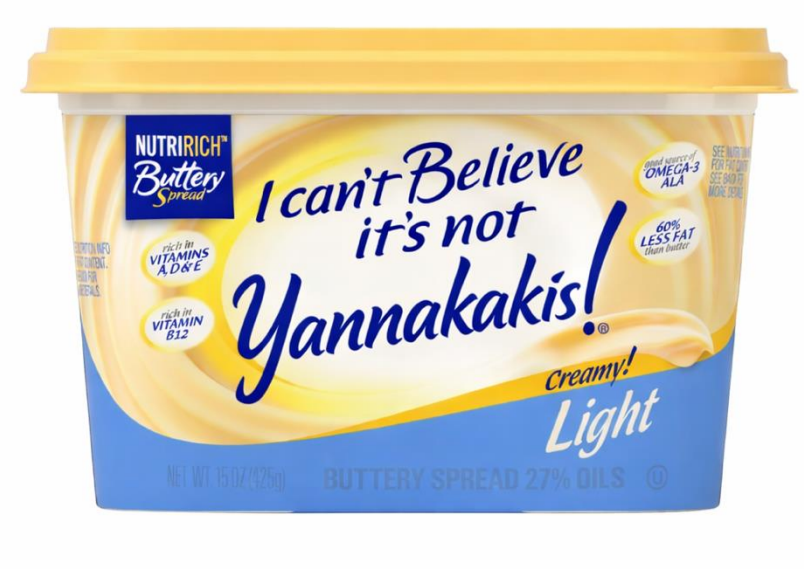
Pragmatic Bitmap Filters in Microsoft SQL Server

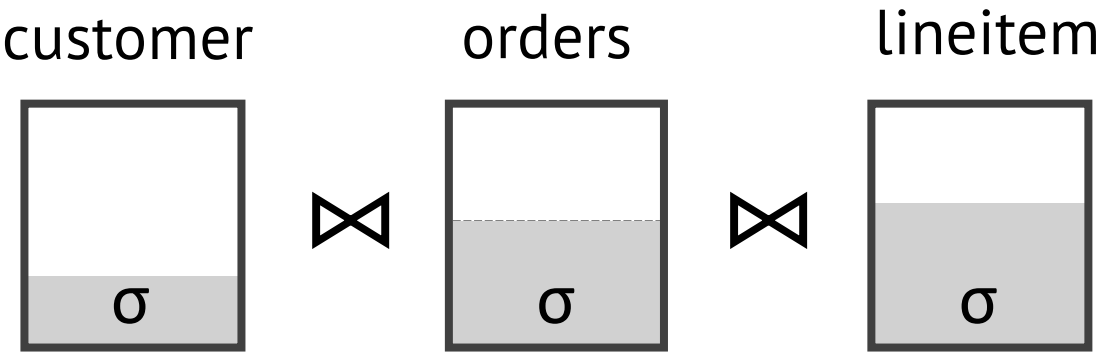
Hangdong Zhao, Yuanyuan Tian, Rana Alotaibi, Bailu Ding, Nicolas Bruno,
Jesús Camacho-Rodríguez, Vassilis Papadimos, Ernesto Cervantes Juárez,
Cesar Galindo-Legaria, Carlo Curino



Microsoft

Pre-filtering is **great**

Example: TPC-H Q3 100 GB



Rows participating in joins after local filtering

20% **49%** **53%**

Pre-filtering is **great**

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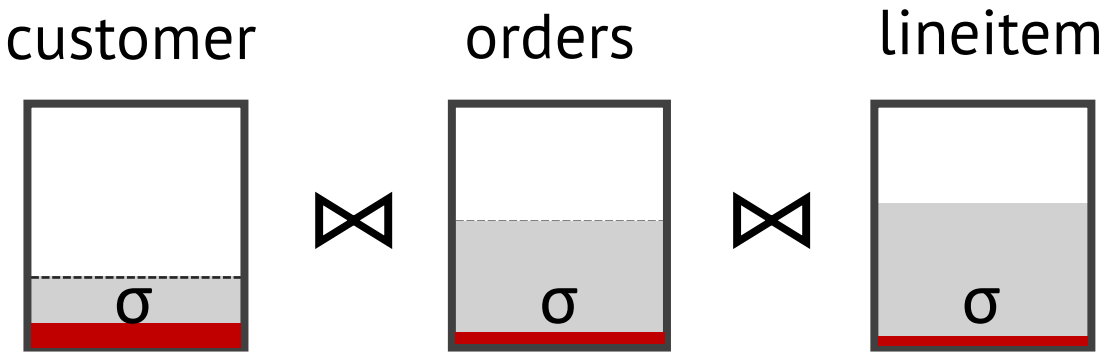

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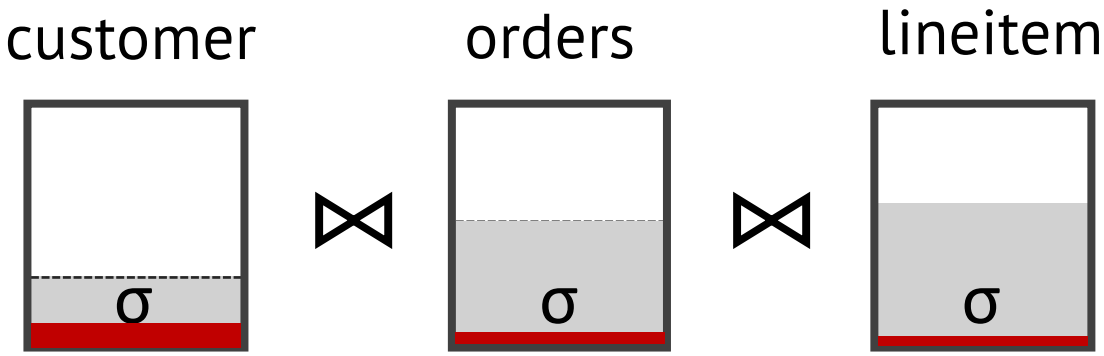

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4–100× size reduction!

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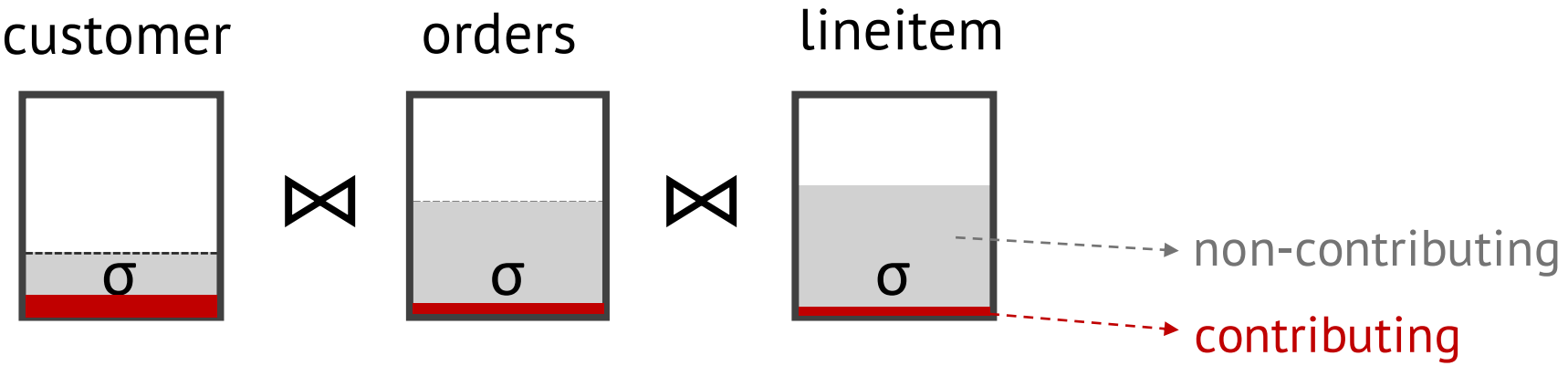

