Data Chunk Compaction in Vectorized Execution

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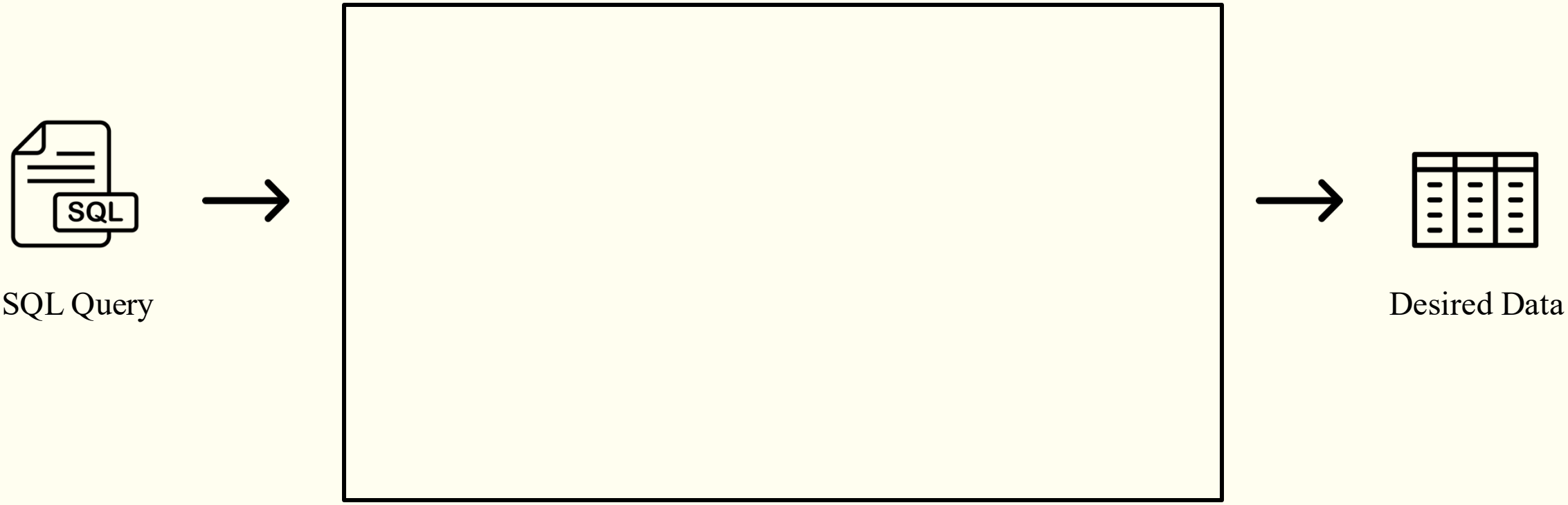
Tsinghua University

Database System



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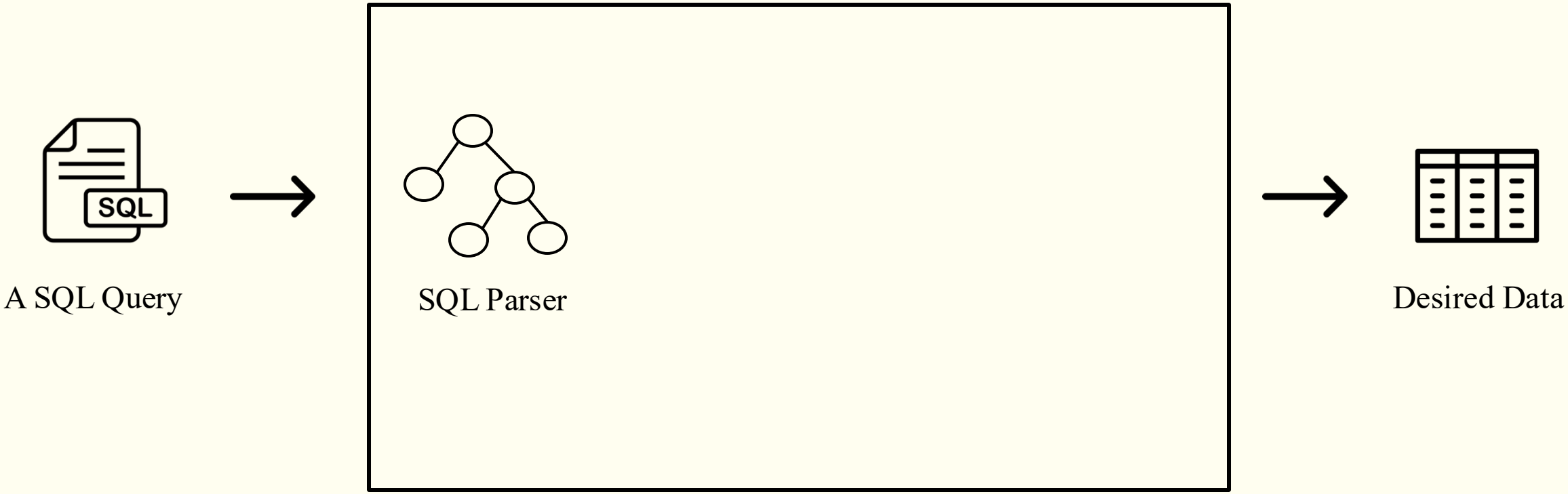

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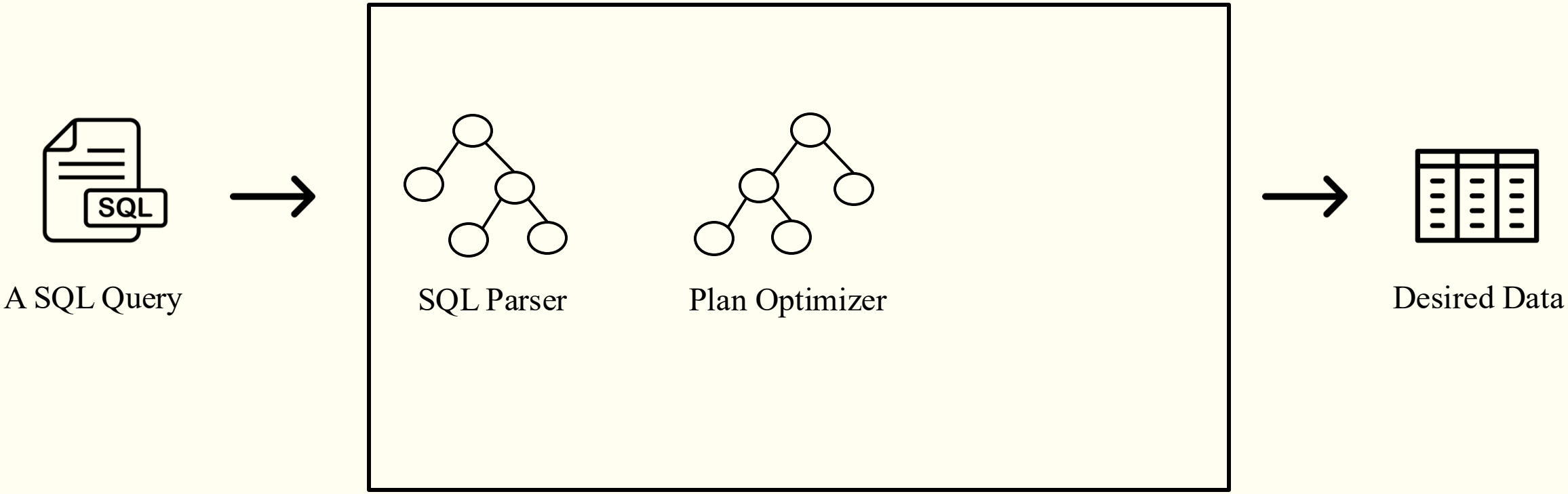

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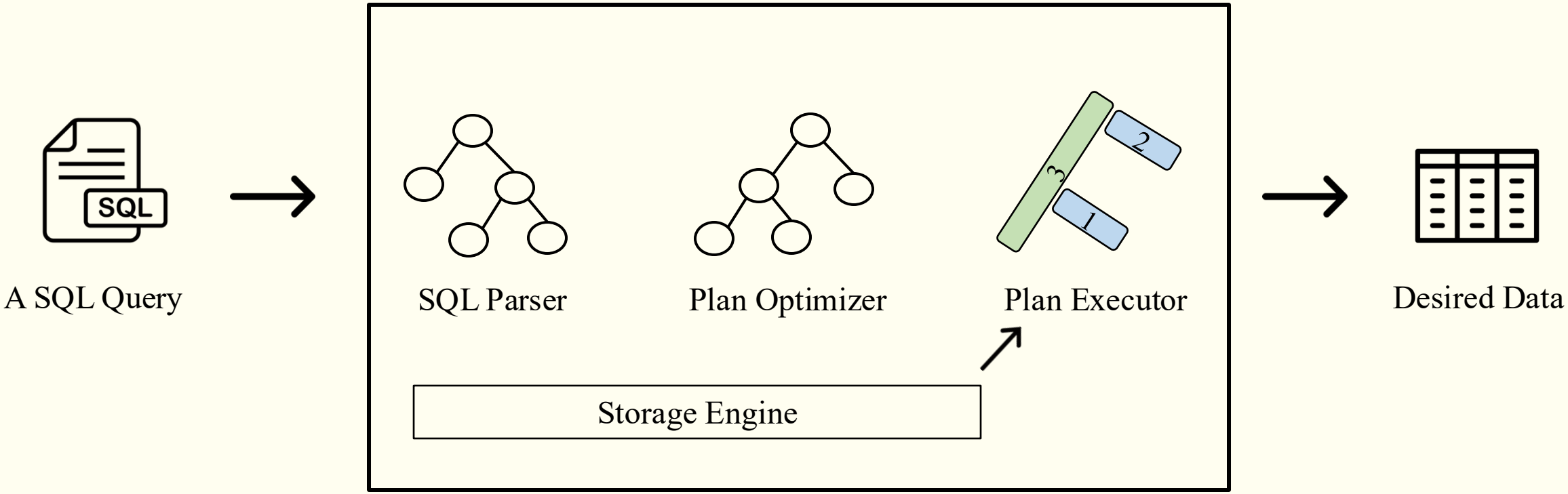

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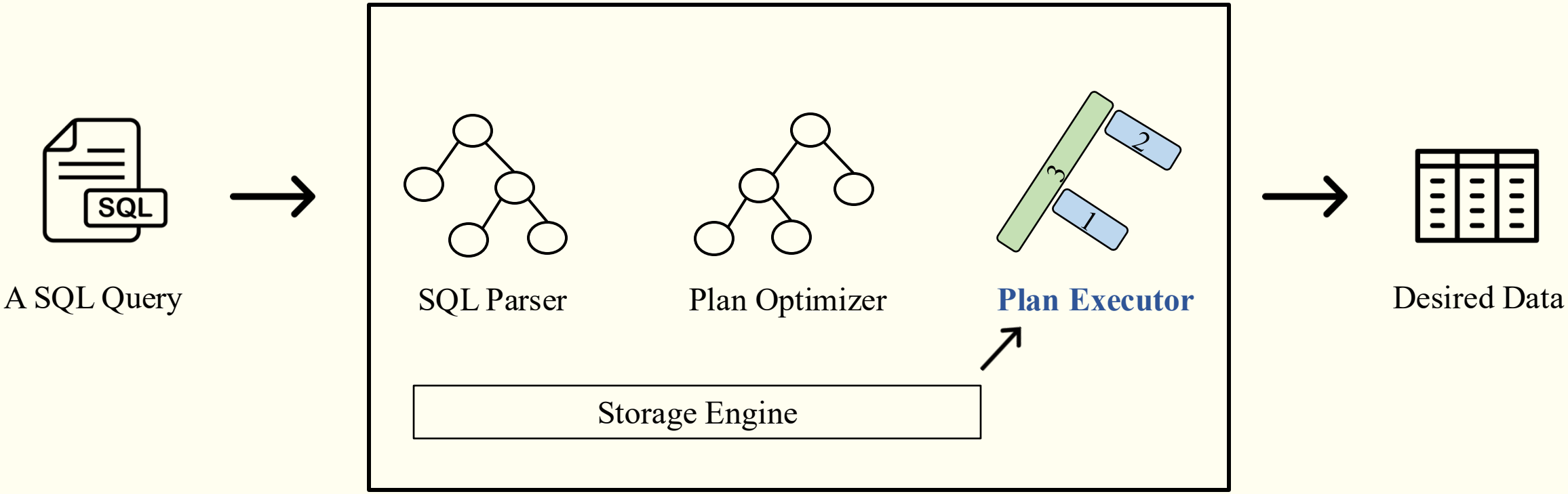

