Optimizing Near-Data Processing for Spark

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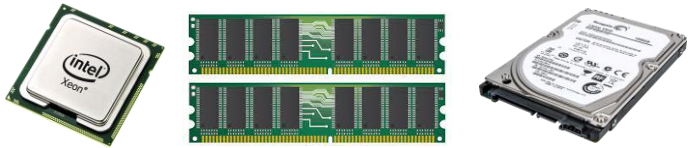
Overview

- General Purpose Servers
  - CPU, Memory, Storage
  - Inefficient utilization
  - Fragmentation of resources



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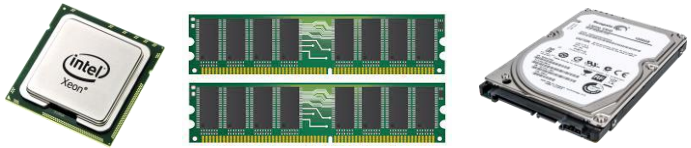

- Disaggregated infrastructure (DI)
  - Optimized for specific resource
  - Reduces amount of unused resources
  - Easy rolling upgrades
  - **High dependence on networks**
    - **Potential performance bottleneck**

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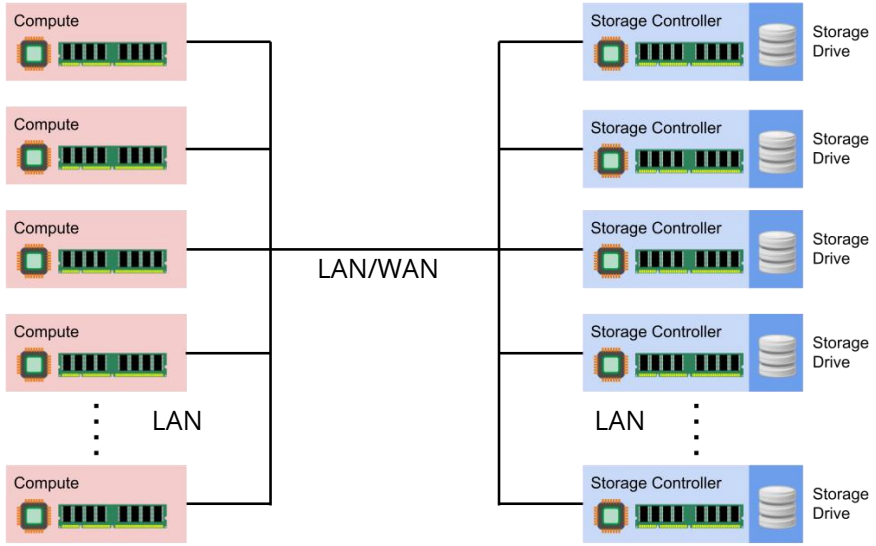
Compute
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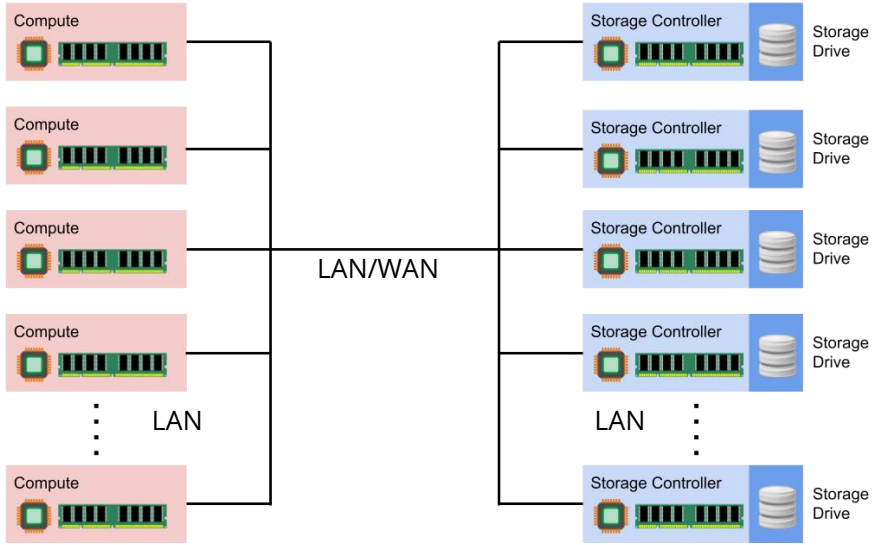

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- Storage Optimized Cluster
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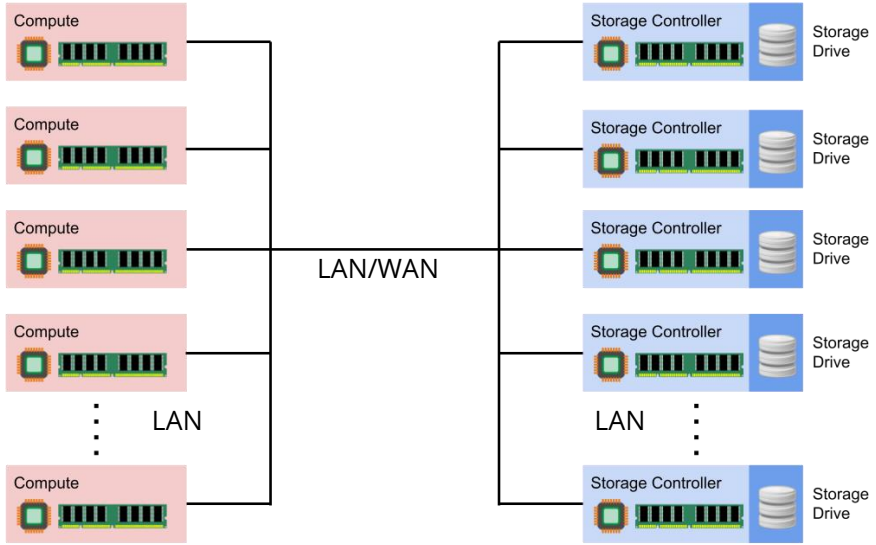

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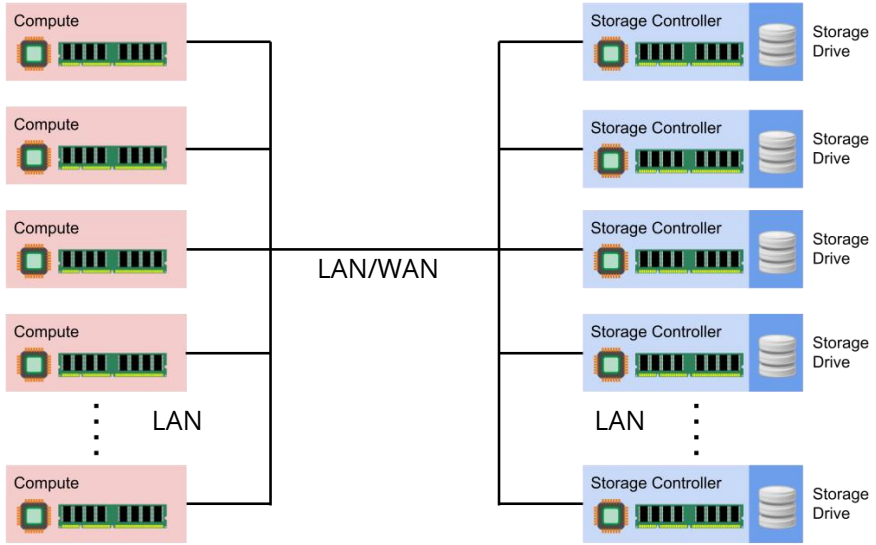
  - Large datasize => high transfer time



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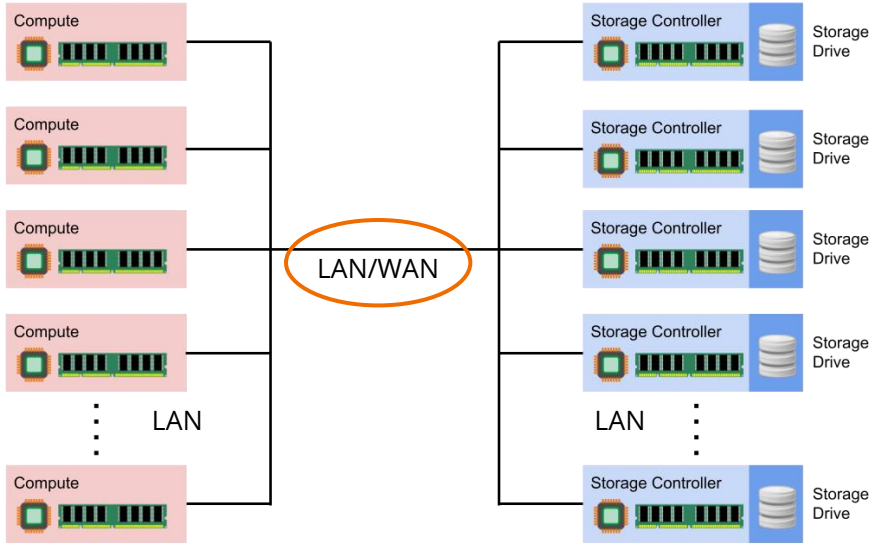
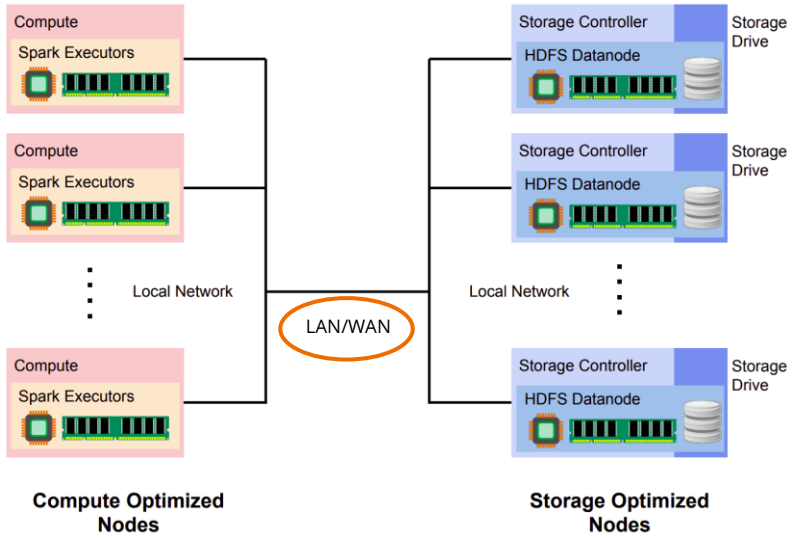


Motivation - NDP



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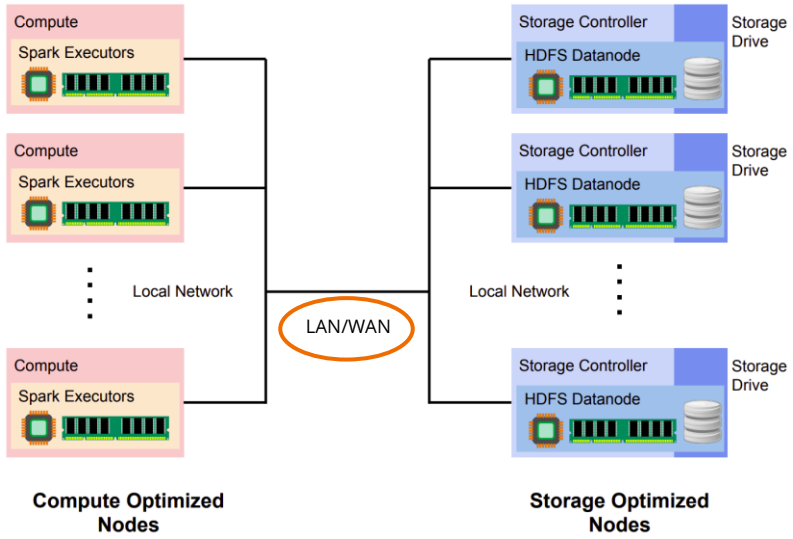

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Example

Calculating total sales of a store in 1994 using records of size 1 TB from 1990 to 2020.

