Optimizing Recursive Joins in Graph Database Management Systems

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Outline

- Background on Graph DBMS & Recursive Joins
- Why are Recursive Joins challenging ?
- Query Processing for Recursive Joins
- Future Work

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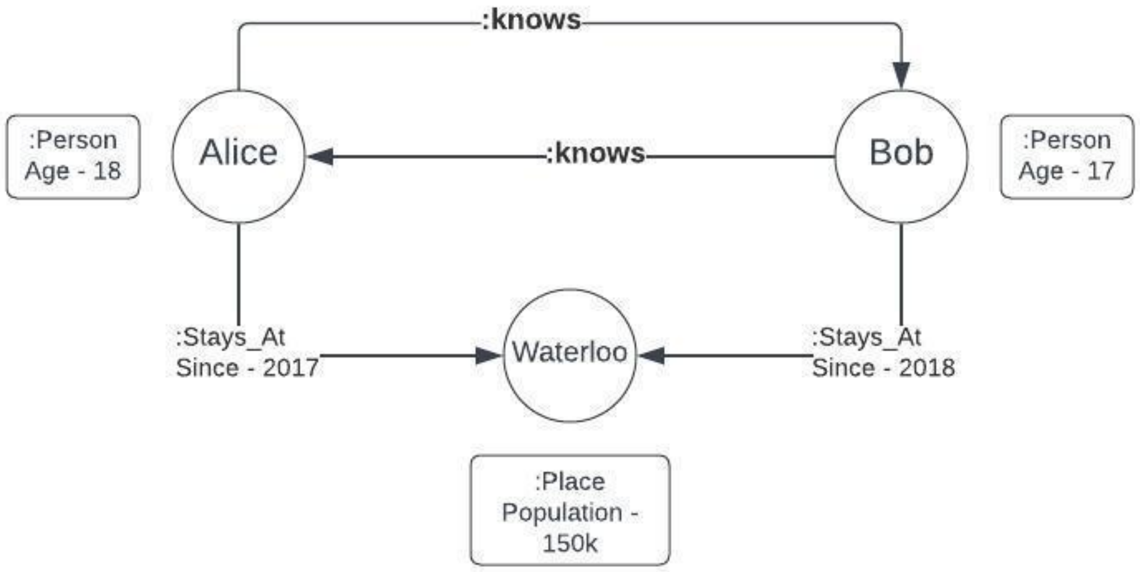
Background on Graph Databases

Data Model

- Labeled Property Graph (LPG)



Query Language

Neo4j
Cypher Query
Language

SQL:2023

```
MATCH
(a:Person)-[r1:Stays_At]->(b:Place)<-[r2:Stays_At]-(c:Person)
RETURN b.Population;
```

- Express subgraph pattern for Pattern Matching

- Express recursive queries for Graph Path Traversal

Background on Recursive Joins

Core competency of GDBMS compared to RDBMS

(1) Easier to express in the query language of GDBMS:

Query: *Return all people 'Alice' knows directly / indirectly and the path length between them*

Cypher:

MATCH ***p = (p1:Person)-[:knows* SHORTEST 1..30]->(p2:Person)***
WHERE p1.name = 'Alice' RETURN p2, *length(p)*

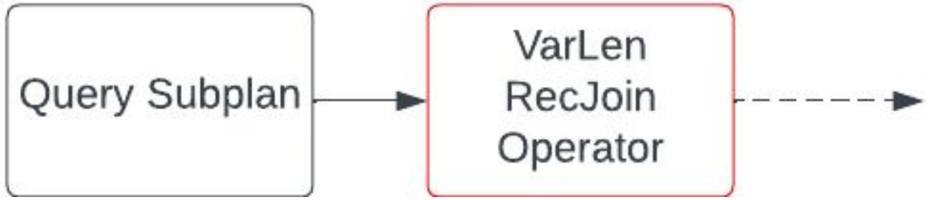
Harder to express in recursive SQL.

Background on Recursive Joins

Core competency of GDBMS compared to RDBMS

(2) Also often faster to execute in GDBMS

*GDBMS have **specialized recursive join** operators*



Query:

MATCH p = (a:Person)-[r:knows* 1..30]->(b:Person)
WHERE a.name = “Alice”
RETURN a.ID, b.ID, length(p)

