CS 764: Topics in Database Management Systems

Lecture 11: Pushdown DBMS

Xiangyao Yu

10/9/2025

Announcements

Submit project proposal by **Oct. 17**

- Create a new submission on Hotcrp (https://wisc-cs764-f25.hotcrp.com)

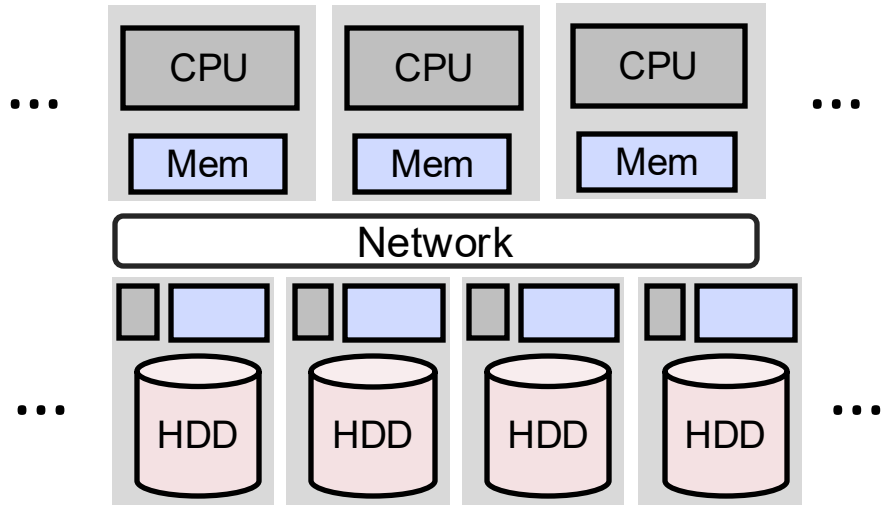
Cover the following aspects (in 1–4 pages)

- Project name
- Author list
- Background and motivation (why important? challenges?)
- Task plan (what will you do? key contributions?)
- Timeline

Recommend ACM format

- https://www.acm.org/publications/proceedings-template

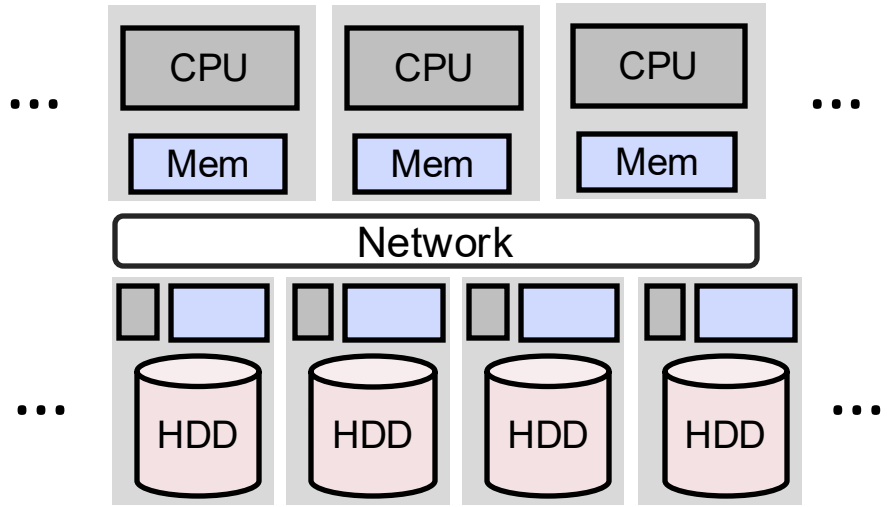
Storage-Disaggregation Architecture



Features of disaggregation architecture

- Computation and storage layers are disaggregated
- Limited computation can happen in the storage layer

Storage-Disaggregation Architecture



Features of disaggregation architecture

- Computation and storage layers are disaggregated
- Limited computation can happen in the storage layer

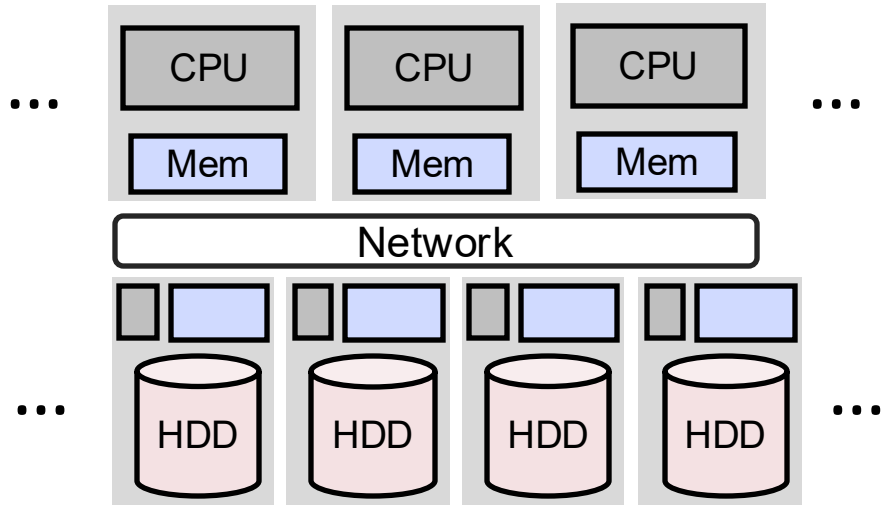
Advantages

- Lower management cost
- Independent scaling of computation and storage

Disadvantages

- **Network becomes a bottleneck**

How to Mitigate the Network Bottleneck?



Solution 1: Move data to computation

- Cache storage data in the computation layer
- Example: Snowflake

Solution 2: **Move computation to data**

- Pushdown computation to the storage layer
- Example: PushdownDB

Today's Papers — Pushdown DBMS

PushdownDB: Accelerating a DBMS Using S3 Computation

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Marco Serafini¶, Ashraf Aboulnaga§, Michael Stonebraker†
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***Abstract*—This paper studies the effectiveness of pushing parts of DBMS analytics queries into the Simple Storage Service (S3) of Amazon Web Services (AWS), using a recently released capability called S3 Select. We show that some DBMS primitives (filter, projection, and aggregation) can always be cost-effectively moved into S3. Other more complex operations (join, top-K, and group-by) require reimplementation to take advantage of S3 Select and are often candidates for pushdown. We demonstrate these capabilities through experimentation using a new DBMS that we developed, *PushdownDB*. Experimentation with a collection of queries including TPC-H queries shows that *PushdownDB* is on average 30% cheaper and 6.7× faster than a baseline that does not use S3 Select.**

I. Introduction

Clouds offer cheaper and more flexible computing than "on-prem". Not only can one add resources on the fly, the large cloud vendors have major economies of scale relative to "on-prem" deployment. Modern clouds employ an architecture where the computation and storage are disaggregated — the two components are independently managed and connected using a network. Such an architecture allows for independent scaling of computation and storage, which simplifies the management of storage and reduces its cost. A number of data warehousing systems have been built to analyze data on disaggregated cloud storage, including Presto [1], Snowflake [2], Redshift Spectrum [3], among others.

In a disaggregated architecture, the network that connects the computation and storage layers can be a major performance bottleneck. Two intuitive solutions are *caching* and *computation pushdown*. With caching, a compute server loads data from the remote storage and caches it in main memory or local storage, amortizing the network transfer cost. Caching has been implemented in Snowflake [2] and Redshift Spectrum [3], [4]. With computation pushdown, a database management system (DBMS) pushes its functionality as close to storage as possible. Previous research [5] and systems (e.g., Britton-Lee IDM 500 [6], Oracle Exadata server [7], and IBM Netezza machine [8]) have shown that this can significantly improve performance.

Recently, Amazon Web Services (AWS) introduced a feature called "S3 Select", through which limited computation can be pushed onto their shared cloud storage service called S3 [9]. This provides an opportunity to revisit the question of how to divide query processing tasks between S3 storage nodes and normal computation nodes. The question is nontrivial as the limited computational interface of S3 Select allows only certain simple query operators to be pushed into the storage layer, namely selections, projections, and simple aggregations. Other operators require new implementations to take advantage of S3 Select. Moreover, S3 Select pricing can be more expensive than computing on normal EC2 nodes.

In this paper, we set our goal to understand the performance of computation pushdown when running queries in a cloud setting with disaggregated storage. Specifically, we consider filter (with and without indexing), join, group-by, and top-K as candidates. We implement these operators to take advantage of computation pushdown through S3 Select and study their cost and performance. We show dramatic performance improvement and cost reduction, even with the relatively high cost of S3 Select. In addition, we analyze queries from the TPC-H benchmark and show similar benefits of performance and cost. We point out the limitations of the current S3 Select service and provide several suggestions based on the lessons we learned from this project. To the best of our knowledge, this is the *first extensive study of pushdown computing for database operators in a disaggregated architecture*. A more detailed description of this work can be found in [10].

II. Data Management in the Cloud

Cloud providers such as AWS offer a wide variety of computing instances (i.e., EC2: Elastic Compute Cloud) and storage services (i.e., EBS: Elastic Block Store, EFS: Elastic File System, and S3: Simple Storage Service). Compared to other storage services, S3 is a highly available object store that provides virtually infinite storage capacity for regular users with relatively low cost, and is supported by many popular cloud databases, including Presto [1], Hive [11], Spark SQL [12], Redshift Spectrum [3], and Snowflake [2]. The storage nodes in S3 are separate from compute nodes. Hence, a DBMS uses S3 as a storage system and transfers needed data over a network for query processing.

To reduce network traffic and the associated processing on compute nodes, AWS released a new service called *S3 Select* [9] in 2018 to push limited computation to the storage nodes. At the current time, S3 Select supports only selection,

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Modern cloud databases adopt a *storage-disaggregation* architecture that separates the management of computation and storage. A major bottleneck in such an architecture is the network connecting the computation and storage layers. Two solutions have been explored to mitigate the bottleneck: *caching* and *computation pushdown*. While both techniques can significantly reduce network traffic, existing DBMSs consider them as orthogonal techniques and support only one or the other, leaving potential performance benefits unexploited.

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doi:10.14778/3476249.3476265

PVLDB Artifact Availability:
The source code, data, and/or other artifacts have been made available at https://github.com/cloud-olap/FlexPushdownDB.git.

1 INTRODUCTION

Database management systems (DBMSs) are gradually moving from on-premises to the cloud for higher elasticity and lower cost. Modern cloud DBMSs adopt a *storage-disaggregation architecture* that divides computation and storage into separate layers of servers connected through the network, simplifying provisioning and enabling independent scaling of resources. However, disaggregation requires rethinking a fundamental principle of distributed DBMSs: "move computation to data rather than data to computation". Compared to the traditional shared-nothing architecture, which embodies that principle and stores data on local disks, the network in the disaggregation architecture typically has lower bandwidth than local disks, making it a potential performance bottleneck.

Two solutions have been explored to mitigate this network bottleneck: *caching* and *computation pushdown*. Both solutions can reduce the amount of data transferred between the two layers. Caching keeps the hot data in the computation layer. Examples include Snowflake [21, 48] and Presto with Alluxio cache service [14]. The Redshift [30] layer in Redshift Spectrum [8] can also be considered as a cache with user-controlled contents. With computation pushdown, filtering and aggregation are performed close to the storage with only the results returned. Examples include Oracle Exadata [49], IBM Netezza [23], AWS Redshift Spectrum [8], AWS Aqua [12], and PushdownDB [53]. The fundamental reasons that caching and pushdown have performance benefits are that local memory and storage have higher bandwidth than the network and that the internal bandwidth within the storage layer is also higher than that of the network.

Existing DBMSs consider caching and computation pushdown as *orthogonal*. Most systems implement only one of them. Some systems, such as Exadata [49], Netezza [23], Redshift Spectrum [8], and Presto [14] consider the two techniques as independent: query operators can either access cached data (i.e., full tables) or push down computation on remote data, but not both.

In this paper, we argue that caching and computation pushdown are *not* orthogonal techniques, and that the rigid dichotomy of existing systems leaves potential performance benefits unexploited. We propose *FlexPushdownDB* (*FPDB* in short), an OLAP cloud DBMS prototype that combines the benefits of caching and pushdown.

FPDB introduces the concept of *separable operators*, which combine local computation on cached segments and pushdown on the segments in the cloud storage. This hybrid execution can leverage cached data at a fine granularity. While not all relational operators are separable, some of the most commonly-used ones are, including filtering, projection, aggregation. We introduce a *merge* operator to combine the outputs from caching and pushdown.