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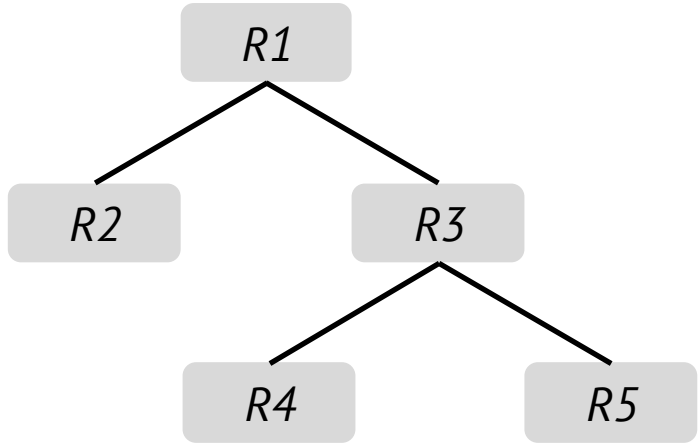
Pre-filtering is **great**

- Often orders-of-magnitude reduction of join input sizes (even in production)
- Yannakakis algorithm is the grand theory for best possible pre-filtering

Yannakakis VLDB'1981

Propagating semijoins first for acyclic joins

...whose join graph is essentially **a tree**

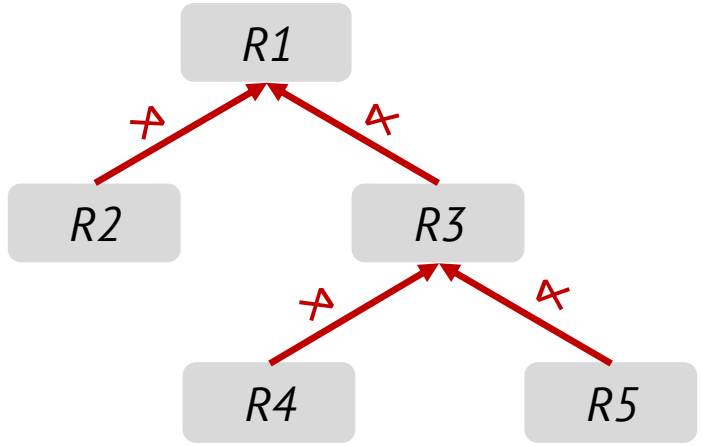


Yannakakis VLDB'1981

Propagating semijoins first for acyclic joins

Bottom-up pass

- Use semijoin to reduce parent table



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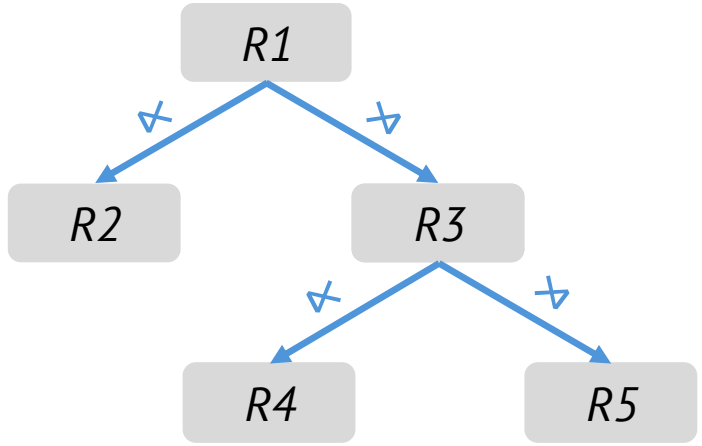


Propagating semijoins first for acyclic joins

Bottom-up pass

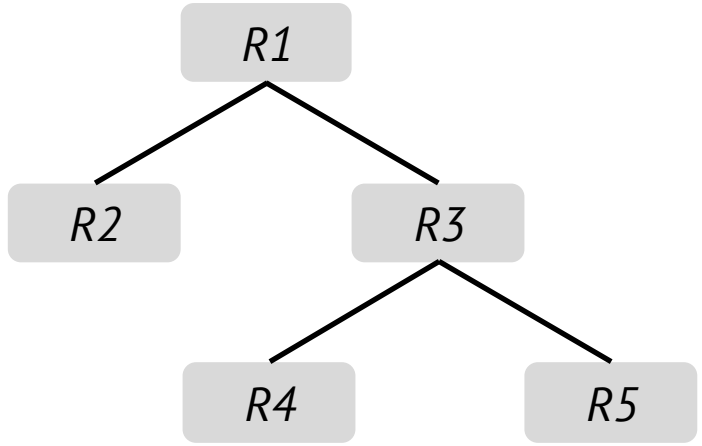
- Use semijoin to reduce parent table

Top-down pass

- Use semijoin to reduce child table

All non-contributing rows are filtered

Yannakakis VLDB'1981



Propagating semijoins first for acyclic joins

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Join the reduced tables

Instance-optimal for acyclic joins

Make Yannakakis Practical

For decades, the Yannakakis algorithm has been '**ignored**' by real database engines

Because it

Accepts **only** acyclic joins

Introduces **high overheads** for scans/semijoins/materialization of pre-filtered tables

Huge impacts on query optimization & execution

Make Yannakakis Practical

But recently, there is a renaissance….

A Common Theme
Replace Yannakakis' semijoins by **Bloom filters**

CIDR 2024

- Predicate Transfer: Efficient Pre-Filtering on Multi-Join Queries

VLDB 2024

- Robust Join Processing with Diamond Hardened Joins

SIGMOD 2025

- Debunking the Myth of Join-ordering: Toward Robust SQL Analytics
- Yannakakis+: Practical Acyclic Query Evaluation with Theoretical Guarantees
- Accelerate Distributed Joins with Predicate Transfer

VLDB 2025

- Parachute: Single-Pass Bi-Directional Information Passing
- Including Bloom Filters in Bottom-up Optimization
- Instance-Optimal Acyclic Join Processing Without Regret: Engineering the Yannakakis Algorithm in Column Stores

So… can I optimize SQL Server now?

I was too naïve :)

Why I give up optimizing SQL Server?

...SQL Server is way ahead of academia

Why I give up optimizing SQL Server?

...thanks to the great SQL Server engineers

Ciprian Clinciu
Campbell Fraser
Cesar Galindo-Legaria
Milind Joshi
Michal Nowakiewicz
Vassilis Papadimos
Andrew Richardson
Aleksandras Surna

Why I give up optimizing SQL Server?

SQL Server has been quietly generating—and executing—**instance-optimal** query plans for most of your SQL queries since 2014!

And not only that, it

Accept ~~only acyclic joins~~ **arbitrary join queries**

Bears no additional scans/semijoins/materialization of pre-filtered tables

Carefully controls ~~huge~~ impacts on query optimization/execution

Three Core Pieces

All that in an elegant design!