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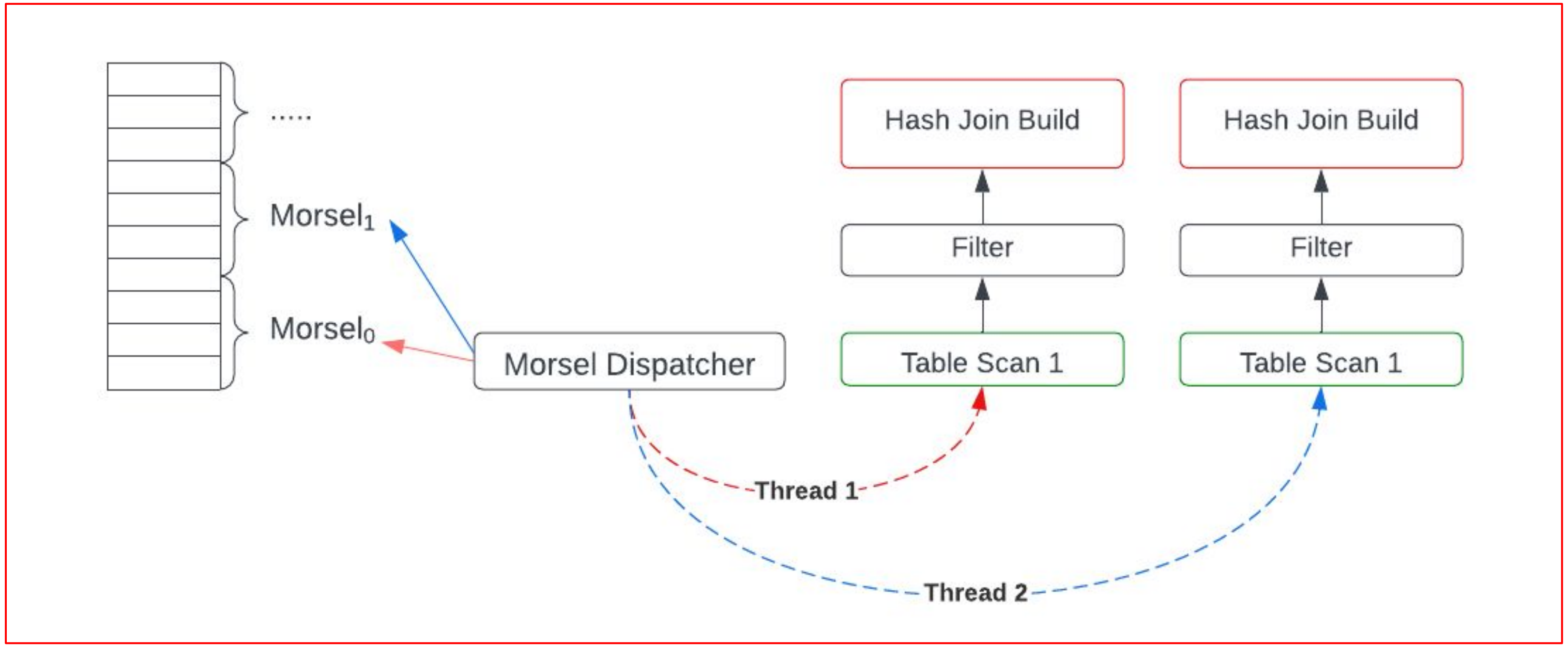
SoTA Approach in Analytical DBMS: Morsel-driven Parallelism

- allot fixed size “morsels” to threads (1024 - 2048 - 100,000 tuples)

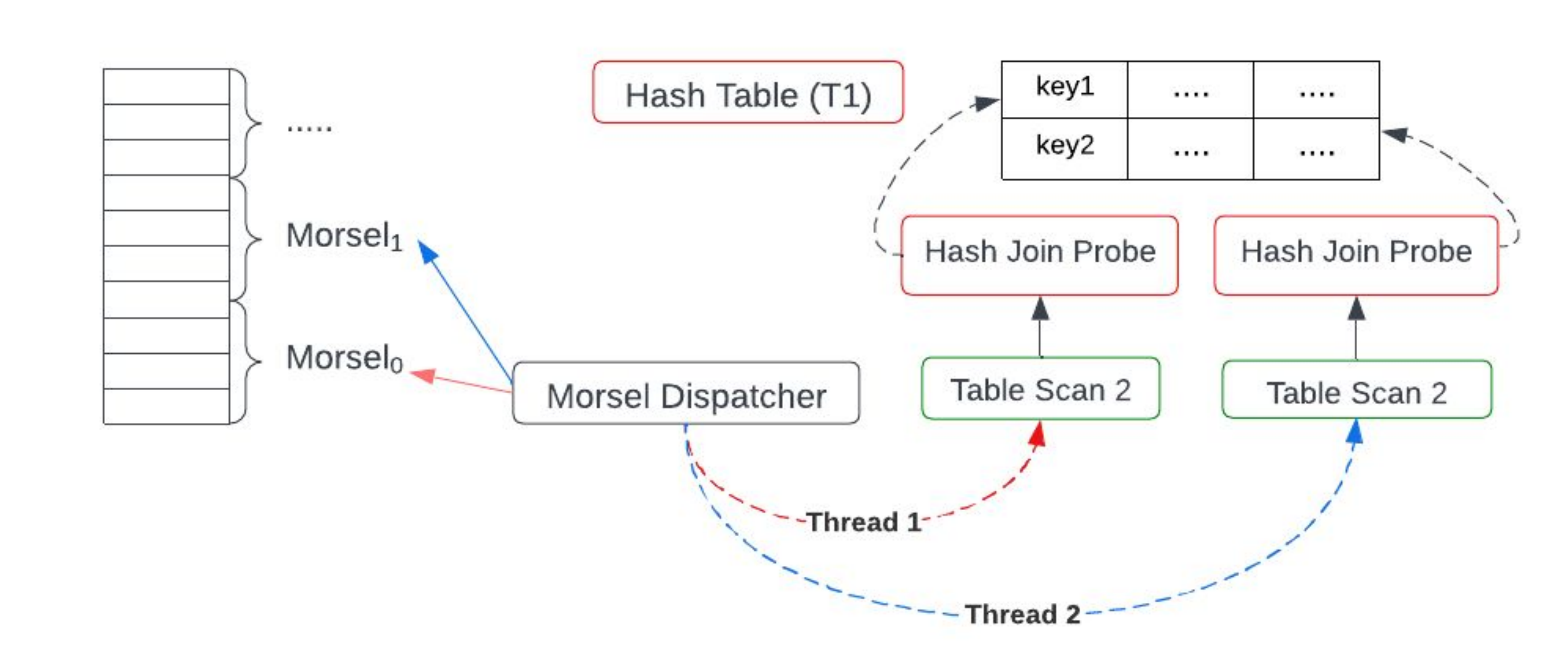
- threads execute on their morsels for 1 pipeline until the pipeline breaker