- Filter by year : ~30x Reduction : 34 GB
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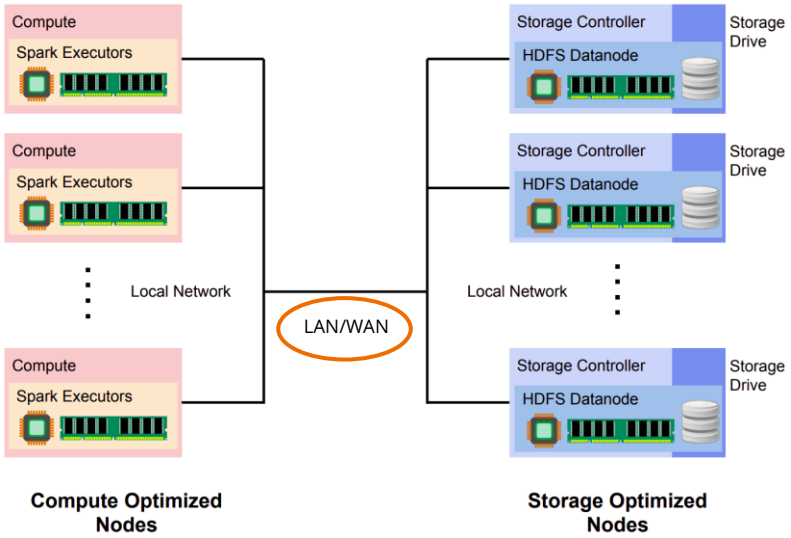
- Sum rows : Returns int : 8 B



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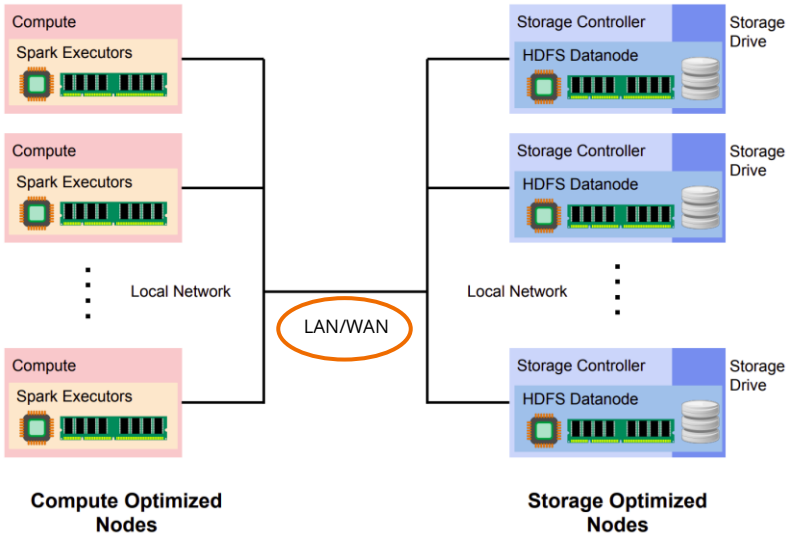

Near Data Processing (NDP)

- Processing in storage cluster - “Pushdown”
- Reduction in transfer size

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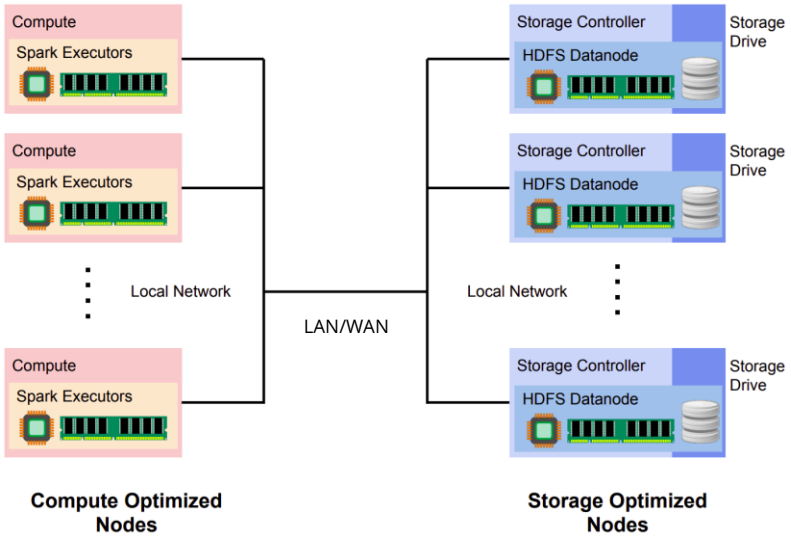

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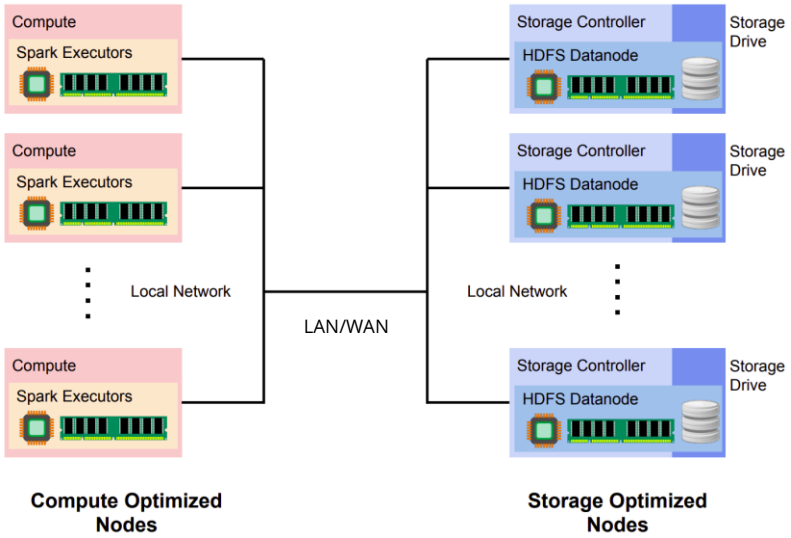

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How to implement NDP?

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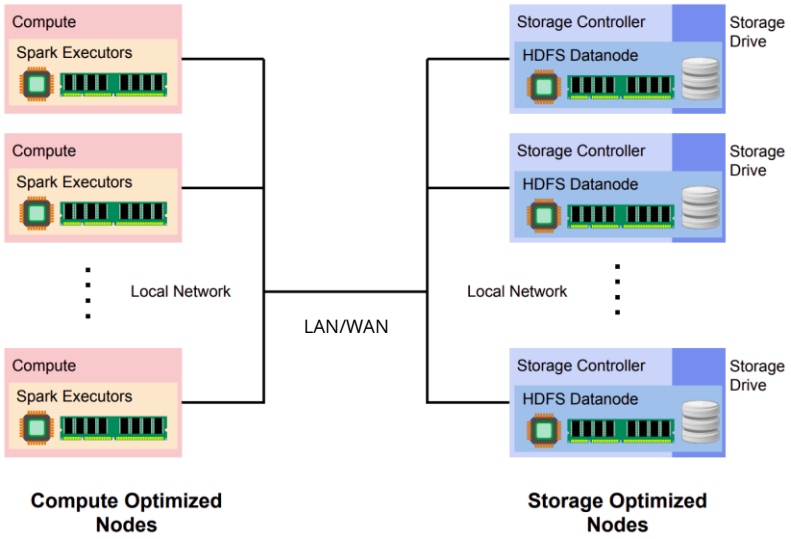

Near Data Processing (NDP)

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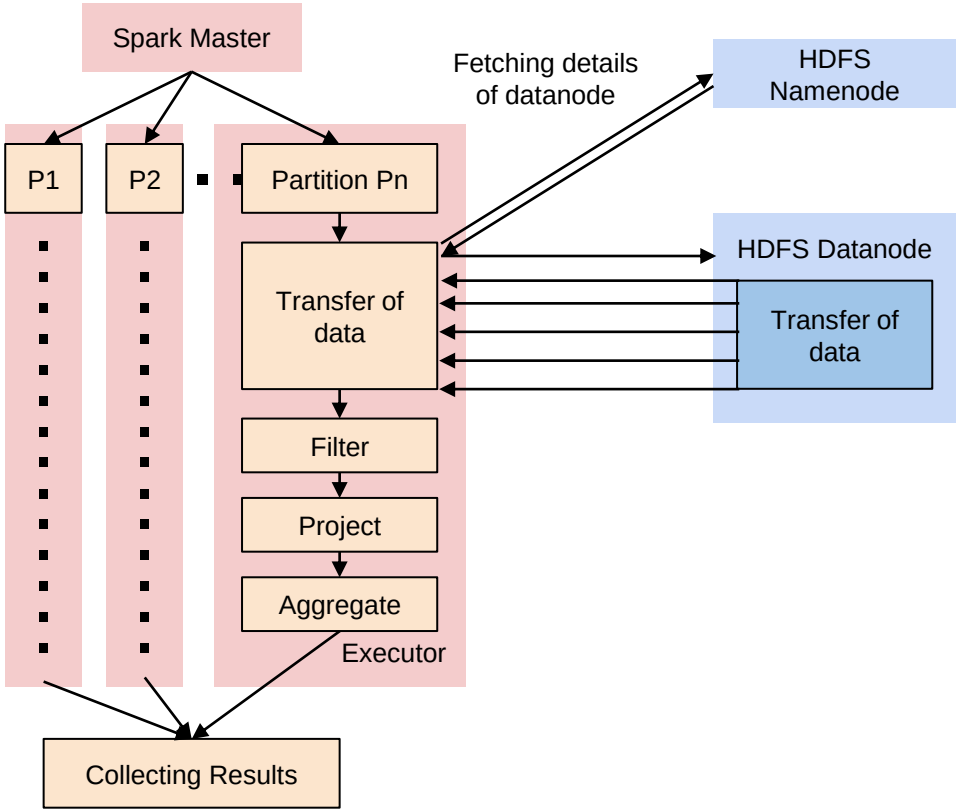
How to implement NDP?

Processing at resource constrained devices: Can they handle the pushdown?

How to implement and optimize NDP pushdown?