We Focus on Improving the Query Plan Executor

Iterator Execution Model

```
SELECT  id,
        (target - 30) * 50 AS bonus
FROM    employee
WHERE   target > 30
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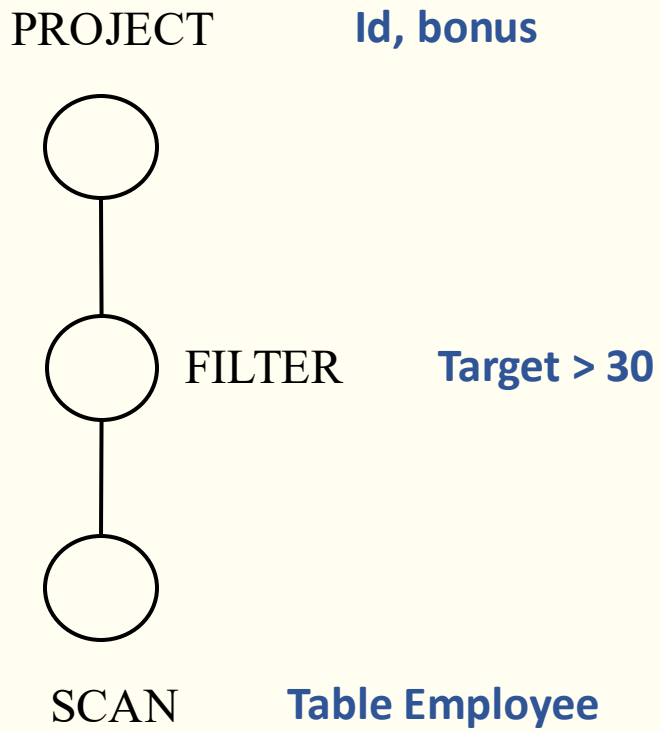

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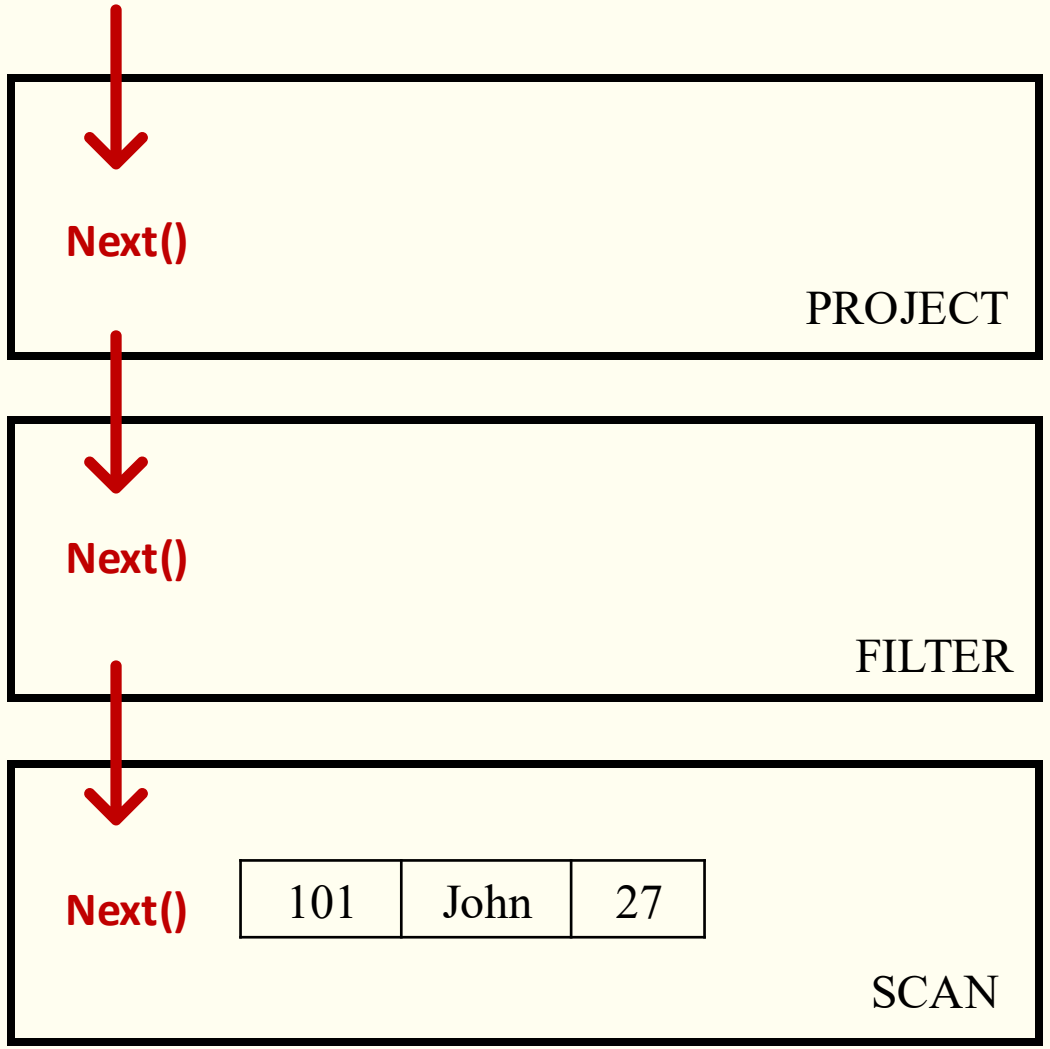

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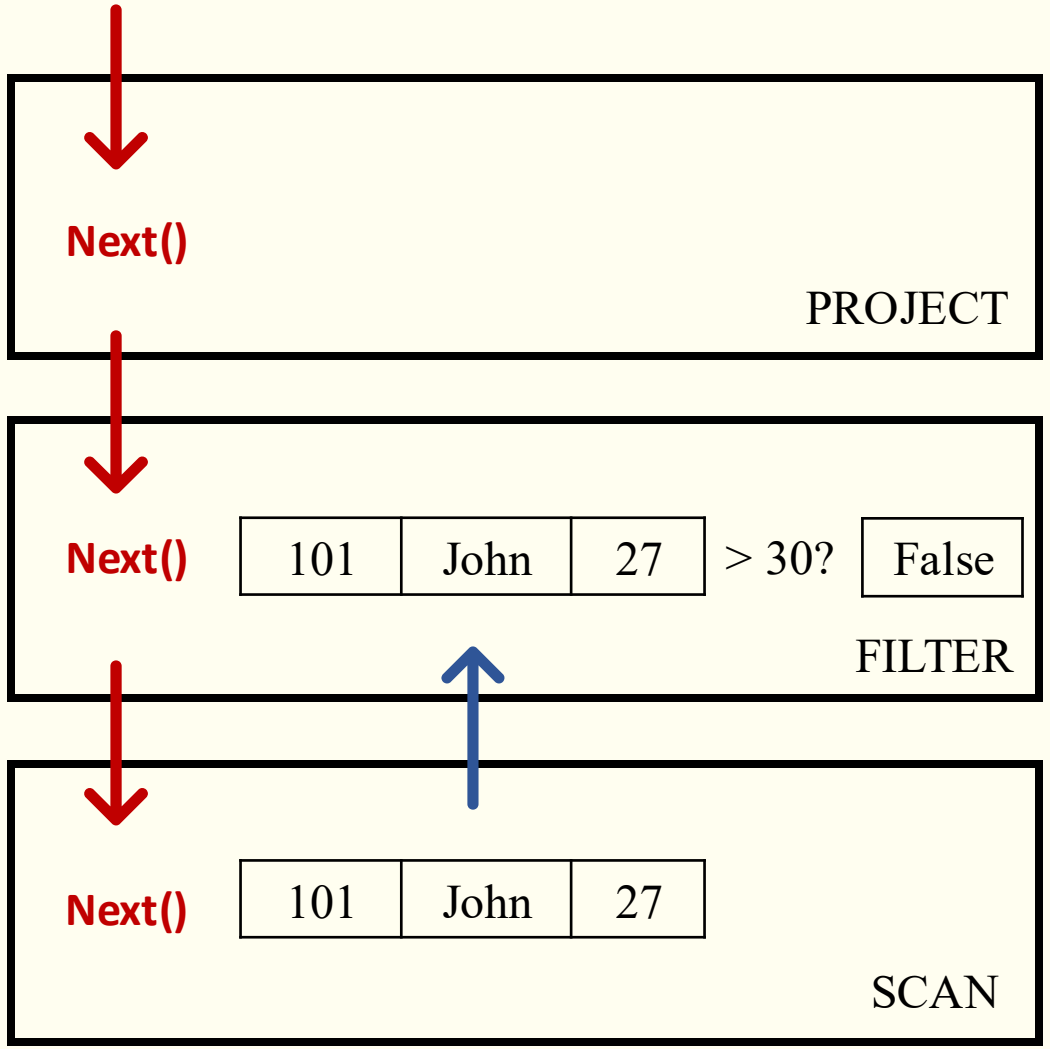

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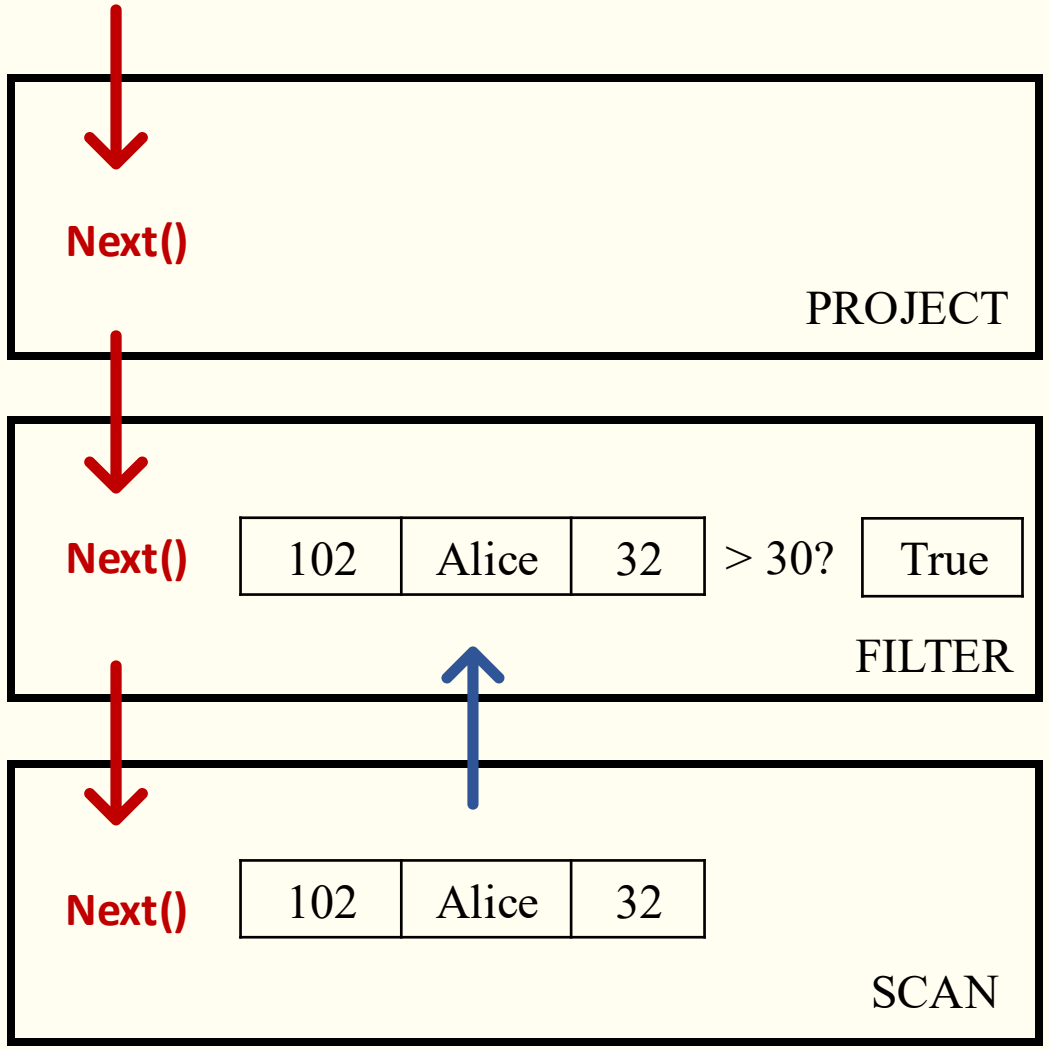

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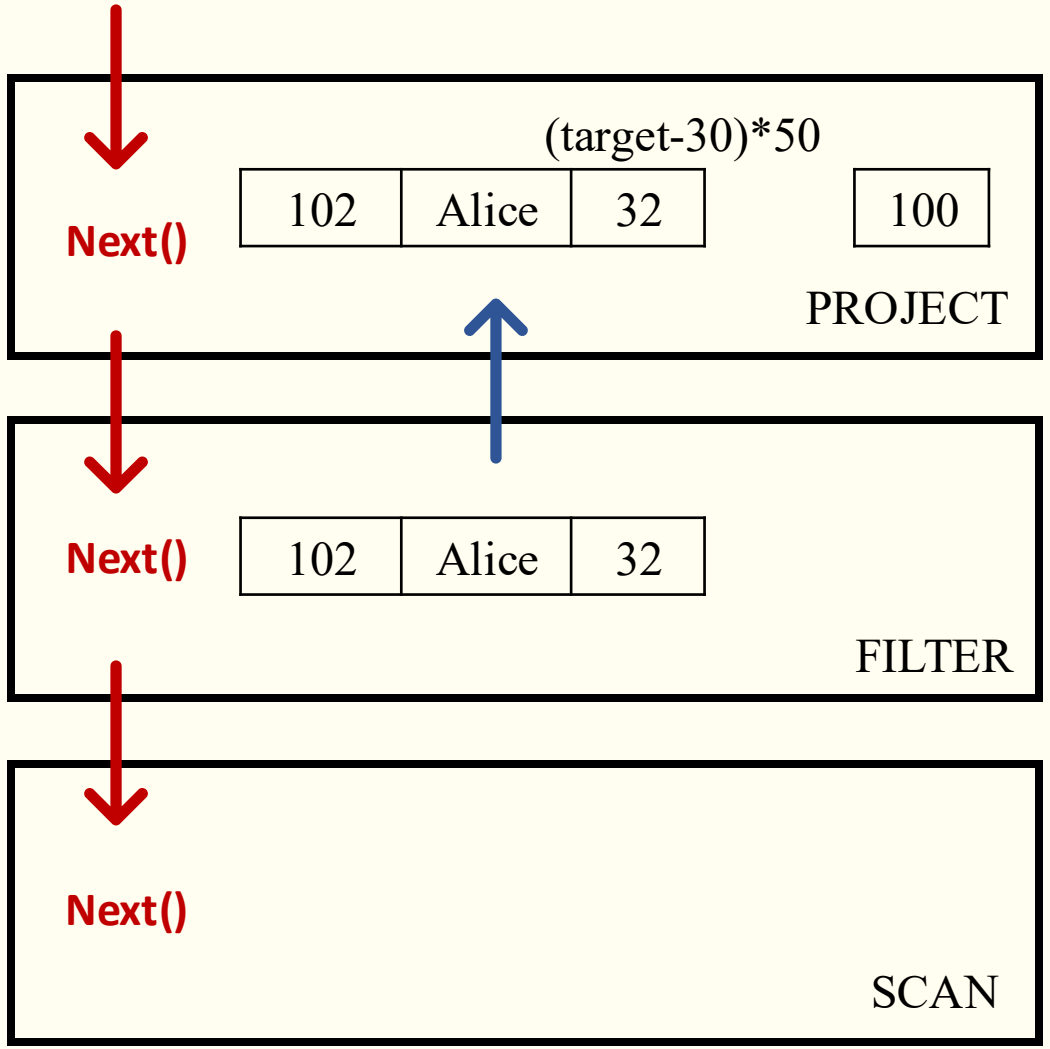

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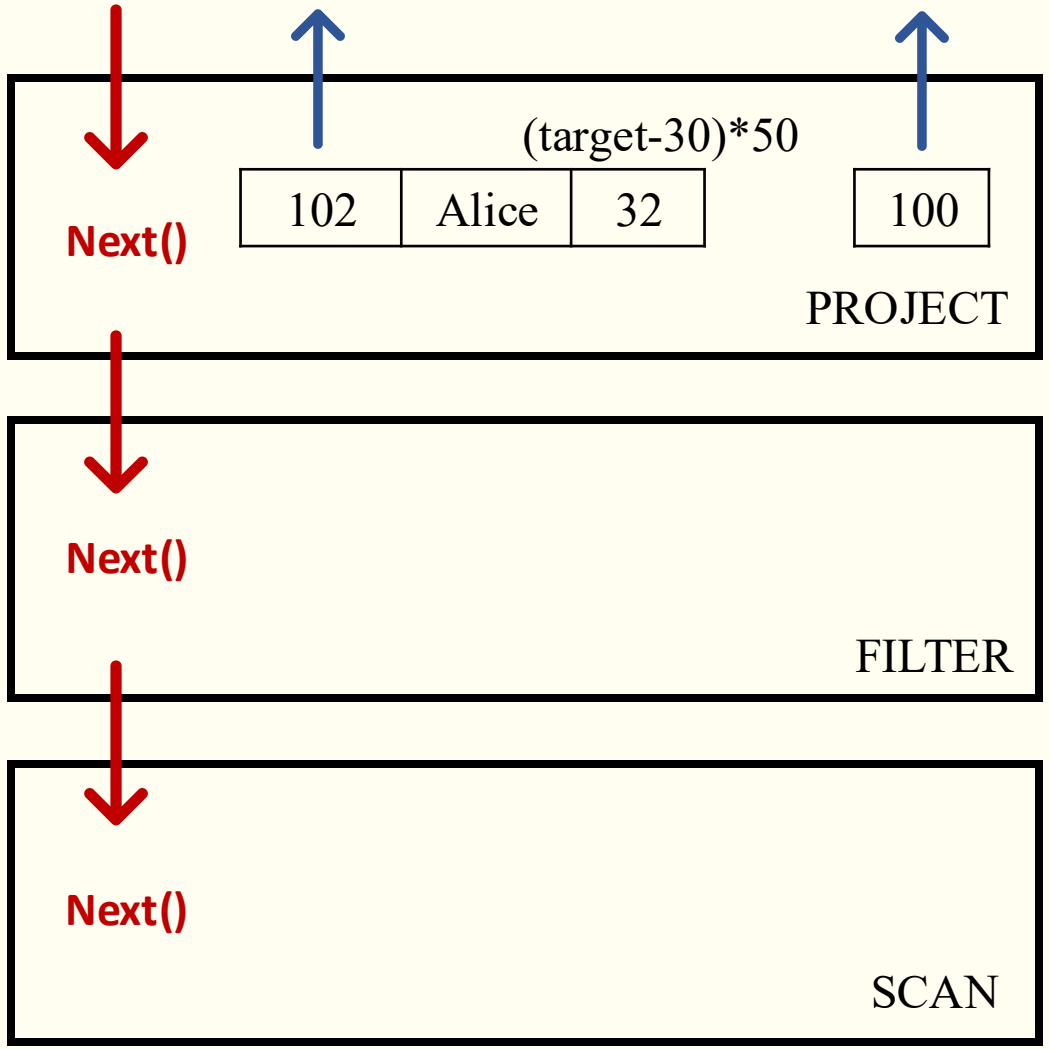
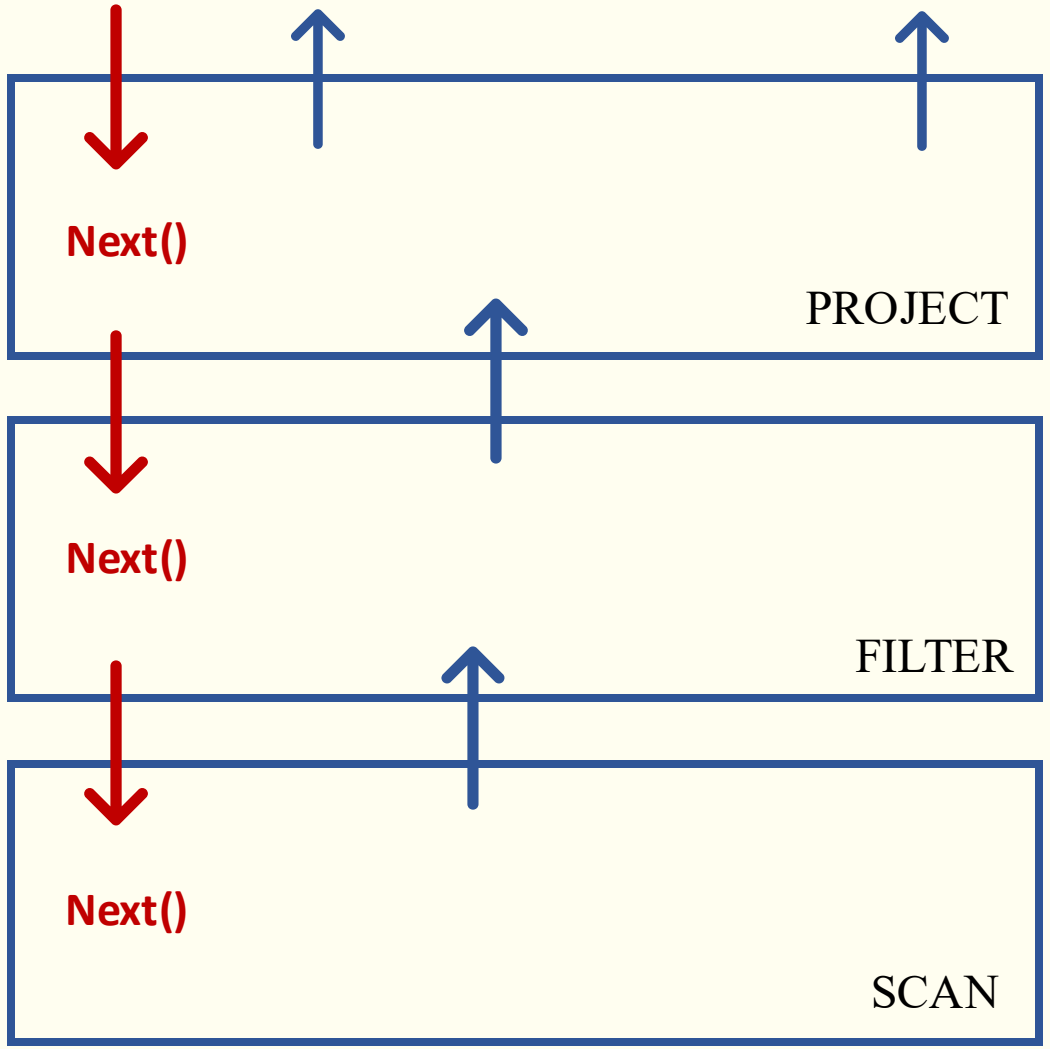


Iterator Execution Model

- Operators: SCAN, FILTER, PROJECT
- Iterator Interface:
  - **Open()**
  - **Next()** # "Next Tuple Please"
  - **Close()**

Three Function Calls for Processing a Single Tuple!



Buying Beer for a Party. The Silly Way.

An Intuitive Example From Peter Boncz

- Go to a store
- Take one beer bottle
- Pay at the register
- Return home
- Put the bottle in the fridge
- Repeat… 100 times!

= “tuple”

Buying Beer for a Party. A Better Way.

An Intuitive Example From Peter Boncz

- Go to a store
- Take two crates of beer (2x24!)
- Pay at the register
- Return home
- Put crates in the fridge
- Repeat 48x less!

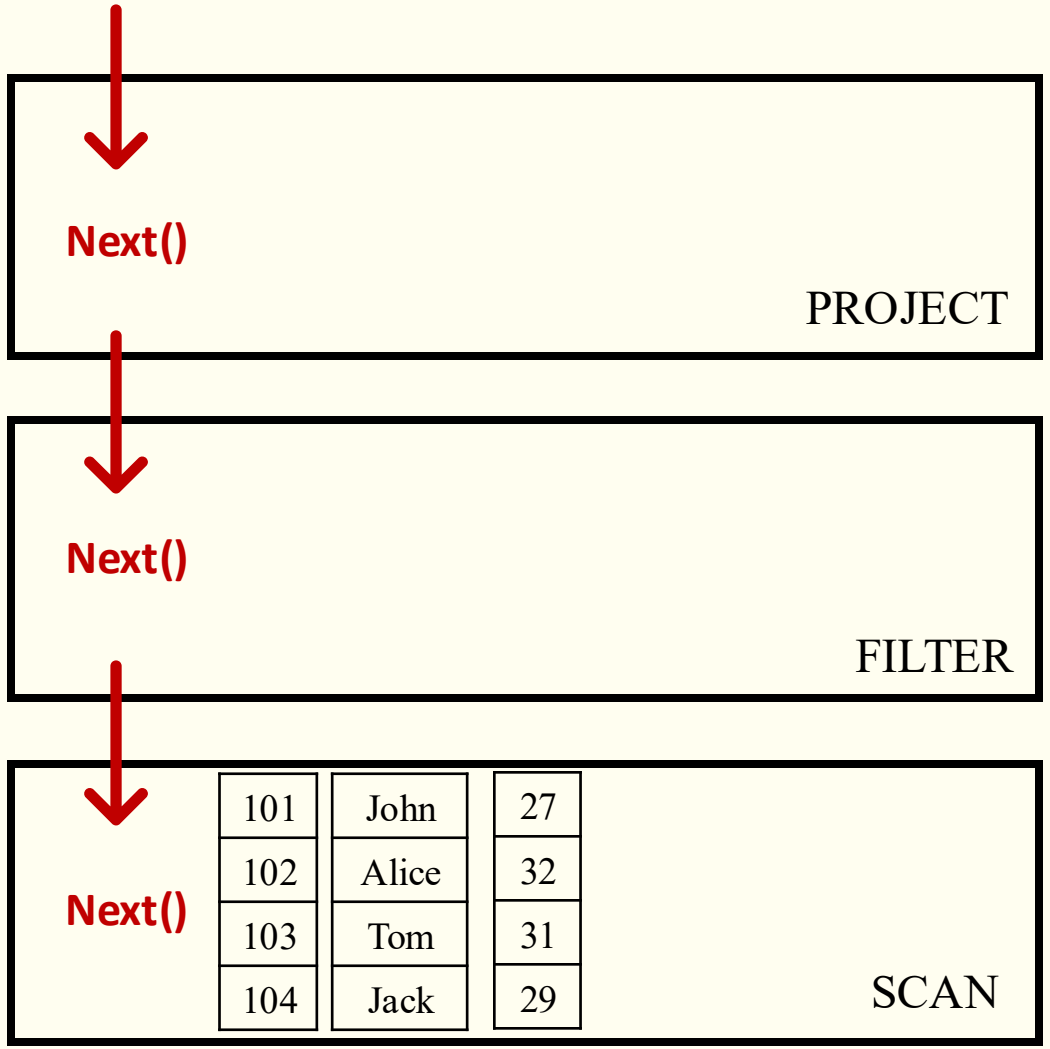
= “vector”

48x less Function Calls for Processing a Single Tuple!

A Smart Way: Vectorized Execution