** Morsel-Driven Parallelism: A NUMA-Aware Query Evaluation Framework for the Many-Core Age, Leis et al.*

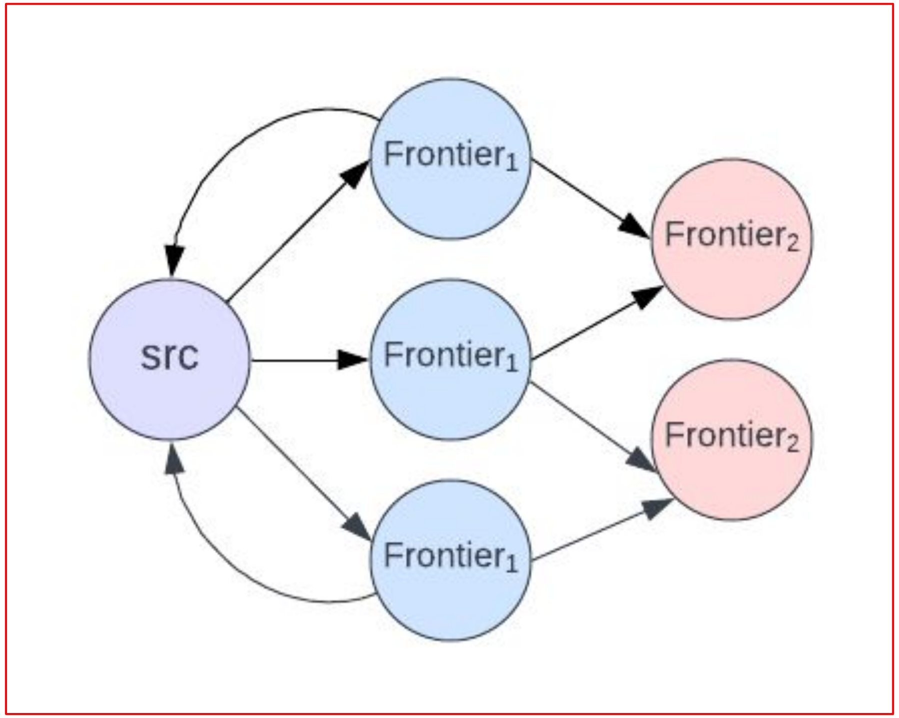
SoTA Approach in Analytical DBMS: Morsel-driven Parallelism

- allot fixed size "morsels" to threads (1024 - 2048 - 100,000 tuples)
- threads execute on their morsels for 1 pipeline until the pipeline breaker
- morsel dispatcher allots other morsels to threads, after completion of previous pipeline



Problem with Morsel-Driven Parallelism for Recursive Joins

1. Recursive Join operators find variable length / shortest path from a single source node. Usually involve some form of BFS style traversal.



Problem with Morsel-Driven Parallelism for Recursive Joins

1. Recursive Join operators find variable length / shortest path from a single source node.

- Most real world graphs display small world network property
- 5 or 6 steps may "traverse" the entire database
- *This makes recursive joins, even from 1 source very **expensive***

Example:

MATCH p = (p1:Person)-[:knows* SHORTEST 1..30]->(p2:Person)
WHERE *p1.name = 'Alice'* RETURN p2, length(p)

