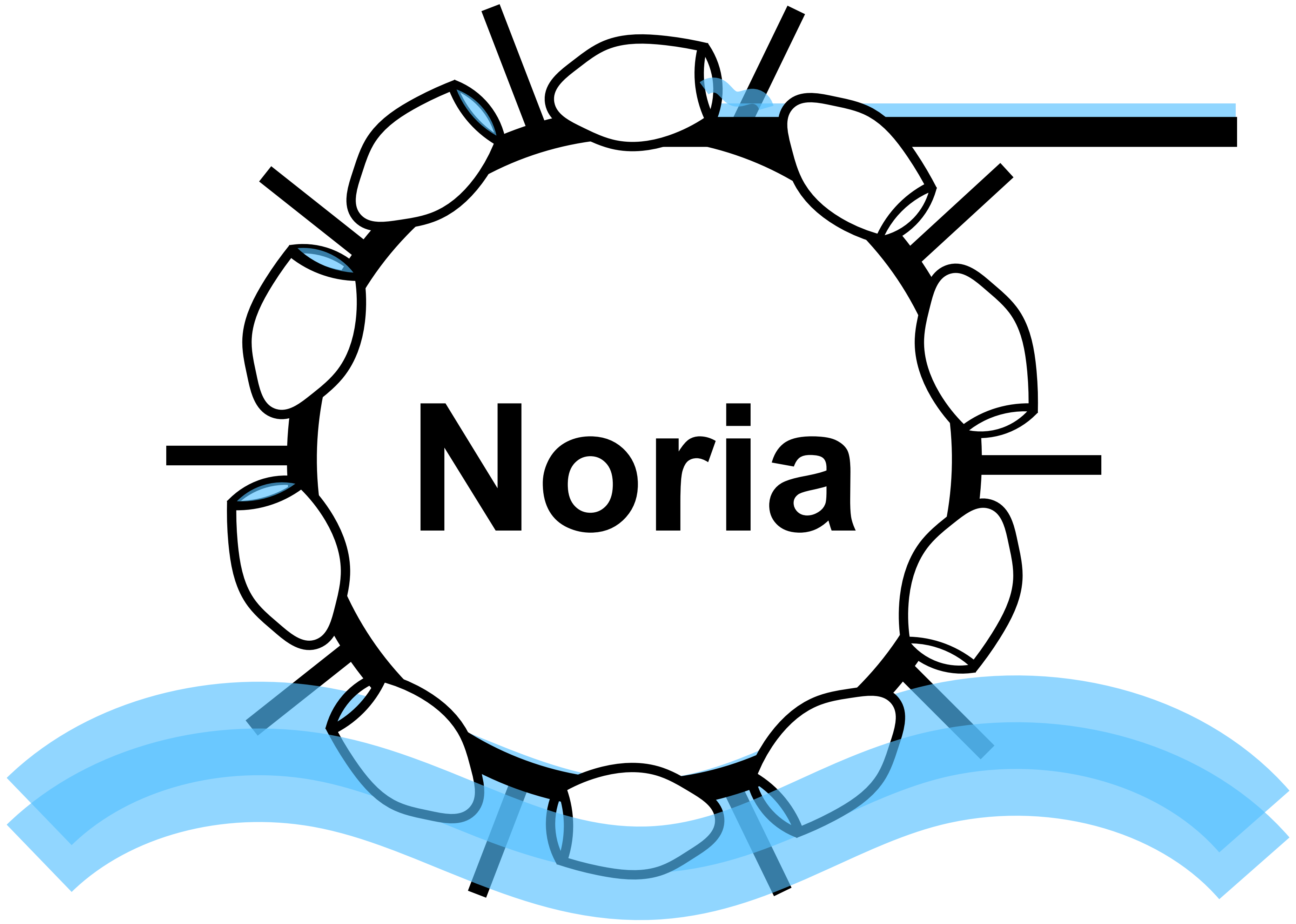


Dynamic, partially-stateful data-flow for high-performance Web applications

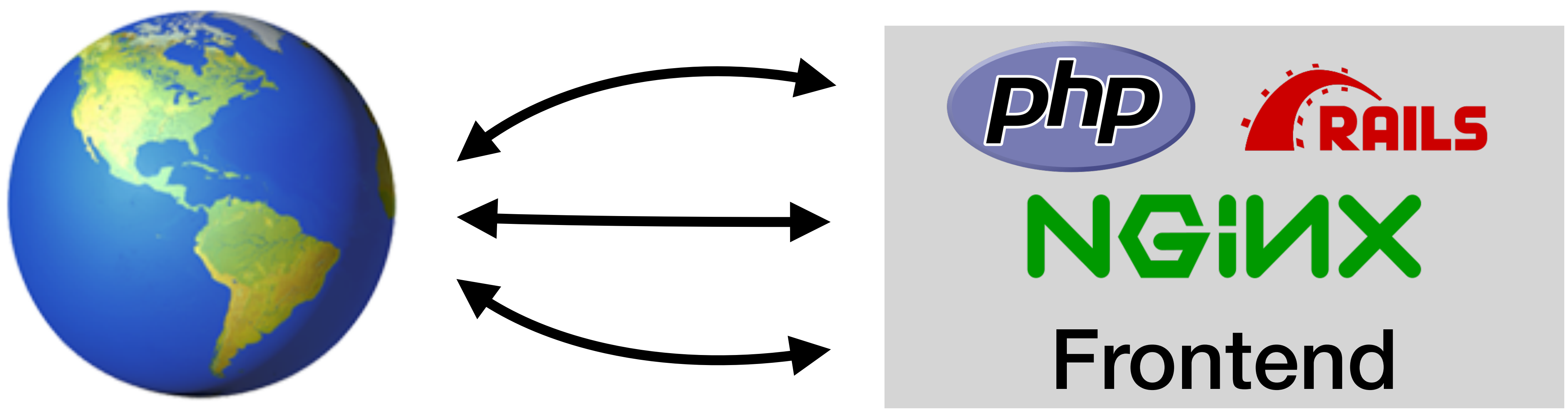