Separable operators open up new possibilities for caching. Traditional cache replacement policies assume that each miss requires

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REGULAR PAPER

FlexpushdownDB: rethinking computation pushdown for cloud OLAP DBMSs

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Abstract

Modern cloud-native OLAP databases adopt a *storage-disaggregation* architecture that separates the management of computation and storage. A major bottleneck in such an architecture is the network connecting the computation and storage layers. Computation pushdown is a promising solution to tackle this issue, which offloads some computation tasks to the storage layer to reduce network traffic. This paper presents *FlexPushdownDB* (*FPDB*), where we revisit the design of computation pushdown in a storage-disaggregation architecture, and then introduce several optimizations to further accelerate query processing. First, FPDB supports *hybrid query execution*, which combines local computation on cached data and computation pushdown to cloud storage at a fine granularity. Within the cache, FPDB uses a novel *Weighted-LFU* cache replacement policy that takes into account the cost of pushdown computation. Second, we design *adaptive pushdown* as a new mechanism to avoid throttling the storage-layer computation during pushdown, which pushes the request back to the computation layer at runtime if the storage-layer computational resource is insufficient. Finally, we derive a general principle to identify pushdown-amenable computational tasks, by summarizing common patterns of pushdown capabilities in existing systems, and further propose two new pushdown operators, namely, *selection bitmap* and *distributed data shuffle*. Evaluation on SSB and TPC-H shows each optimization can improve the performance by 2.2×, 1.9×, and 3× respectively.

Keywords OLAP · Cloud databases · Caching · Computation pushdown · Adaptive query processing · Query optimization

1 Introduction

Database management systems (DBMSs) are gradually moving to the cloud for high elasticity and low cost. Modern cloud DBMSs adopt a *storage-disaggregation architecture* that divides computation and storage into separate layers connected through the network, which simplifies provisioning and enables independent scaling of resources. Disaggregation requires rethinking a fundamental principle of distributed DBMSs: "move computation to data rather than data to computation". Conventionally, the network in the disaggregation architecture is recognized as the major performance bottleneck [70]. *Computation pushdown* is a promising solution to mitigate the network bottleneck, where some computation logic is sent and evaluated close to the storage, thereby reducing the network data transfer. Examples of pushdown systems include Oracle Exadata [79], IBM Netezza [41], AWS Redshift Spectrum [4], AWS Aqua [11], and PushdownDB [84]. While recent improvements in network and storage mitigate the performance bottleneck of disaggregation, reducing data transfer from storage can still provide performance improvement and cost reduction. Moreover, computation pushdown can help alleviate the issues of request throttling and instability incurred by noisy neighbors [44, 60] and the usage of packet-switch algorithms like token bucket [68, 71], which can potentially improve the reliabil-

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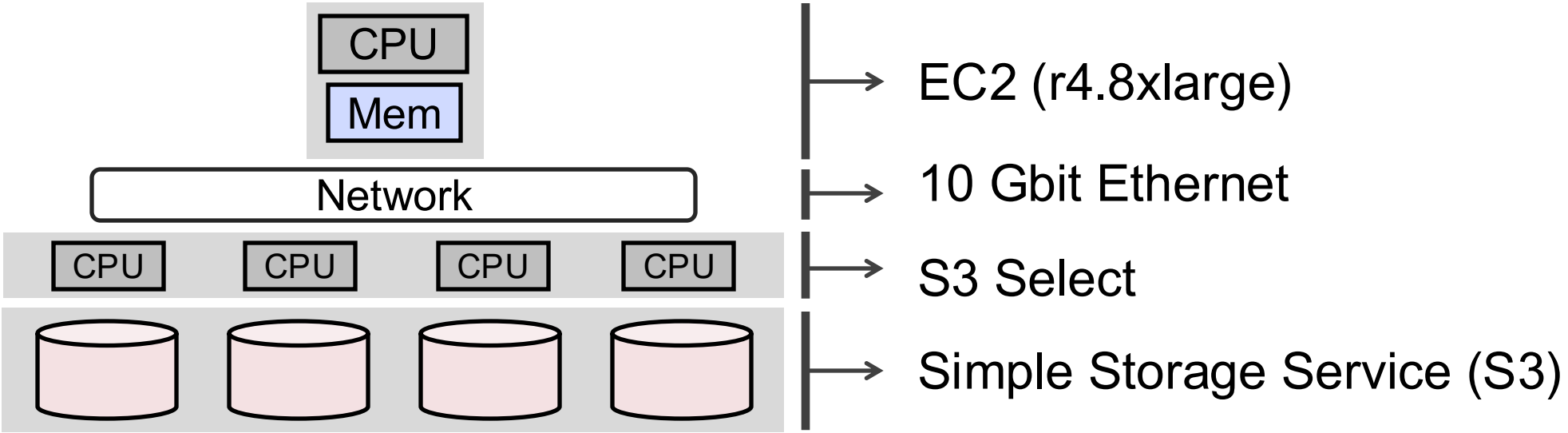
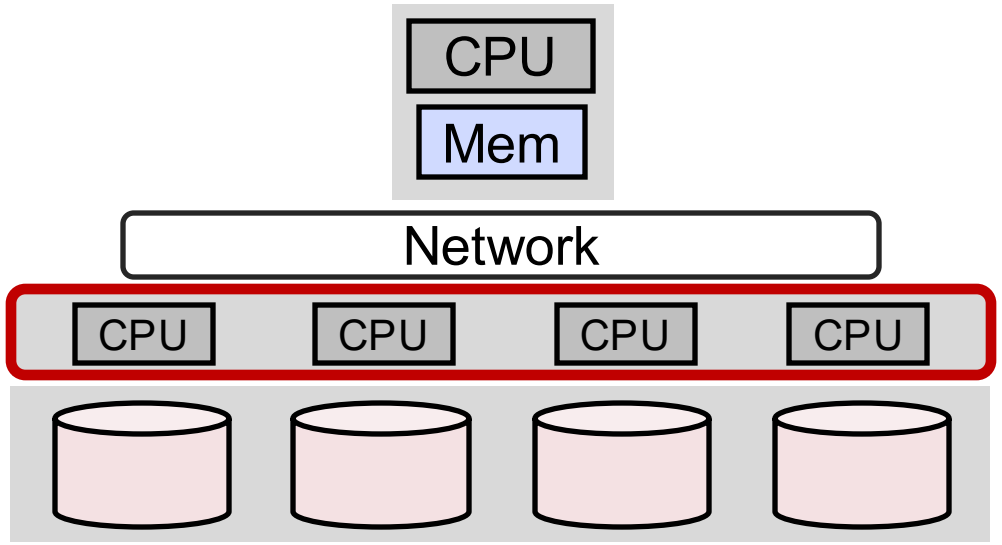
PushdownDB – Architecture

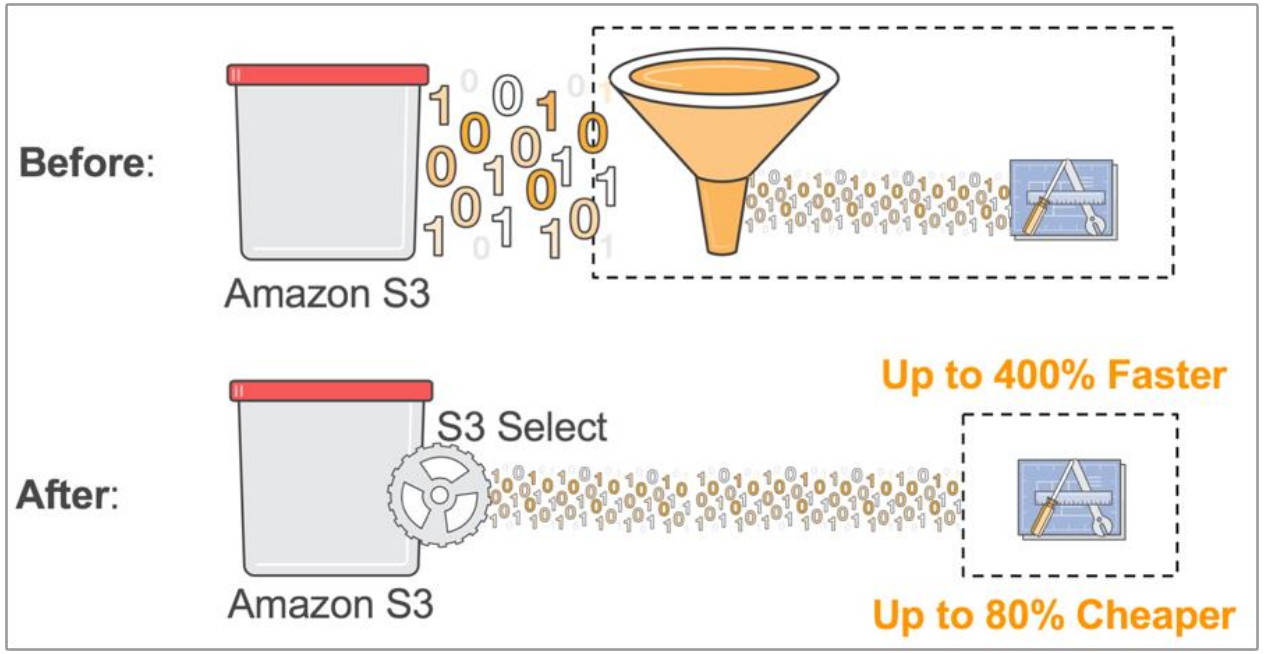


PushdownDB implementation

- Single-node, multi-process Python-based database
- Ubuntu 16.04.5 LTS, Python version 2.7.12.

S3 Select





Supports limited SQL queries on **CSV** and **Parquet** data format

- S3 Select recognizes database schema for both data formats
- **Simple queries with predicates and aggregation** (no join, no group-by, no sort, etc.)

PushdownDB – Supported Operators

S3 Select supports

- Filter
- Project
- Aggregate without group-by

PushdownDB supports

- Filter
- Project
- **Top-K**
- **Join**
- **Group-by**

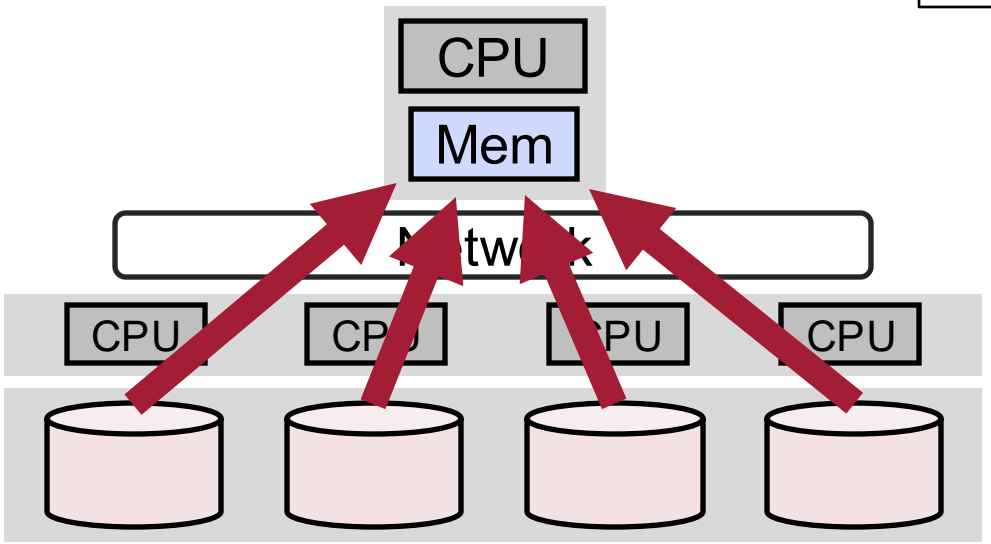
Filter

Server-side filtering

– Compute server loads entire table from S3 and filters locally

Example query:

```
SELECT col1, col2
FROM R
WHERE col1 < 10
```



Filter

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S3-side filtering

– Push down predicate evaluation using S3 Select

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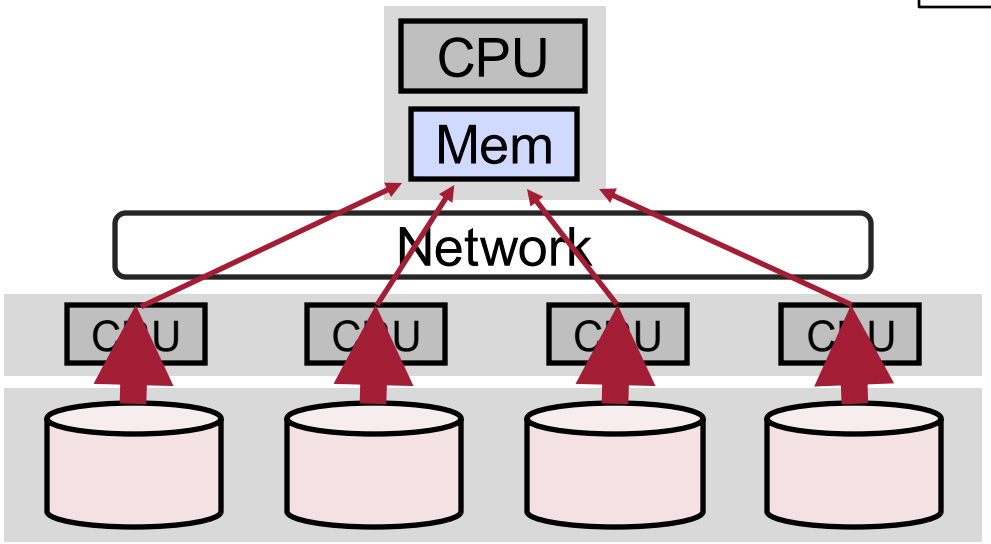