Problem with Morsel-Driven Parallelism for Recursive Joins

2. Dispatcher may allot a morsel with disproportionate no. of sources to a single thread

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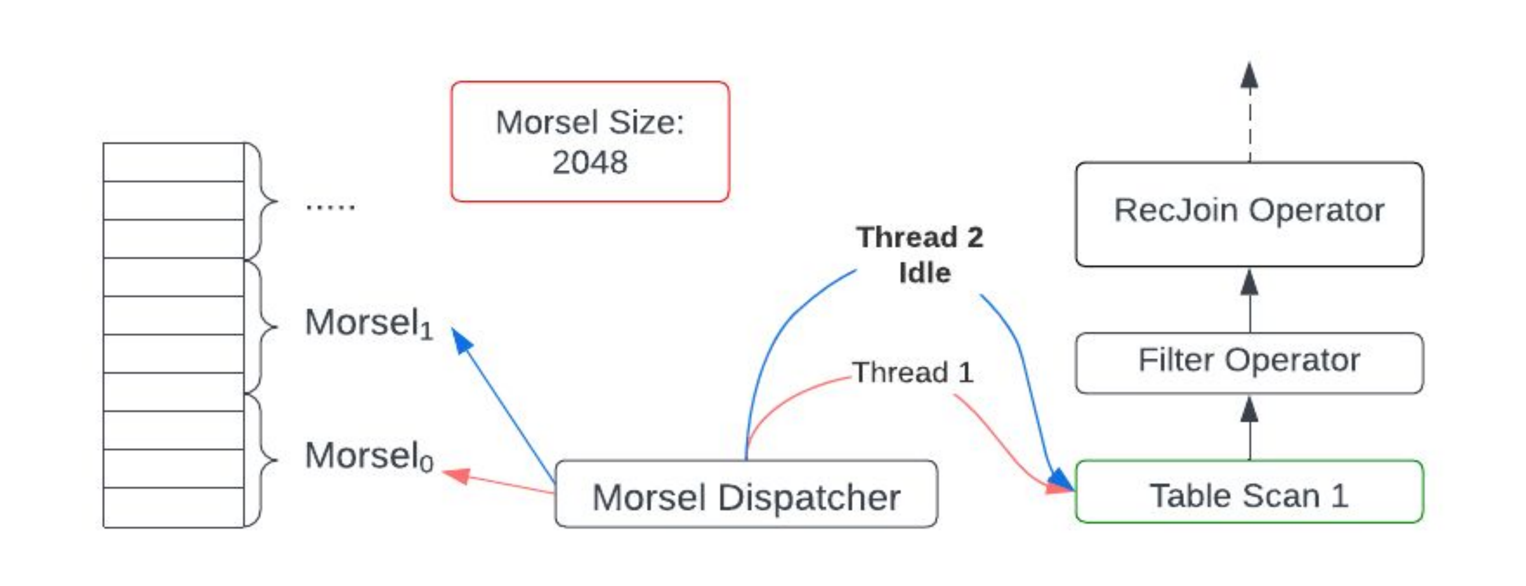
Example:
MATCH
p = (p1:Person)-[:knows* SHORTEST 1..30]->(p2:Person)
WHERE *p1.ID < 50* RETURN *length(p)*



Problem with Morsel-Driven Parallelism for Recursive Joins

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Example:
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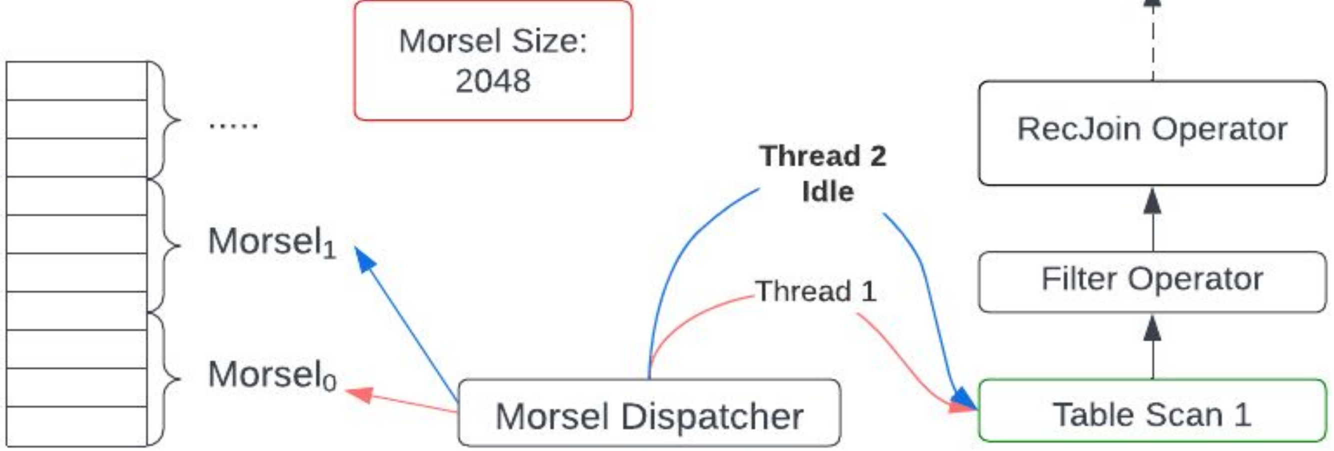
Q.) How can we parallelize pipelines with recursive join operators robustly ?