Batch-mode Hash Join
the only building block needed

Pull-based Execution
cascading bitmap pushdown

Cascades Optimizer
cost-based optimizations
considering bitmap filters

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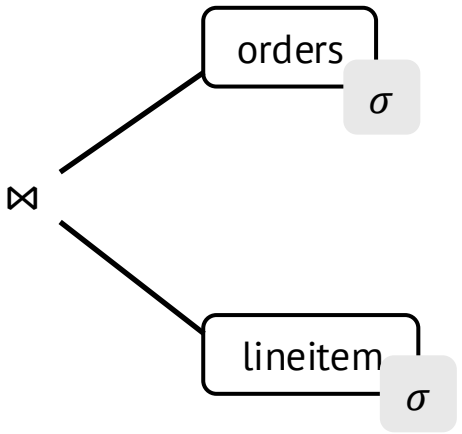
Batch-mode Hash Join

- pull-based execution of a batch-mode hash join



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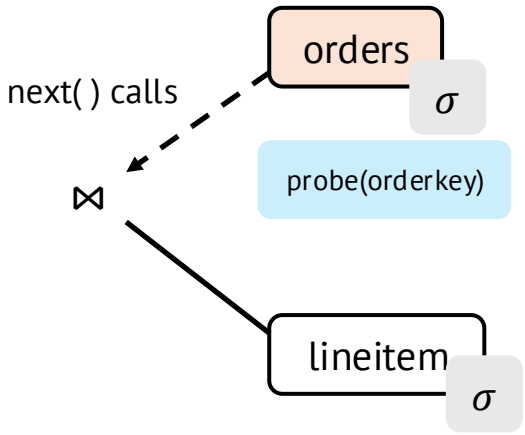

bitmap filter decisions

- Columns to create bitmap filters
- Bit-array or Bloom filters
- Sizes of bitmap filters

Batch-mode Hash Join

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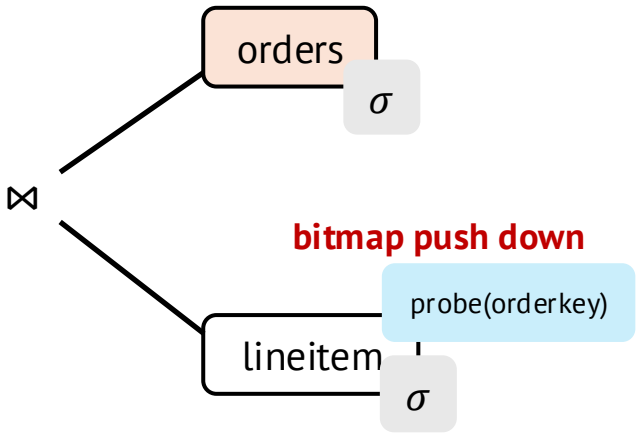

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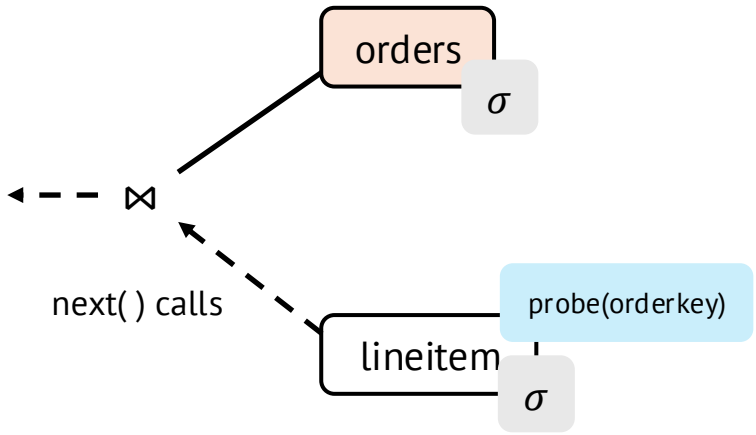

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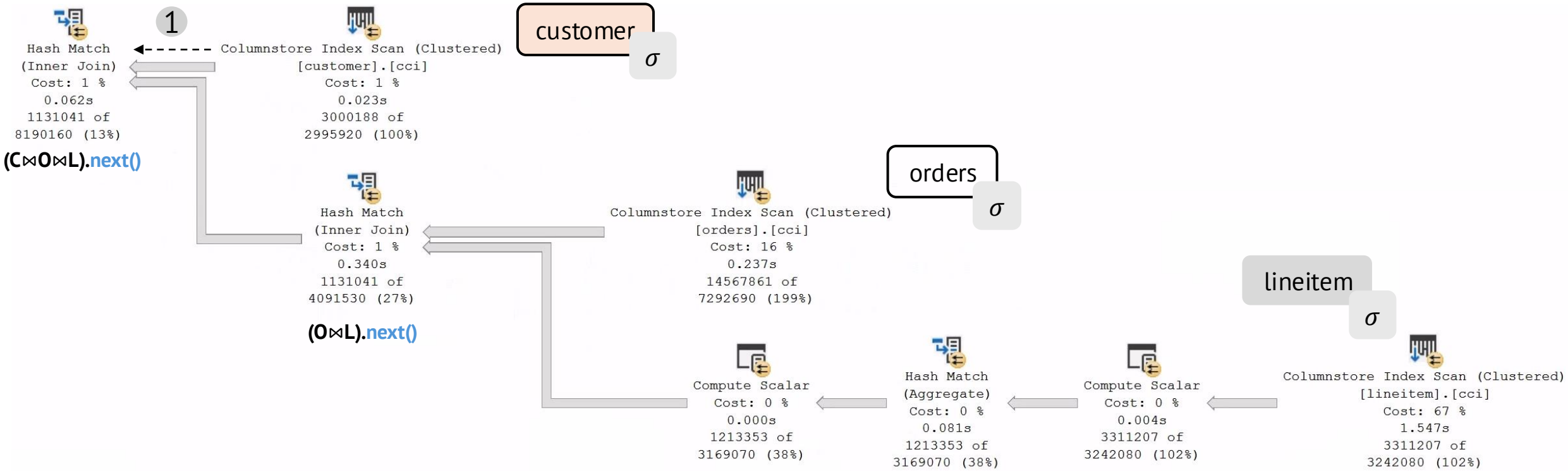
Composing Hash Join



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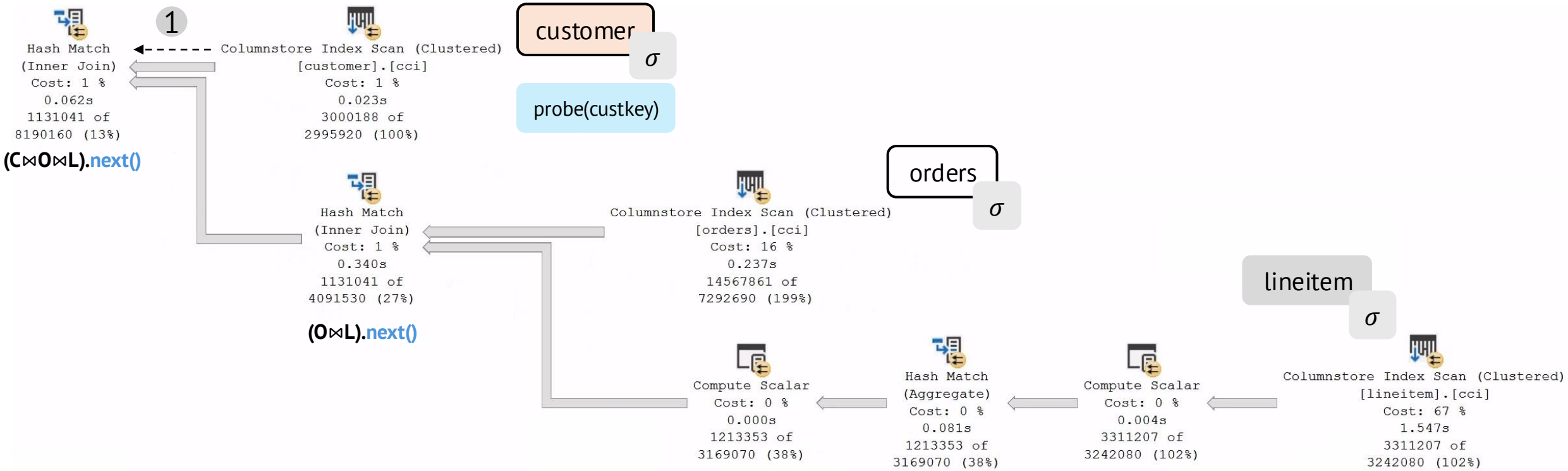