Jon Gjengset Malte Schwarzkopf

Jonathan Behrens Lara Timbó Araújo Martin Ek

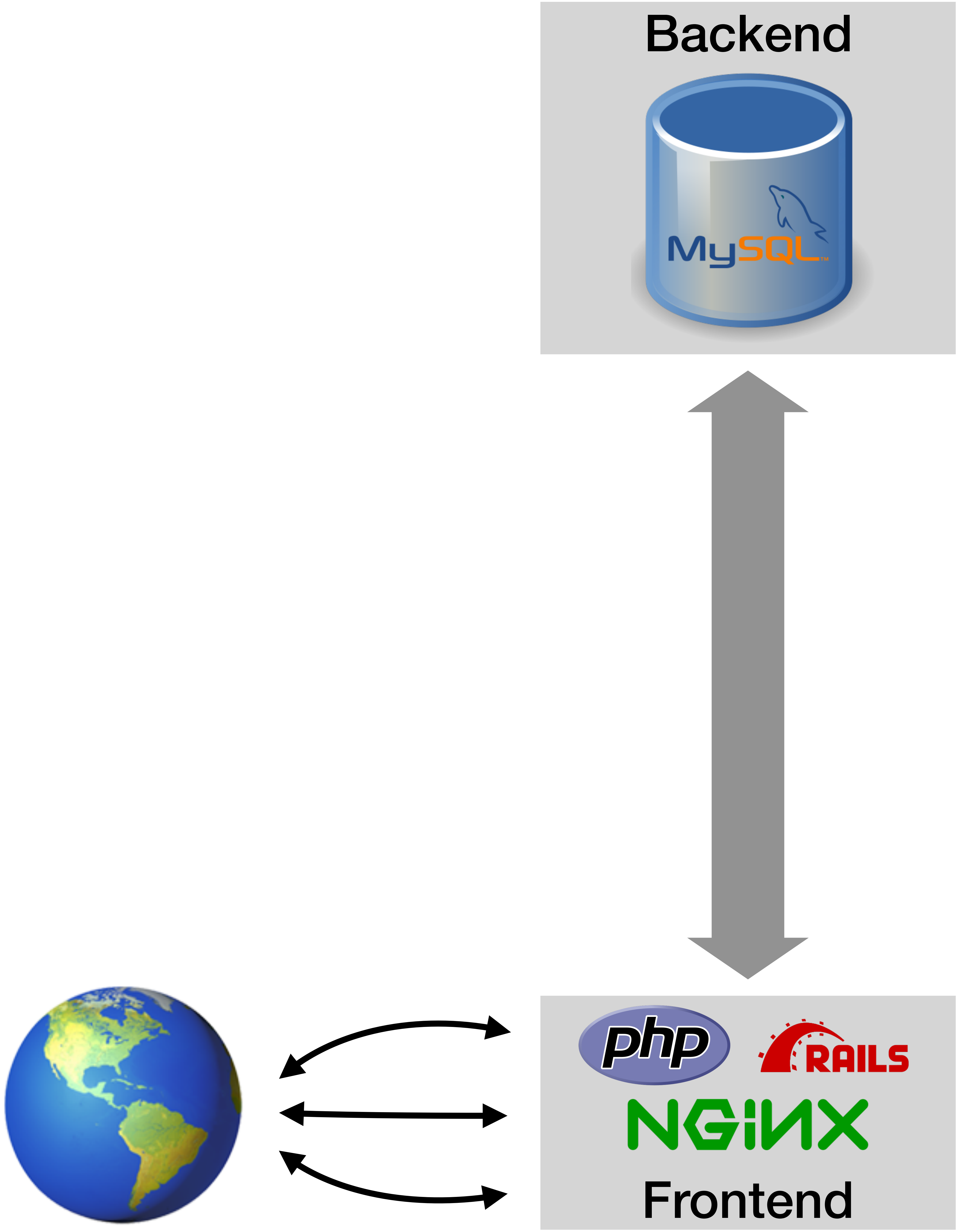
Eddie Kohler M. Frans Kaashoek Robert Morris