Background

Spark and HDFS without NDP



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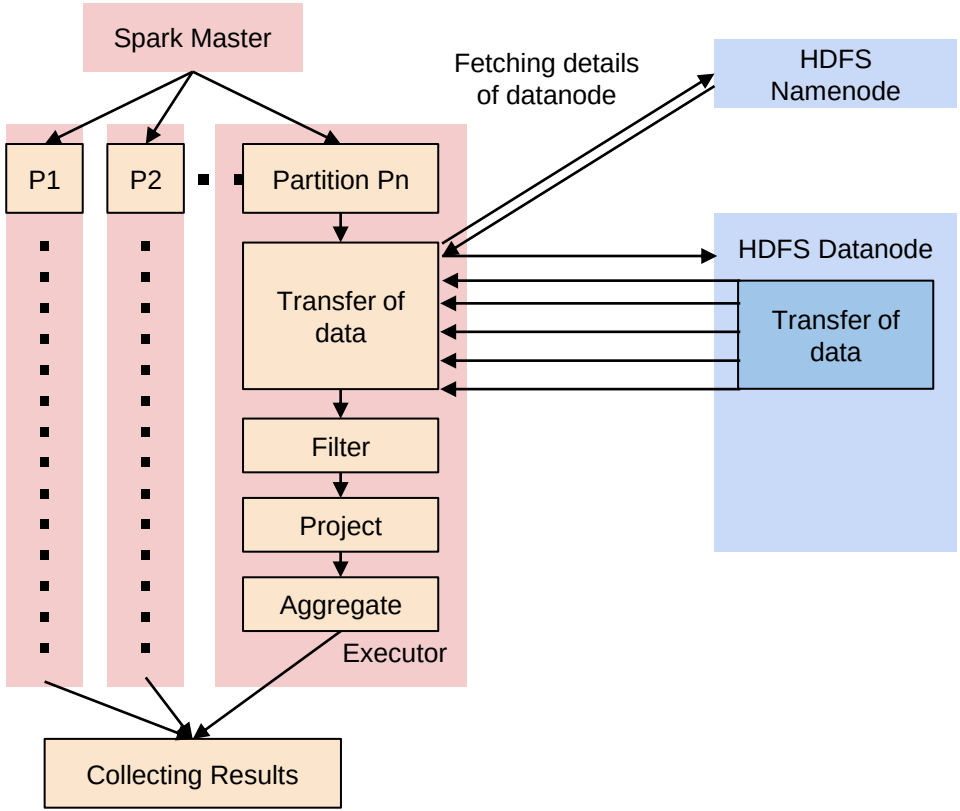
Spark and HDFS with NDP

- Operations pushed to datanodes



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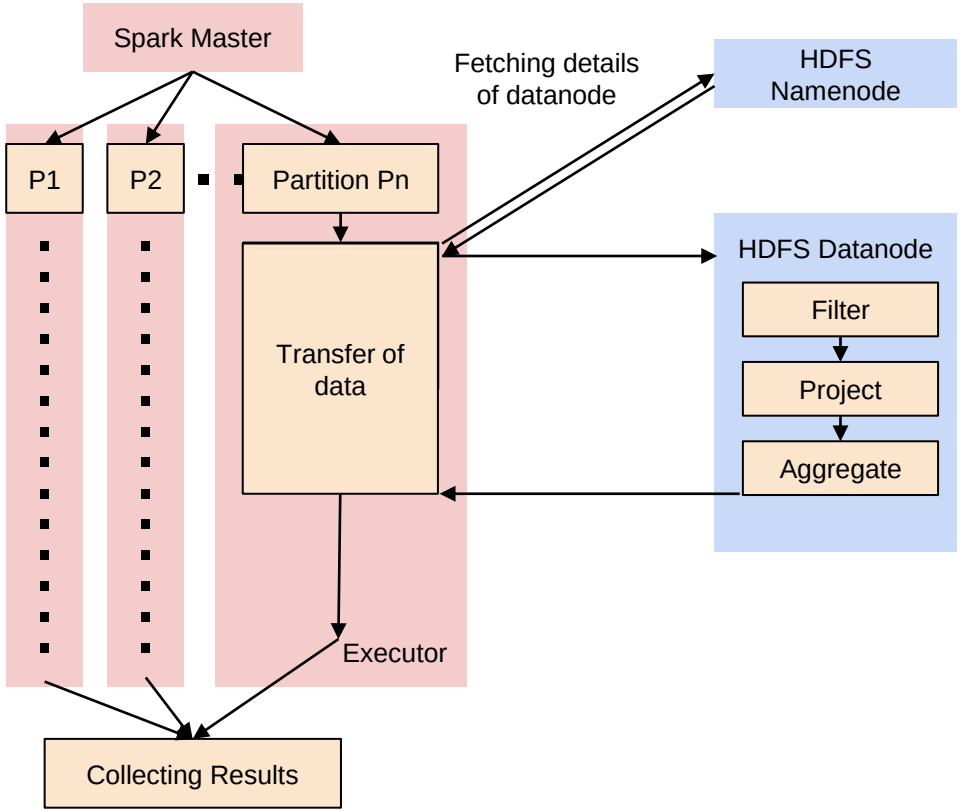

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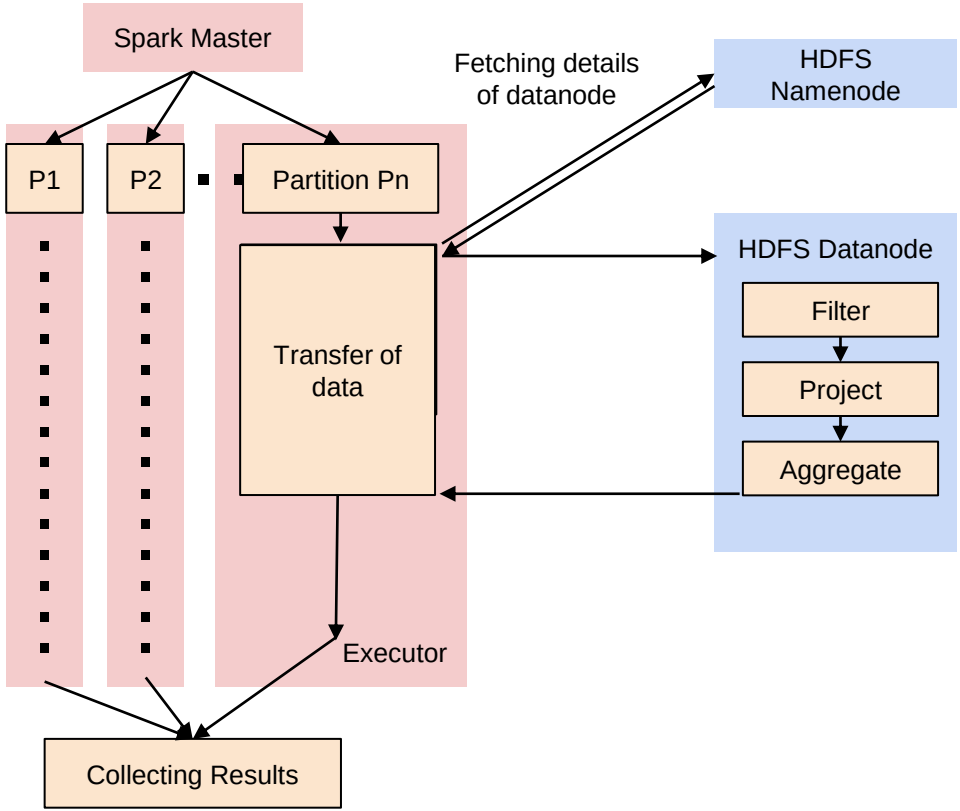
Selective Pushdown

- Some operations pushed to datanodes



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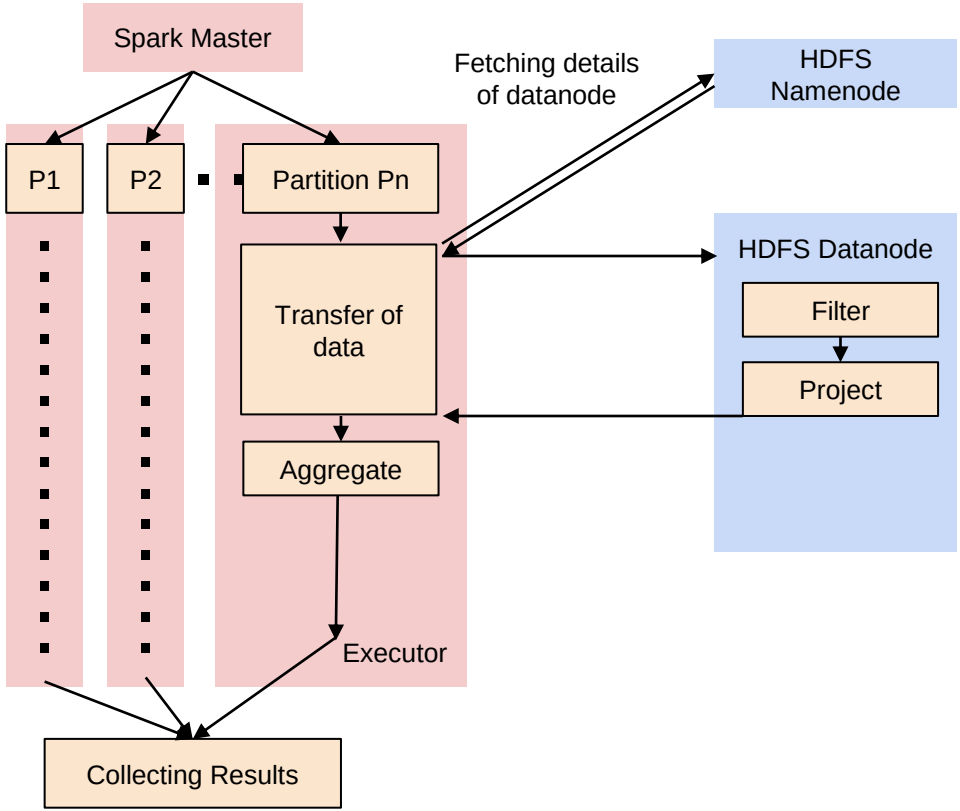

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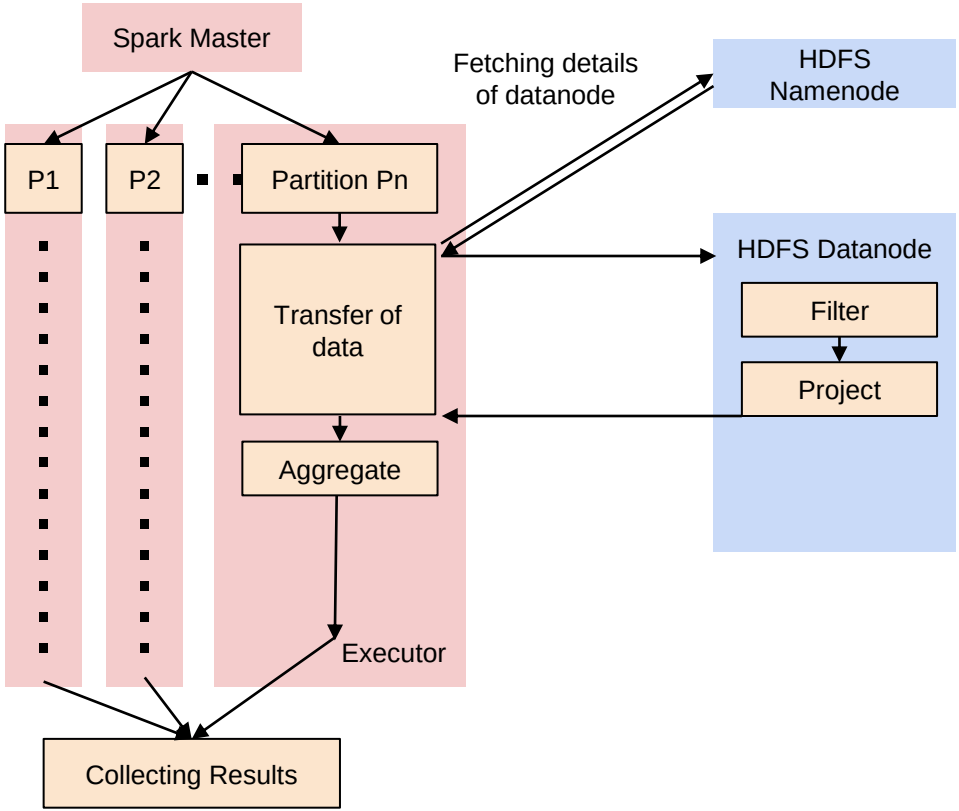
Which operations to Pushdown?



