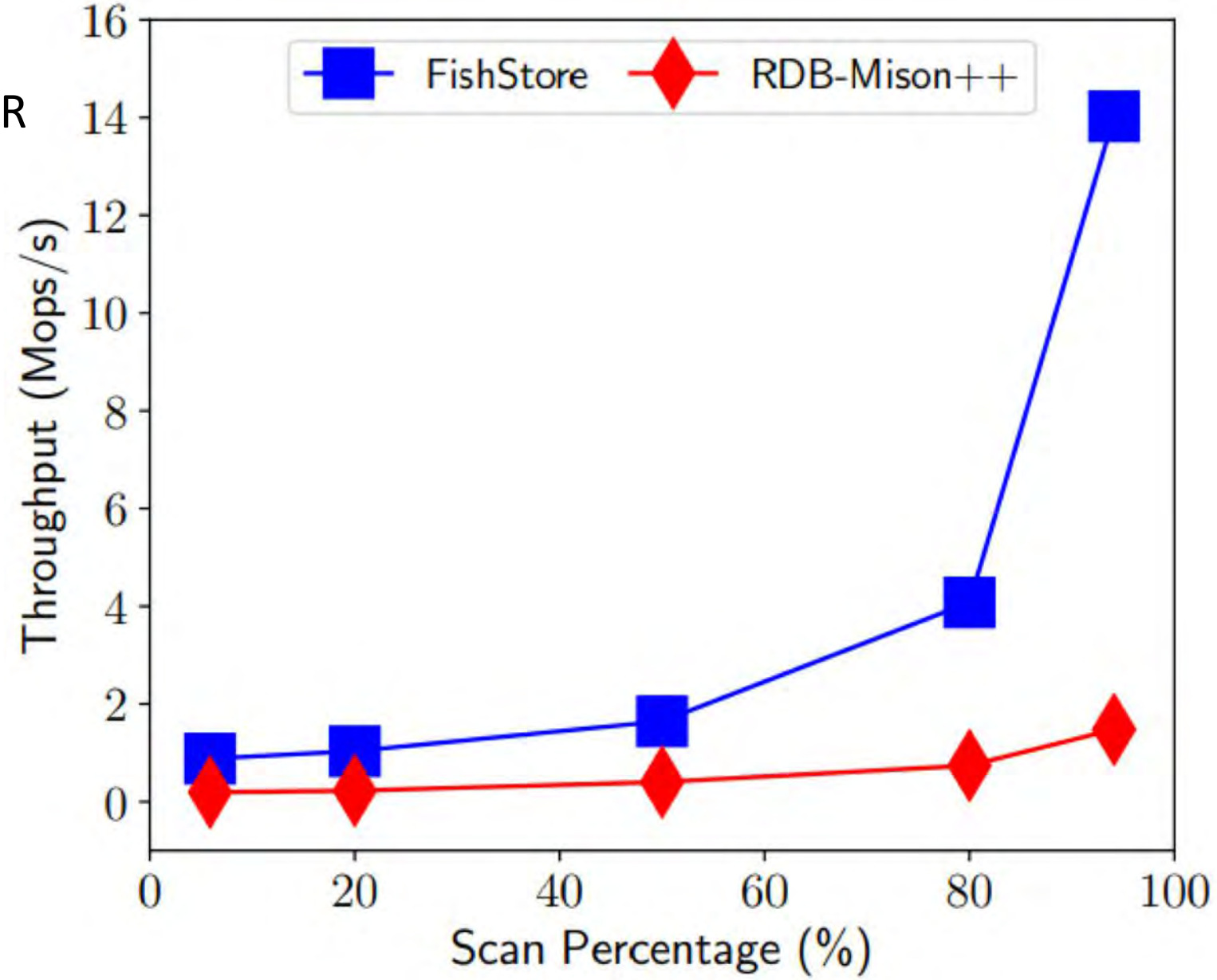
*LOWER IS BETTER



(d) Mixed Workload

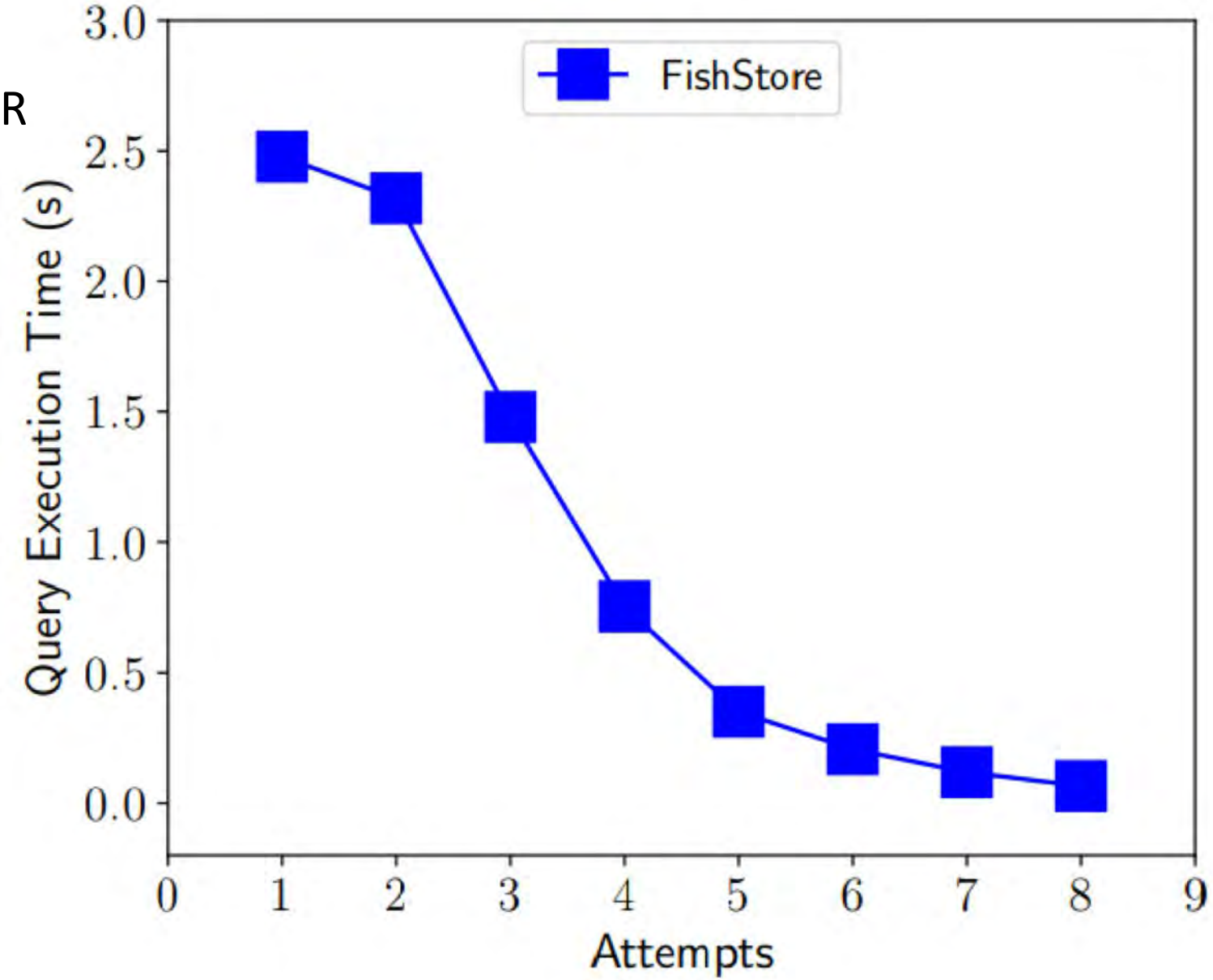
*LOWER IS BETTER

FishStore achieves higher throughput, because short scans are cheaper with no parsing or index update