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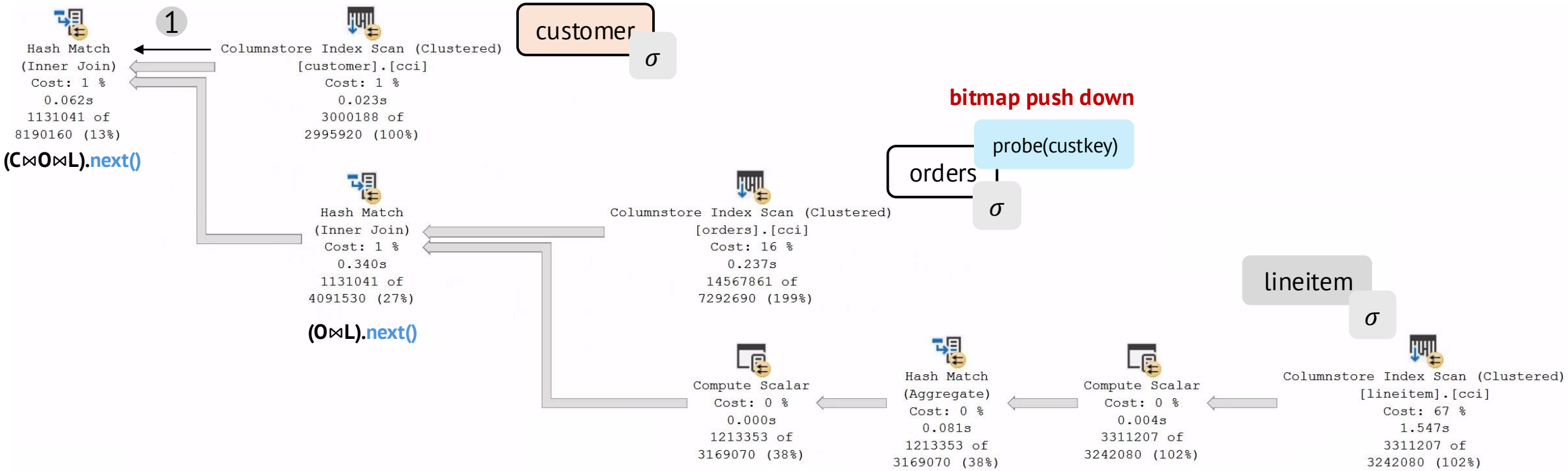

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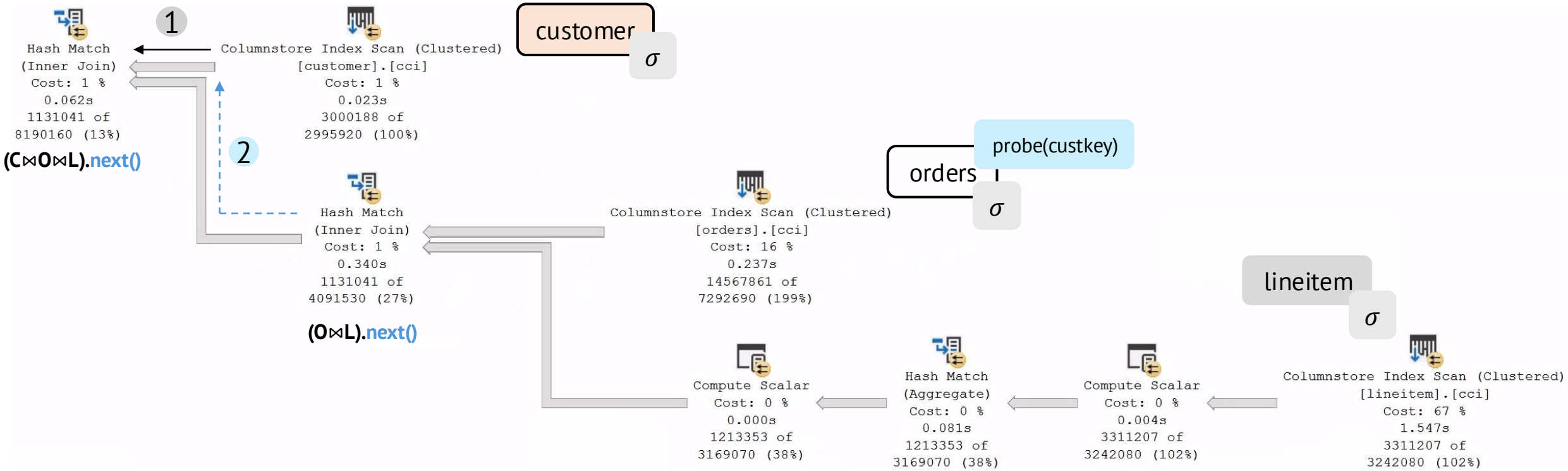

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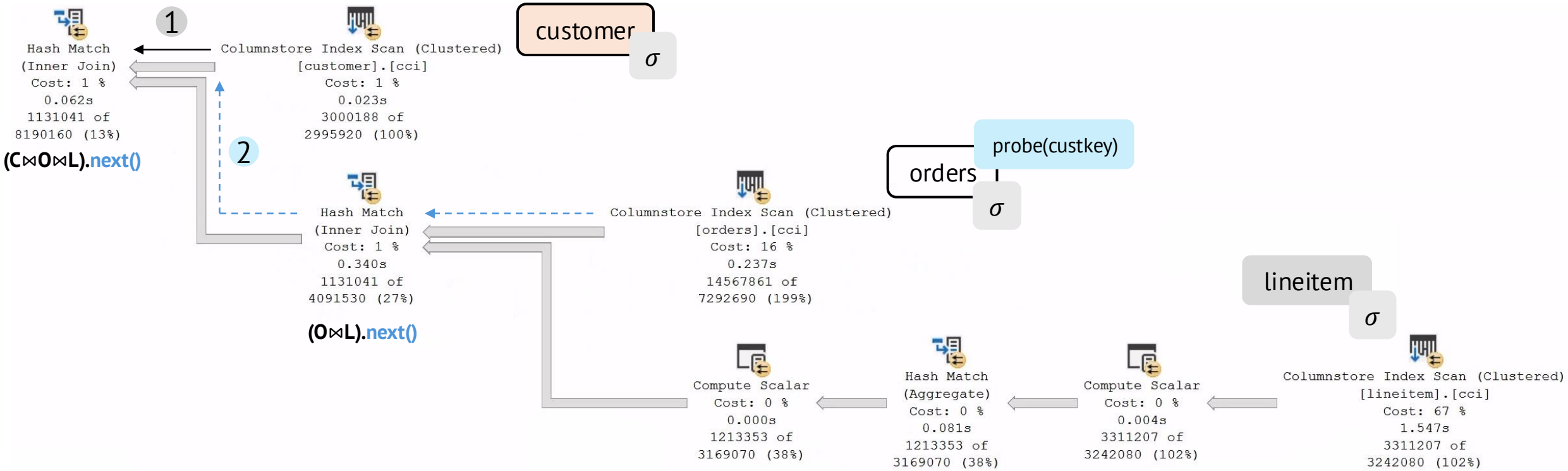