Join

Baseline Join

- Server loads both tables from S3 and joins locally

```
SELECT SUM(O_TOTALPRICE)
FROM CUSTOMER, ORDER
WHERE
   O_CUSTKEY = C_CUSTKEY
   AND C_ACCTBAL <= upper_c_acctbal
   AND O_ORDERDATE < upper_o_orderdate
```

Join

Baseline Join

- Server loads both tables from S3 and joins locally

Filtered Join

- Server pushes filtering predicates to S3 to load both tables

```
SELECT SUM(O_TOTALPRICE)
FROM CUSTOMER, ORDER
WHERE
   O_CUSTKEY = C_CUSTKEY
   AND C_ACCTBAL <= upper_c_acctbal
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```

Join

Bloom Join

- Step 1: Server loads the smaller table, builds a bloom filter using join key
- Step 2: Server sends the filter via S3 Select to load the bigger table
- Bloom filter is pushed down as a predicate

```
SELECT ...
FROM S3Object
WHERE SUBSTRING('1000011...111101101',
       ((69 * CAST(attr as INT) + 92) % 97) % 68 + 1, 1 ) = '1'
```

```
SELECT SUM(O_TOTALPRICE)
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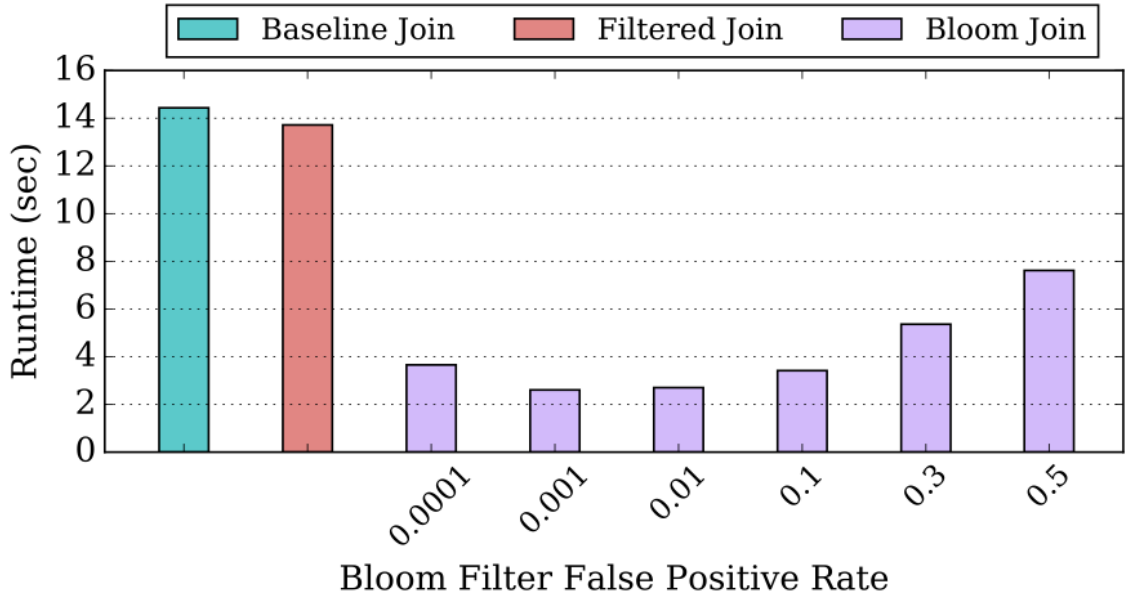
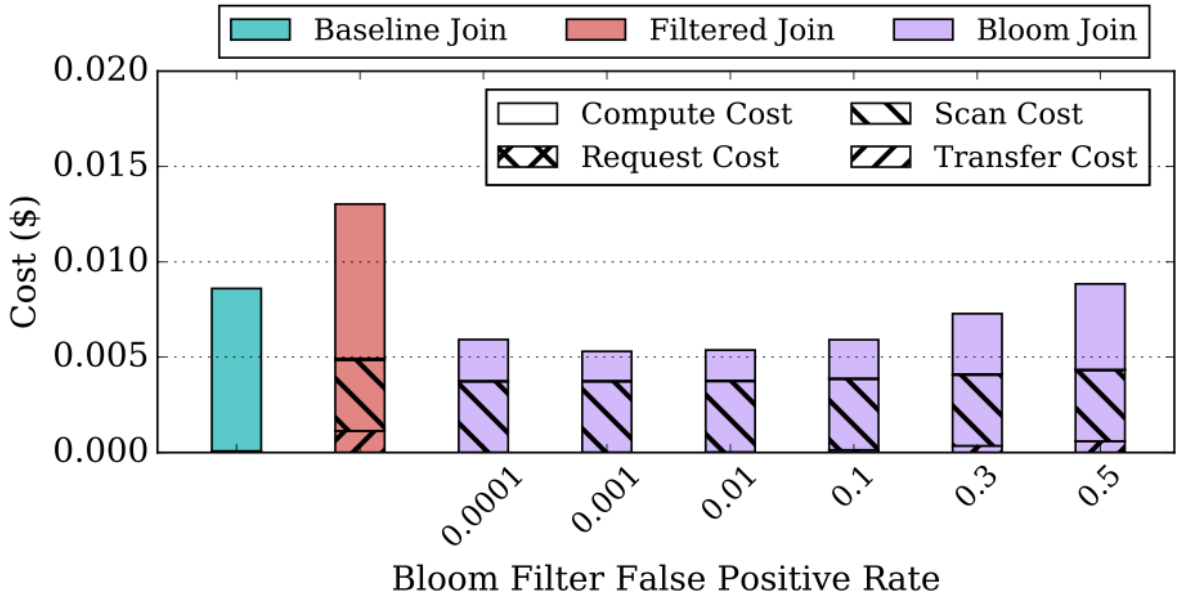
Evaluation – Join

Runtime



Cost Breakdown

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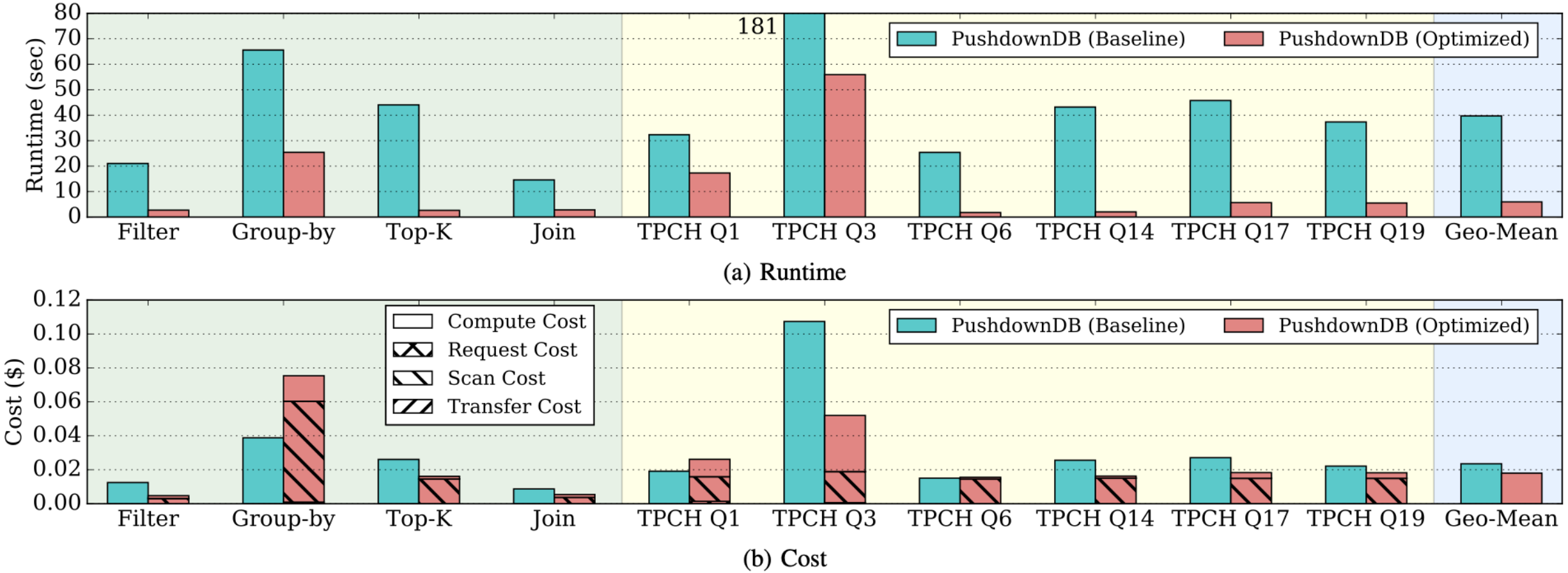
Evaluation – All Operators and TPC-H



Overall, PushdownDB **reduces runtime by 6.7×** and **reduces cost by 30%**

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Two solutions have been explored to mitigate this network bottleneck: *caching* and *computation pushdown*. Both solutions can reduce the amount of data transferred between the two layers. Caching keeps the hot data in the computation layer. Examples include Snowflake [21, 48] and Presto with Alluxio cache service [14]. The Redshift [30] layer in Redshift Spectrum [8] can also be considered as a cache with user-controlled contents. With computation pushdown, filtering and aggregation are performed close to the storage with only the results returned. Examples include Oracle Exadata [49], IBM Netezza [23], AWS Redshift Spectrum [8], AWS Aqua [12], and PushdownDB [53]. The fundamental reasons that caching and pushdown have performance benefits are that local memory and storage have higher bandwidth than the network and that the internal bandwidth within the storage layer is also higher than that of the network.

Existing DBMSs consider caching and computation pushdown as *orthogonal*. Most systems implement only one of them. Some systems, such as Exadata [49], Netezza [23], Redshift Spectrum [8], and Presto [14] consider the two techniques as independent: query operators can either access cached data (i.e., full tables) or push down computation on remote data, but not both.

In this paper, we argue that caching and computation pushdown are *not* orthogonal techniques, and that the rigid dichotomy of existing systems leaves potential performance benefits unexploited. We propose *FlexPushdownDB* (*FPDB* in short), an OLAP cloud DBMS prototype that combines the benefits of caching and pushdown.

FPDB introduces the concept of *separable operators*, which combine local computation on cached segments and pushdown on the segments in the cloud storage. This hybrid execution can leverage cached data at a fine granularity. While not all relational operators are separable, some of the most commonly-used ones are, including filtering, projection, aggregation. We introduce a *merge* operator to combine the outputs from caching and pushdown.