```
SELECT  id,
        (target - 30) * 50 AS bonus
FROM    employee
WHERE   target > 30
```

Process a Chunk of Tuples at a Time, with Columnar Store



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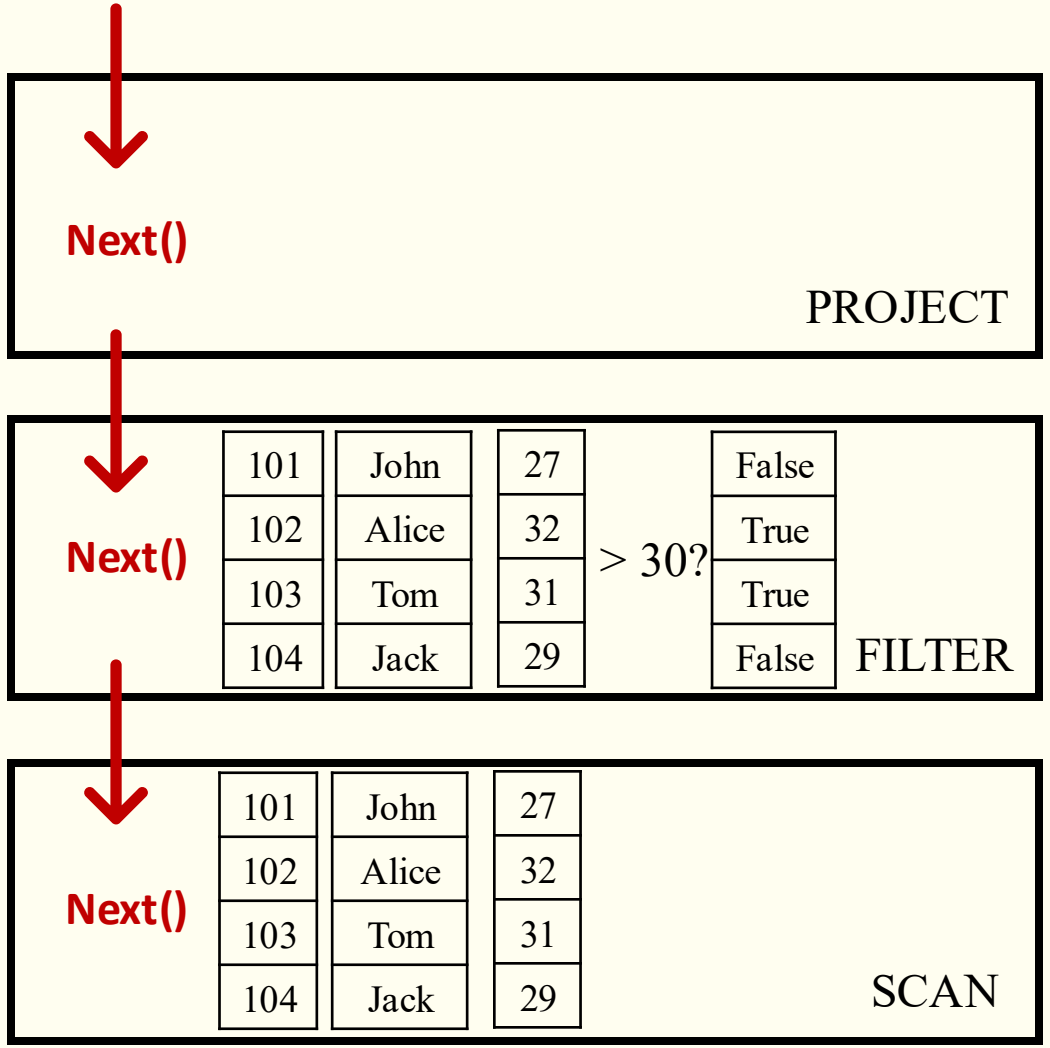

A Smart Way: Vectorized Execution

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FROM    employee
WHERE   target > 30
```
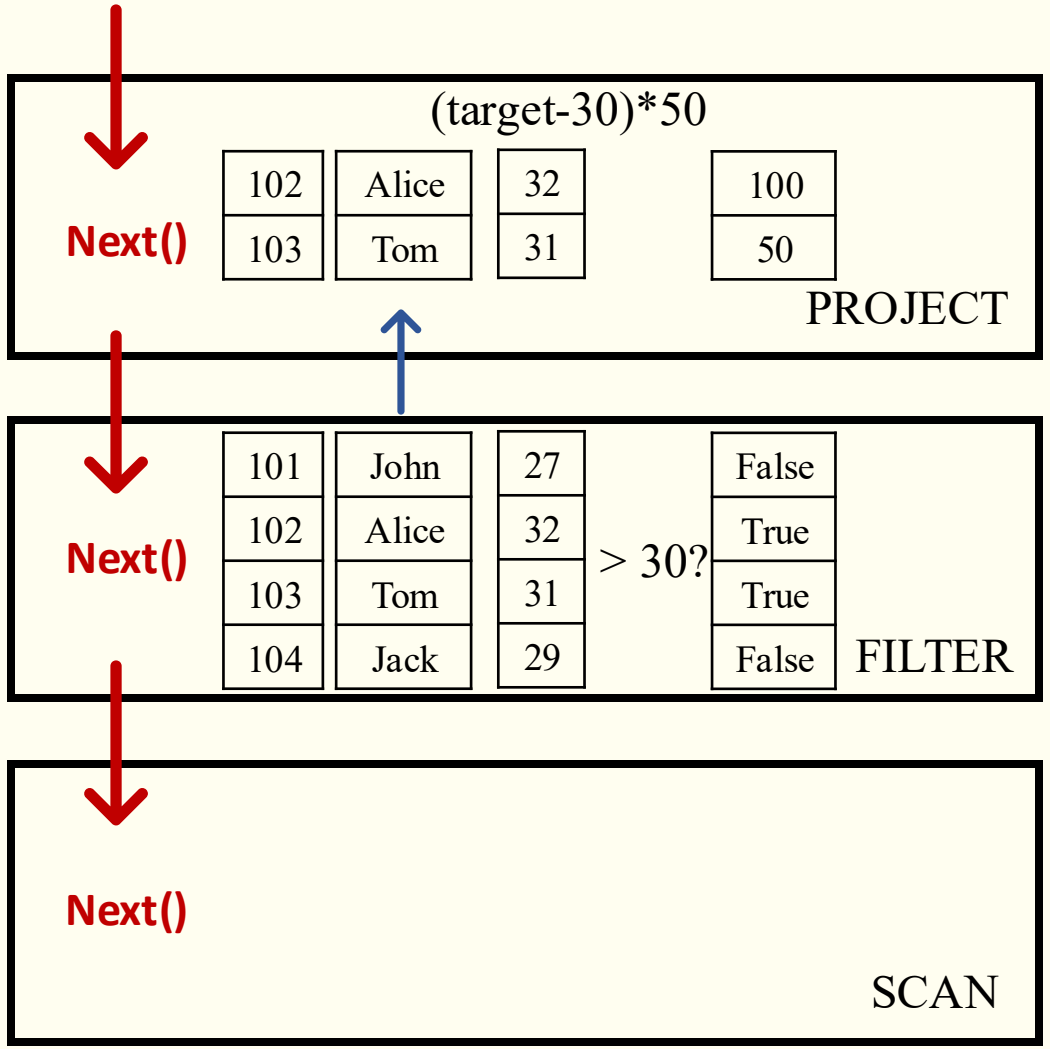
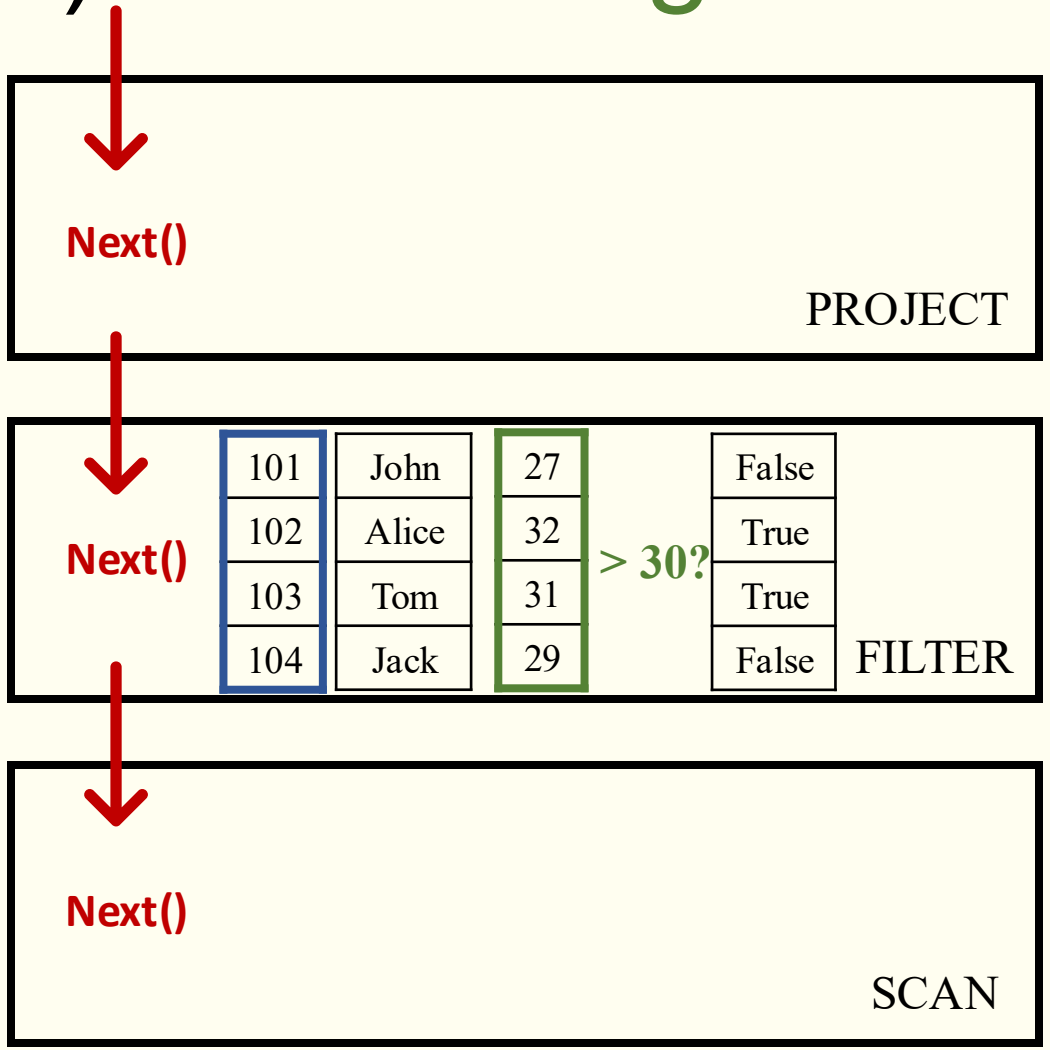