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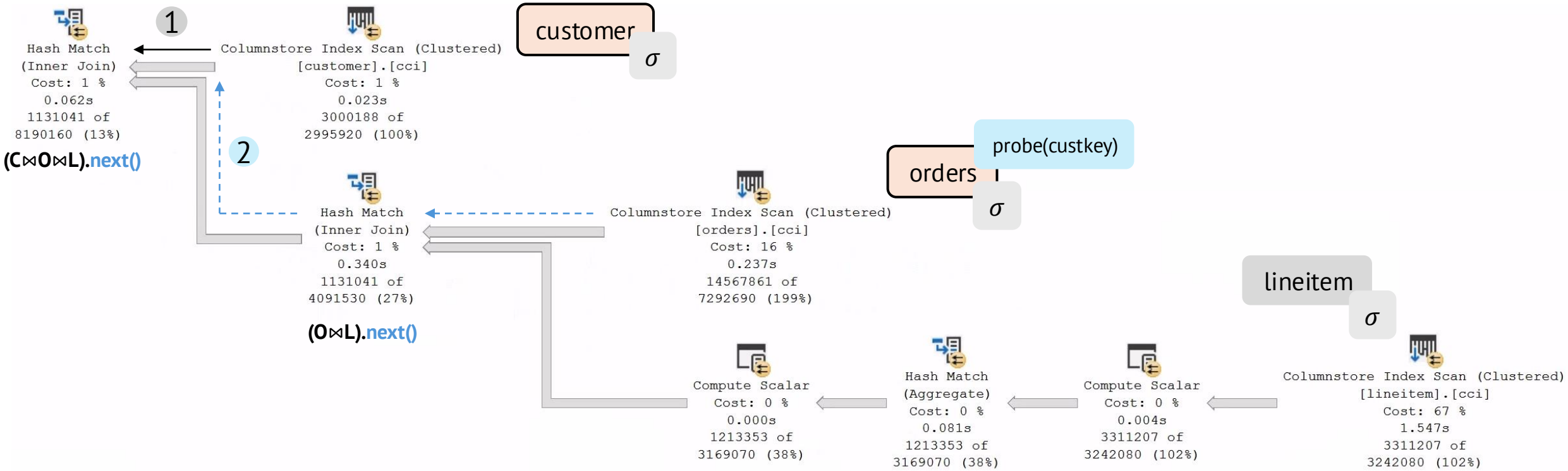

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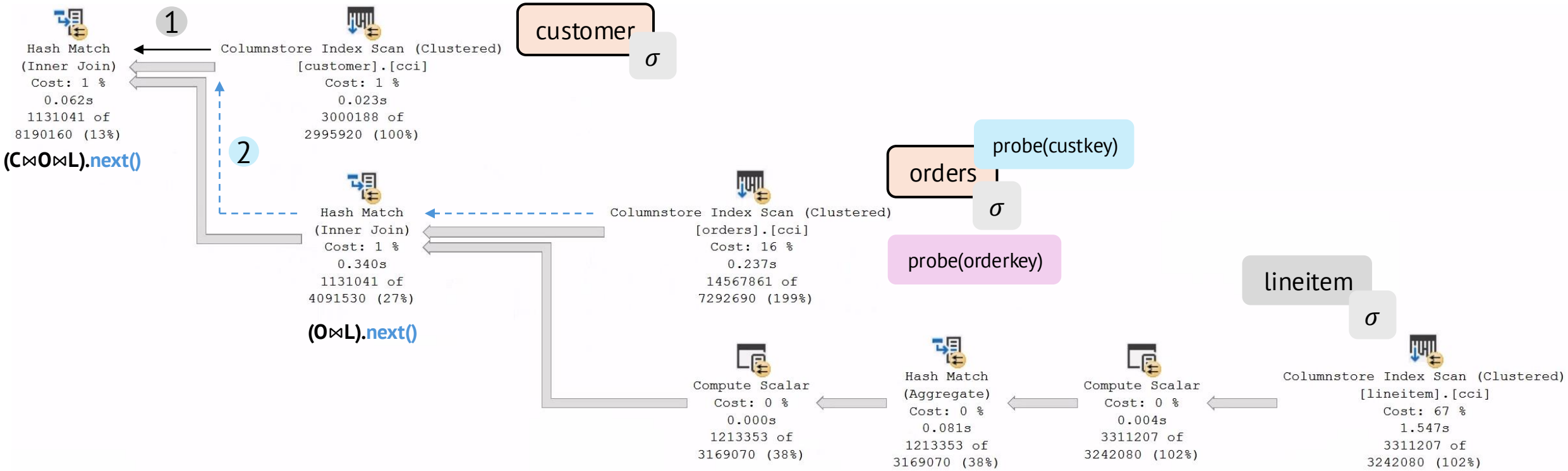

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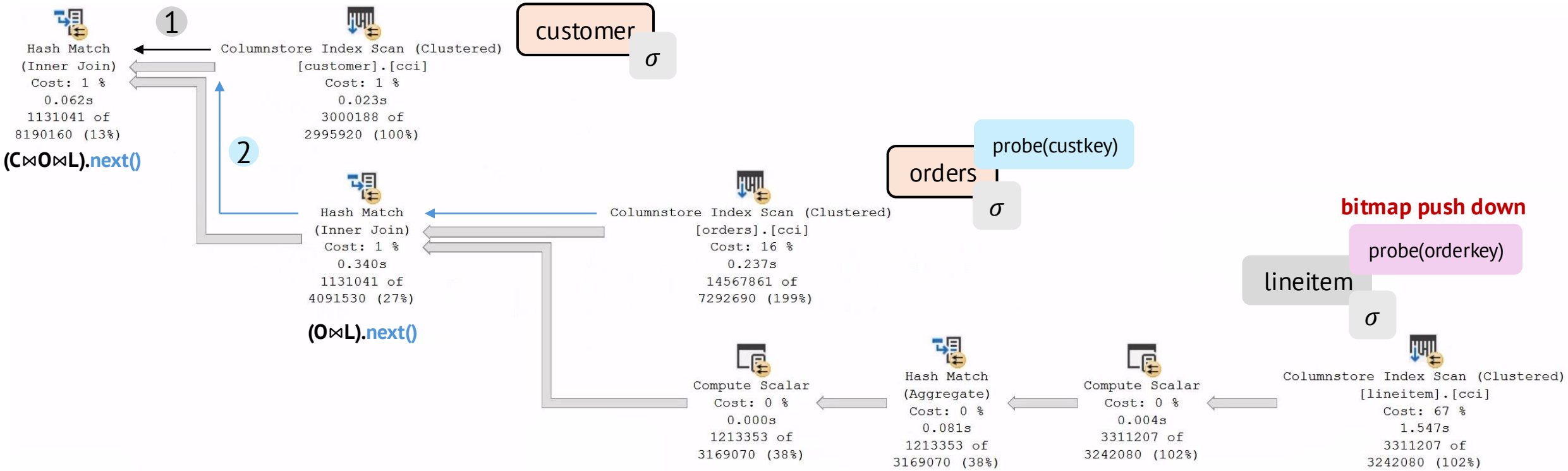