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REGULAR PAPER

FlexpushdownDB: rethinking computation pushdown for cloud OLAP DBMSs

Yifei Yang[1] · Xiangyao Yu[1] · Marco Serafini[2] · Ashraf Aboulnaga[3] · Michael Stonebraker[4]

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Abstract
Modern cloud-native OLAP databases adopt a *storage-disaggregation* architecture that separates the management of computation and storage. A major bottleneck in such an architecture is the network connecting the computation and storage layers. Computation pushdown is a promising solution to tackle this issue, which offloads some computation tasks to the storage layer to reduce network traffic. This paper presents *FlexPushdownDB* (*FPDB*), where we revisit the design of computation pushdown in a storage-disaggregation architecture, and then introduce several optimizations to further accelerate query processing. First, FPDB supports *hybrid query execution*, which combines local computation on cached data and computation pushdown to cloud storage at a fine granularity. Within the cache, FPDB uses a novel *Weighted-LFU* cache replacement policy that takes into account the cost of pushdown computation. Second, we design *adaptive pushdown* as a new mechanism to avoid throttling the storage-layer computation during pushdown, which pushes the request back to the computation layer at runtime if the storage-layer computational resource is insufficient. Finally, we derive a general principle to identify pushdown-amenable computational tasks, by summarizing common patterns of pushdown capabilities in existing systems, and further propose two new pushdown operators, namely, *selection bitmap* and *distributed data shuffle*. Evaluation on SSB and TPC-H shows each optimization can improve the performance by 2.2×, 1.9×, and 3× respectively.

Keywords OLAP · Cloud databases · Caching · Computation pushdown · Adaptive query processing · Query optimization

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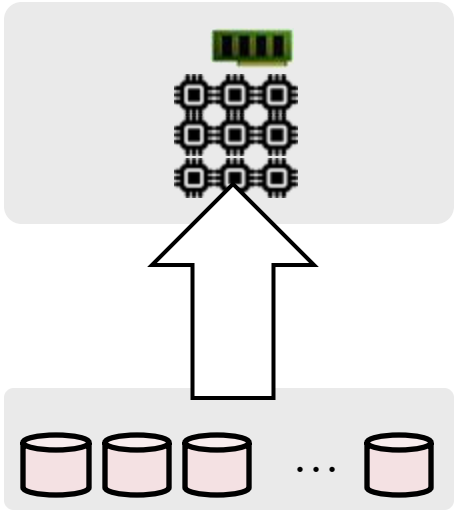
Mitigate Network Bottleneck



Baseline: always load data from cloud storage (e.g., S3)

- Examples: default presto, hive, SparkSQL, etc.

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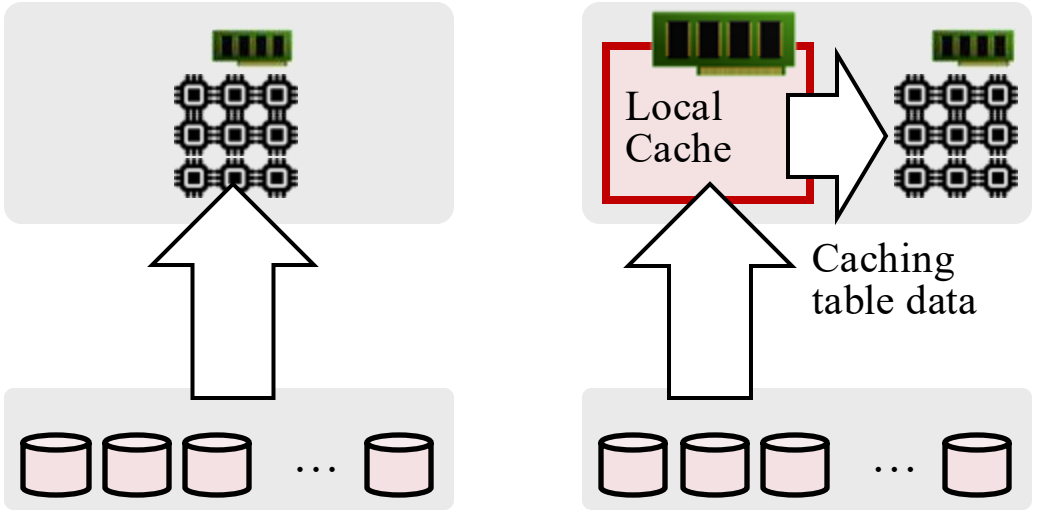
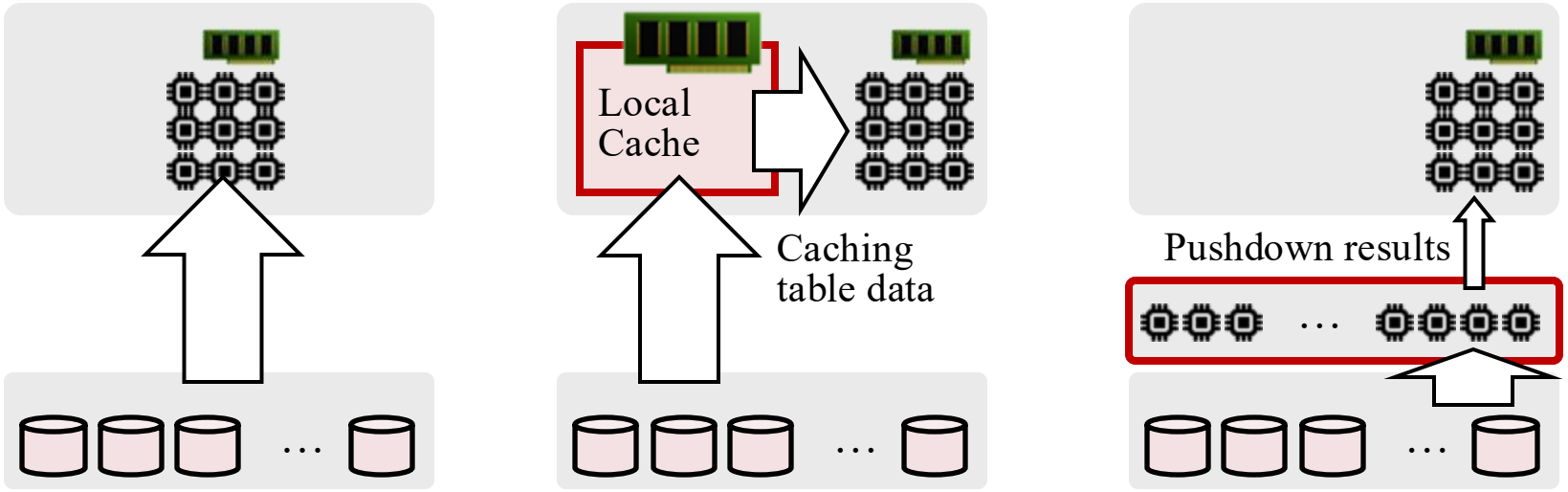


Baseline: always load data from cloud storage (e.g., S3)

Caching: cache hot table data in the compute node

- Examples: Snowflake, redshift spectrum (static), Alluxio, etc.

Mitigate Network Bottleneck



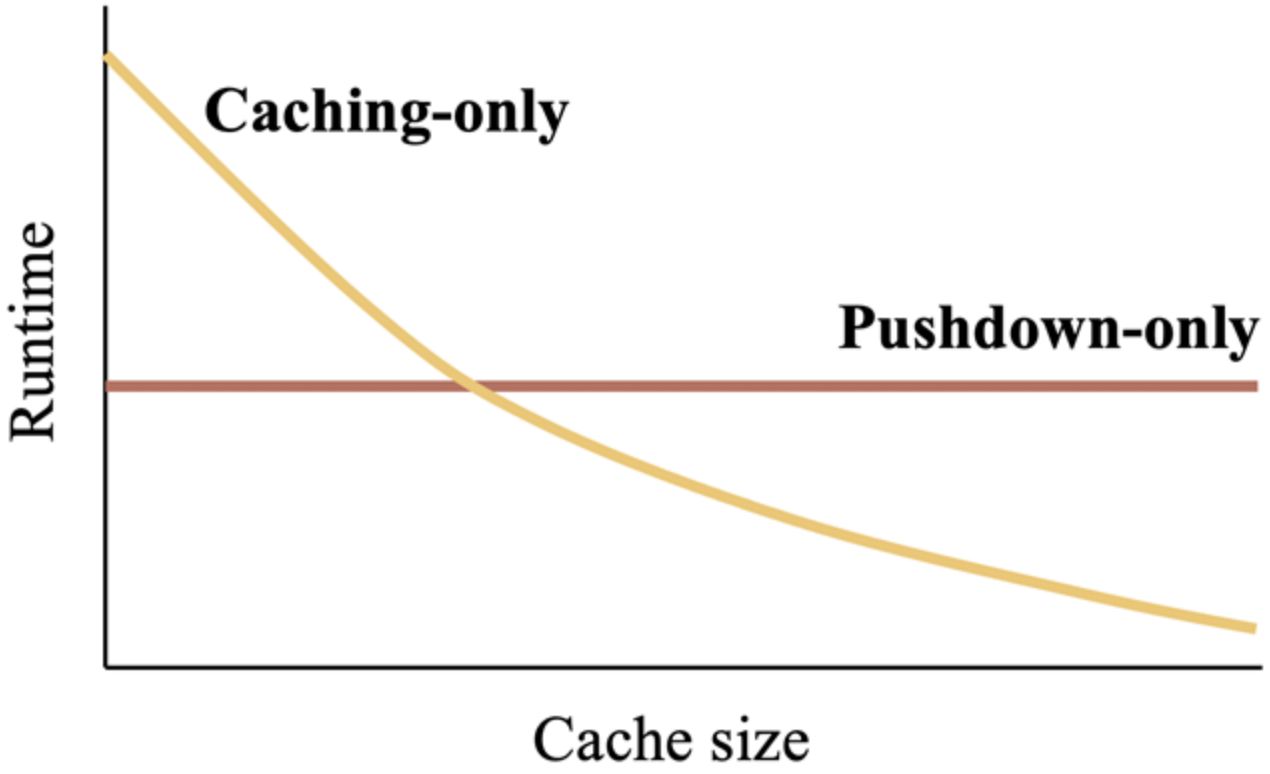
Baseline: always load data from cloud storage (e.g., S3)

Caching: cache hot table data in the compute node

Pushdown: push down selection, projection, aggregation to storage

- Examples: Redshift spectrum, Aqua, PushdownDB, etc.