php
RAILS
NGINX

Frontend

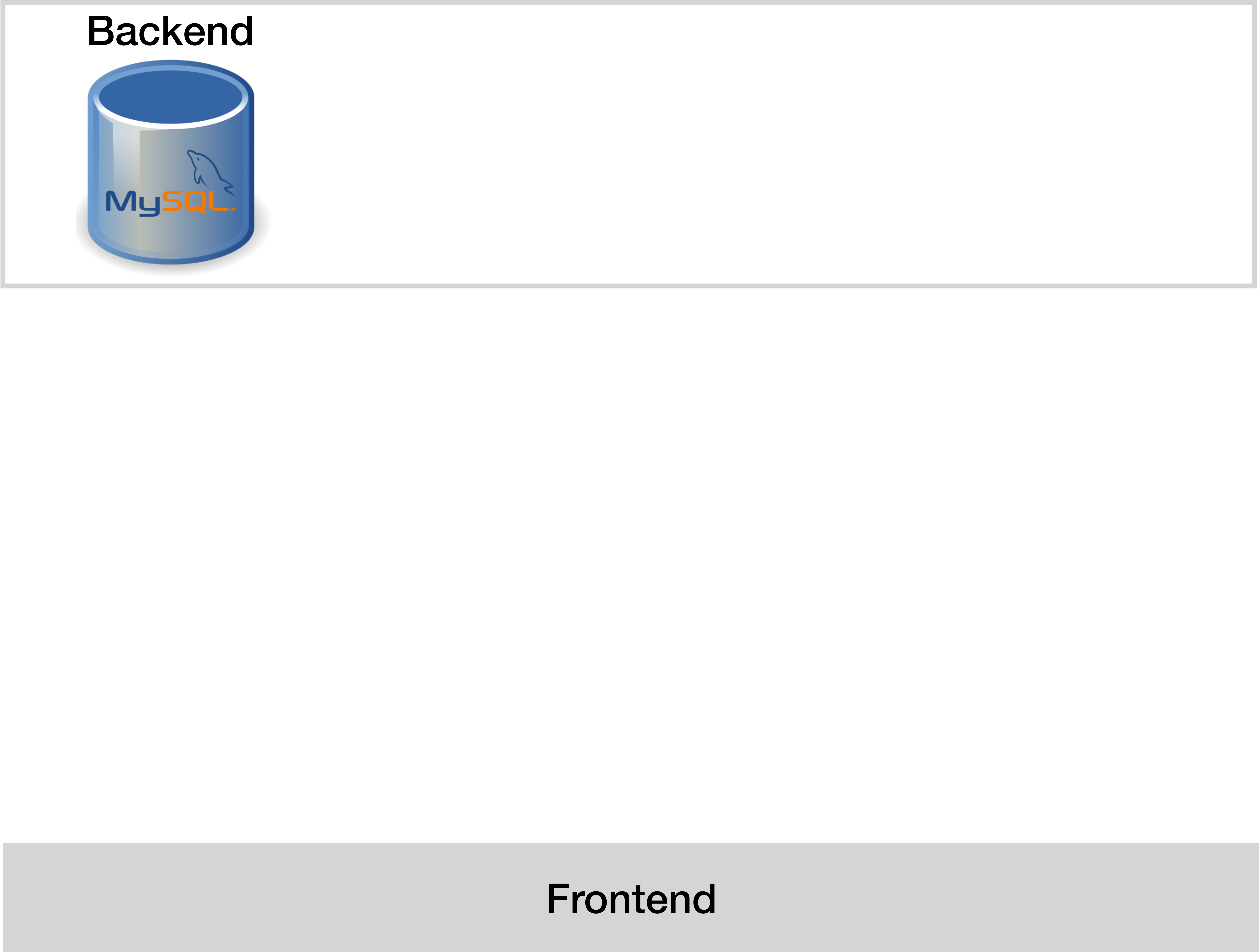


Frontend



Backend

Frontend