Solution

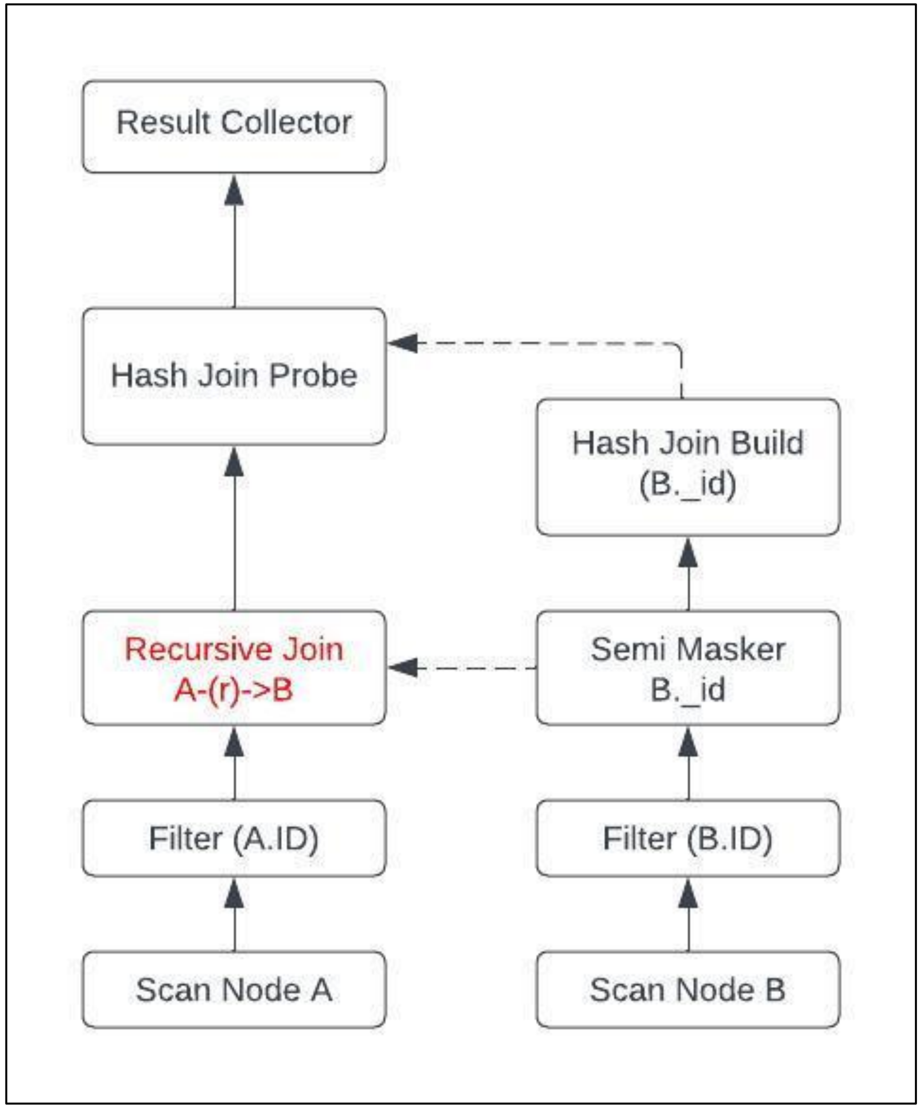
(1) Make Recursive Join operator into a source operator to start the query pipeline. Threads should start BFS with ***a single source*** from this operator.

Solution (Query Plan)

Cypher query:

MATCH p = (a:Person)-[r:knows*
SHORTEST 1..30]->(b:Person)
WHERE a.ID < 1000 AND b.ID < 1000
RETURN a.ID, b.ID, length(p)

Recursive Join (RecJoin) operator must be the start of a pipeline



Solution

(2) Morselize as before among threads with effective morsel size as 1 BFS source node (*Inter-RecJoin* parallelism)

(3) When threads are idle, morselize a single RecJoin's BFS Level (frontier) into granular morsels among these threads (*Intra-RecJoin* parallelism)

Solution

(2) Morselize as before among threads with effective morsel size as 1 BFS source node (*Inter-RecJoin* parallelism)

(3) When threads are idle, morselize a single RecJoin's BFS Level (frontier) into granular morsels among these threads (*Intra-RecJoin* parallelism)

- Define two types of morsels: (i) **BFSMorsel** (single source recursive join)
  (ii) **BFSLevelMorsel** (subset of *BFSMorsel's join*)