A Selection Vector/Bit Map is used to Mark Tuples



Vectorized (In-Cache) Processing

- Vector-at-a-time:
  - About 1000 tuples
- Processed in a tight loop:
  - >, +, *
- Cache-friendly:
  - A vector is sequentially accessed



Part 1

Data Chunk Compaction in Vectorized Execution

Small Chunk Problem

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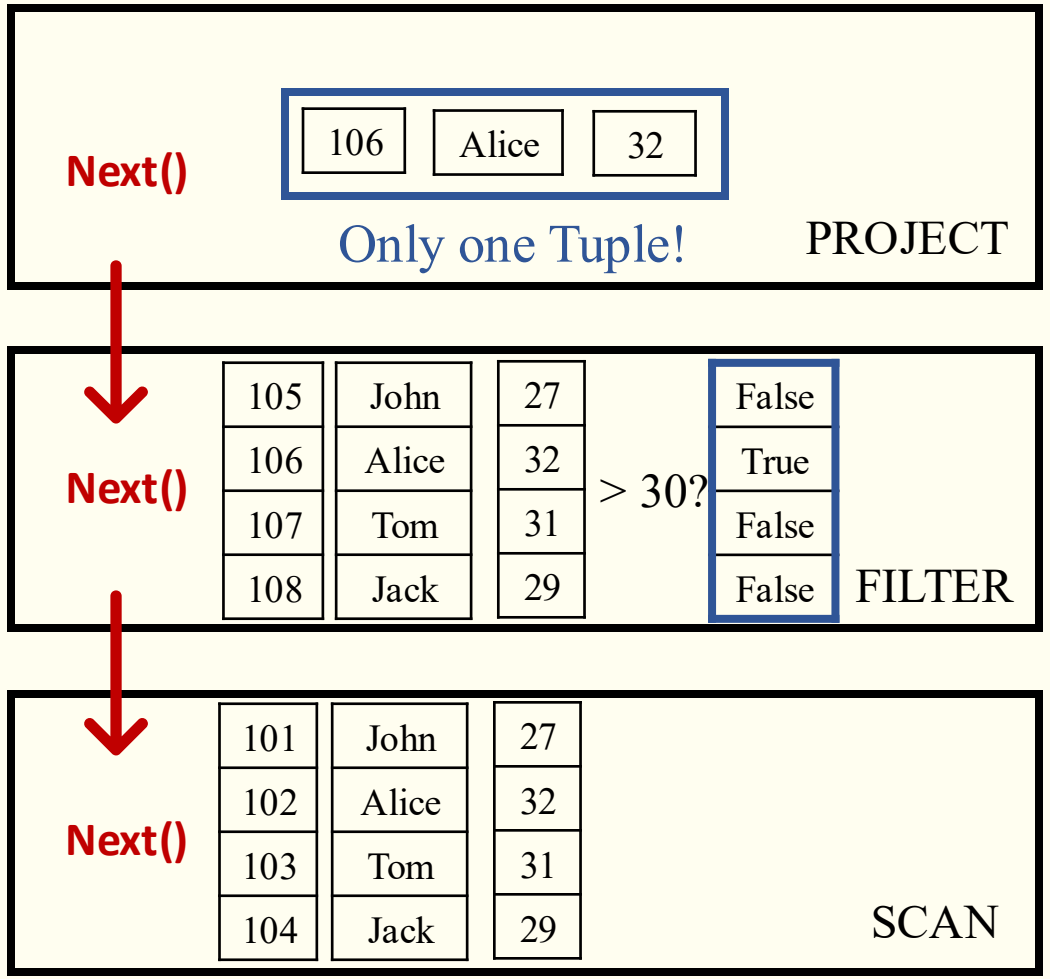
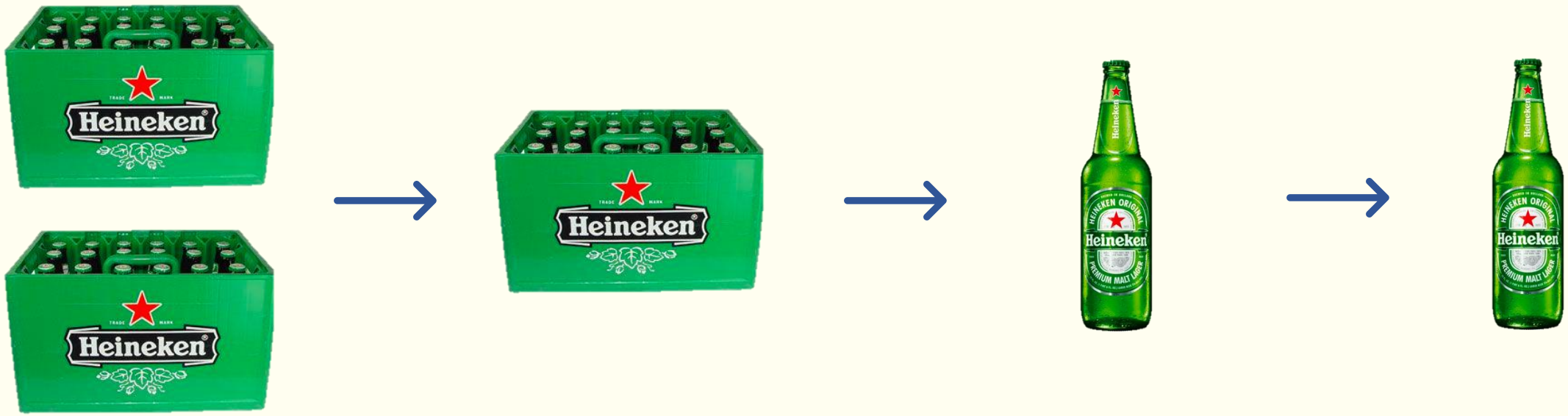
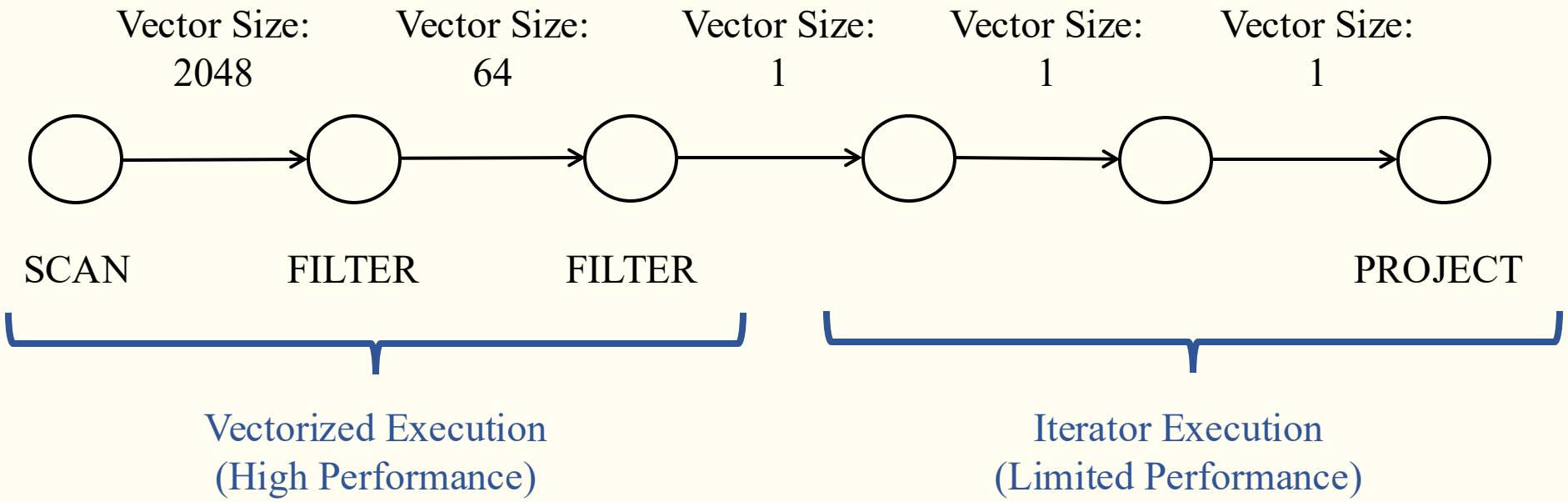


Buying Beer for a Party. An Accident.