Prior Work

NDP implementations

- Octopus [CloudCom'15]
- PushdownDB [ICDE'2020]
- λFlow [CCGRID'2019]

More related works and detailed comparisions can be found in the paper

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NDP implementations

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We aim to study performance of NDP in λFlow-like systems and then optimize it

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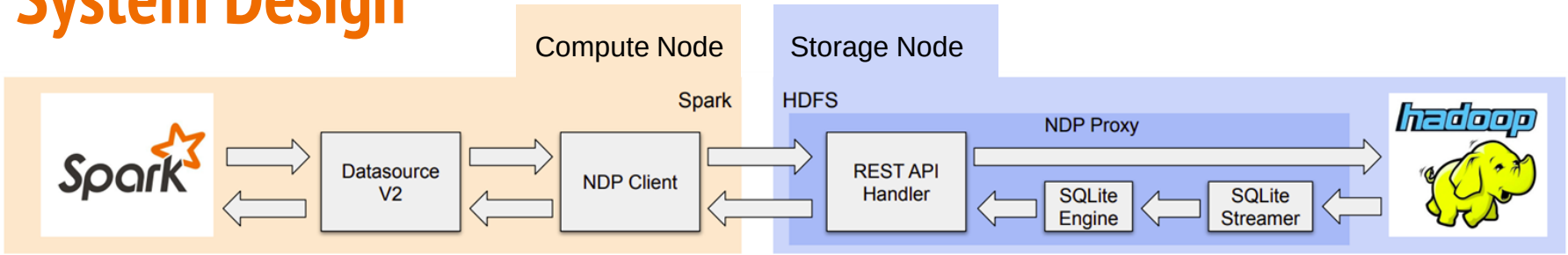
System Design



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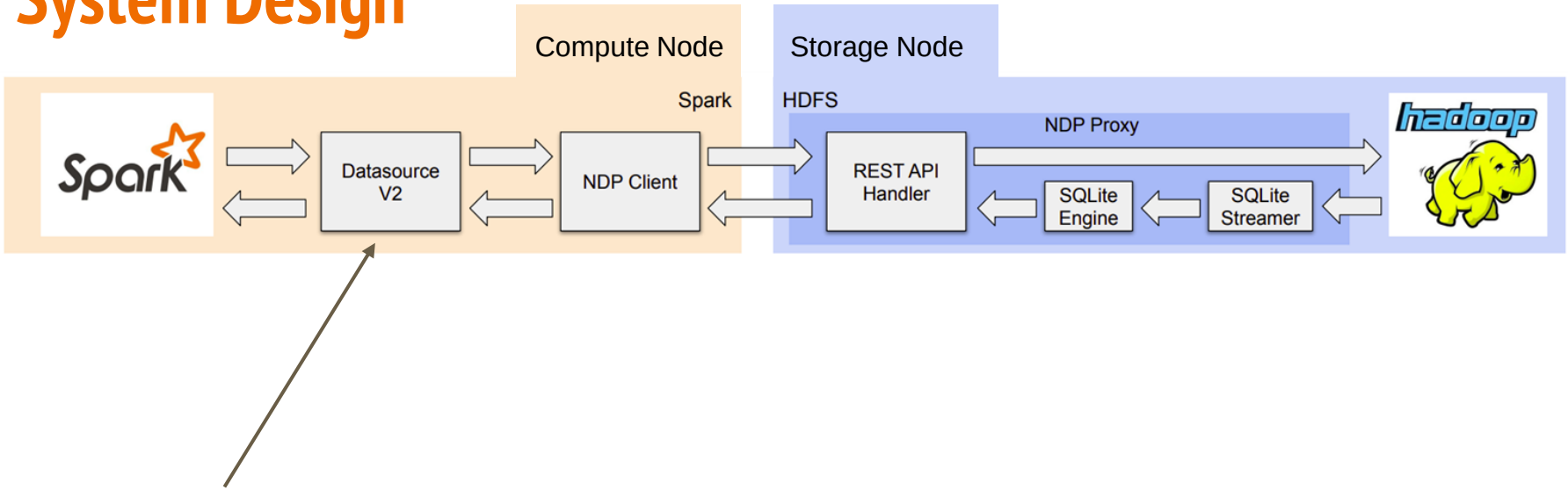
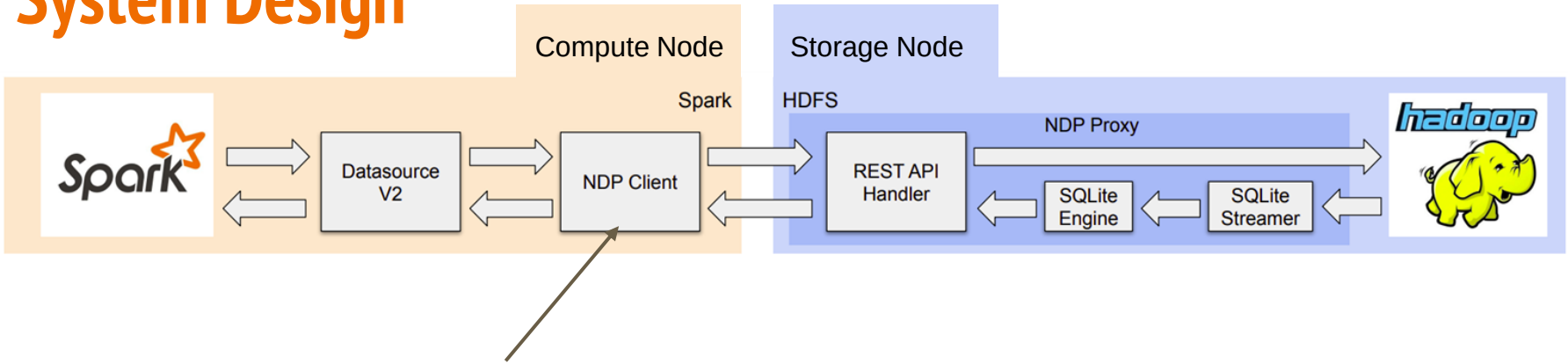


NDP Datasource API

- Spark driver for NDP Client
- Post processing of results

System Design



NDP Client

- Extracts attributes required for NDP
- Translates query into SQL command

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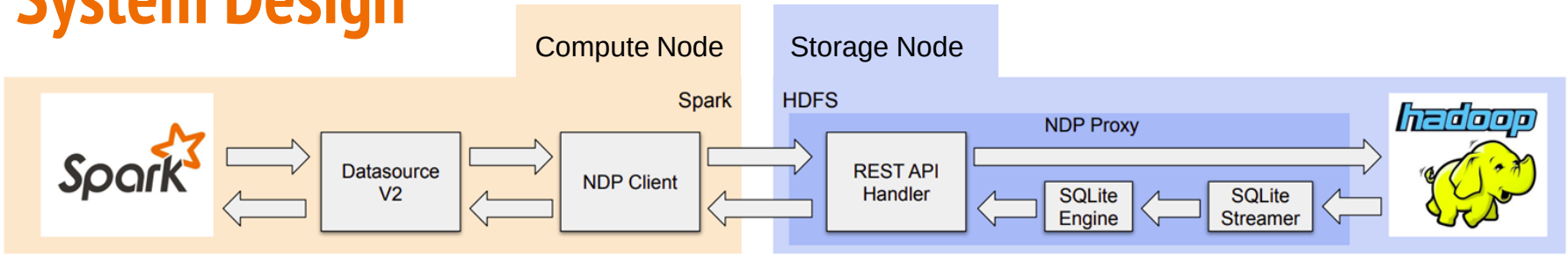

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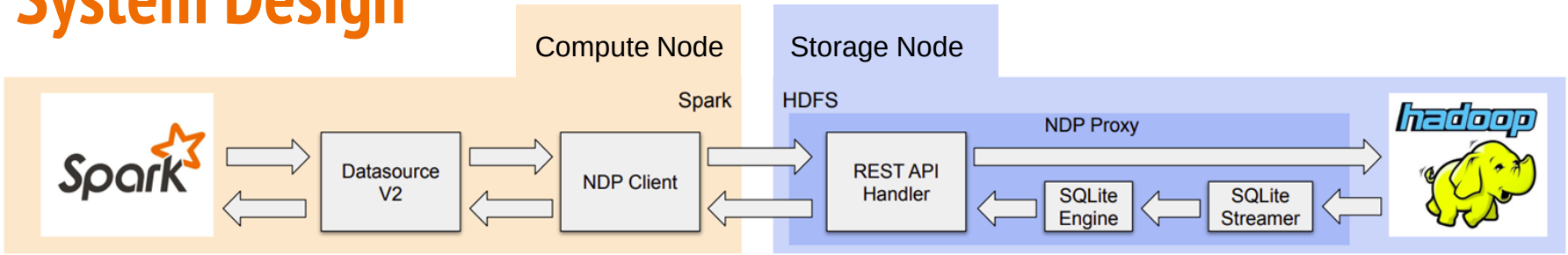

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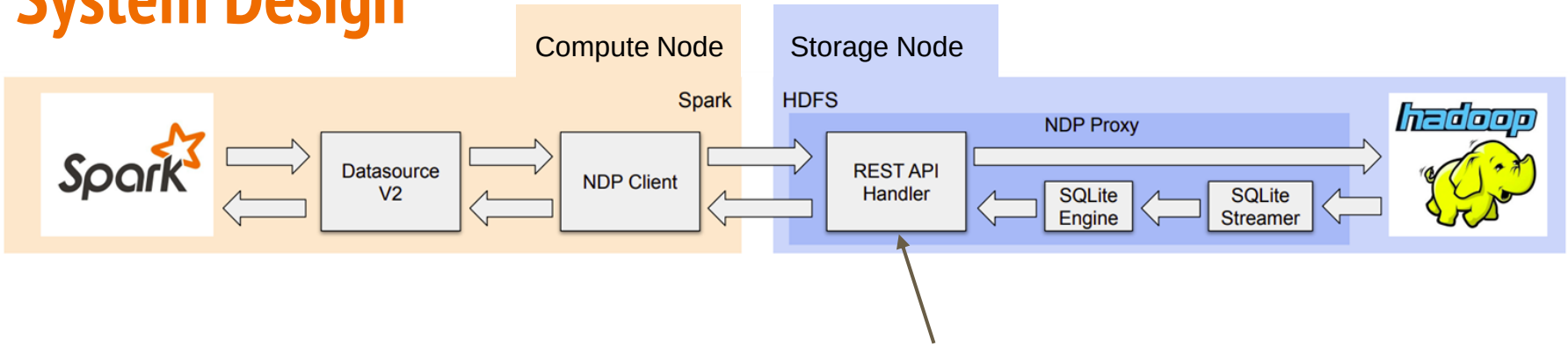
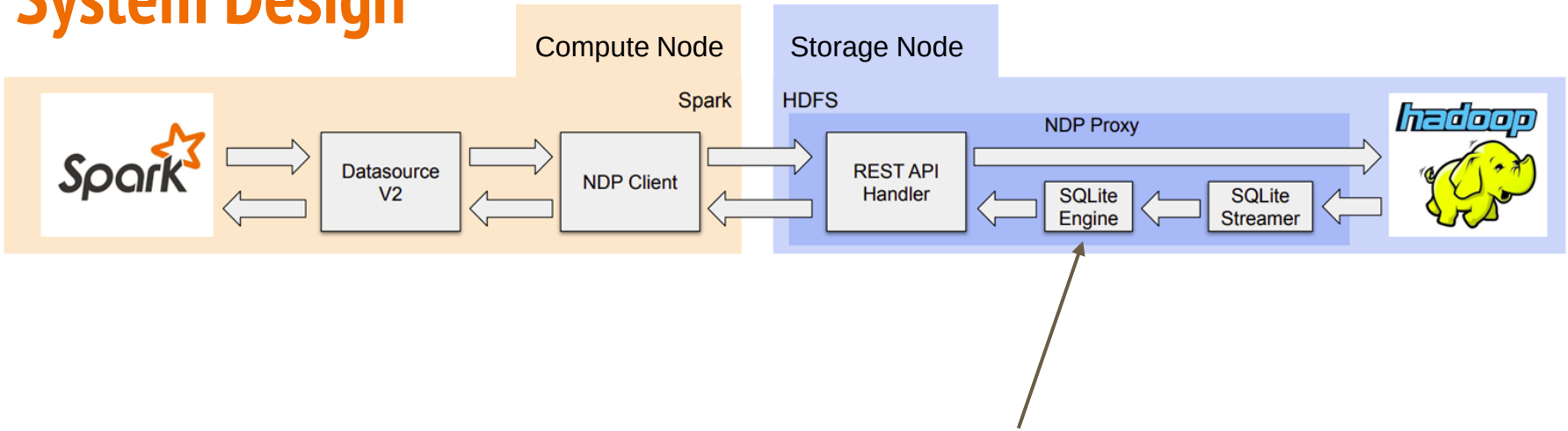