Caching vs. Pushdown



Caching performance increases with a bigger cache

Pushdown performance is independent of cache size

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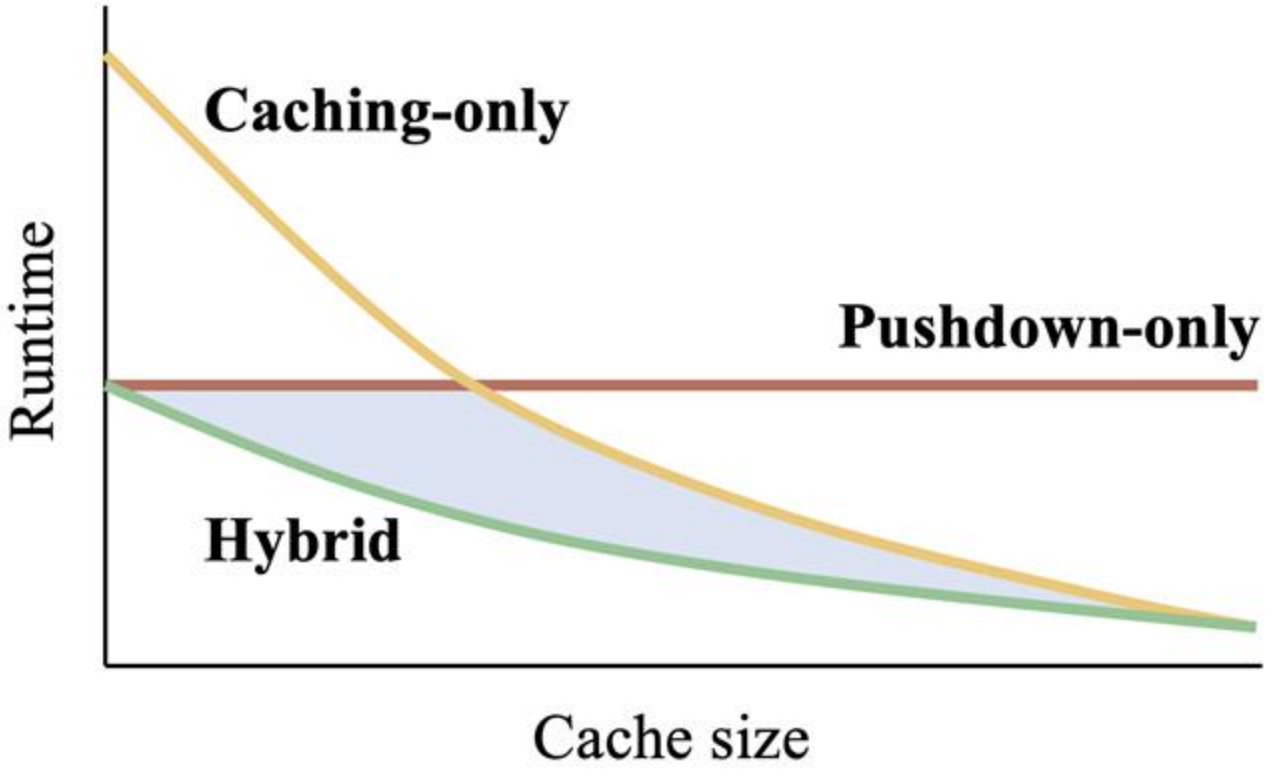
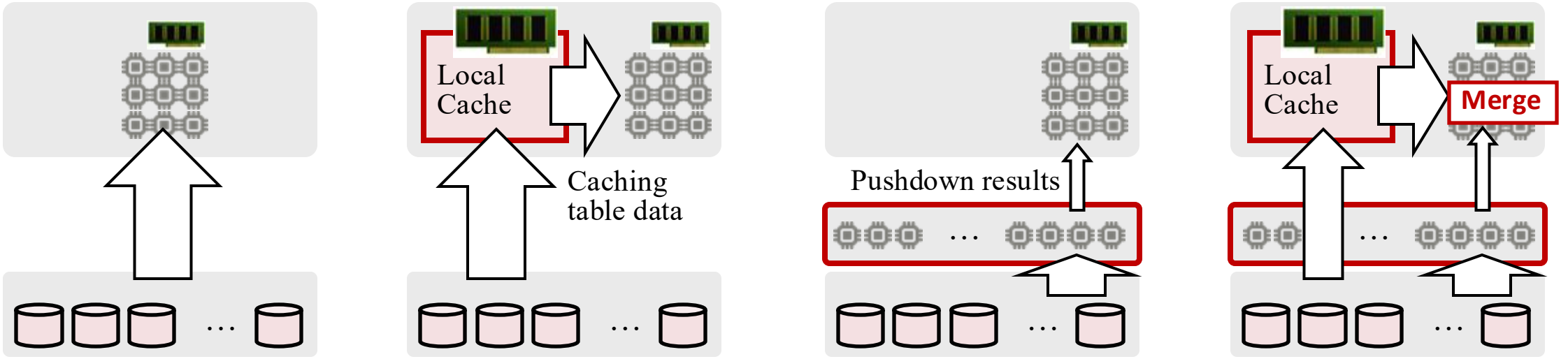


Caching performance increases with a bigger cache

Pushdown performance is independent of cache size

A **hybrid** design may achieve the best of both worlds

Mitigate Network Bottleneck



Baseline (Pullup): always load data from cloud storage (e.g., S3)

Caching: cache hot table data in the compute node

Pushdown: push down selection, projection, aggregation to storage

Hybrid: hybrid caching and pushdown at fine granularity

FlexPushdownDB (FPDB) Overview

Design choices

- Cache table data rather than query results for simplicity

Source code: https://github.com/cloud-olap/FlexPushdownDB

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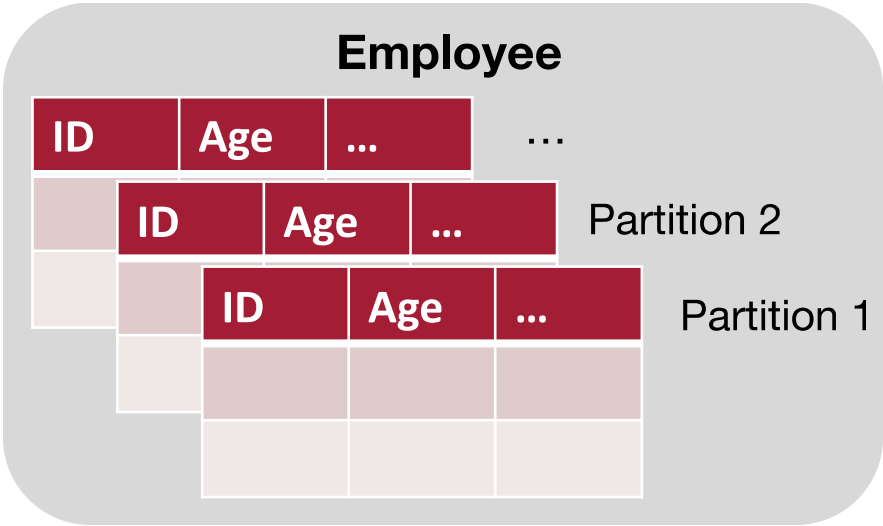

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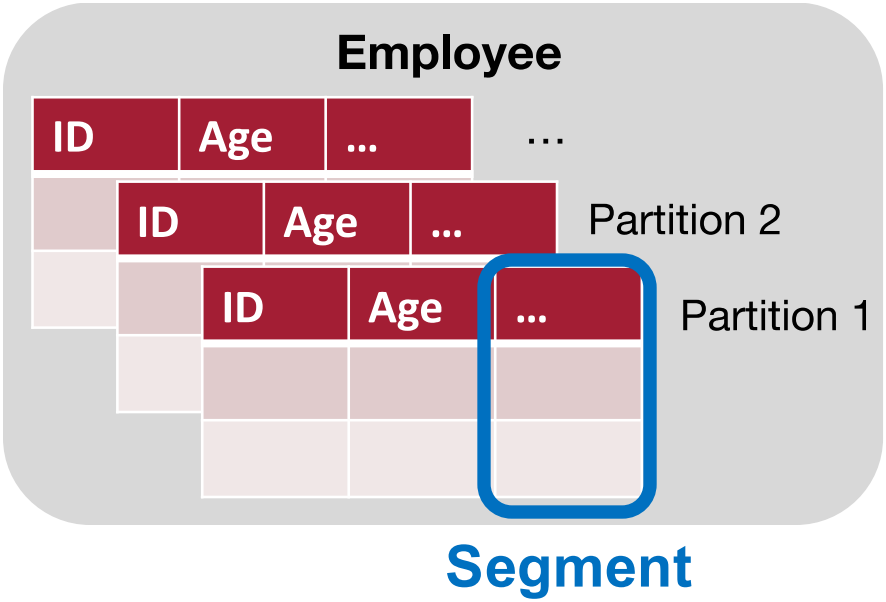

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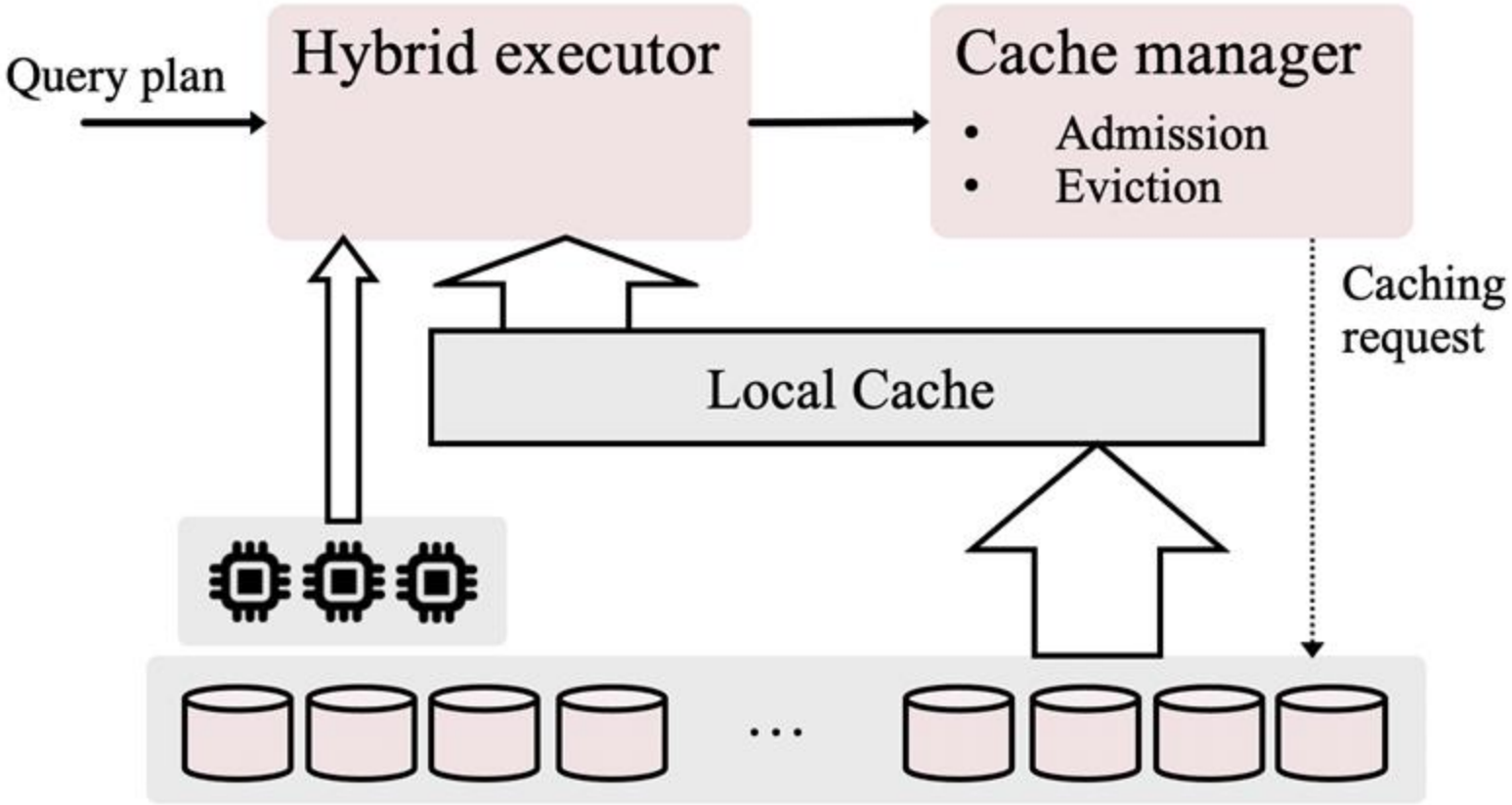
FlexPushdownDB (FPDB) Overview

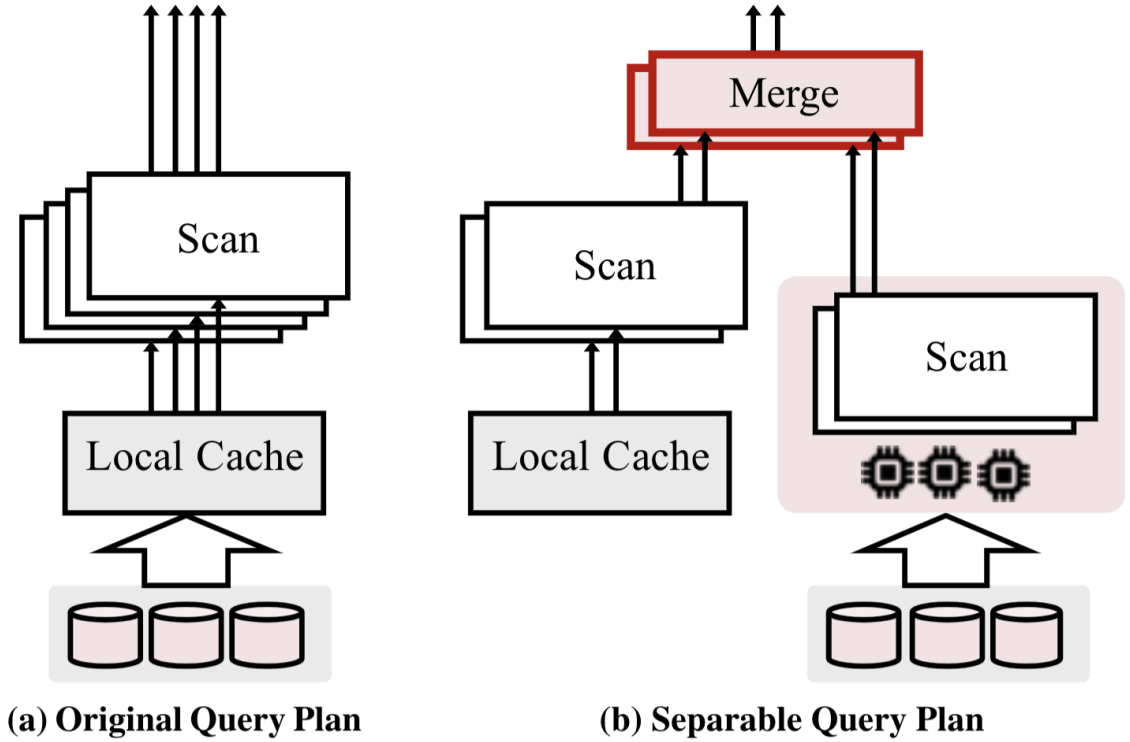
Main modules



FlexPushdownDB (FPDB)