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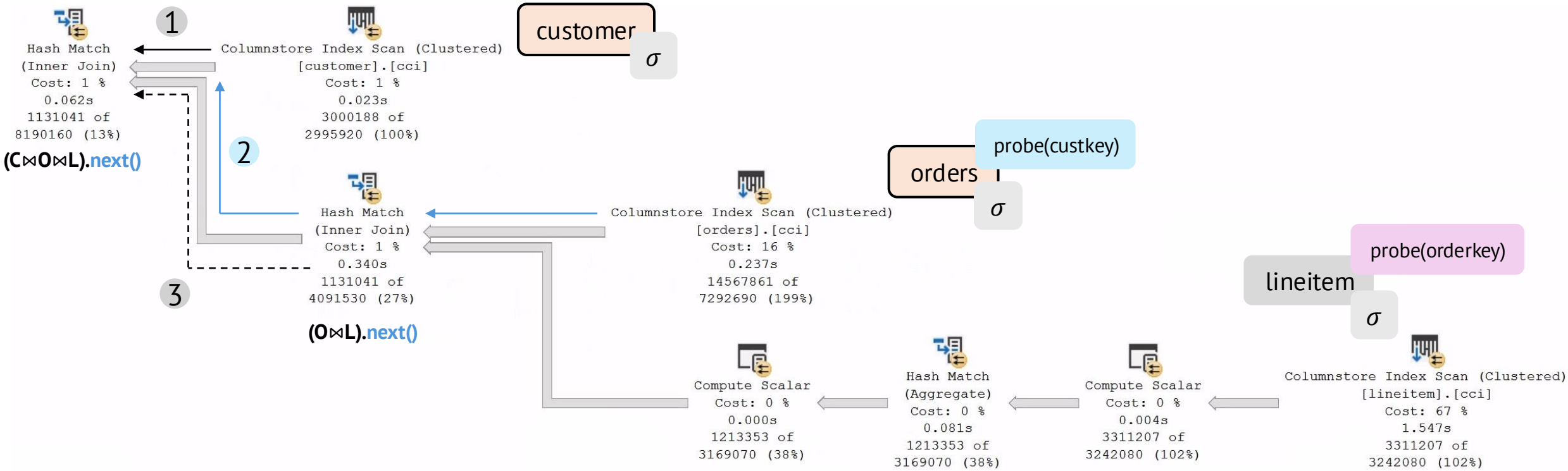

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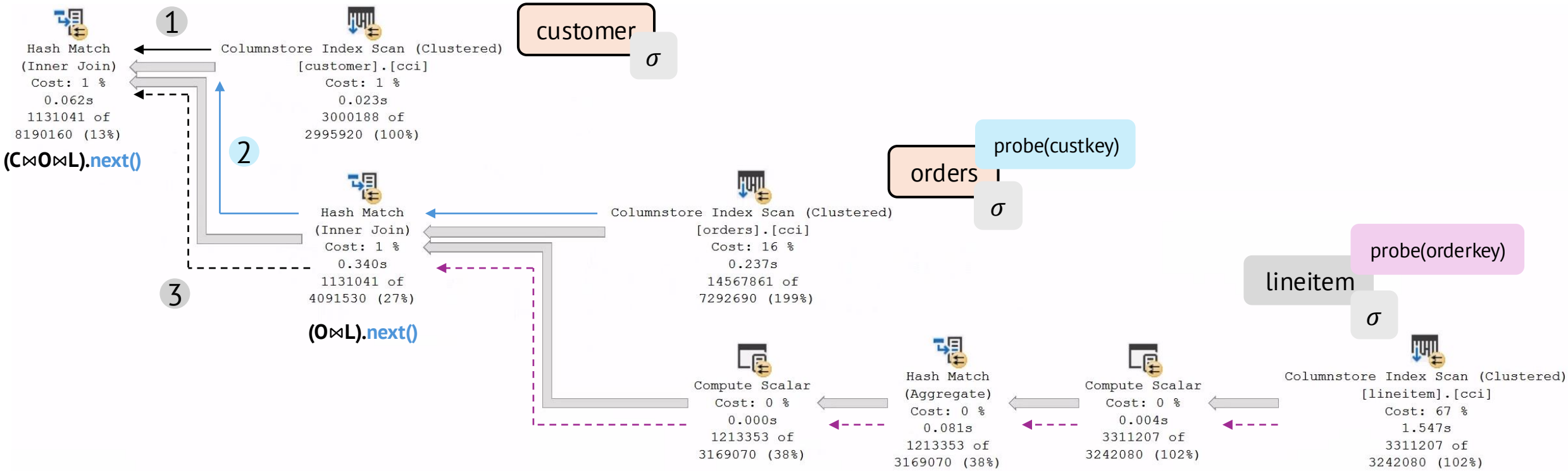
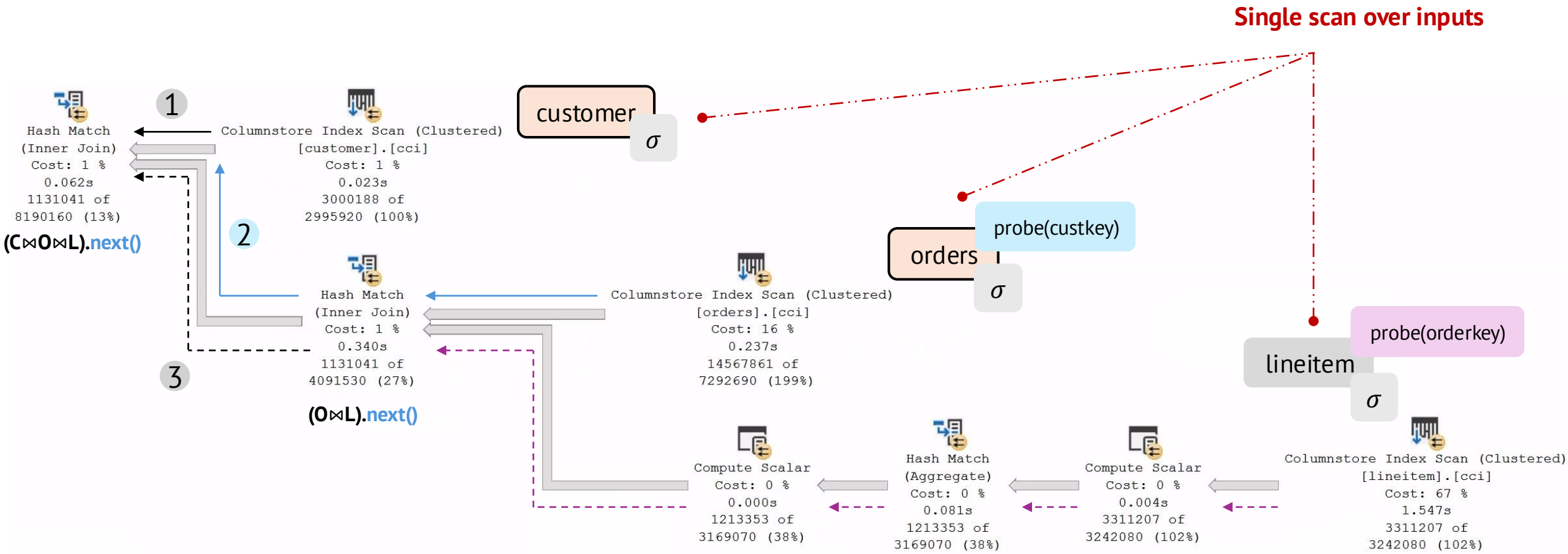