REST API Handler

- Intercepts HTTP connections from executors to datanodes
- Starts HDFS and SQLite subprocesses

System Design



SQLite Engine

- Parses CSV files to create tables
- Run operations that are pushdowned

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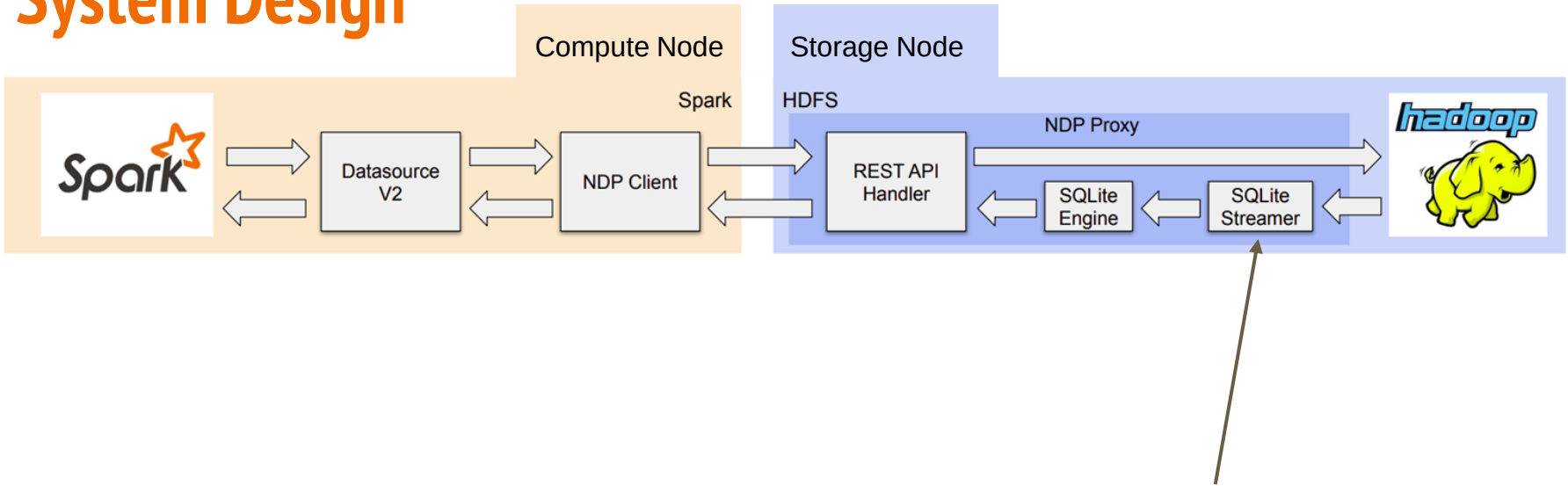

SQLite Streamer

- Enables processing while loading data

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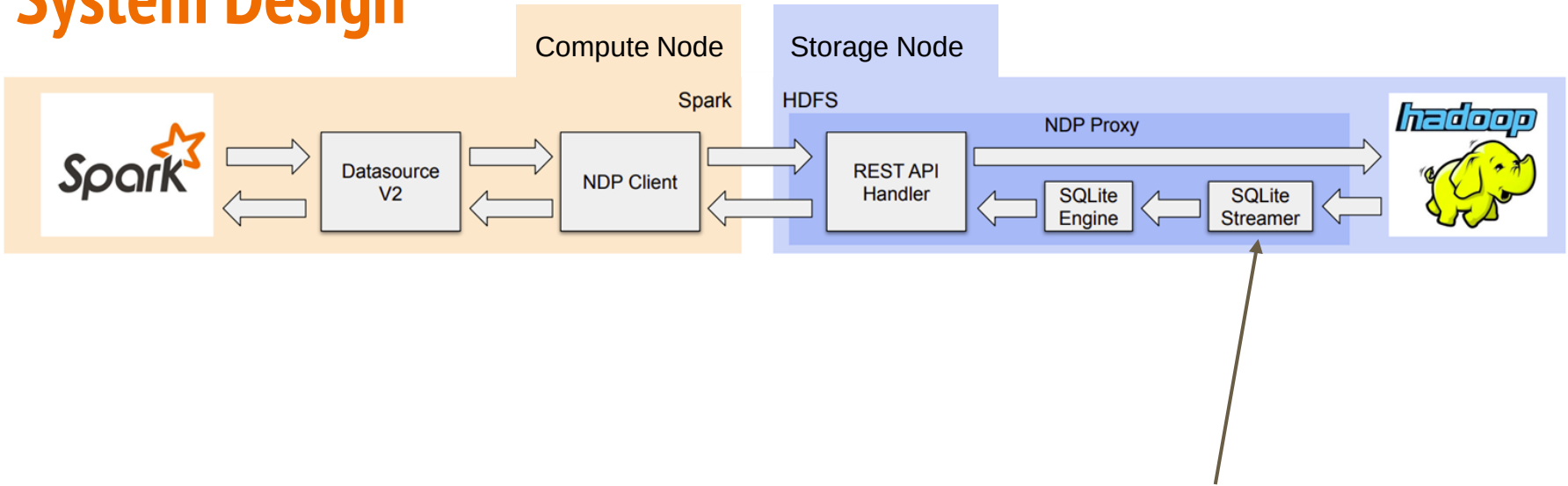

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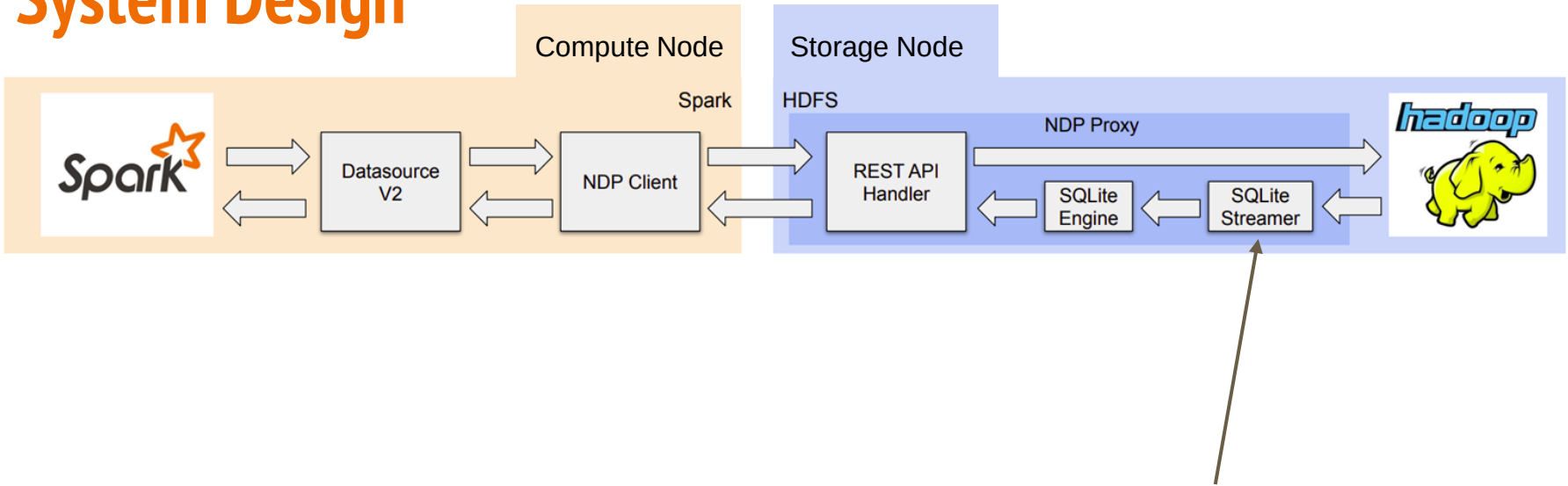

SQLite Streamer

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More details in the paper

Code published at - https://github.com/open-infrastructure-labs/caerus-dike/

Which operations to Pushdown?

System Design

System Design

Analytical model - “Net-Aware”

- Predict the best pushdown strategy for an operation
- Using the parameters
  1. Estimated execution time of operations
     - At Spark
     - At HDFS
  2. Estimated time to transfer
     - Input data
     - Output data

System Design

NDP of an operation is useful if time taken for

Transfer input (HDFS → Spark) + Compute at Spark

> Compute at HDFS + Transfer output (HDFS → Spark)

Analytical model - “Net-Aware”

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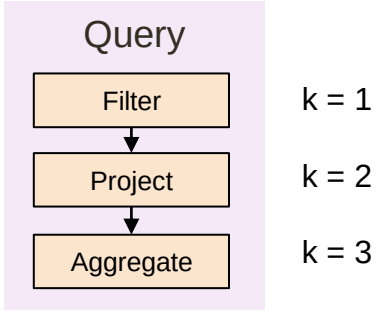
System Design

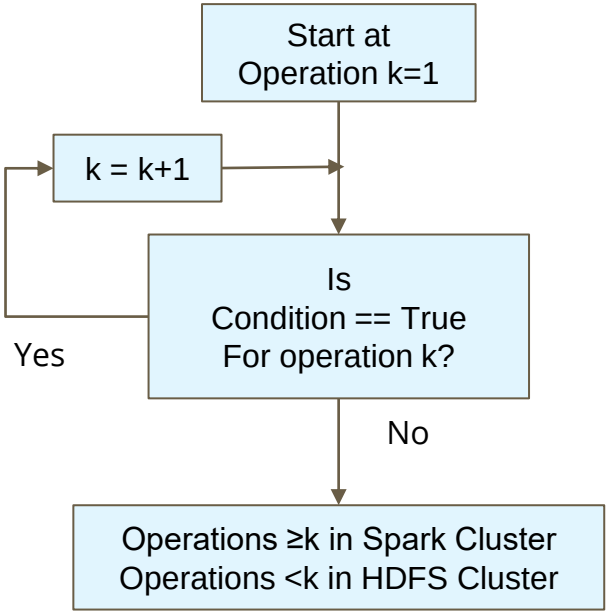
- NDP decision for a particular operation

$$T_c(Q_{Spark}, X_{Spark}) + T_n(D_{input}) > T_c(Q_{HDFS}, X_{HDFS}) + T_n(D_{output})$$

- Decide # of operations to pushdown while initializing (design constraints)

- Once in Spark need to continue in Spark (design constraints)





Evaluation - Experimental Results

- 6 Spark nodes
  - Total **70 cores** for executors
  - Total 17.5 GB memory for executors
  - TPC-H Queries

- **10 Gbps** between the clusters
- 1 Gbps per host

- 4 Datanodes (HDFS)
  - **1-4 cores** each
    - Using Docker
  - CPU Freq - 2.67 GHz (original)
    1.6 GHz (underclock)
    - Using cpufrequtils
  - Replication factor - 4
  - **100 GB dataset** by DBGEN

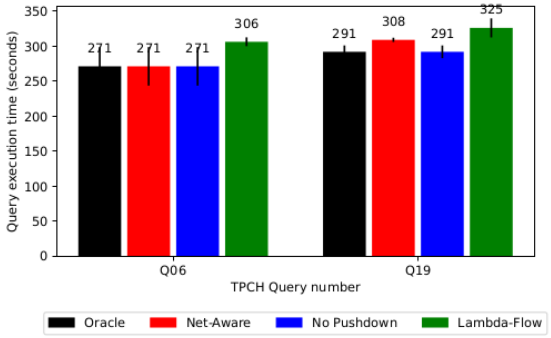
- 1 Gbps per host
  - Changed using Tc and NetEm