Separable operators

- Can execute separately using cached segments and cloud storage
- Example: projection, selection, aggregation, hash join (partially)



(a) Original Query Plan (b) Separable Query Plan

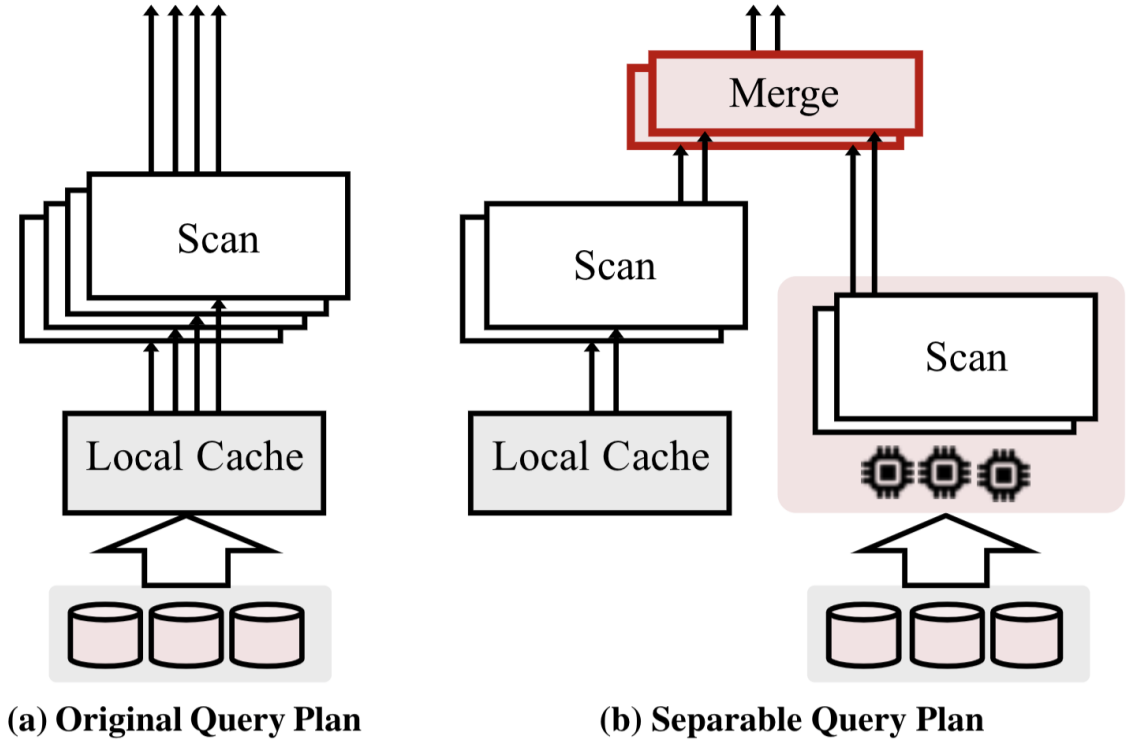
FlexPushdownDB (FPDB)

Separable operators

- Can execute separately using cached segments and cloud storage
- Example: projection, selection, aggregation, hash join (partially)

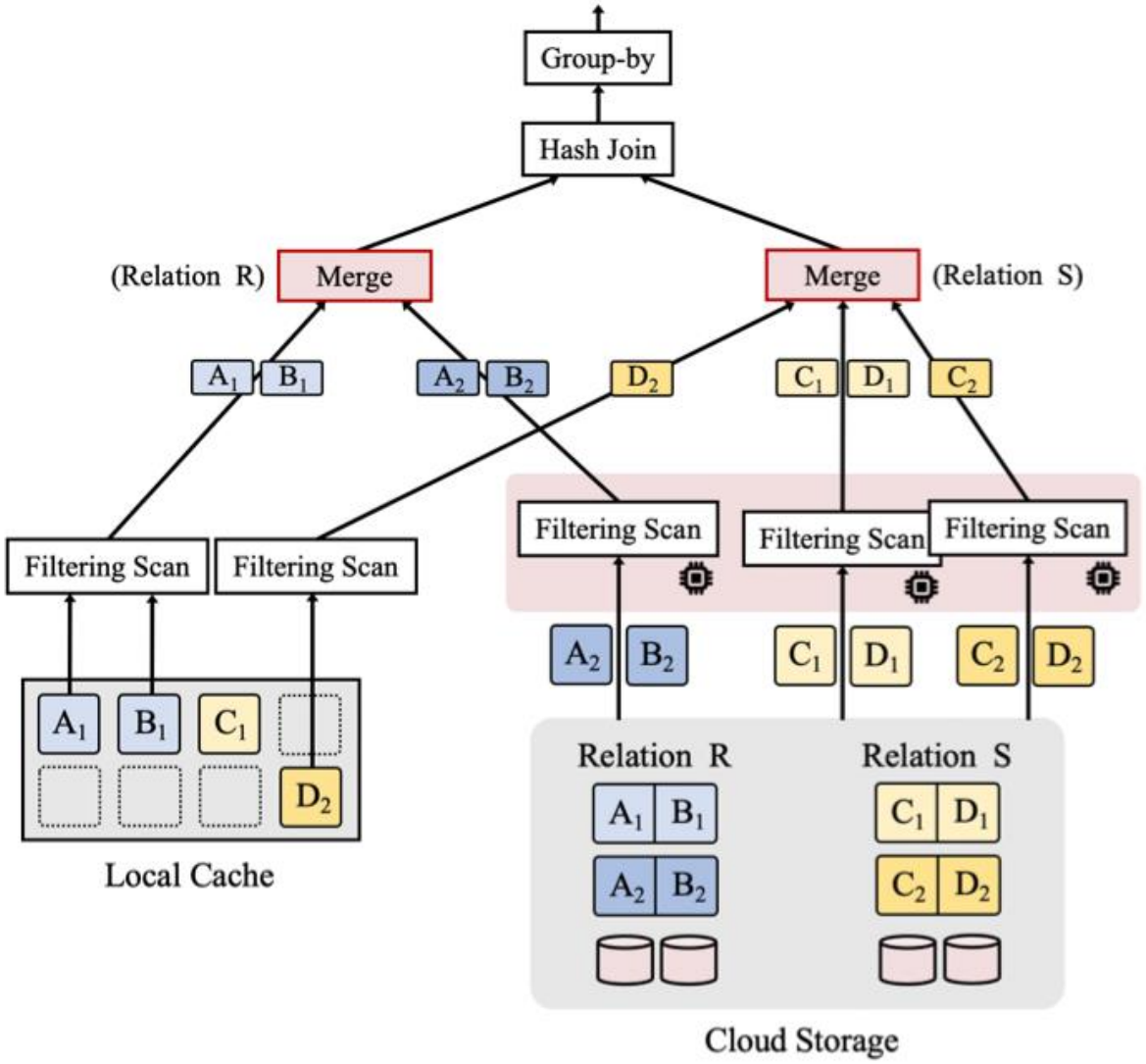
Query execution

- Heuristic: exploit caching when possible, otherwise pushdown as much as possible



(a) Original Query Plan (b) Separable Query Plan

Separable Query Plan — Example




```
SELECT R.B, sum(S.D)
FROM R, S
WHERE R.A = S.C AND R.B > 10 AND S.D > 20
GROUP BY R.B
```

Cache Manager

Traditional caching assumption: **Equal-size cache misses incur the same cost**

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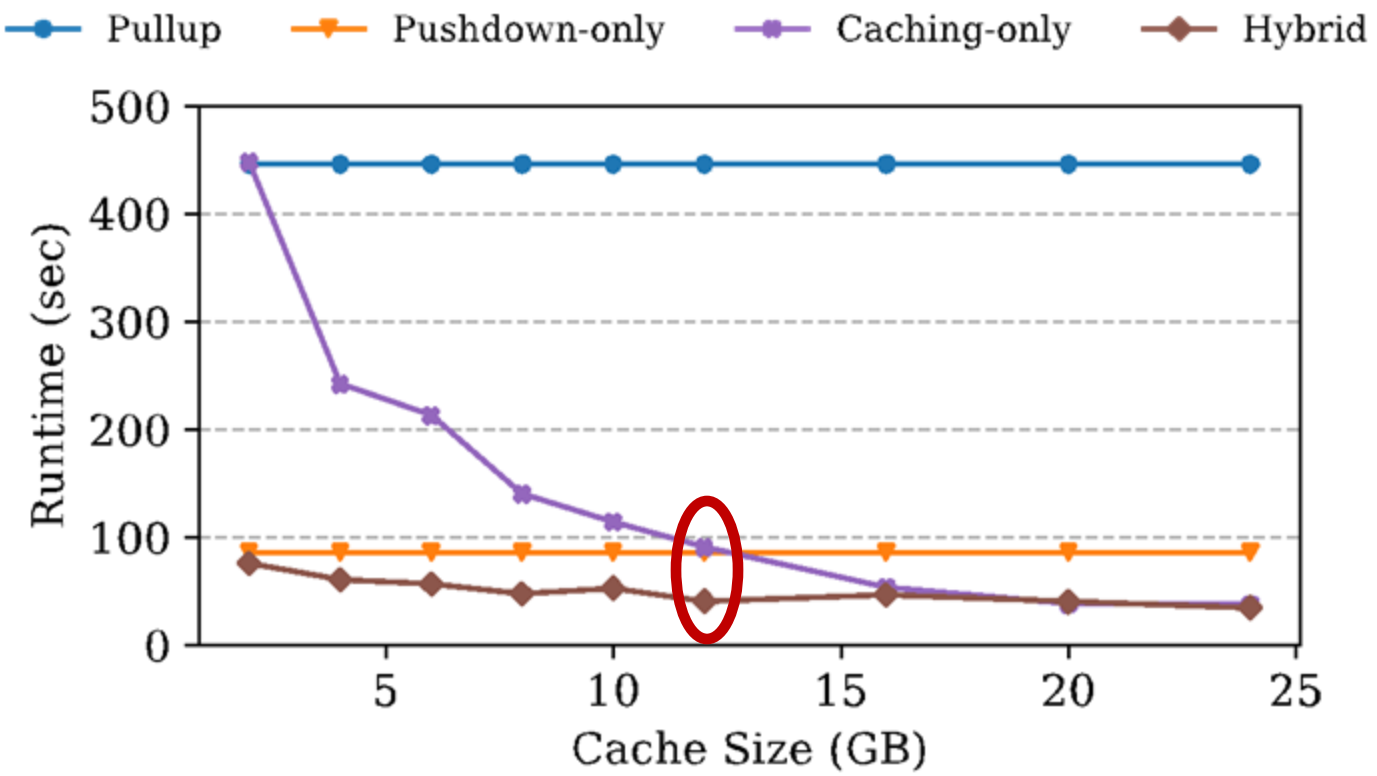
Weighted-LFU cache replacement policy