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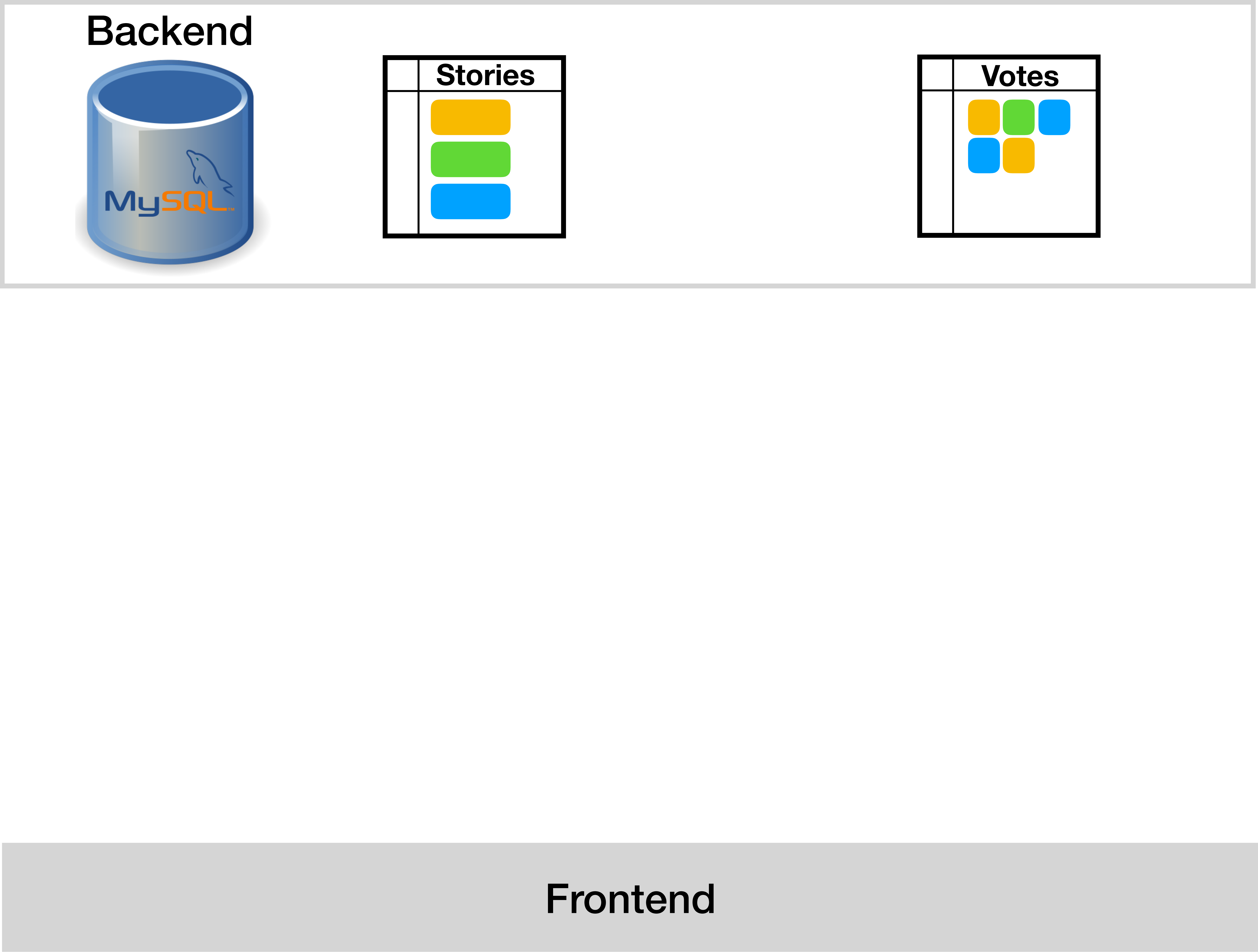