More details in the paper

Evaluation - Experimental Results

- 1 Job at a time
- Varying cores in datanodes

- Oracle is the best of all selective pushdowns
- Net-aware is our policy
- No pushdown is native spark without NDP
- λFlow is full pushdown



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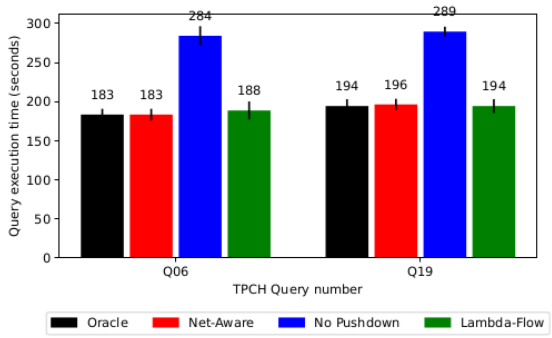

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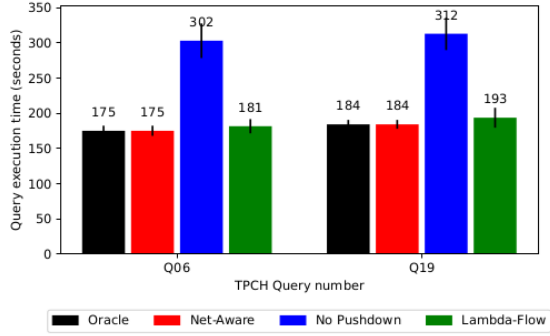

(iii) 4 cores

Configuration: Number of storage nodes = 4, storage nodes clock speed = 1.60 GHz, network bandwidth between clusters = 4 Gbps.

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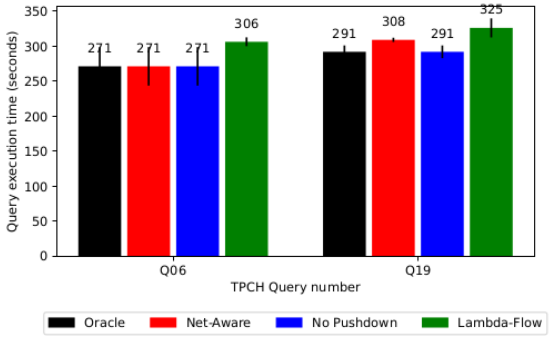

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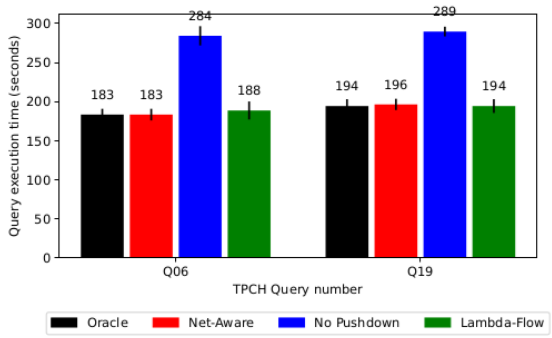

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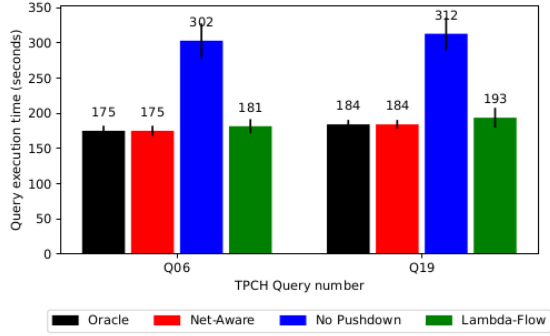

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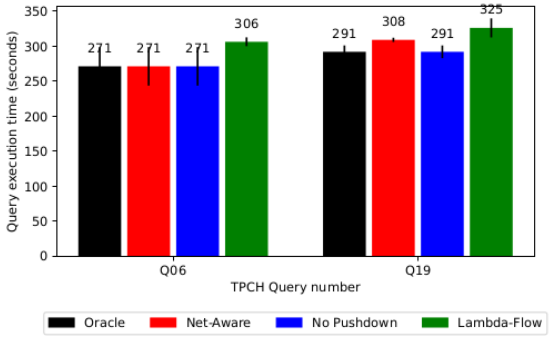

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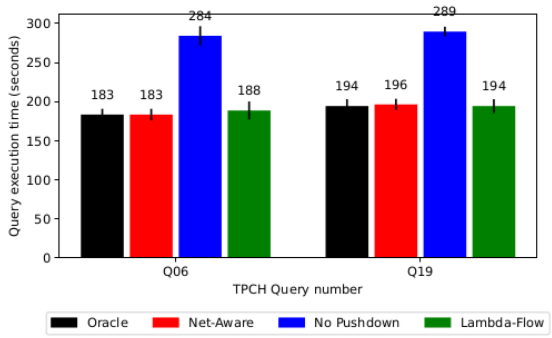

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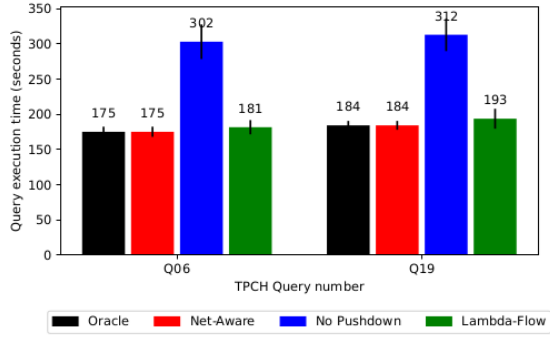

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Full pushdown is not useful with weaker storage

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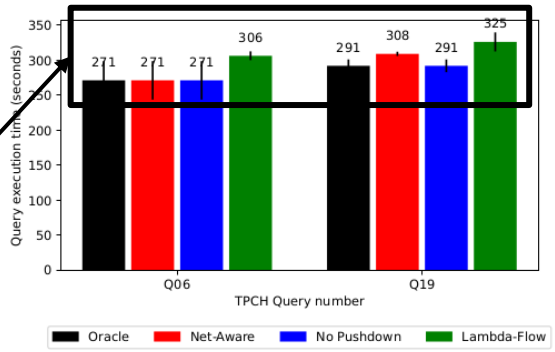

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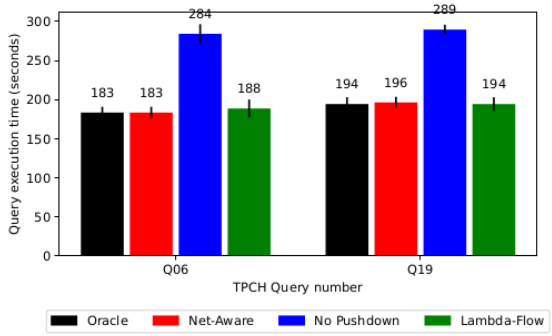

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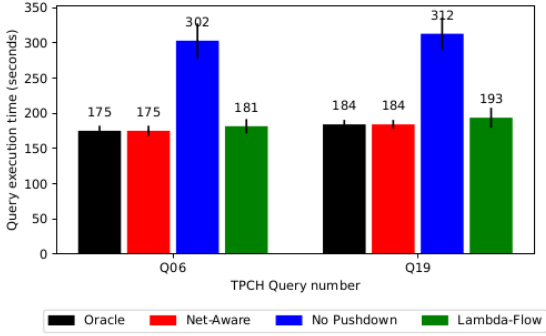

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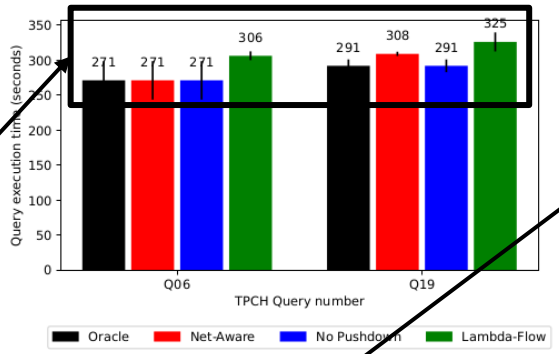
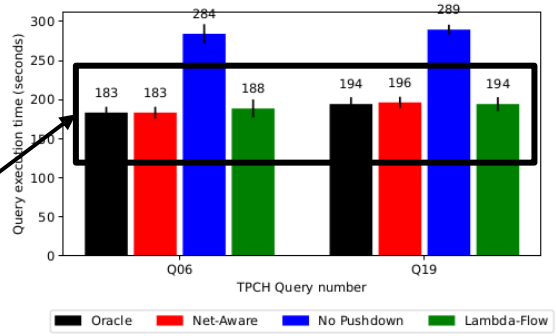
Full pushdown is not useful with weaker storage

Gets better with more cores

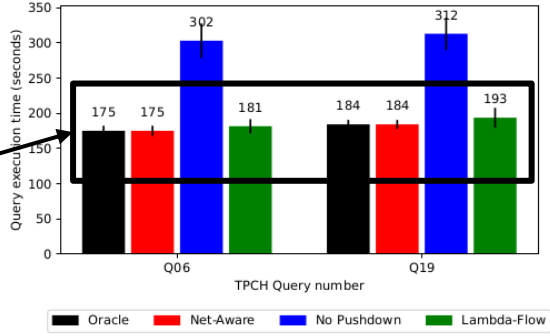
- No pushdown is native spark without NDP
- λFlow is full pushdown



(i) 1 core



(ii) 2 cores



(iii) 4 cores

Configuration: Number of storage nodes = 4, storage nodes clock speed = 1.60 GHz, network bandwidth between clusters = 4 Gbps.

Evaluation - Experimental Results

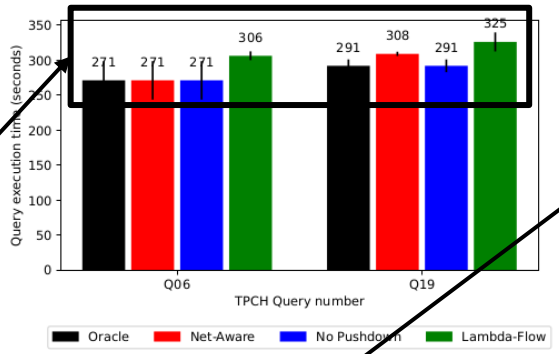
- 1 Job at a time
- Varying cores in datanodes

Full pushdown is not useful with weaker storage

Gets better with more cores

- No pushdown is native spark without NDP

Net-Aware is always close to oracle



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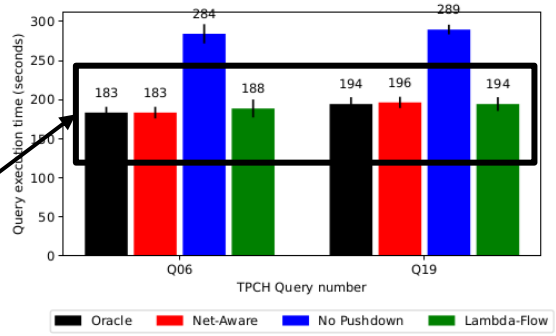
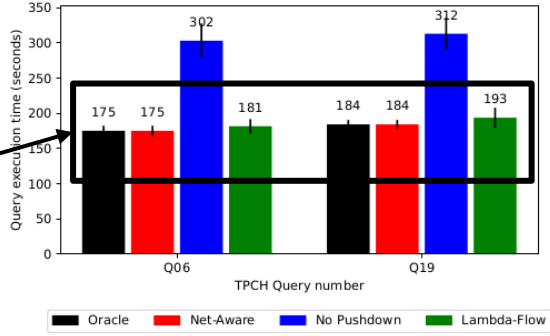


(ii) 2 cores

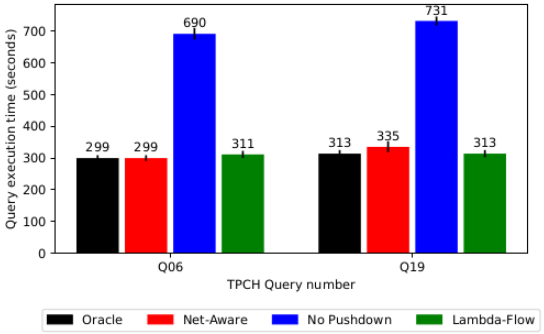


(iii) 4 cores

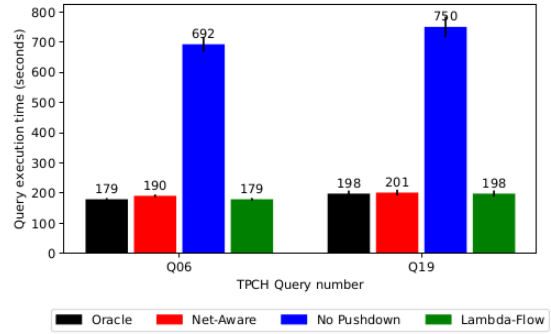
Configuration: Number of storage nodes = 4, storage nodes clock speed = 1.60 GHz, network bandwidth between clusters = 4 Gbps.