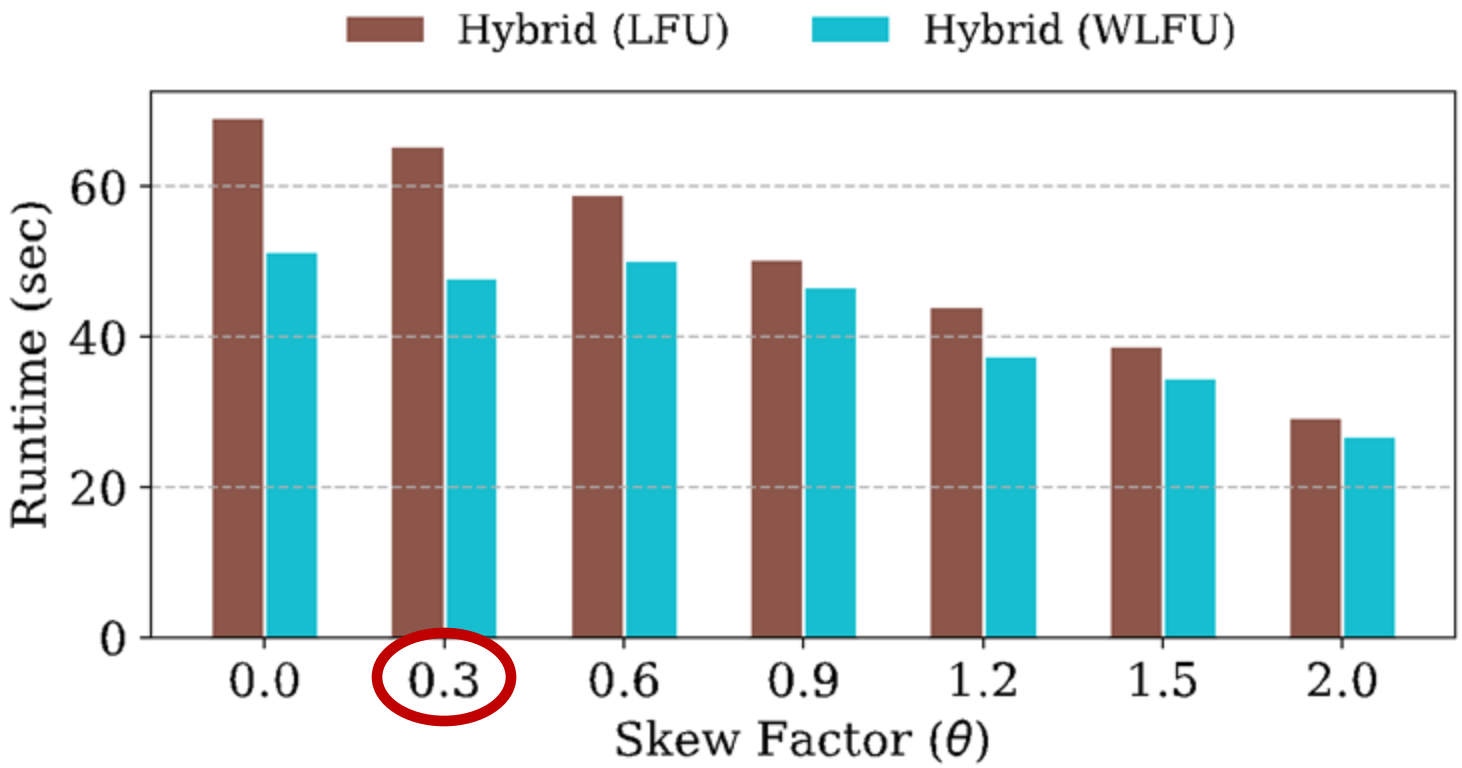
- Increment the frequency counter with the estimate miss cost
- Estimated miss cost = network cost + scan cost + compute cost

Performance Evaluation



Conclusion: FPDB outperforms baselines by 2.2x

Evaluation – Weighted-LFU



Weighted-LFU outperforms the baseline LFU by 37%

Evaluation – Resource Usage

Table 2: Network Usage (GB) of different architectures.

Architecture	Pullup	PD-only	CA-only	Hybrid
Usage	460.9	37.1	112.6	7.9

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Architecture	Pullup	PD-only	CA-only	Hybrid
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Table 3: CPU Usage (with dedicated compute servers) — CPU time (in minutes) of different architectures (normalized to the time of 1 vCPU).

Architecture	Pullup	PD-only	CA-only	Hybrid
Compute	249.6	48.5	70.3	23.2
Storage	0.0	31.1	0.0	7.4
Total	249.6	79.6	70.3	30.6

Today's Papers — Pushdown DBMS

PushdownDB: Accelerating a DBMS Using S3 Computation

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Marco Serafini¶, Ashraf Aboulnaga§, Michael Stonebraker†
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***Abstract*—This paper studies the effectiveness of pushing parts of DBMS analytics queries into the Simple Storage Service (S3) of Amazon Web Services (AWS), using a recently released capability called S3 Select. We show that some DBMS primitives (filter, projection, and aggregation) can always be cost-effectively moved into S3. Other more complex operations (join, top-K, and group-by) require reimplementation to take advantage of S3 Select and are often candidates for pushdown. We demonstrate these capabilities through experimentation using a new DBMS that we developed, *PushdownDB*. Experimentation with a collection of queries including TPC-H queries shows that *PushdownDB* is on average 30% cheaper and 6.7× faster than a baseline that does not use S3 Select.**

I. Introduction

Clouds offer cheaper and more flexible computing than "on-prem". Not only can one add resources on the fly, the large cloud vendors have major economies of scale relative to "on-prem" deployment. Modern clouds employ an architecture where the computation and storage are disaggregated — the two components are independently managed and connected using a network. Such an architecture allows for independent scaling of computation and storage, which simplifies the management of storage and reduces its cost. A number of data warehousing systems have been built to analyze data on disaggregated cloud storage, including Presto [1], Snowflake [2], Redshift Spectrum [3], among others.

In a disaggregated architecture, the network that connects the computation and storage layers can be a major performance bottleneck. Two intuitive solutions are *caching* and *computation pushdown*. With caching, a compute server loads data from the remote storage and caches it in main memory or local storage, amortizing the network transfer cost. Caching has been implemented in Snowflake [2] and Redshift Spectrum [3], [4]. With computation pushdown, a database management system (DBMS) pushes its functionality as close to storage as possible. Previous research [5] and systems (e.g., Britton-Lee IDM 500 [6], Oracle Exadata server [7], and IBM Netezza machine [8]) have shown that this can significantly improve performance.

Recently, Amazon Web Services (AWS) introduced a feature called "S3 Select", through which limited computation can be pushed onto their shared cloud storage service called S3 [9]. This provides an opportunity to revisit the question of how to divide query processing tasks between S3 storage nodes and normal computation nodes. The question is nontrivial as the limited computational interface of S3 Select allows only certain simple query operators to be pushed into the storage layer, namely selections, projections, and simple aggregations. Other operators require new implementations to take advantage of S3 Select. Moreover, S3 Select pricing can be more expensive than computing on normal EC2 nodes.

In this paper, we set our goal to understand the performance of computation pushdown when running queries in a cloud setting with disaggregated storage. Specifically, we consider filter (with and without indexing), join, group-by, and top-K as candidates. We implement these operators to take advantage of computation pushdown through S3 Select and study their cost and performance. We show dramatic performance improvement and cost reduction, even with the relatively high cost of S3 Select. In addition, we analyze queries from the TPC-H benchmark and show similar benefits of performance and cost. We point out the limitations of the current S3 Select service and provide several suggestions based on the lessons we learned from this project. To the best of our knowledge, this is the *first extensive study of pushdown computing for database operators in a disaggregated architecture*. A more detailed description of this work can be found in [10].

II. Data Management in the Cloud

Cloud providers such as AWS offer a wide variety of computing instances (i.e., EC2: Elastic Compute Cloud) and storage services (i.e., EBS: Elastic Block Store, EFS: Elastic File System, and S3: Simple Storage Service). Compared to other storage services, S3 is a highly available object store that provides virtually infinite storage capacity for regular users with relatively low cost, and is supported by many popular cloud databases, including Presto [1], Hive [11], Spark SQL [12], Redshift Spectrum [3], and Snowflake [2]. The storage nodes in S3 are separate from compute nodes. Hence, a DBMS uses S3 as a storage system and transfers needed data over a network for query processing.

To reduce network traffic and the associated processing on compute nodes, AWS released a new service called *S3 Select* [9] in 2018 to push limited computation to the storage nodes. At the current time, S3 Select supports only selection,

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PVLDB Reference Format:
Yifei Yang, Matt Youill, Matthew Woicik, Yizhou Liu, Xiangyao Yu, Marco Serafini, Ashraf Aboulnaga, Michael Stonebraker. FlexPushdownDB: Hybrid Pushdown and Caching in a Cloud DBMS. PVLDB, 14(11): 2101 - 2113, 2021.
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PVLDB Artifact Availability:
The source code, data, and/or other artifacts have been made available at https://github.com/cloud-olap/FlexPushdownDB.git.

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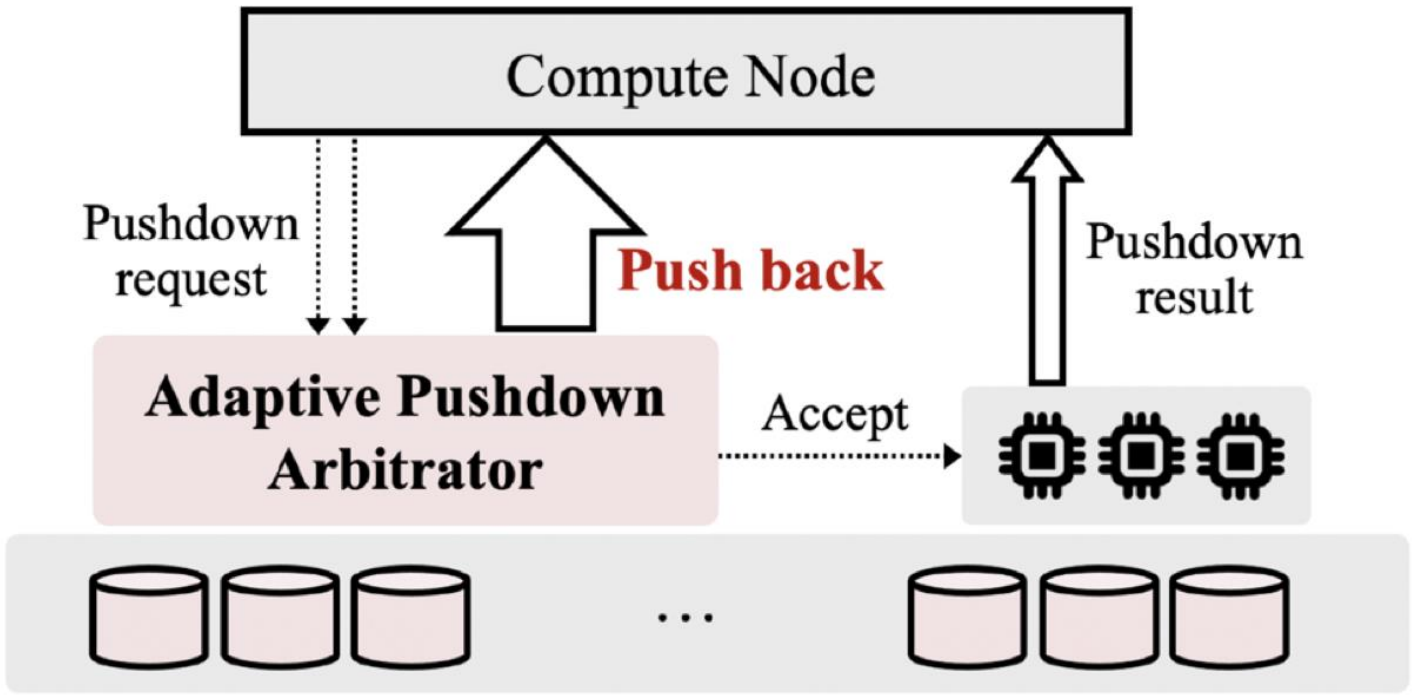
Adaptive Pushdown

Adaptive Pushdown: If pushdown computation is saturated, fallback to pullup through pushback



Pushback when *estimated pushdown time > estimated pushback time*

Adaptive Pushdown - Evaluation

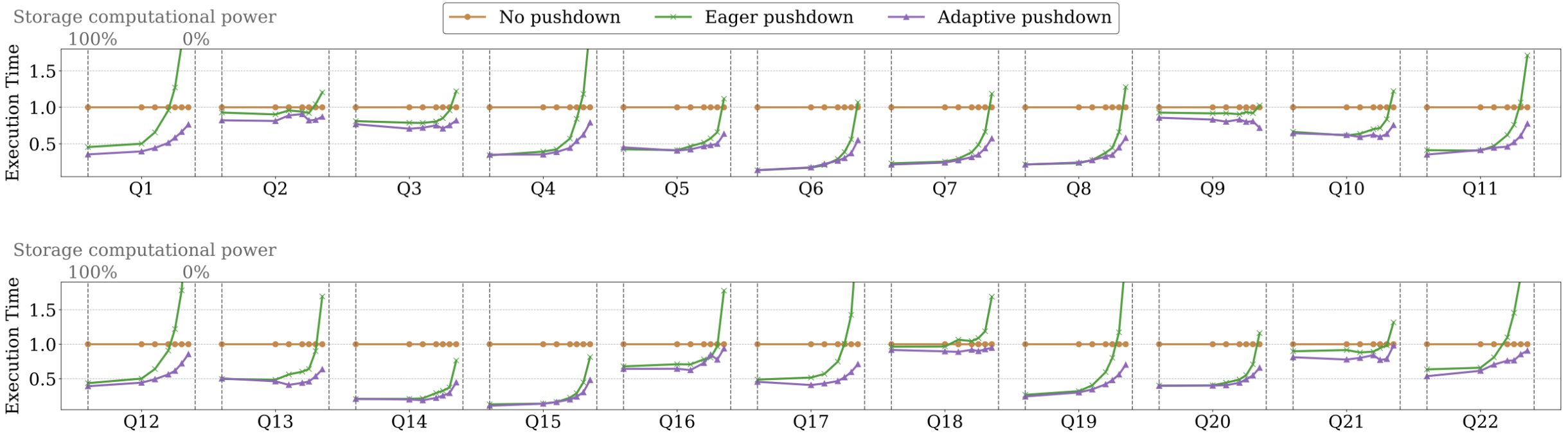


Fig. 18 Performance Evaluation of ADAPTIVE PUSHDOWN on TPC-H (Execution time is normalized to NO PUSHDOWN)