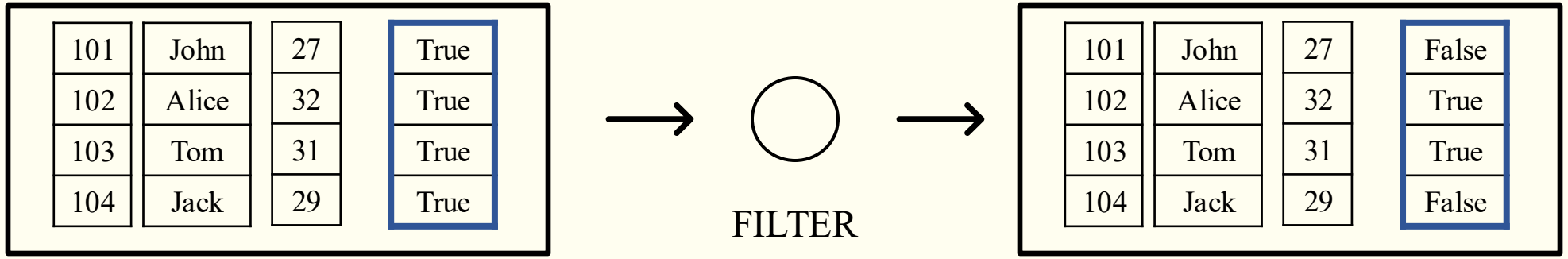
We take two crates from the shop
but only put one bottle in the fridge!

Small Chunk Problem



Chunk Size (and Data Volume) is Greatly Reduced During Execution

Chunk-reducing Operators: Filter



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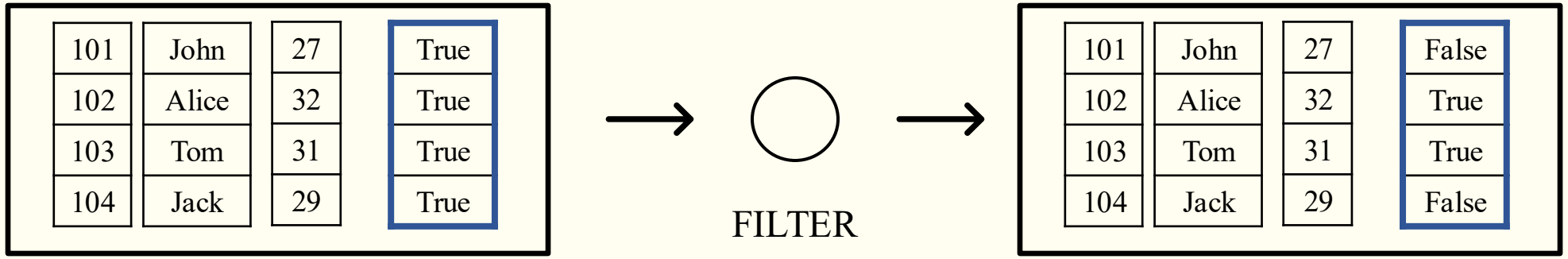
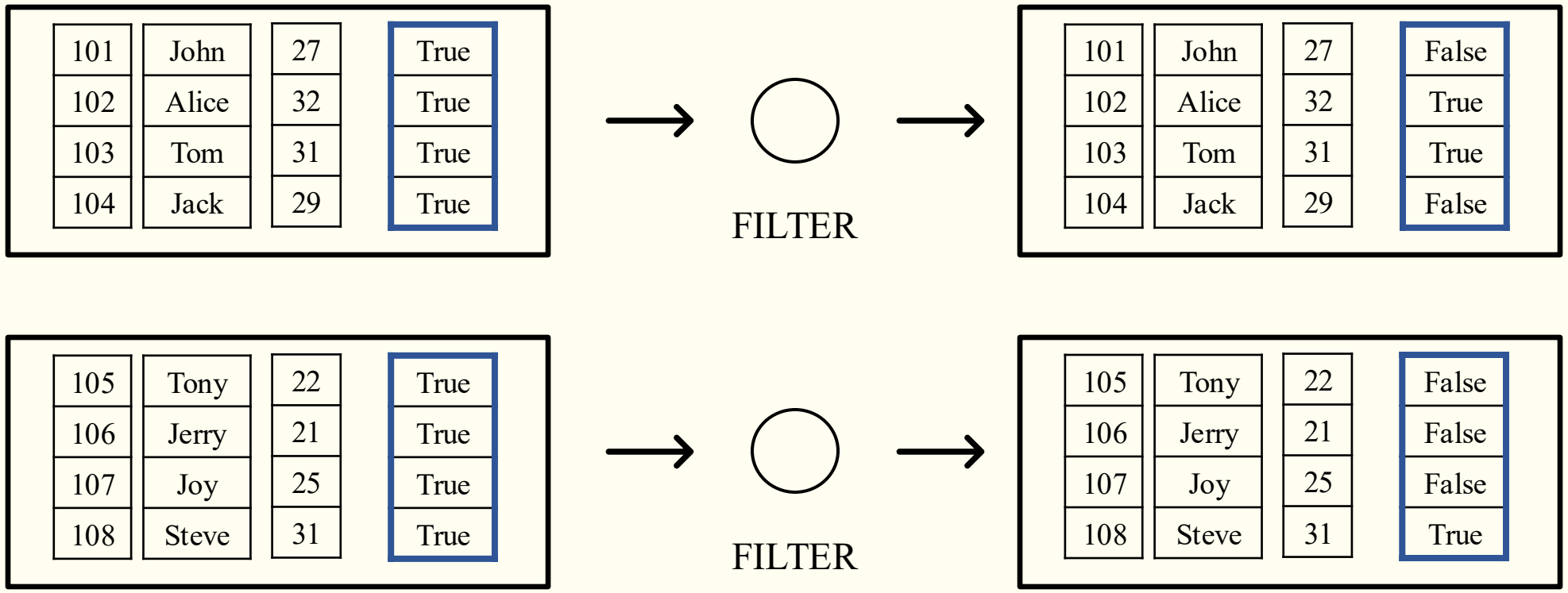


- Data Chunk Structure: Some Data Vectors + One Selection Vector
- Zero-copy Benefit

Chunk-reducing Operators: Filter



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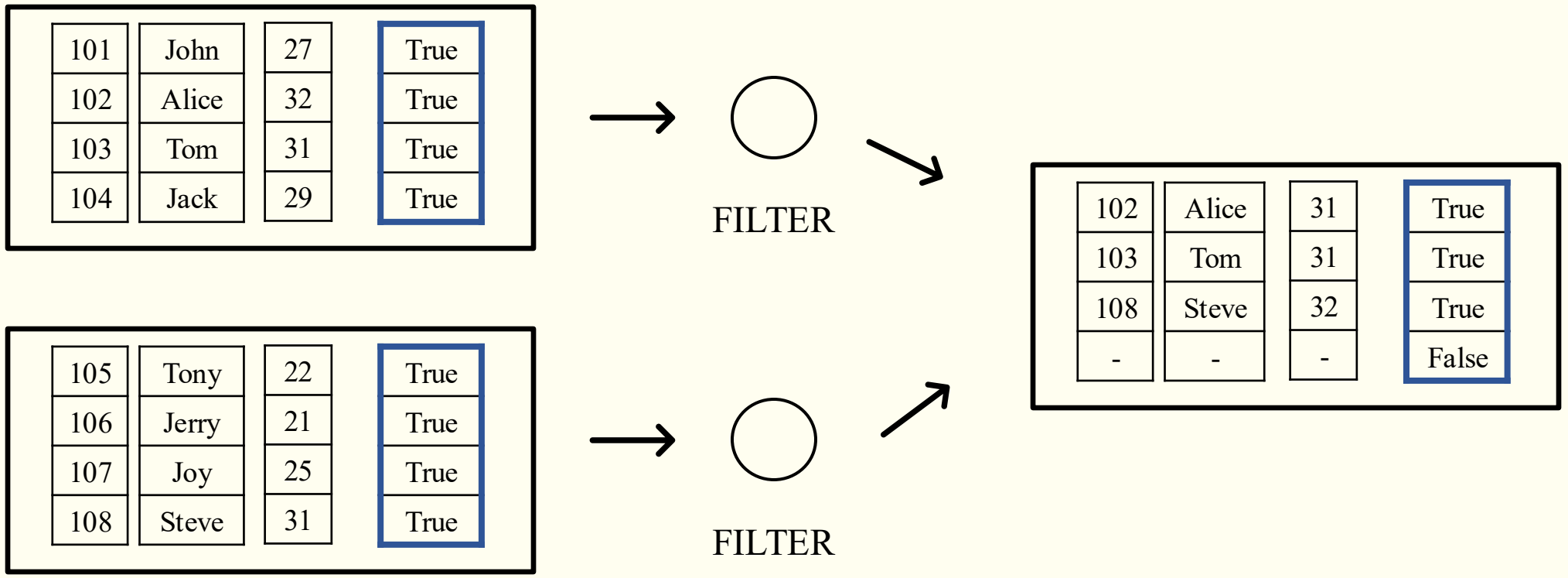
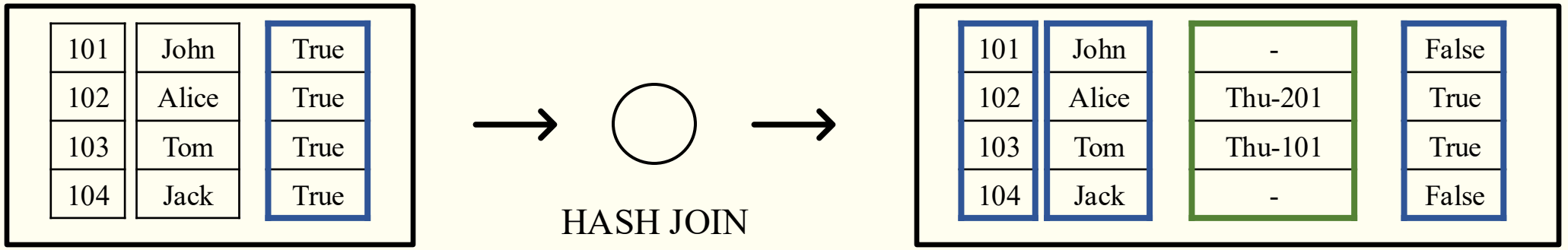


If we compact them, we have additional memory copies; otherwise, the vectorized execution suffers.

Chunk-reducing Operators: Hash Join

SELECT id, name, course_id,

FROM students, courses



Chunk-reducing Operators: Hash Join

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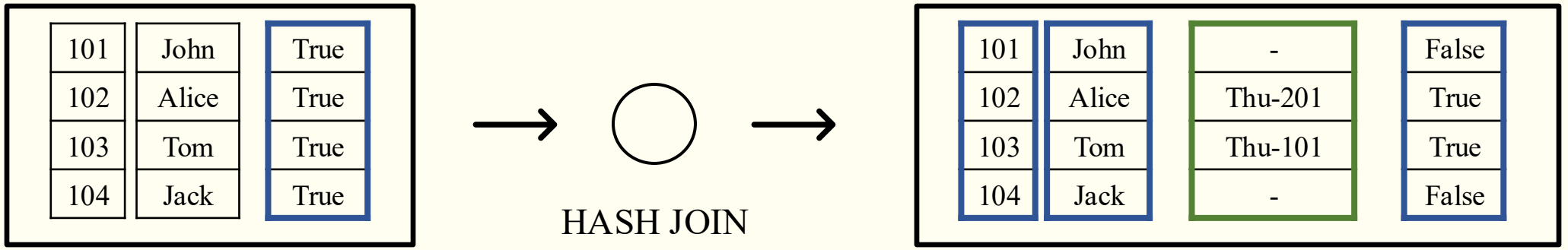
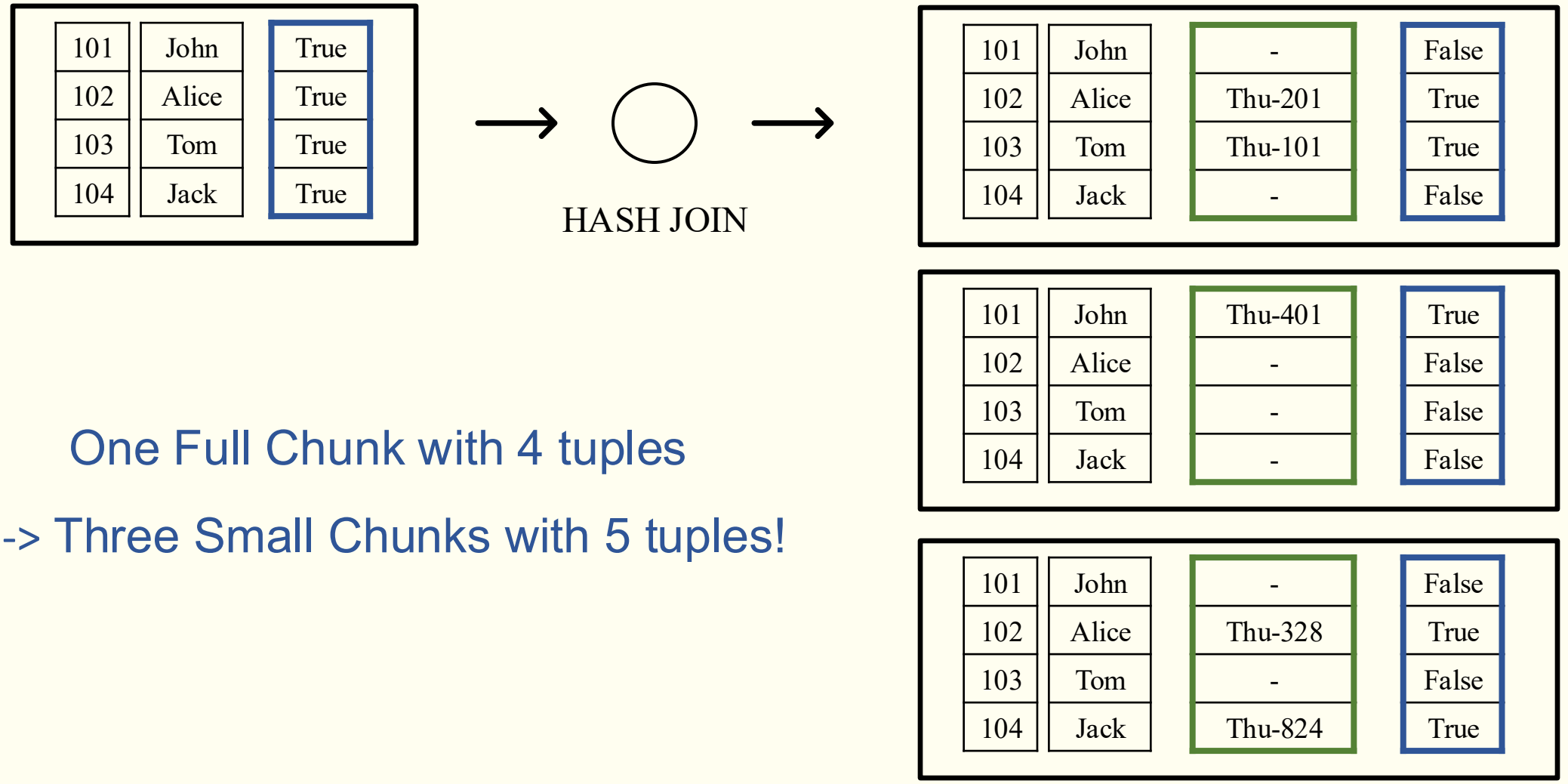


- Zero-copy Benefit: Reuse the data in the column id and name.
- Copy the New Vector Values into the Result Chunk.