(d) Mixed Workload

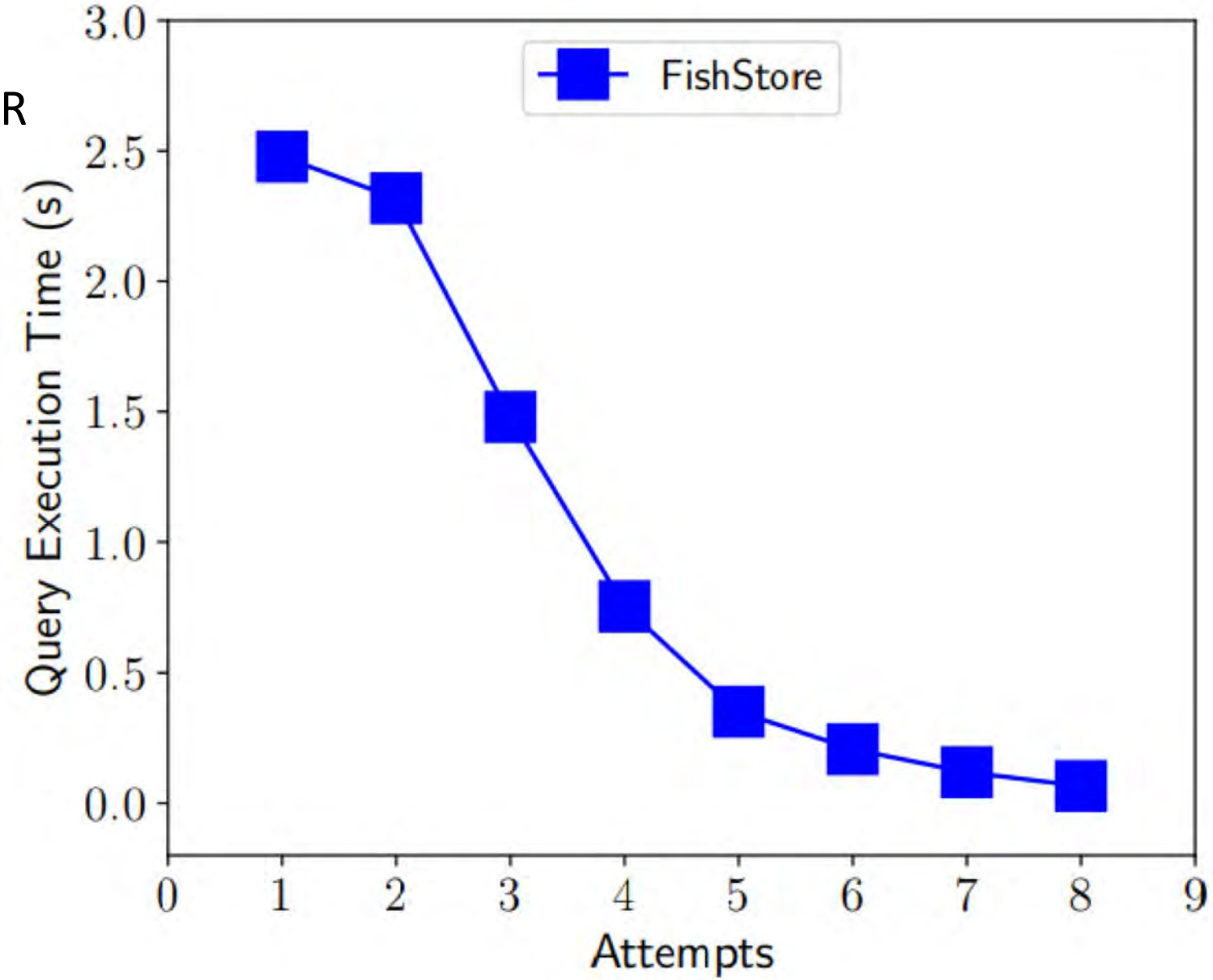
*LOWER IS BETTER



(e) Recurring Query

*LOWER IS BETTER

FISHSTORE performance betters because less of the data requires a full scan!



(e) Recurring Query

CONCLUSION

- Huge volumes of structured and unstructured data are being ingested into the cloud from a variety of data sources which no current methodology can ingest at high throughput with low CPU cost.
- Building on faster, FISHSTORE is a concurrent storage layer for data with flexible schema, based on the notion of hash indexing user chosen, dynamically registered predicated subset functions.