Evaluation - Experimental Results

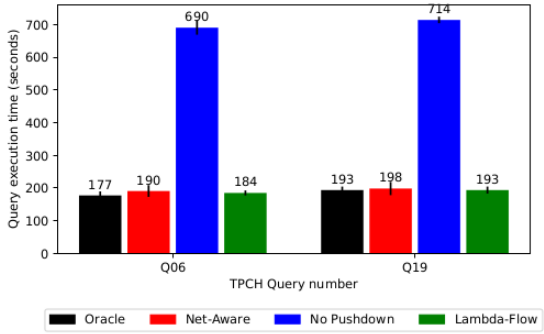
- Changed bandwidth between clusters



(i) 1 core



(ii) 2 cores

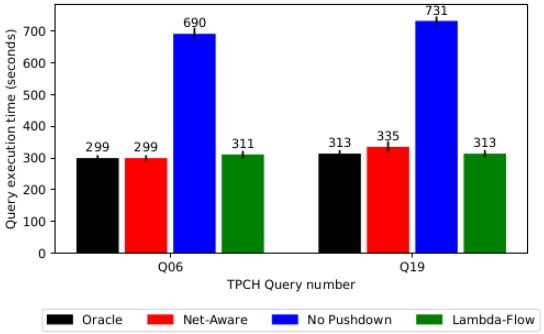


(iii) 4 cores

Configutation: Number of storage nodes = 4, storage nodes clock speed = 1.60 GHz, network bandwidth between clusters = 1 Gbps.

Evaluation - Experimental Results

- Changed bandwidth between clusters



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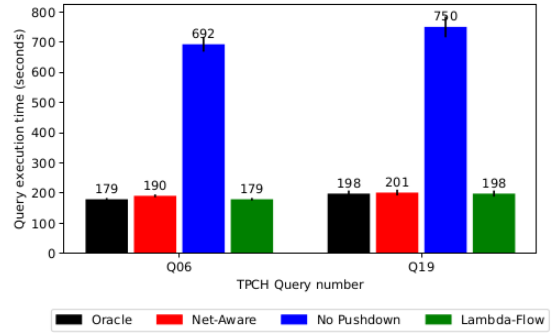
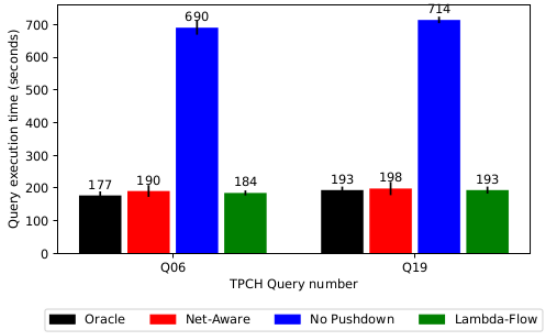


(ii) 2 cores



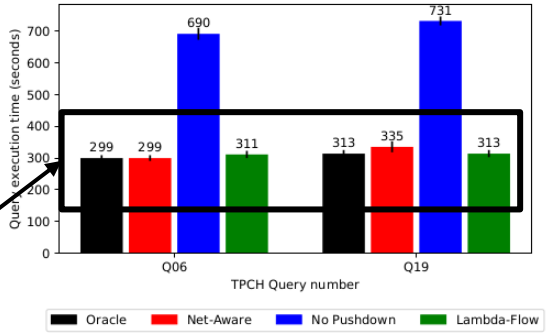
(iii) 4 cores

Configutation: Number of storage nodes = 4, storage nodes clock speed = 1.60 GHz, network bandwidth between clusters = 1 Gbps.

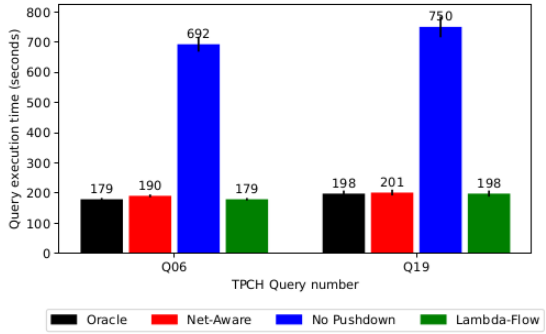
Evaluation - Experimental Results

- Changed bandwidth between clusters

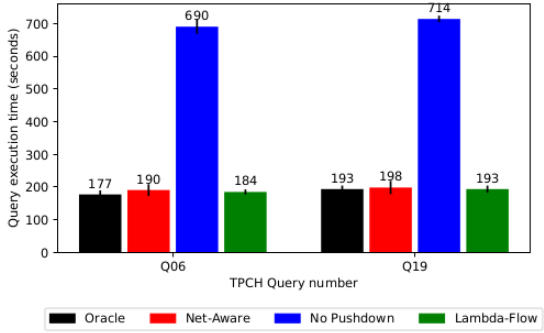
Full pushdown is now useful with weaker storage because of the weak network link



(i) 1 core



(ii) 2 cores



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Evaluation - Experimental Results

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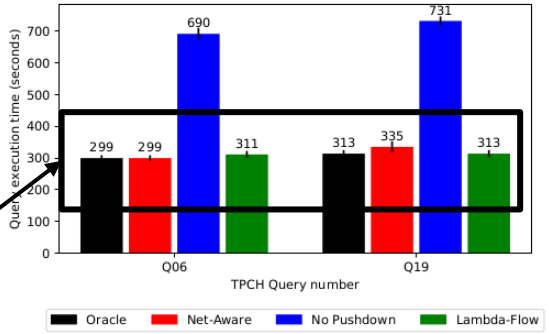
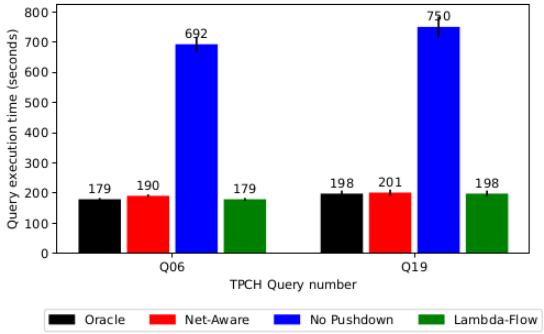
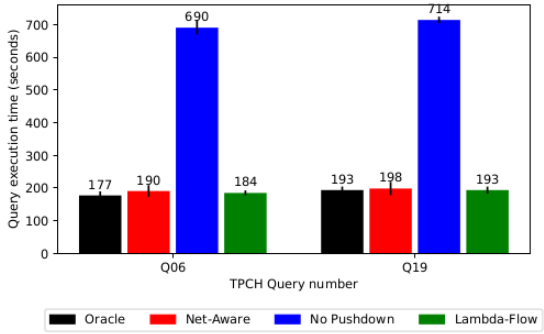


(i) 1 core



(ii) 2 cores

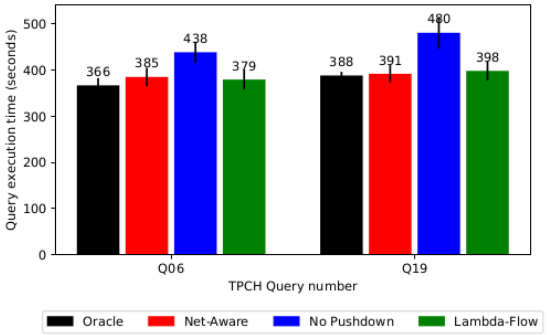


(iii) 4 cores

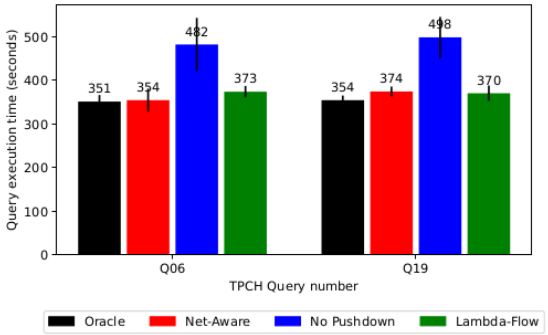
Configutation: Number of storage nodes = 4, storage nodes clock speed = 1.60 GHz, network bandwidth between clusters = 1 Gbps.

Evaluation - Experimental Results

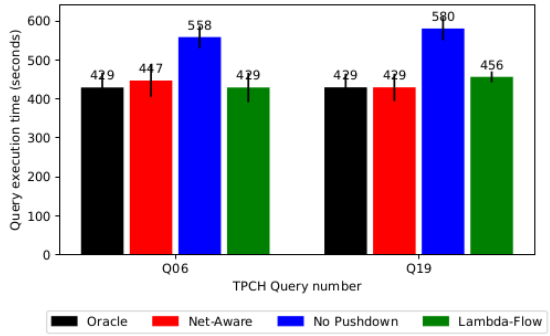
- Fewer nodes in HDFS and moderate bandwidth



(i) 1 core



(ii) 2 cores



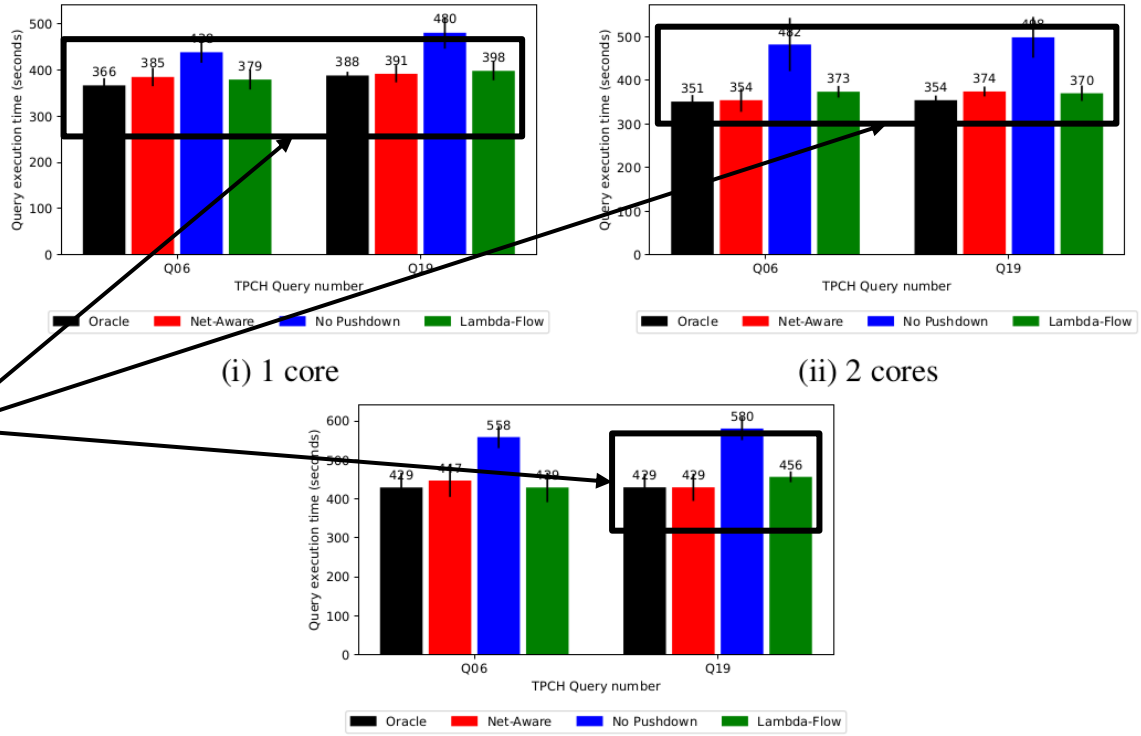
(iii) 4 cores

Configutation: Number of storage nodes = 2, storage nodes clock speed = 2.67 GHz, network bandwidth between clusters = 2 Gbps.