Advanced Pushdown Operators

Key Characteristics of Pushdown. The required storage-layer computation is **local** and **bounded**

- **Local**: Pushdown computation does not incur network traffic among storage servers
- **Bounded**: pushdown tasks require at most linear amount of CPU and memory resources over the accessed data size

Selection Bitmap Pushdown

```
SELECT A, B FROM R
WHERE [predicates on B]
```

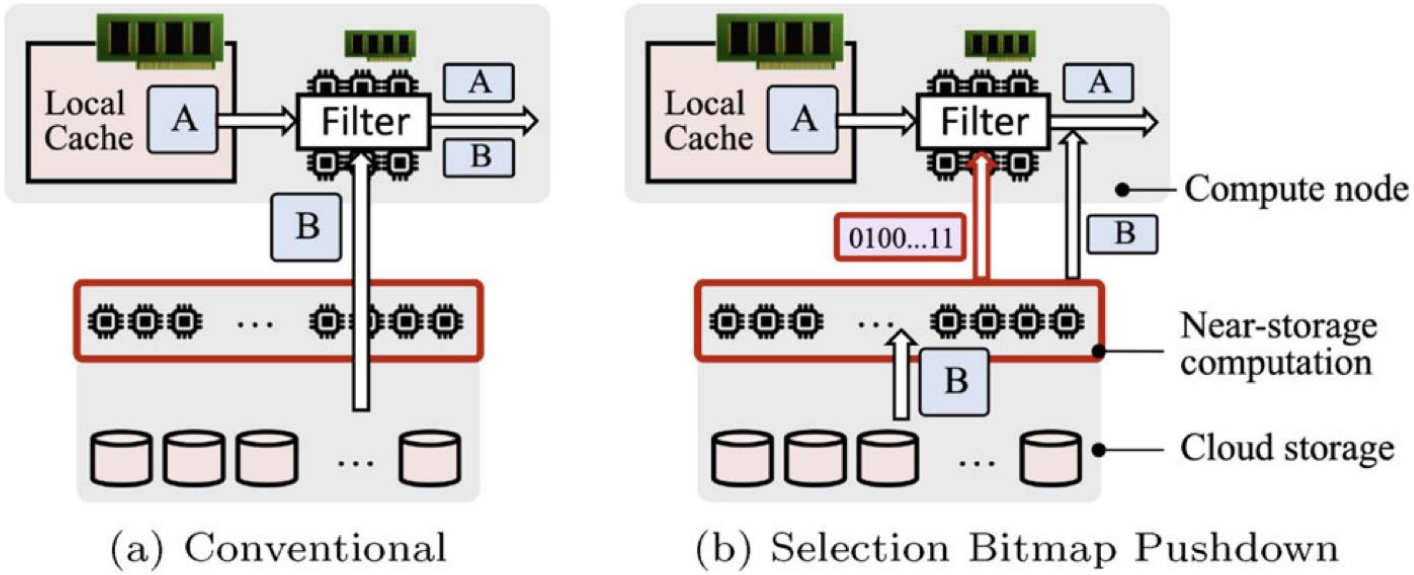
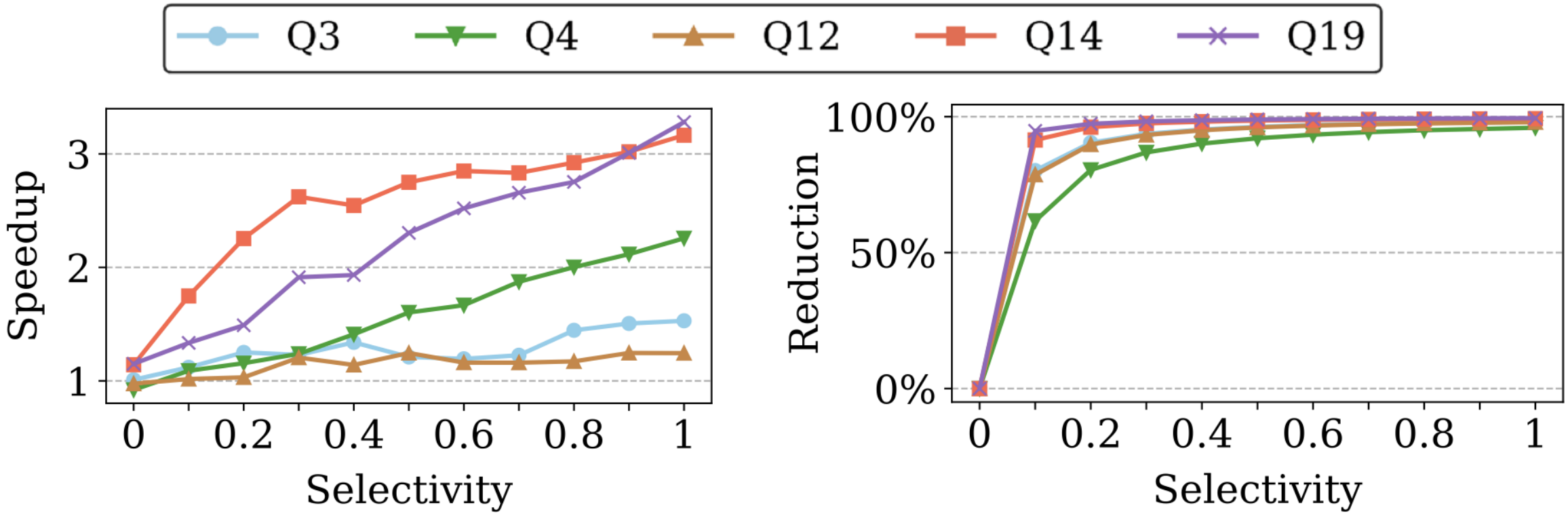


Fig. 9 Selection Bitmap Pushdown (from the Storage Layer)—Selection bitmap constructed at storage can be used to filter cached data at the compute layer

Selection Bitmap Pushdown - Evaluation



(a) Execution Time

(b) Network Traffic

Distributed Shuffle Pushdown

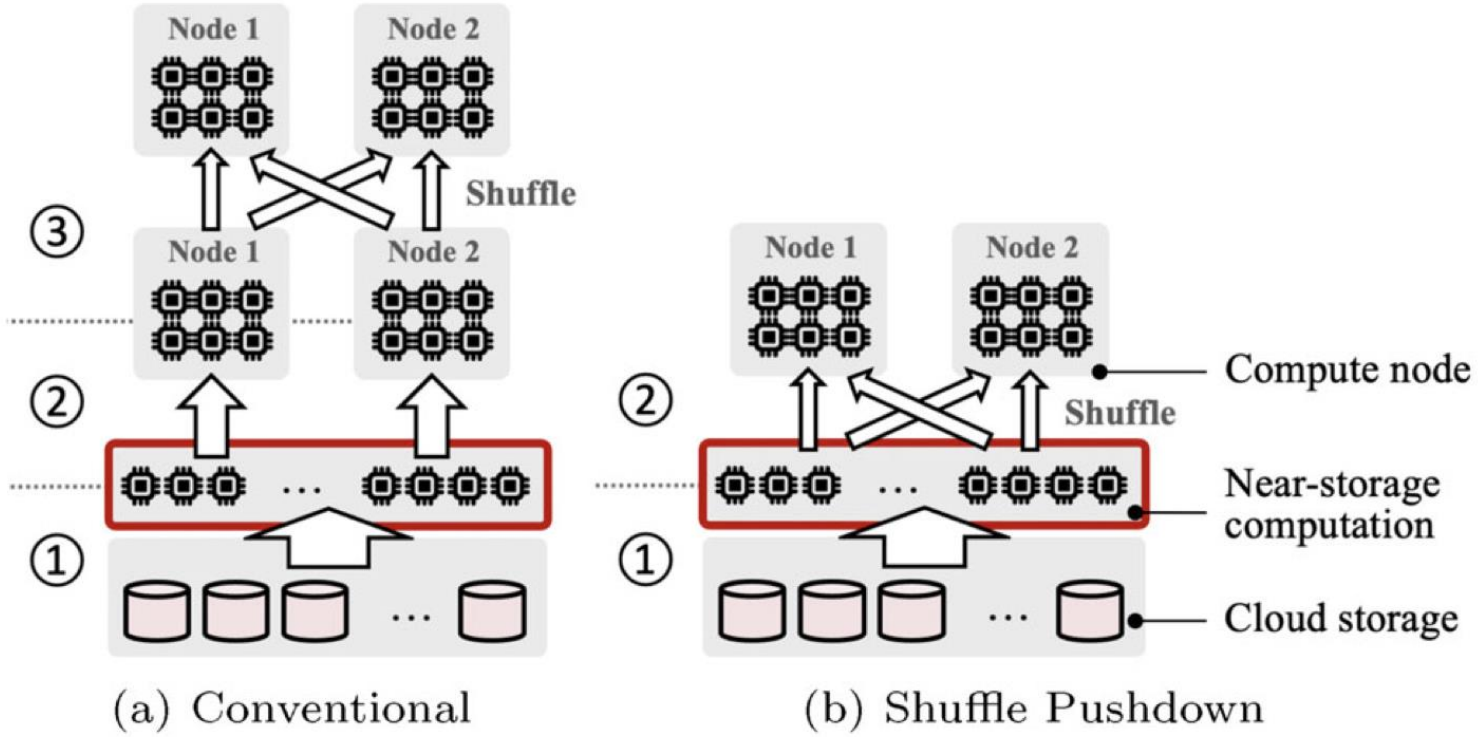


Fig. 11 Distributed Data Shuffle Pushdown—Data is directly redistributed to the target compute node from the storage layer

Distributed Shuffle Pushdown - Evaluation

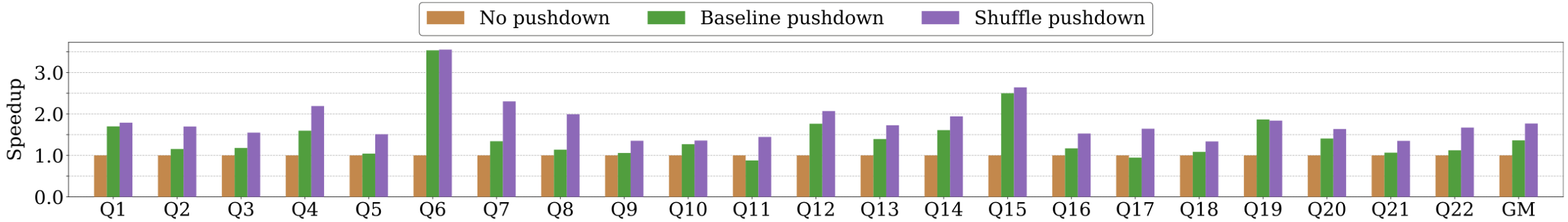


Fig. 27 Performance Evaluation of Distributed Data Shuffle Pushdown on TPC-H (normalized to NO PUSHDOWN)

Pushdown DBMS – Q/A

- GPU acceleration in compute and pushdown layers?
- Separable operator for multi-way joins?
- Updates and mutable data?
- What about caching intermediate results?
- Compute frequency counter of a missing segment?

Next Lecture

Elena Milkai, Xiangyao Yu, Jignesh Patel, Hermes: Off-the-Shelf Real-Time Transactional Analytics. VLDB, 2025