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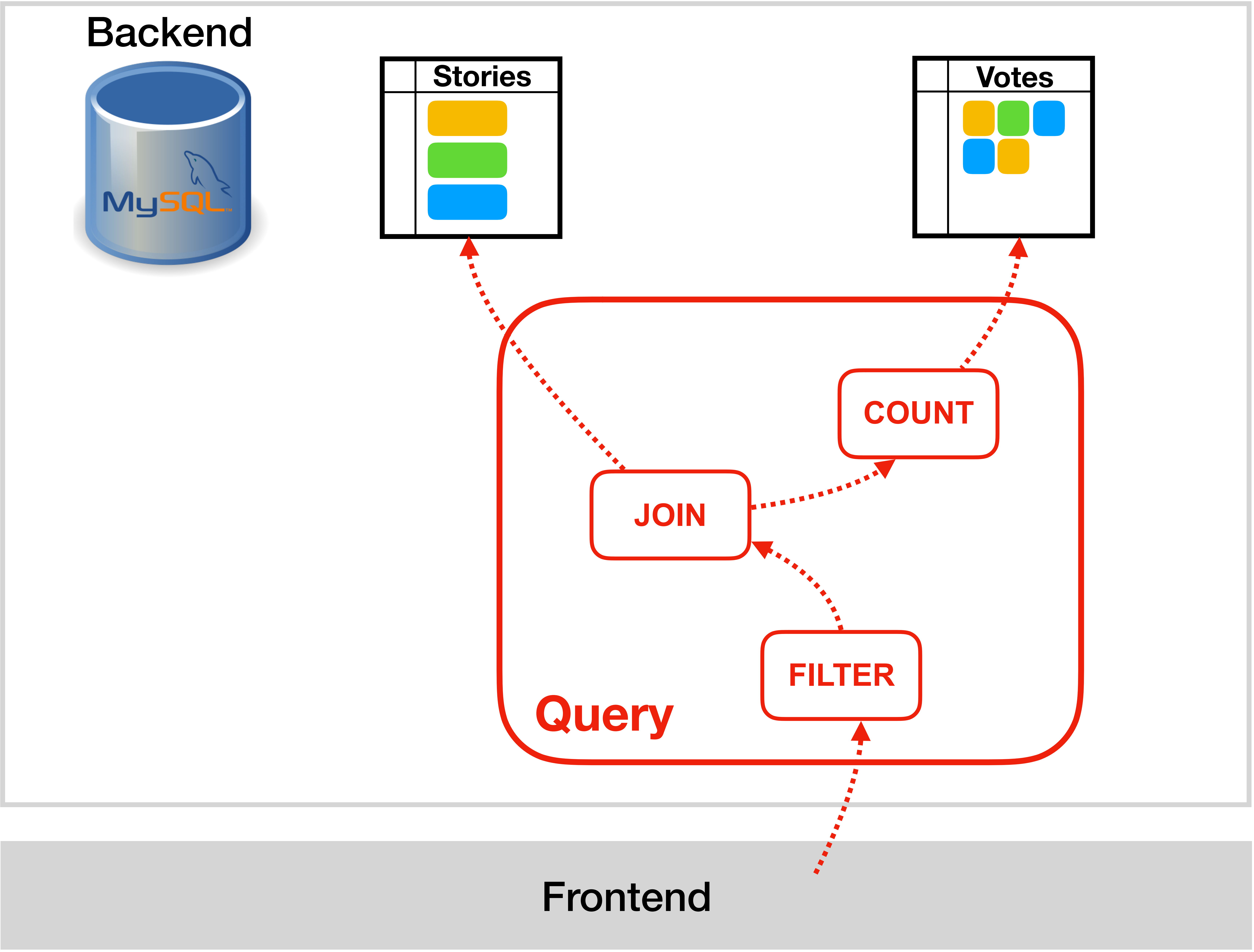
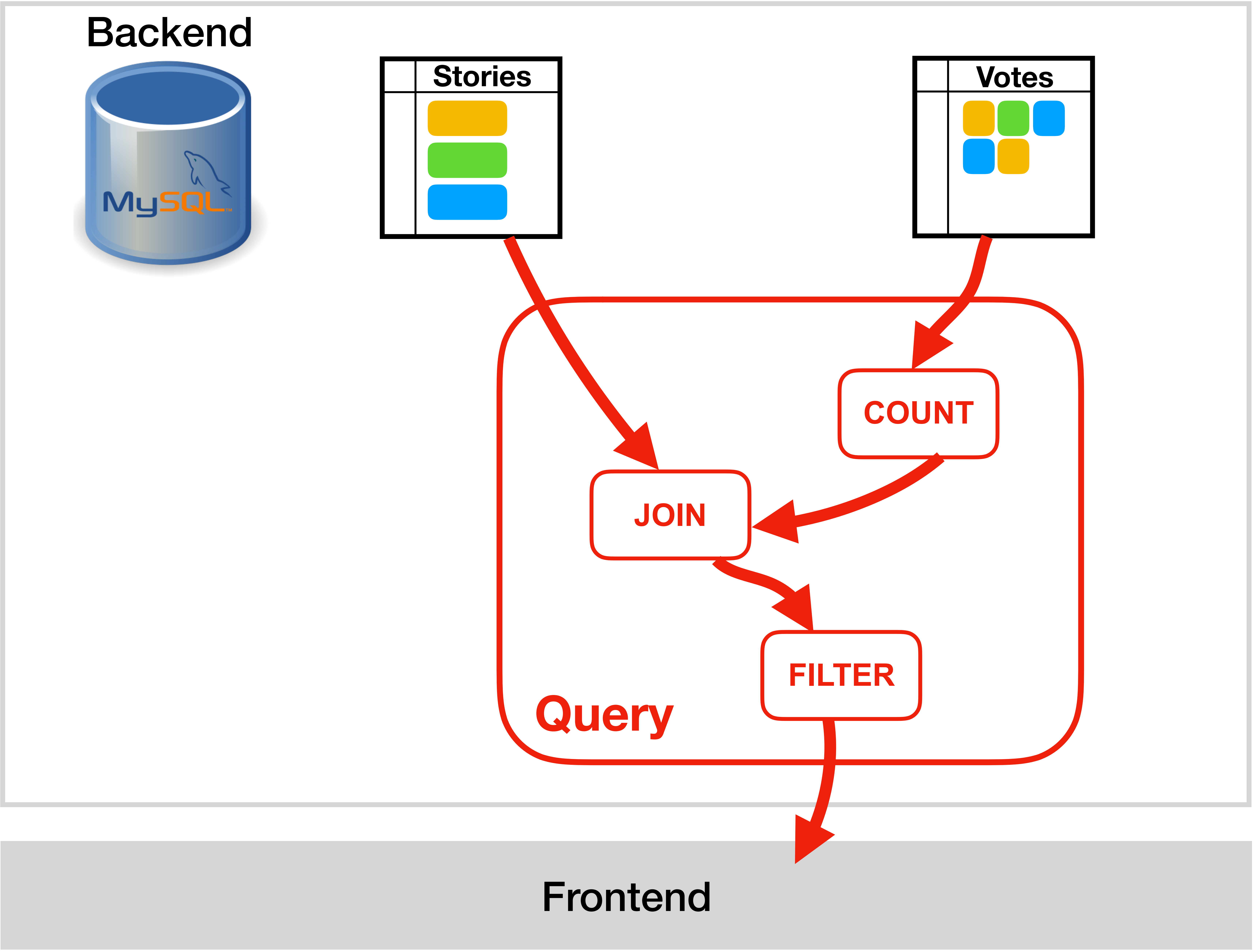