Instance-optimal Query Execution



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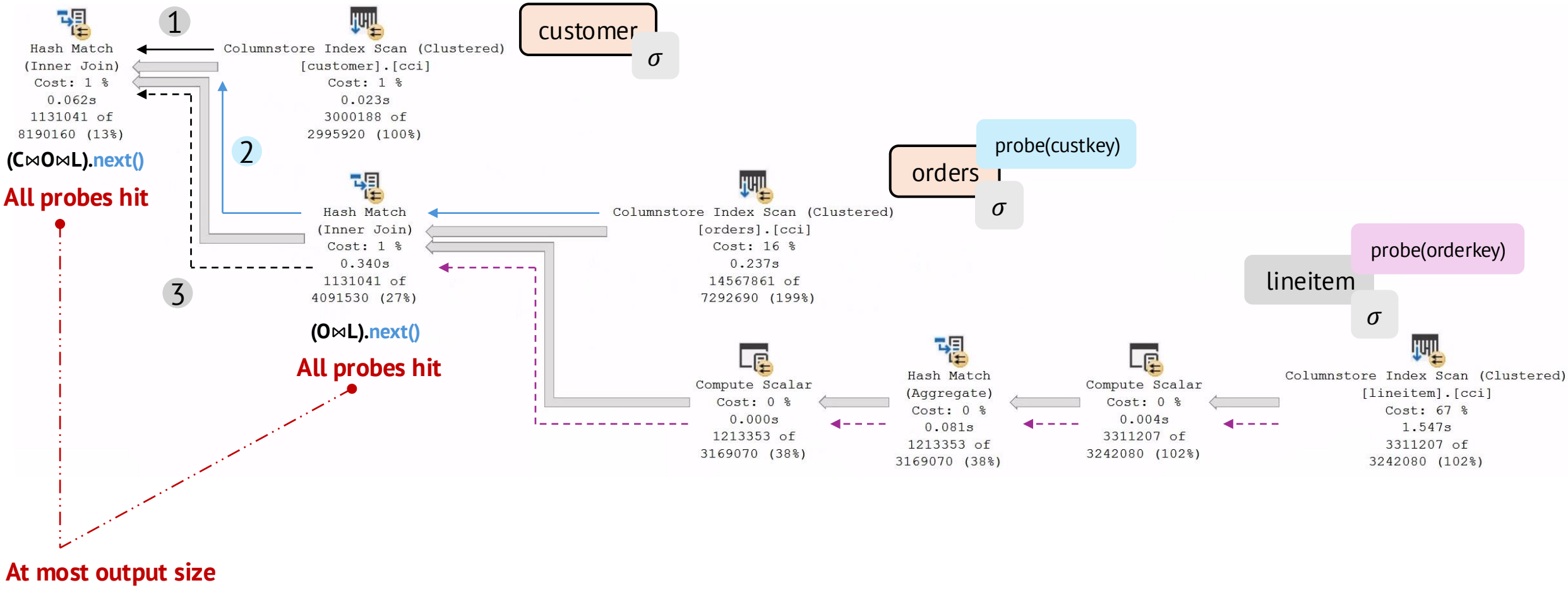

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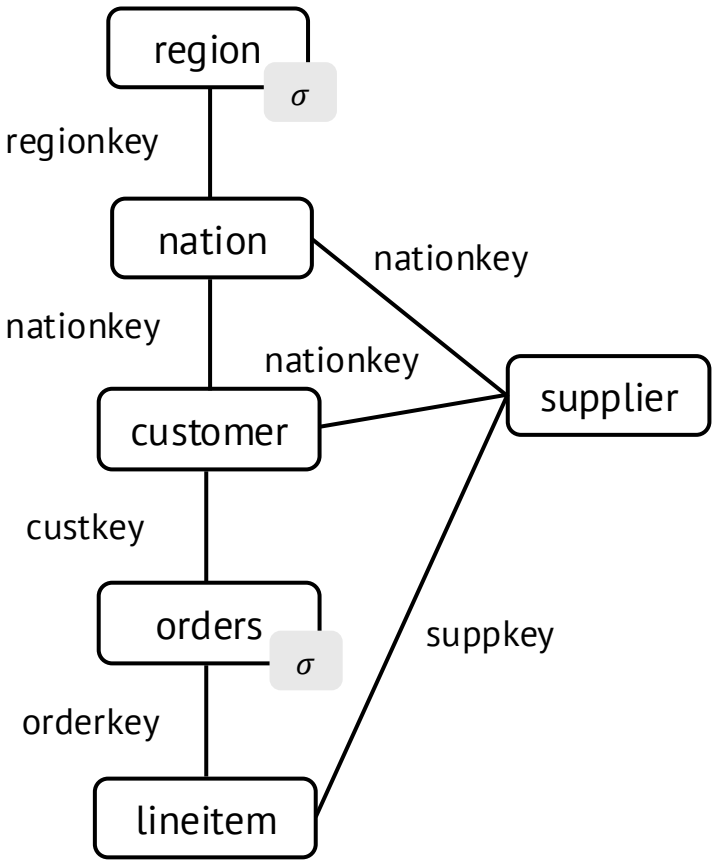