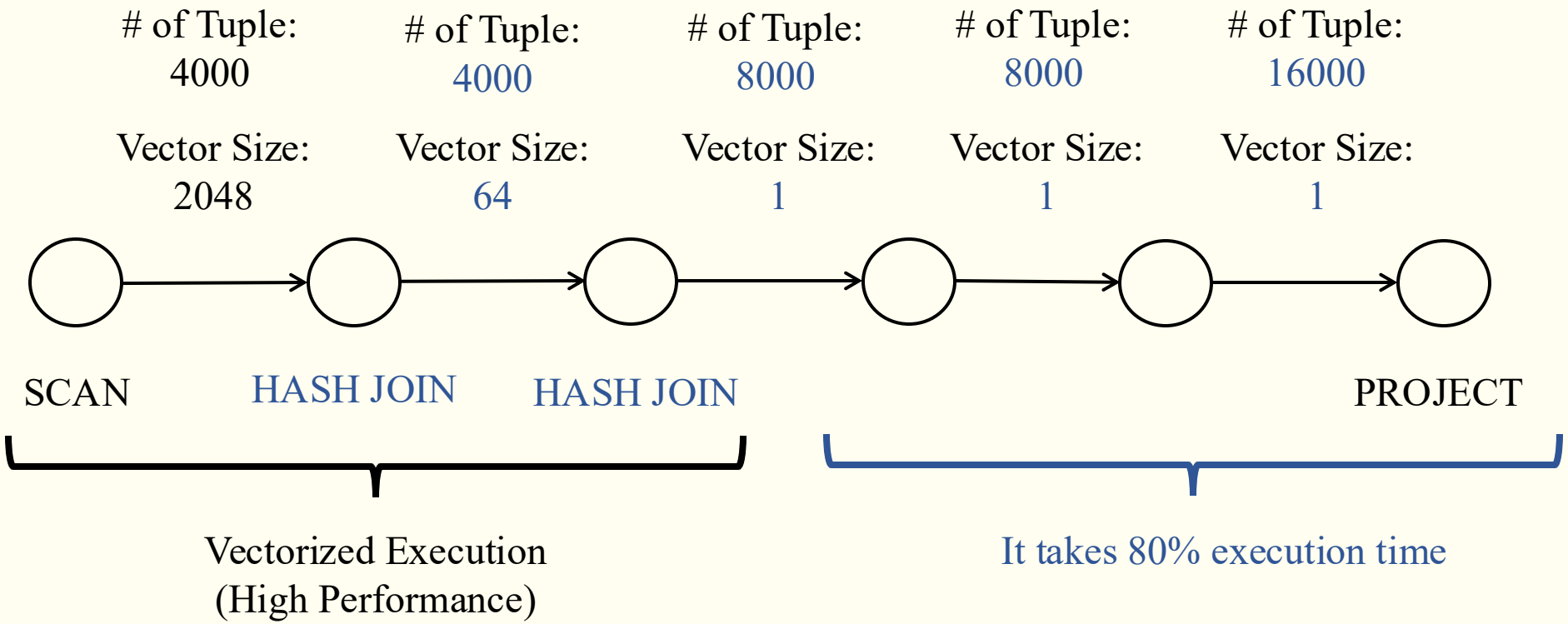
Chunk-reducing Operators: Hash Join



One Full Chunk with 4 tuples

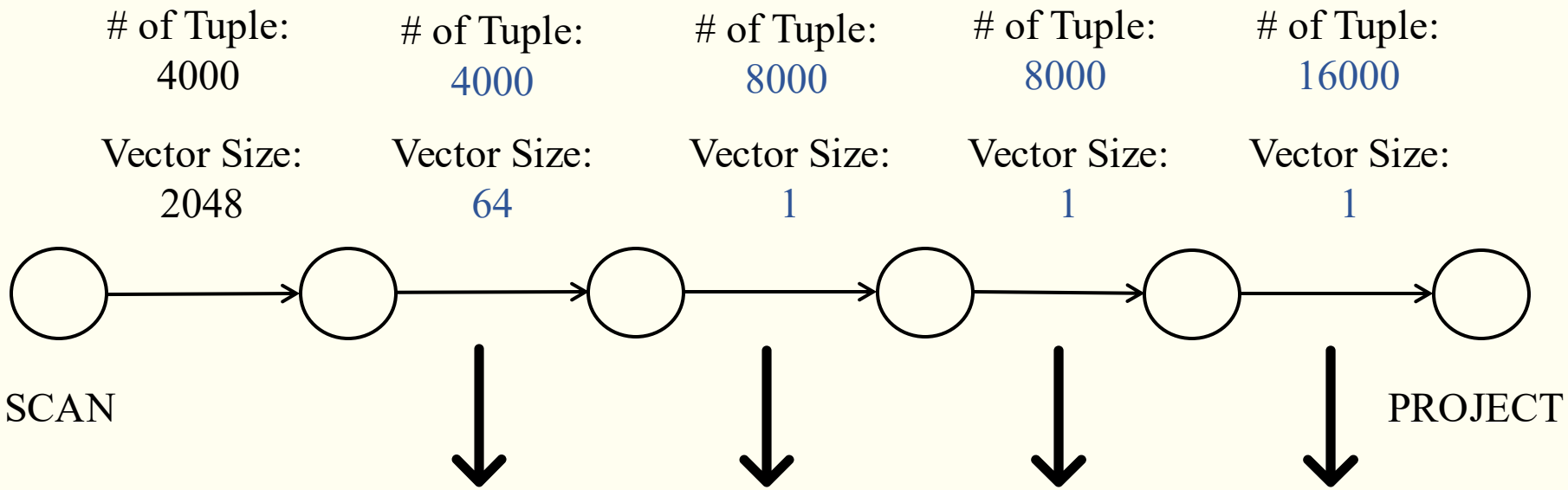
-> Three Small Chunks with 5 tuples!

Small Chunk Problem



Chunk Size is Greatly Reduced During Execution, but Data Volume is not Necessarily Reduced.

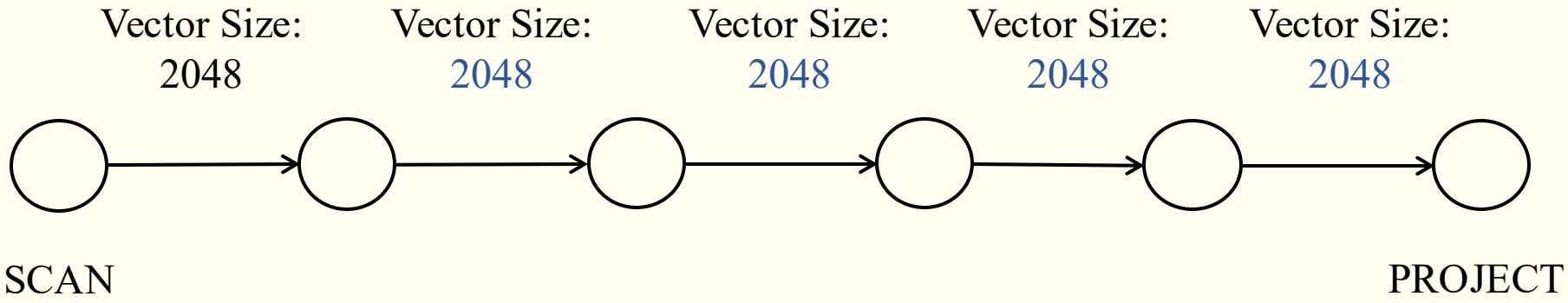
Small Chunk Problem



Given a Set of Data Chunks, Determine How to Compact Them to Minimize the Total Execution Time (= compaction time + compute time).

Compact as More as Possible

- **Full Compaction**: compacts all chunks containing less than 2048 tuples.

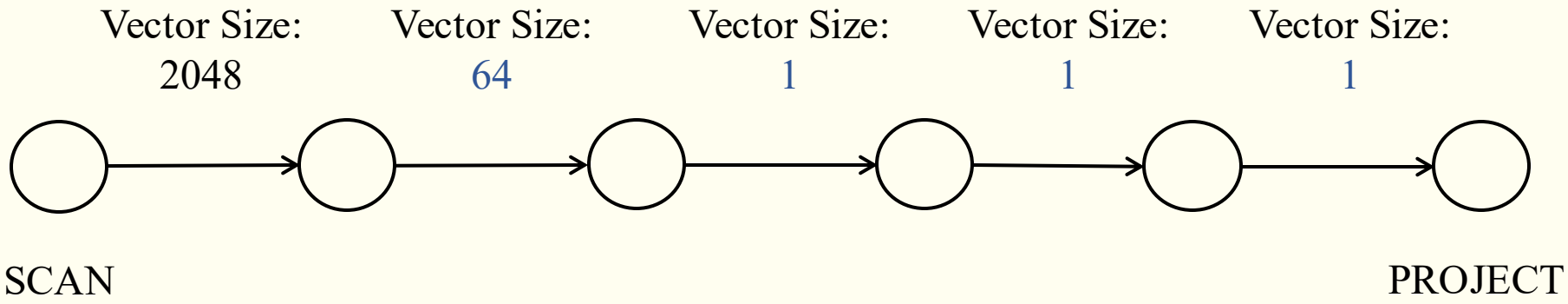


Too Many Memory Copies!

Consider the Case Where a Tuple is in the Length of 1 MB…

Compact as Less as Possible

- **No Compaction**: no chunks are compacted



Too Many Small Chunks!

Consider the Case Where a Tuple is in the Length of 10 Bytes…

Compact Small Chunks Only

- **Binary Compaction**: chunks smaller than a predefined threshold are compacted.
- A Trade-off Between Interpretation Overhead vs. Memory Copy
  - The smaller the chunk, the greater the benefit from such compaction.

Choosing a Predefined Threshold is Difficult

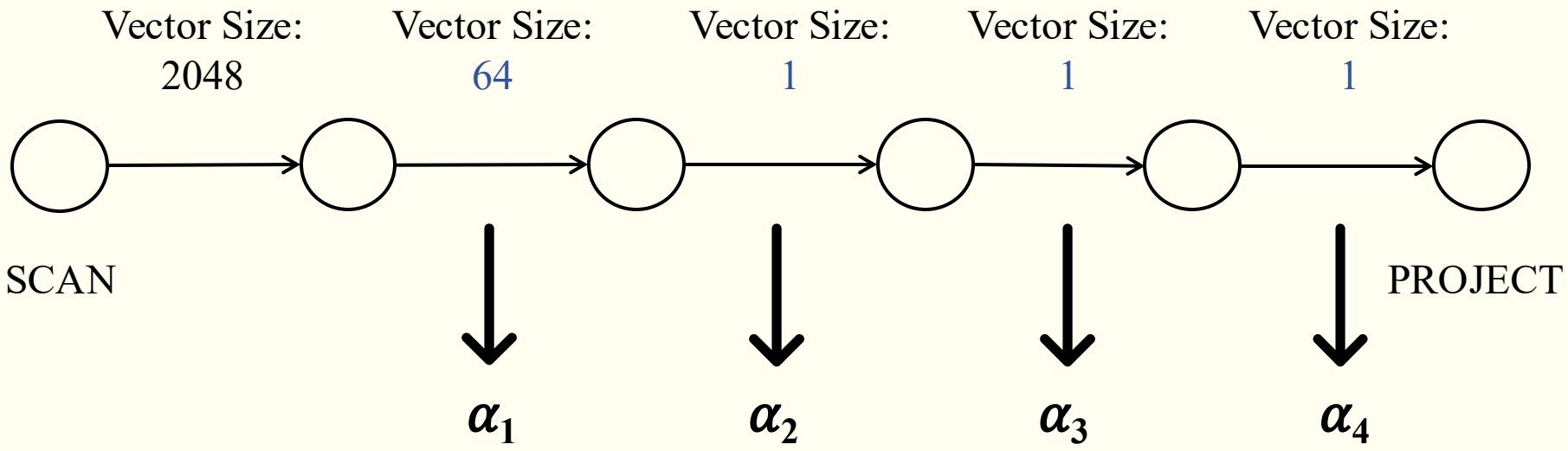
Because it involves Database Design and Workload Characteristics.

Our Solution 1: Learning Compaction

- **Learning Compaction**: chunks smaller than a Learned threshold are compacted.
- Morsel-driven Parallelism: data is divided into chunks, with each thread responsible for fetching and processing a chunk through the entire pipeline before moving on to the next.
  - Then, each chunk can serve as a sample for a learning algorithm
- Multi-armed Bandit Problem: select the optimal thresholds

Learning Compaction

- **Learning Compaction**: chunks smaller than a learned threshold are compacted.