- Introduce a *Recursive Join scheduler* that distributes this work

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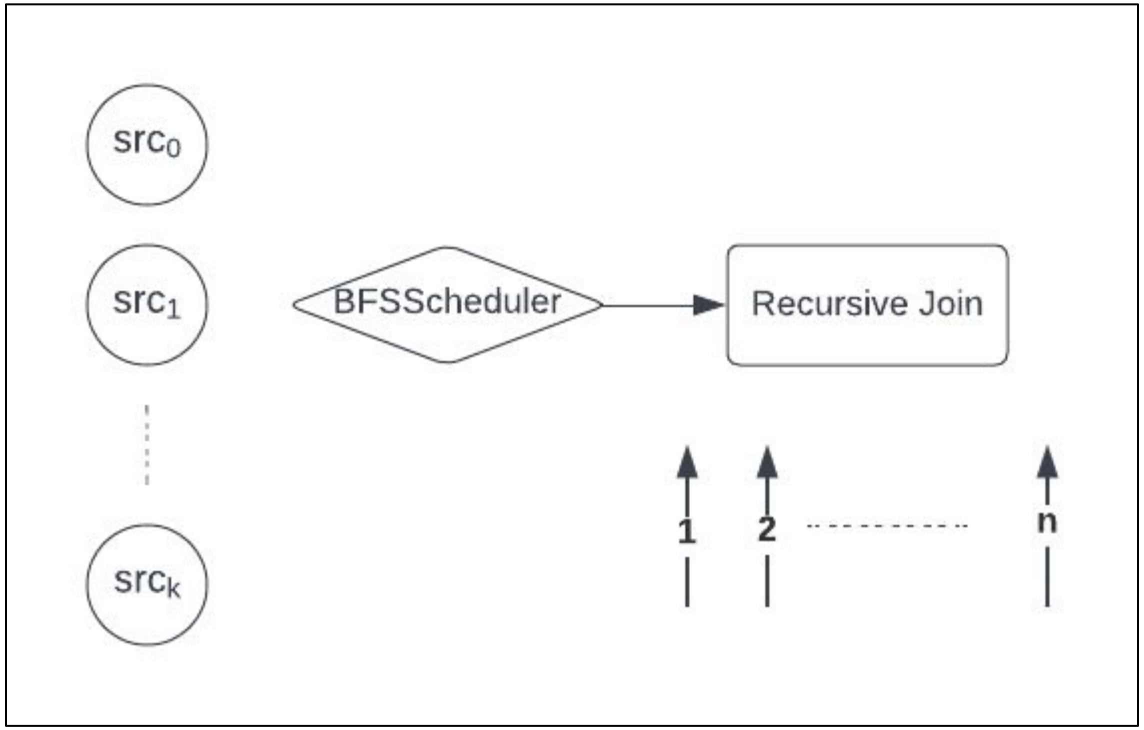
Recursive Join Physical Operator

- *BFSScheduler*: Operators own scheduler that distributes work to the threads.

BFSScheduler controls total no. of concurrent *BFSMorsel* to at most ***k***. Max limit is set to n (total threads).

n Threads, *k* BFSMorsel

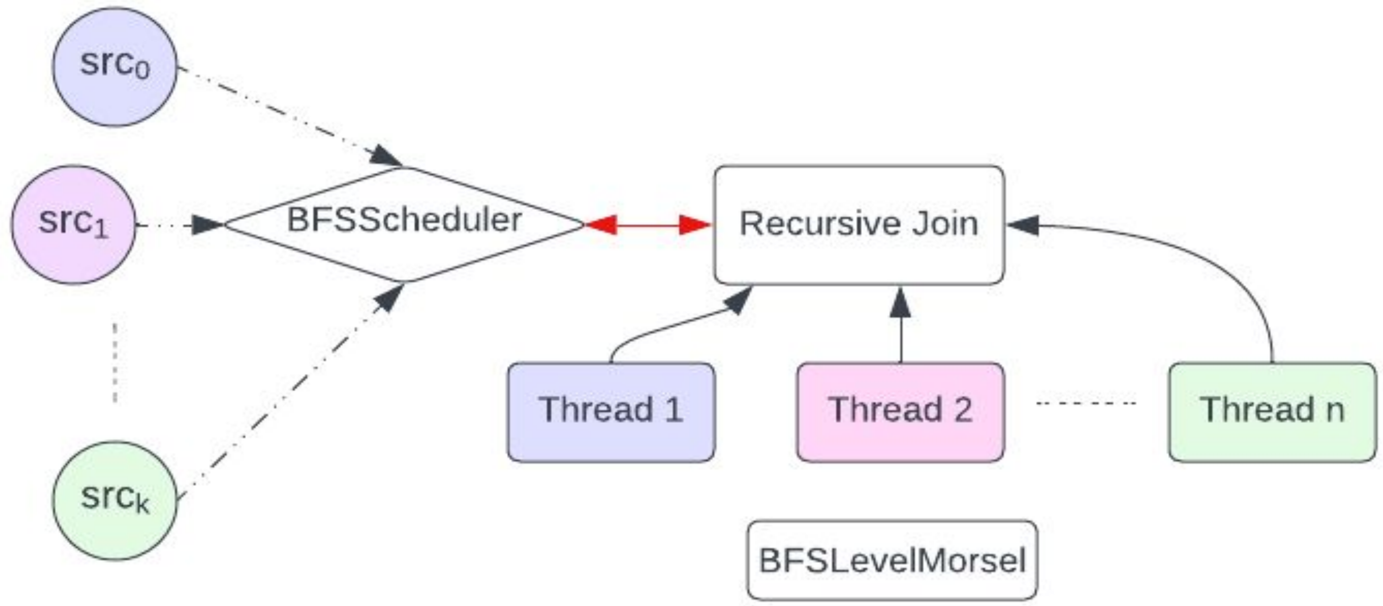
nTkS scheduler



Recursive Join Physical Operator

- *BFSScheduler*: Operators own scheduler that distributes work to the threads.