Evaluation - Experimental Results

- Fewer nodes in HDFS and moderate bandwidth

A better selective pushdown exists than Full pushdown and No pushdown



(i) 1 core (ii) 2 cores

(iii) 4 cores

Configutation: Number of storage nodes = 2, storage nodes clock speed = 2.67 GHz, network bandwidth between clusters = 2 Gbps.

Evaluation - Experimental Results

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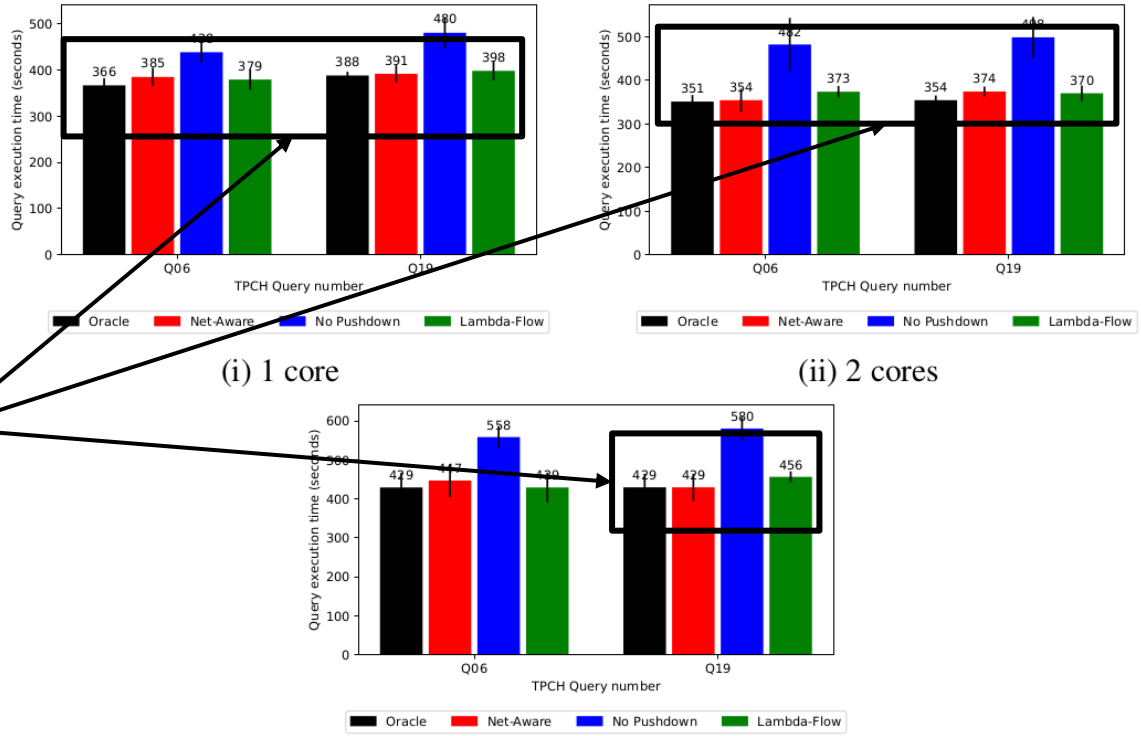

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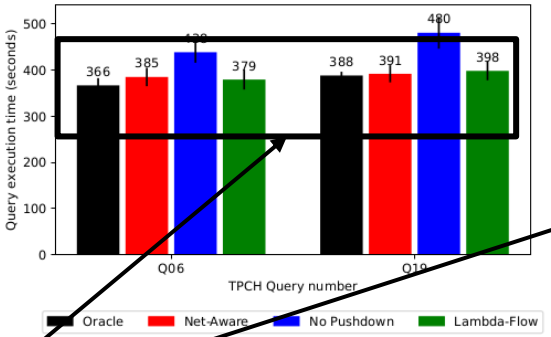
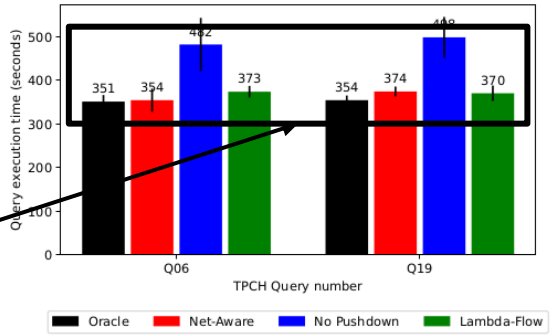
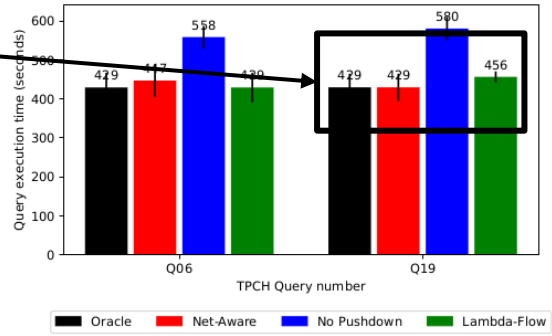


(i) 1 core



(ii) 2 cores



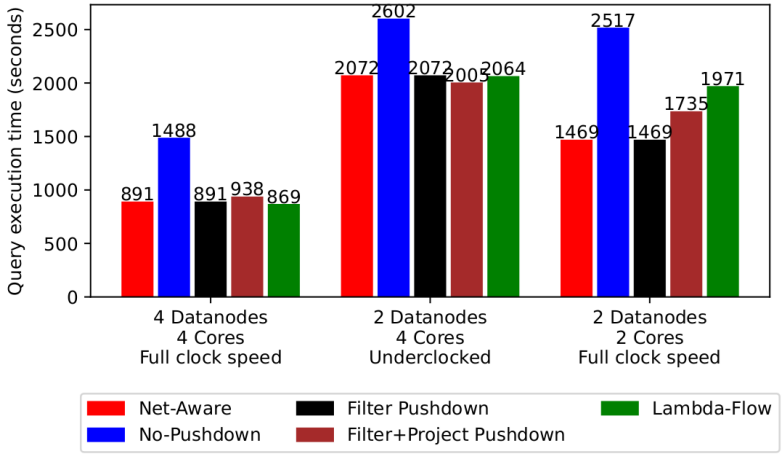
(iii) 4 cores

Configutation: Number of storage nodes = 2, storage nodes clock speed = 2.67 GHz, network bandwidth between clusters = 2 Gbps.

Net-Aware is always close to oracle

Evaluation - Experimental Results

- 1 job arrives every 50 seconds
- Averaged over 10 jobs

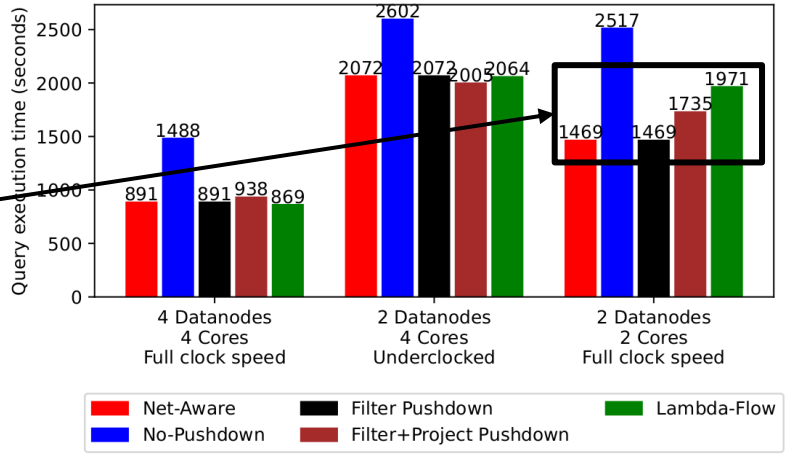


More experimental results and simulations in the paper

Evaluation - Experimental Results

- 1 job arrives every 50 seconds
- Averaged over 10 jobs

Selective pushdown can make significant difference



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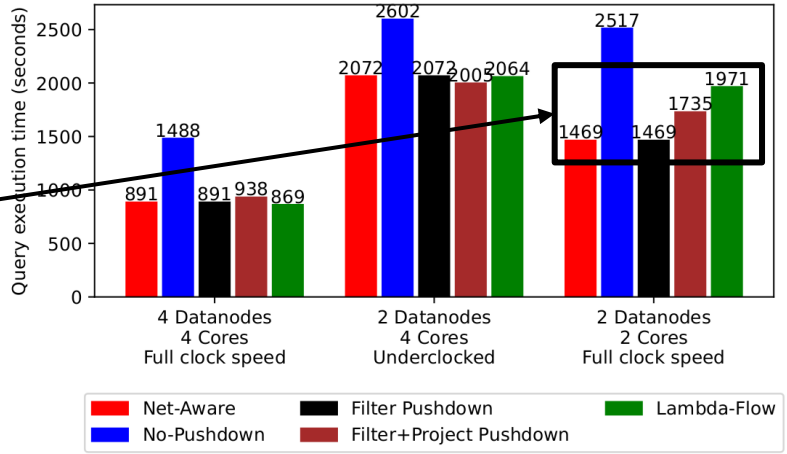


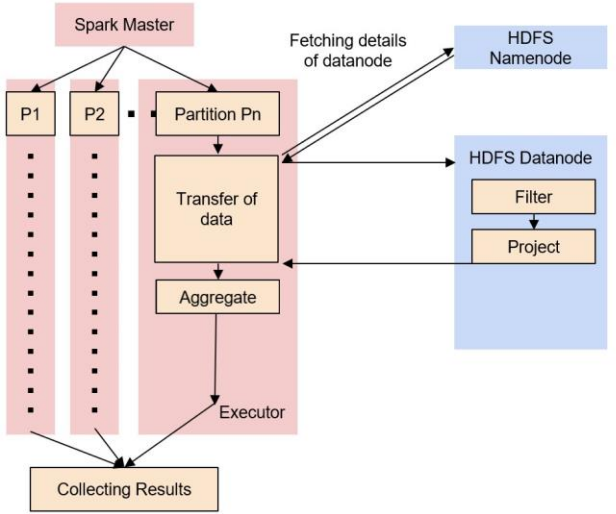
Net-Aware is always close to optimal

More experimental results and simulations in the paper

Conclusion

Summary of our paper

- NDP implementation
- Constructed an analytical model for optimizing NDP
- Experimental evaluation – Net-Aware is close to optimal
- Implemented a discrete event simulator for large clusters
  (skipped in the interest of time)



Thanks for your attention

Any Questions?

Summary-

- NDP for Spark+HDFS
- Analytical Model
- Experimental evaluation
- Discrete event simulator