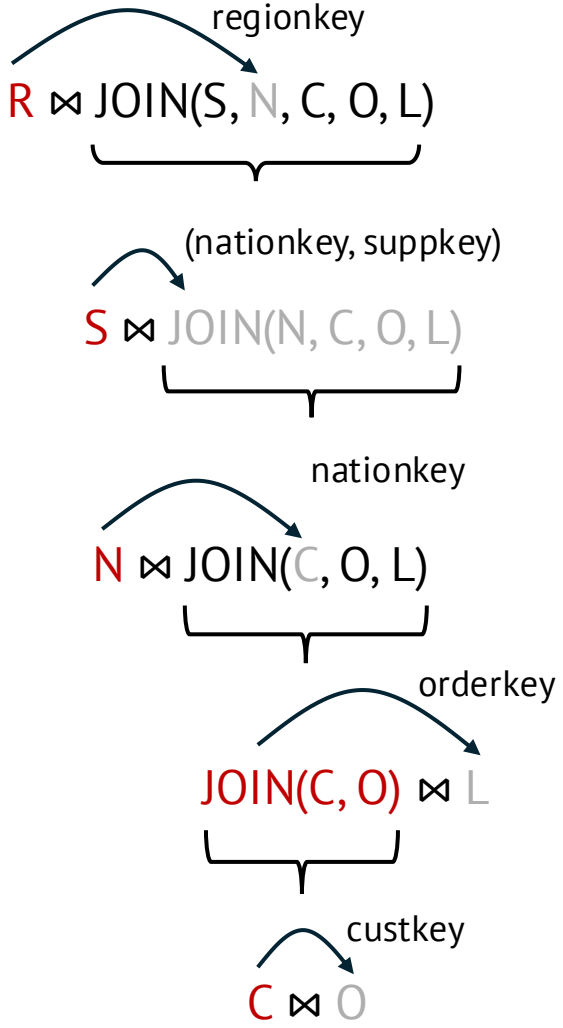

Example: TPC-H Q5 100 GB

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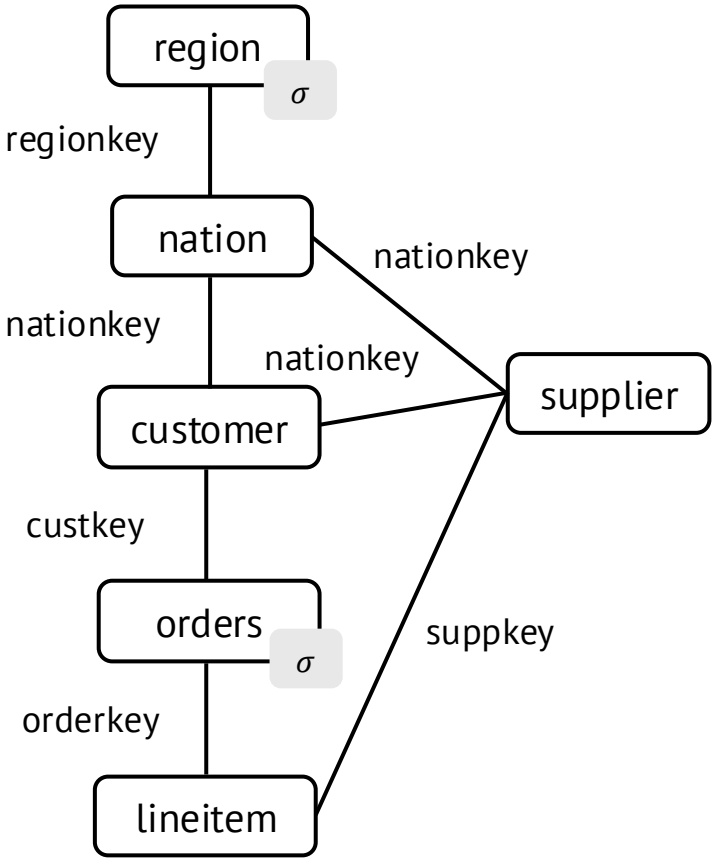

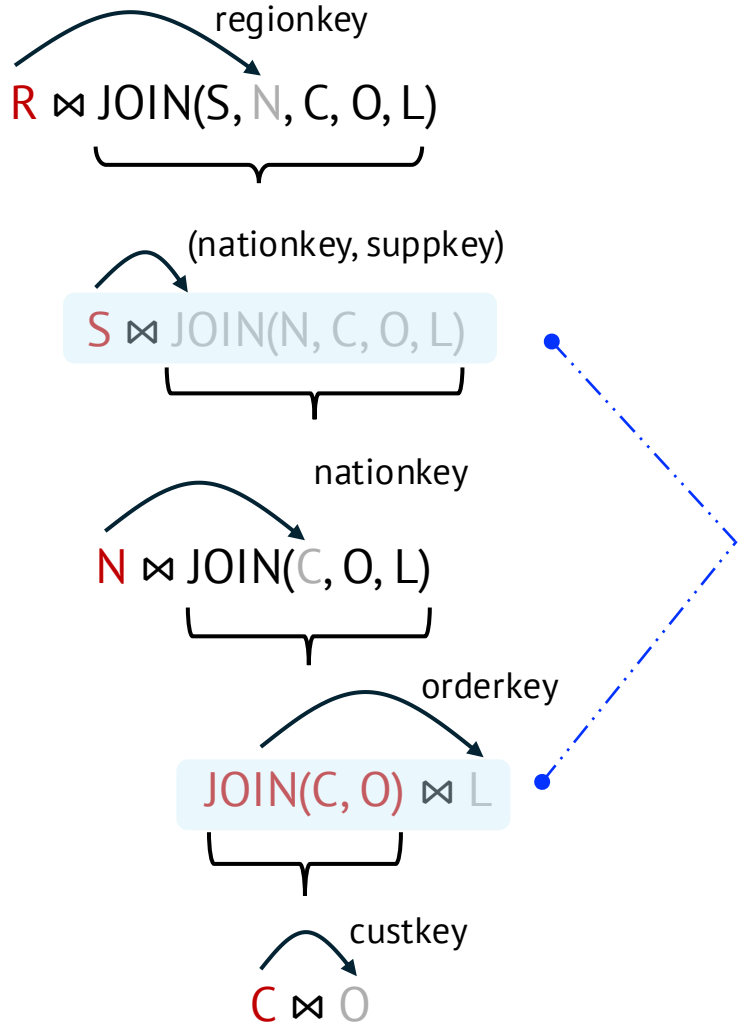

Cost-based decisions on bitmap passing from & to any intermediate result

Experiments

- TPC-H 22 queries (100 GB)
- 7 queries become **>2x** faster

ID	Shape of join graph	Runtime speedup	Inst.-opt.?	#rows to join	SQL Srv. reads (%)	Yannak. reads (%)
1	No join	–	–	–	–	–
2	Line	**3.47×**	✓	81.1M	0.43%	0.21%
3	Line (C-O-L)	1.91×	✓	399.4M	**5.23%**	**1.25%**
4	A semijoin	1.92×	✓	385.1M	5.28%	5.14%
5▲	Cyclic join	**2.33×**	–	638.8M	**4.2%**	**1.21%**
6	No join	–	–	–	–	–
7▲	Line	**3.00×**	✓	348.4M	**4.15%**	**0.81%**
8▲	Snowflake	**2.86×**	✗	661.8M	**1.92%**	**0.16%**
9	Snowflake	1.47×	✗	832.2M	8.23%	8.22%
10	Line (N-C-O-L)	1.23×	✓	168.8M	12.51%	12.01%
11	Line	1.75×	✓	81.1M	8.01%	8.01%
12	Single join	1.21×	✓	153.2M	3.97%	3.95%
13	An outer join	–	–	–	–	–
14	Single join	1.14×	✓	27.5M	49.98%	49.98%
15	Single join	1.07×	✓	23.7M	95.78%	95.78%
16	Antijoin & join	1.03×	✓	83.0M	17.91%	17.91%
17	Correlate joins	**2.55×**	–	51.5M	1.22%	1.21%
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20	Correlate joins	**2.01×**	–	172.3M	0.2%	0.07%
21	Correlate joins	**2.36×**	–	379.4M	**21.43%**	**19.24%**
22	An antijoin	1.27×	✓	155.8M	**17.41%**	**15.94%**

Table 1: TPC-H (SF=100) results. ✓ (×) mark instance-optimal plans (not) chosen; – are inapplicable cases; ▲ denotes optimizer slowdown. Last three columns show total rows (in millions) for all joins and % after pre-filtering of SQL Server and Yannakakis.

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- 5 have **>1% gaps (but <4%)** from Yannakakis
  - SQL Server already gets most pre-filtering benefits

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Future Directions

- Accurate bitmap-aware Cardinality Estimations & Cost Models
- Robust Query Plans for Complex SQL Workloads
- Pre-filtering Solutions for Modern Data Platforms & Analytics

Thank you

Check out our papers for

- Formal proof of instance optimality for SQL Server
- Careful costing to generate optimal plans
- Robustness and semi-robustness guarantees come as by-product
- A better presentation