- Multi-armed Bandit Problem: select each alpha from 0, 32, 64, 128, …, 2048

Learning Compaction

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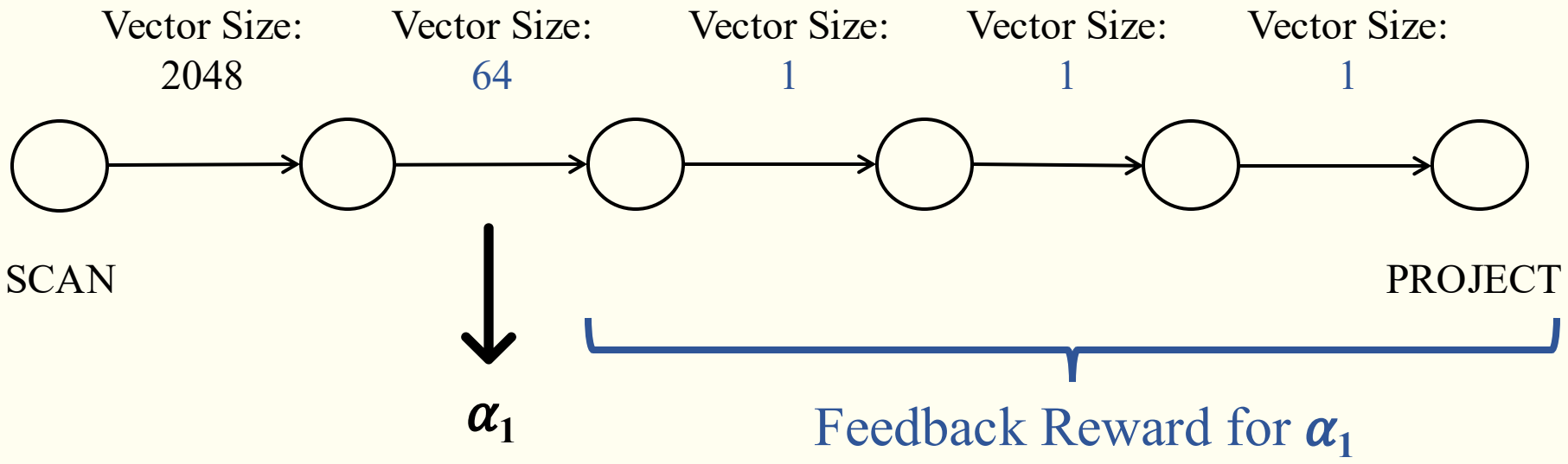

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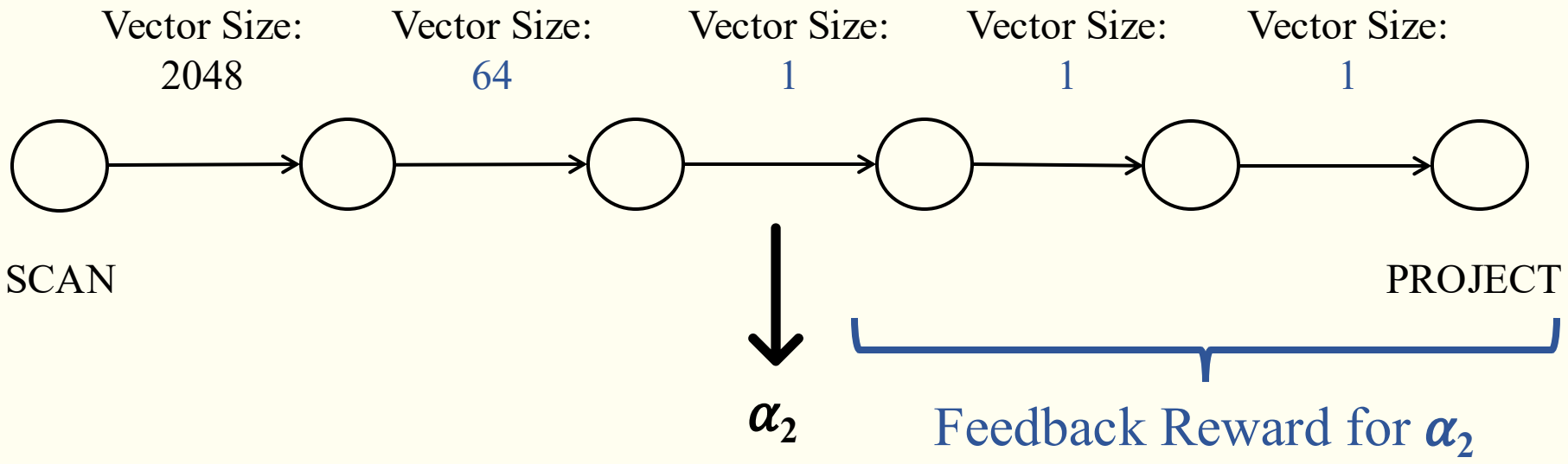

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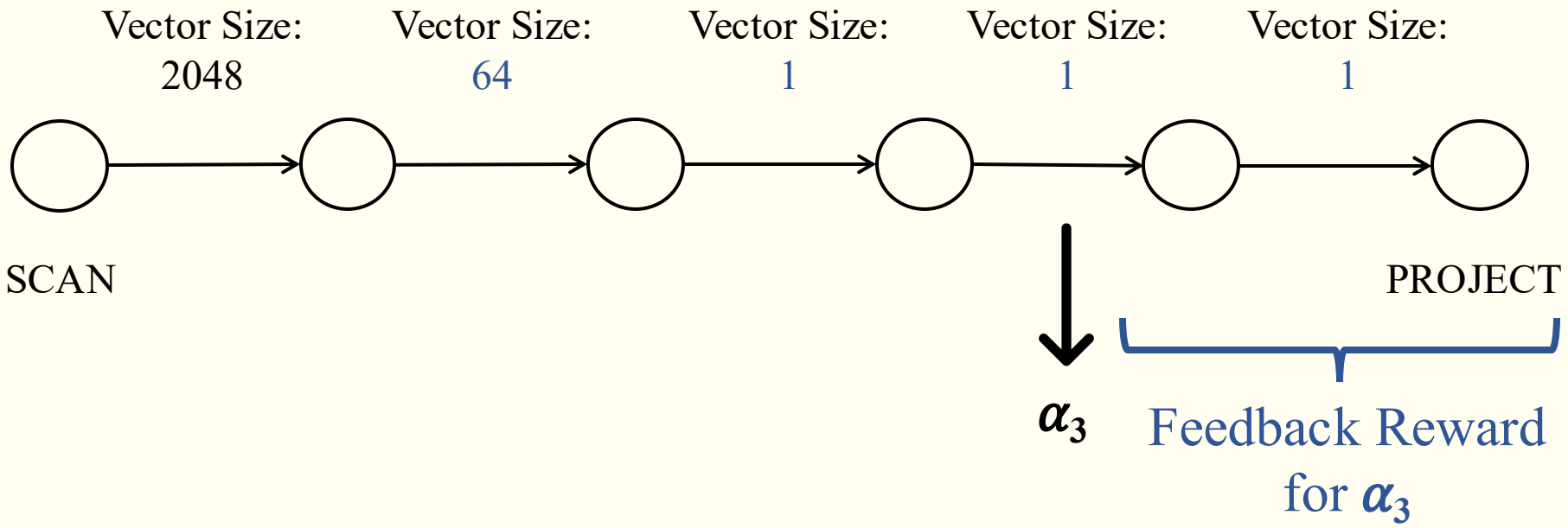
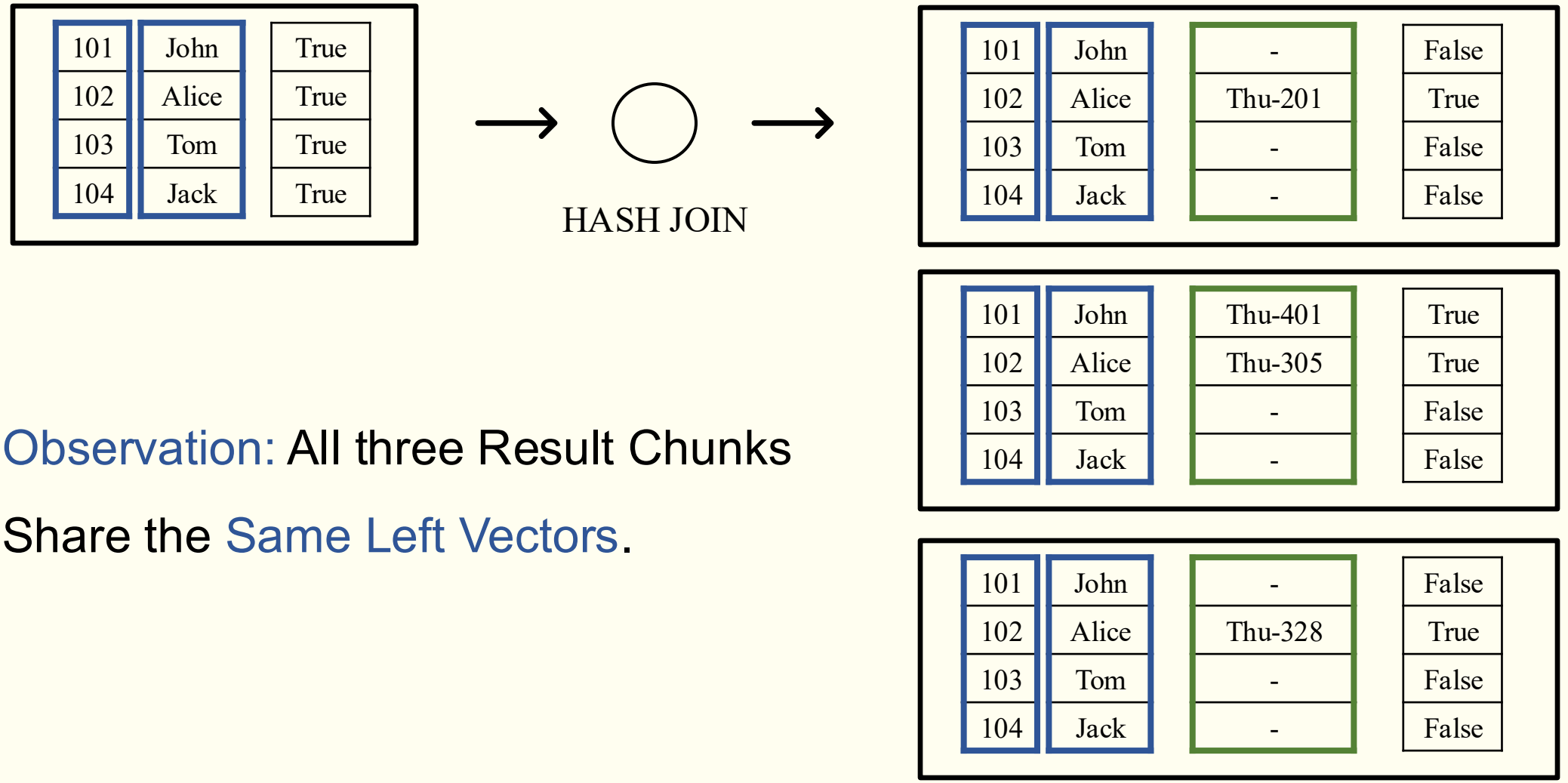


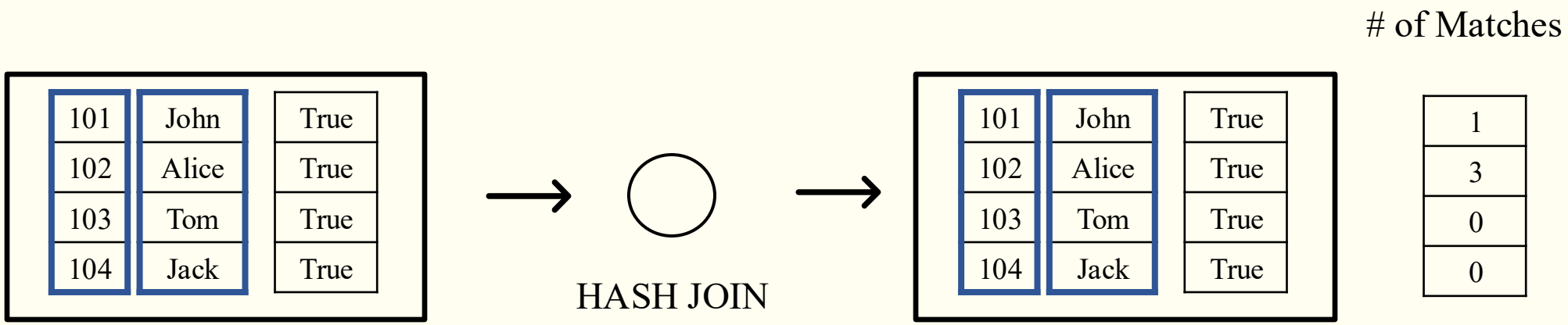
Our Solution 2: Logical Compaction



Observation: All three Result Chunks

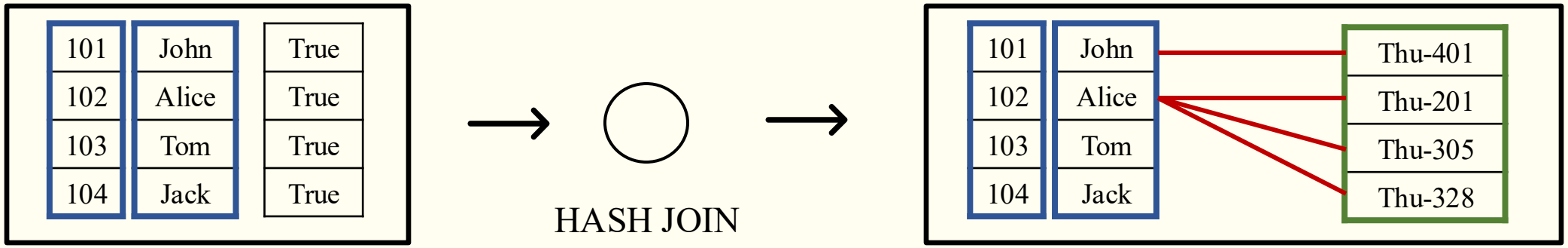
Share the Same Left Vectors.

Logical Compaction



Putting all generated tuples in one chunk seems to be a good idea, but how to keep the zero-copy property of the Left Side Vectors…

Logical Compaction



Requirements:

- Left-side vectors should be zero-copied.
- The mapping relationship between the left-side and right-side vectors should be maintained.
- The resulting chunk can be an input chunk to other operators.