(1) BFS Scheduler launches a new BFS recursive join from a source if total (***active BFSMorsel < k***)

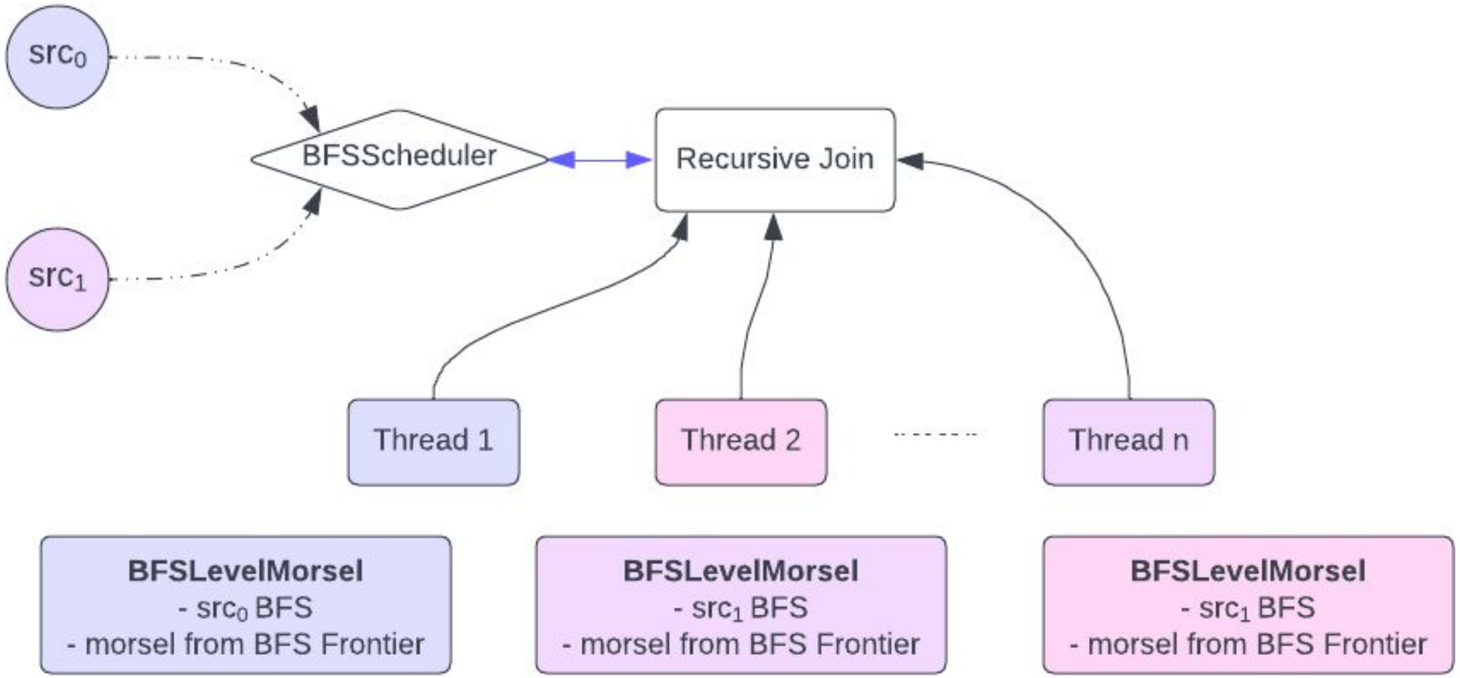


Recursive Join Physical Operator

- *BFSScheduler*: Operators own scheduler that distributes work to the threads.

(1) BFS Scheduler launches a new BFS recursive join from a source if total (active BFS < k)

(2) If not, scheduler iterates over all active BFSMorsel to find BFS with most work and allot subset of the join as a BFSLevelMorsel.



Returning Path (Shortest / All Shortest)

- maintain a global ***visited array***

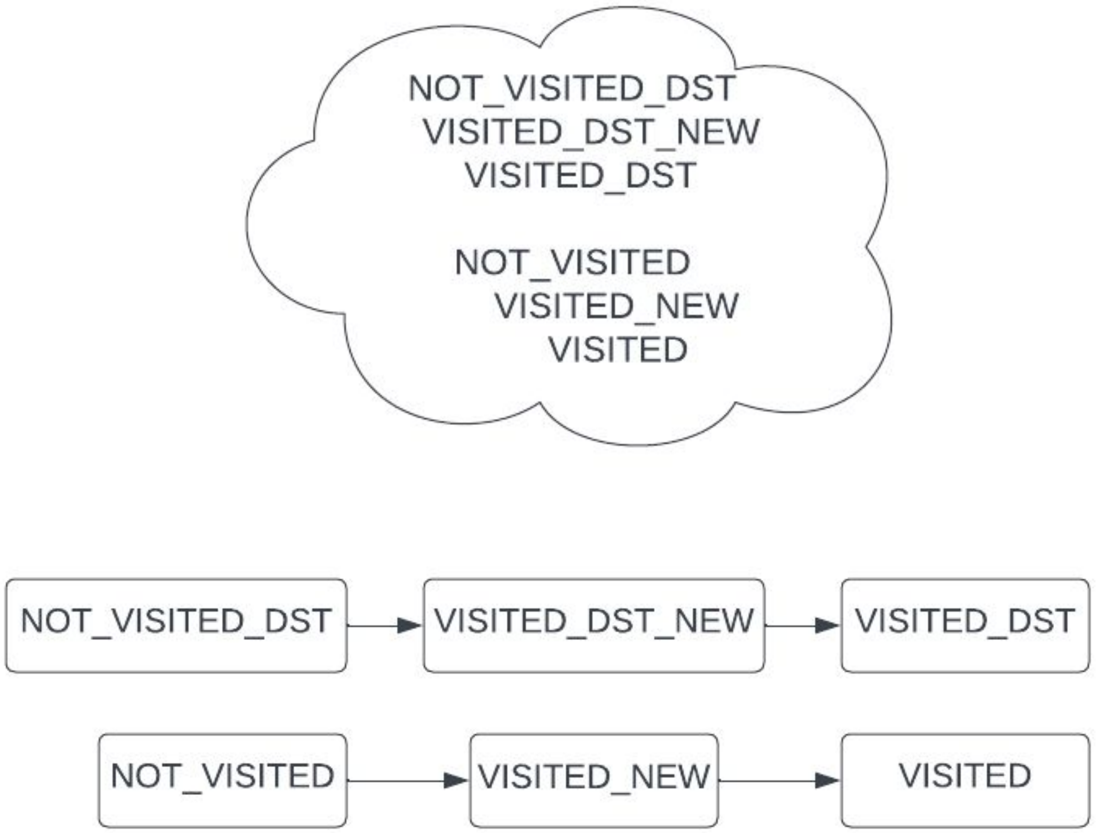
- update node states as they are encountered