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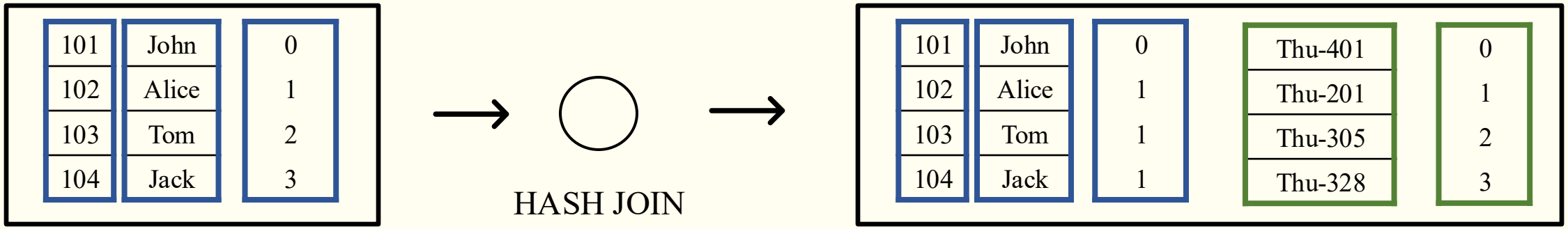
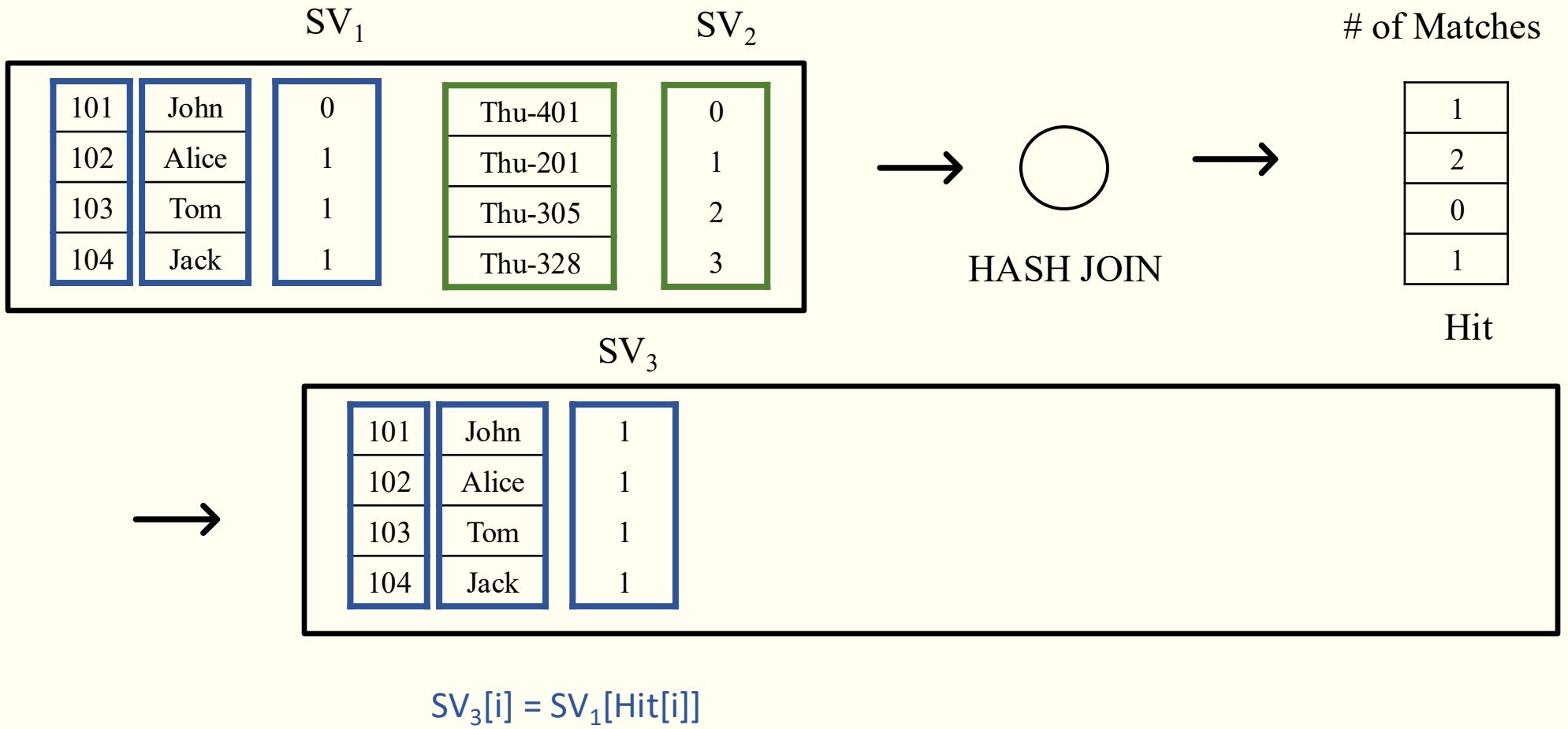


Our Solution: Selection Vector (SV) with Repeated Values:

- Left-side vectors have an SV.
- Right-side vectors have another SV.

Hash Probe the Result Chunk Again



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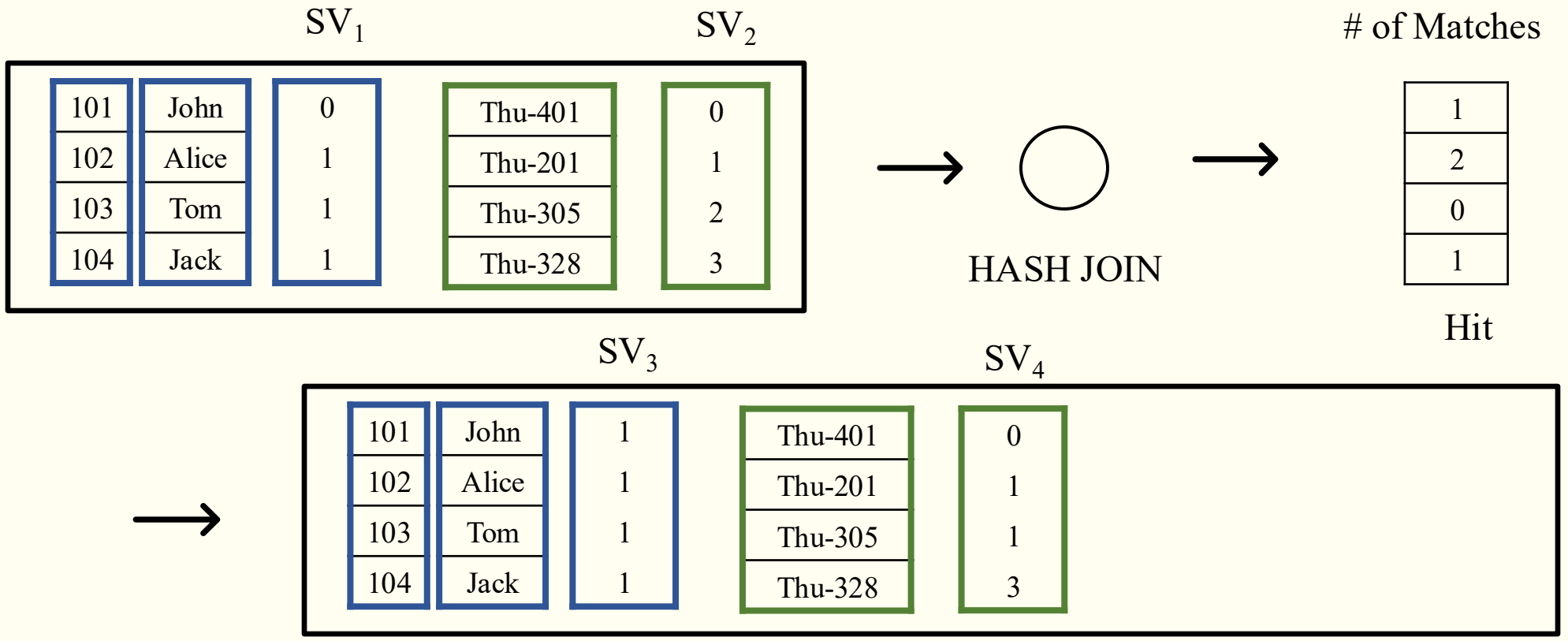
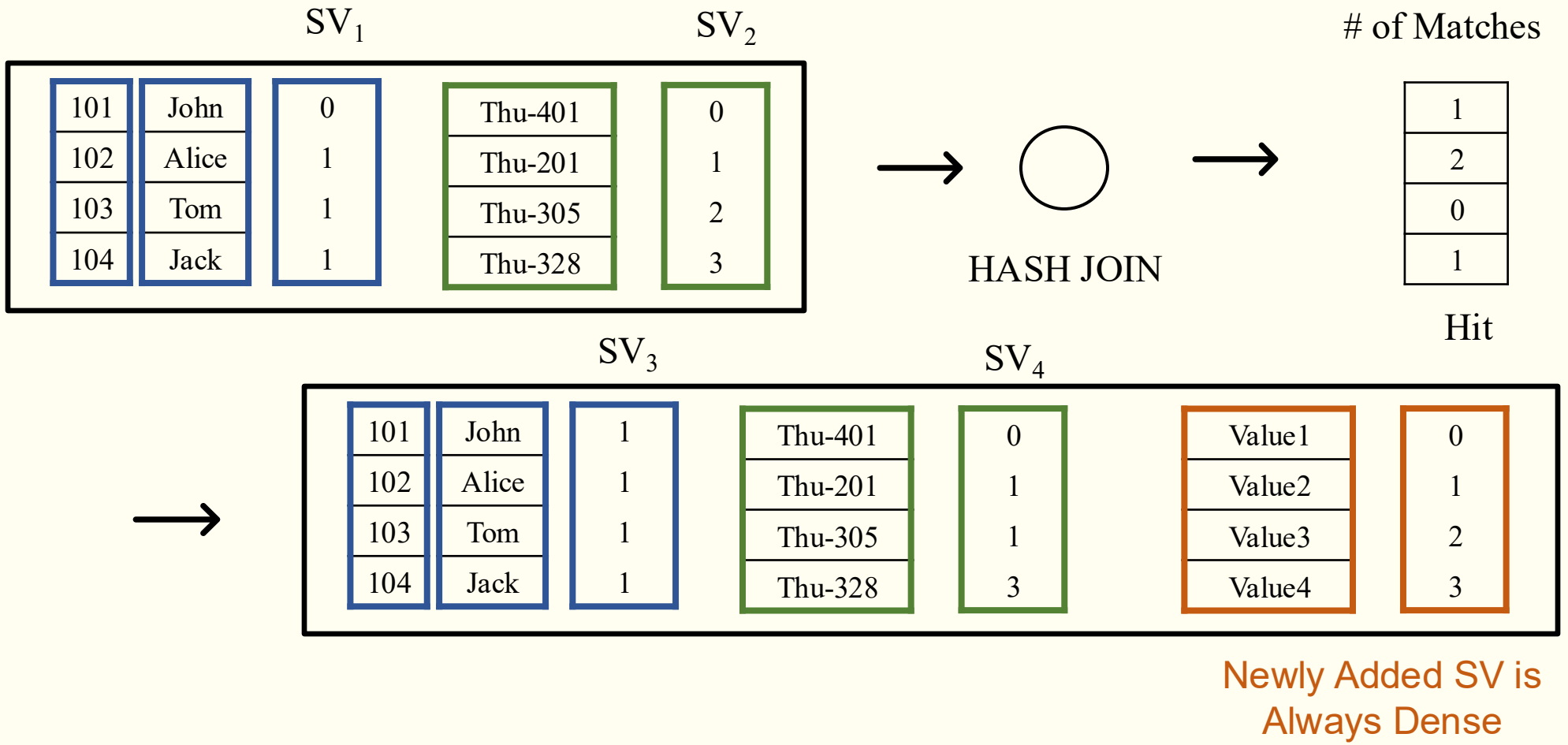


$SV_4[i] = SV_2[Hit[i]]$

Hash Probe the Result Chunk Again



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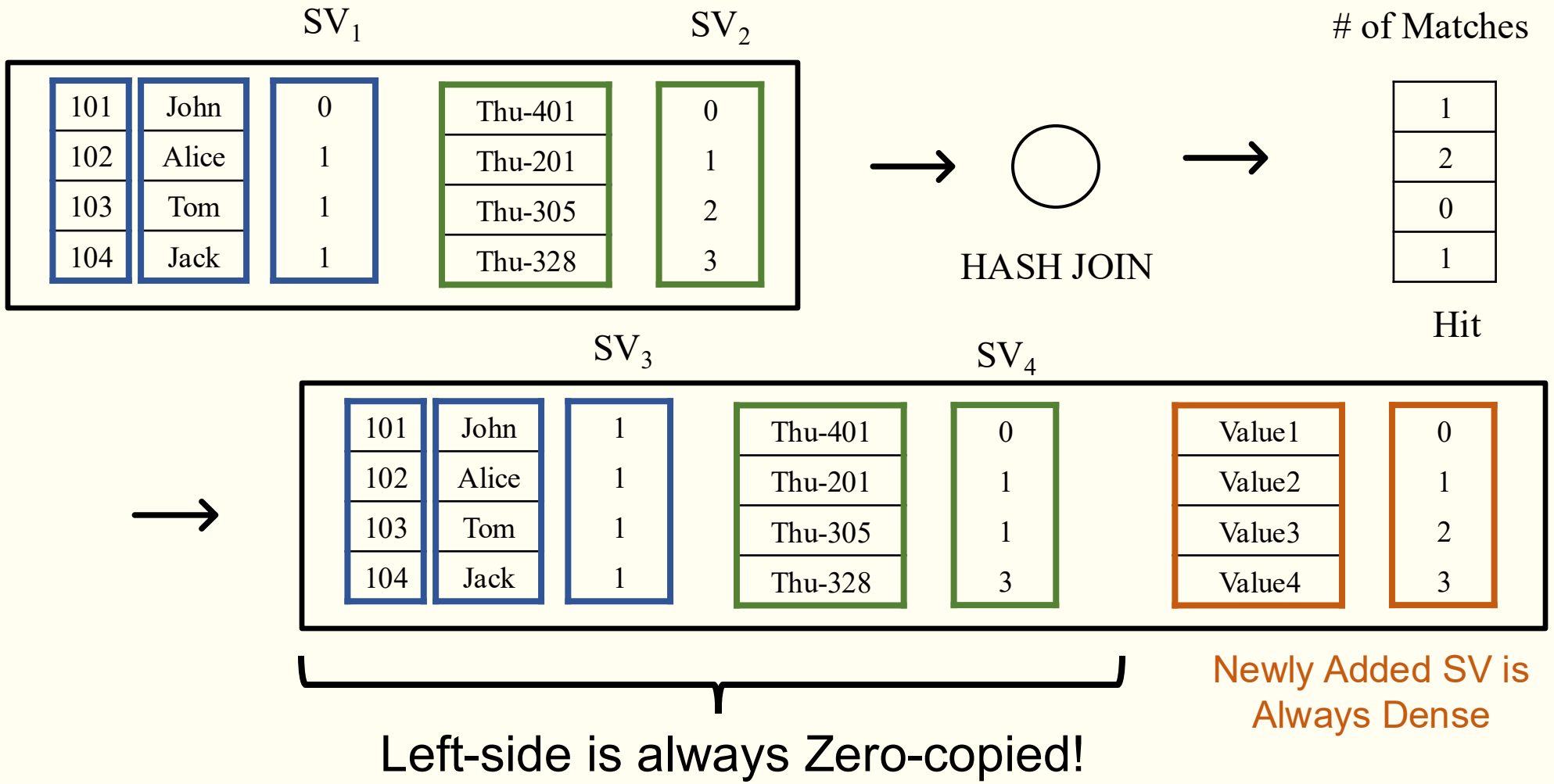

End-to-End Performance in DuckDB

- We integrate our solutions into DuckDB and measure the end-to-end performance.
- Smart Compaction: Learning Compaction + Logical Compaction

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