- use lightweight ***lock-free*** synchronization

- additionally maintain ***multiplicity*** (all shortest path)

- use ***atomic CAS*** operations to update states and track {source node, edge} of nodes

- use ***atomic fetch and add (faa)*** operations to update multiplicity (for path length)



Returning Path (Variable Length)

- maintain a global ***visited array***

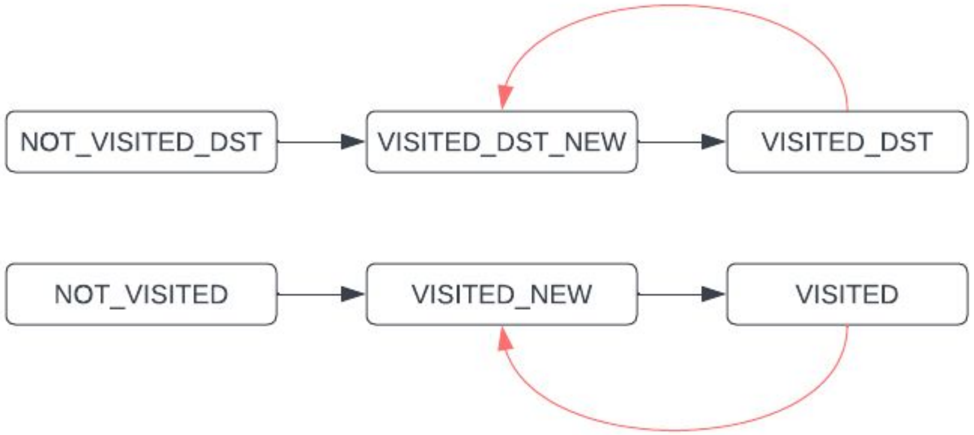
- update node states as they are encountered

- use lightweight ***lock-free*** synchronization

- additionally maintain ***multiplicity*** at ***different levels***

- use ***atomic CAS*** operations to update states and track {source node, edge} of nodes at ***different levels***

- use ***atomic fetch and add (faa)*** operations to update multiplicity (for path length)



Results

Microbenchmark: (LDBC-100)

MATCH (a:Person)-[r:knows* **SHORTEST** 1..30]->(b:Person) WHERE a.ID = 94 return b.ID, length(r);
Total tuples: *407,396*

Kùzu (Baseline MDP - 32 threads)	Kùzu (nTkS - 32 threads)
728.6 ms	61 ms *(12x faster)*

Microbenchmark: (LiveJournal)

MATCH (a:lj_node)-[r:lj_rel* **SHORTEST** 1..30]->(b:lj_node) WHERE a.id < 1000 return b.ID, length(r);
Total tuples: *4,237,533,225*

Kùzu (Baseline MDP - 32 threads)	Kùzu (nTkS - 32 threads)
158 s	105 s *(1.5x faster)*

Results

<u>Microbenchmark:</u> (graph500-23)

MATCH (a:nodes)-[r:rels* **ALL SHORTEST** 1..30]->(b:nodes) WHERE a.id = 307 RETURN r;
Total tuples: *105,576,064*

Kùzu (Baseline MDP - 32 threads)	Kùzu (nTkS - 32 threads)
511s	35s *(14.6x faster)*

<u>Microbenchmark:</u> (graph500-24)

MATCH (a:nodes)-[r:rels* **1..4**]->(b:nodes) WHERE a.id = 0 RETURN r;
Total tuples: *126,749,073*

Kùzu (Baseline MDP - 32 threads)	Kùzu (nTkS - 32 threads)
634s	37.6s *(16.9x faster)*

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Future Work

- Integrating other techniques [Multi source BFS (MS-BFS), Bidirectional BFS]
- Storing paths in a compressed manner for vectorized execution ?
- Weighted Shortest Path (Dijkstra, Bellman Ford, ...) ?

Thank You