Backend
MySQL
Stories
Votes
COUNT
JOIN
FILTER
Query
Frontend



Backend

Stories

Votes

COUNT

JOIN

FILTER

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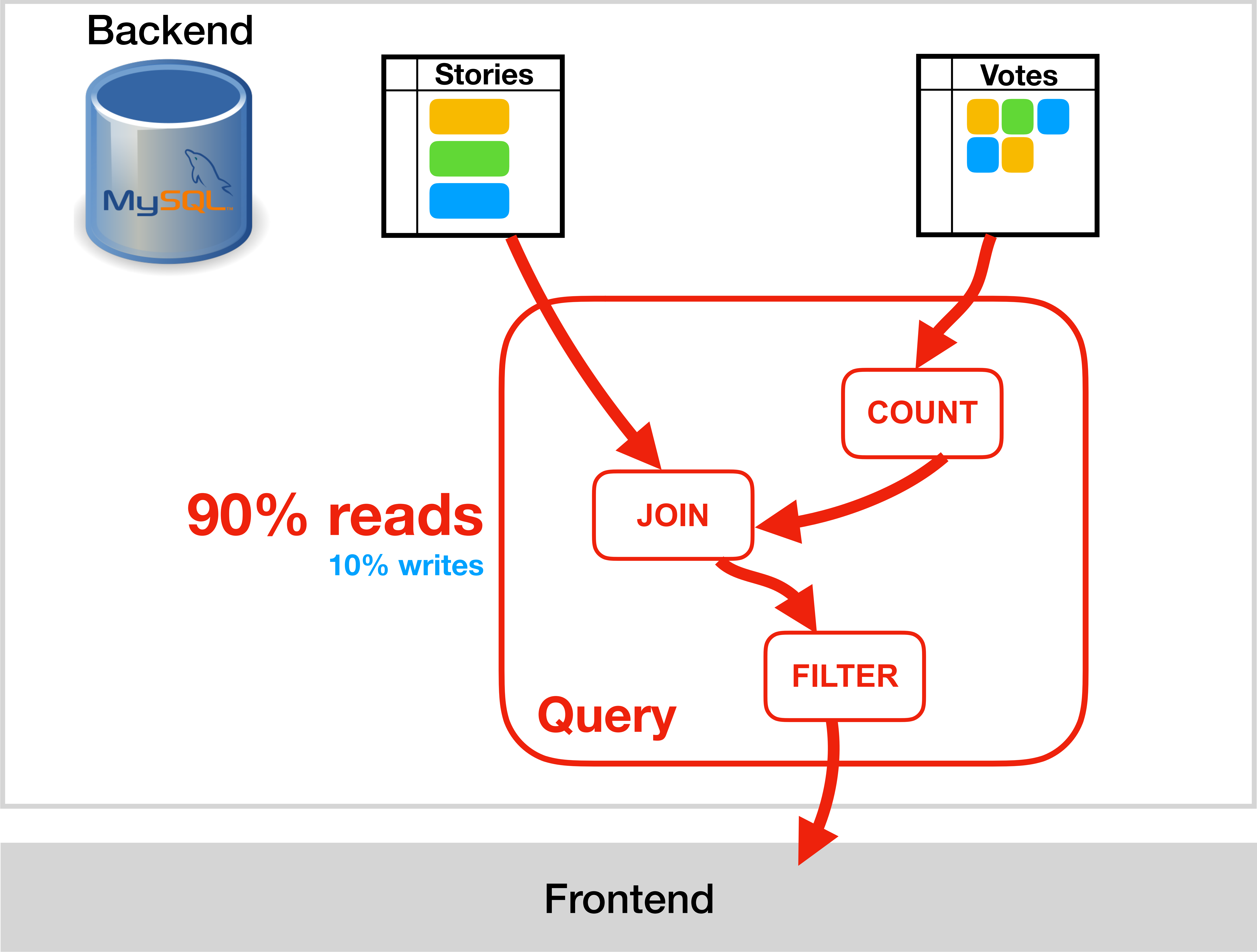
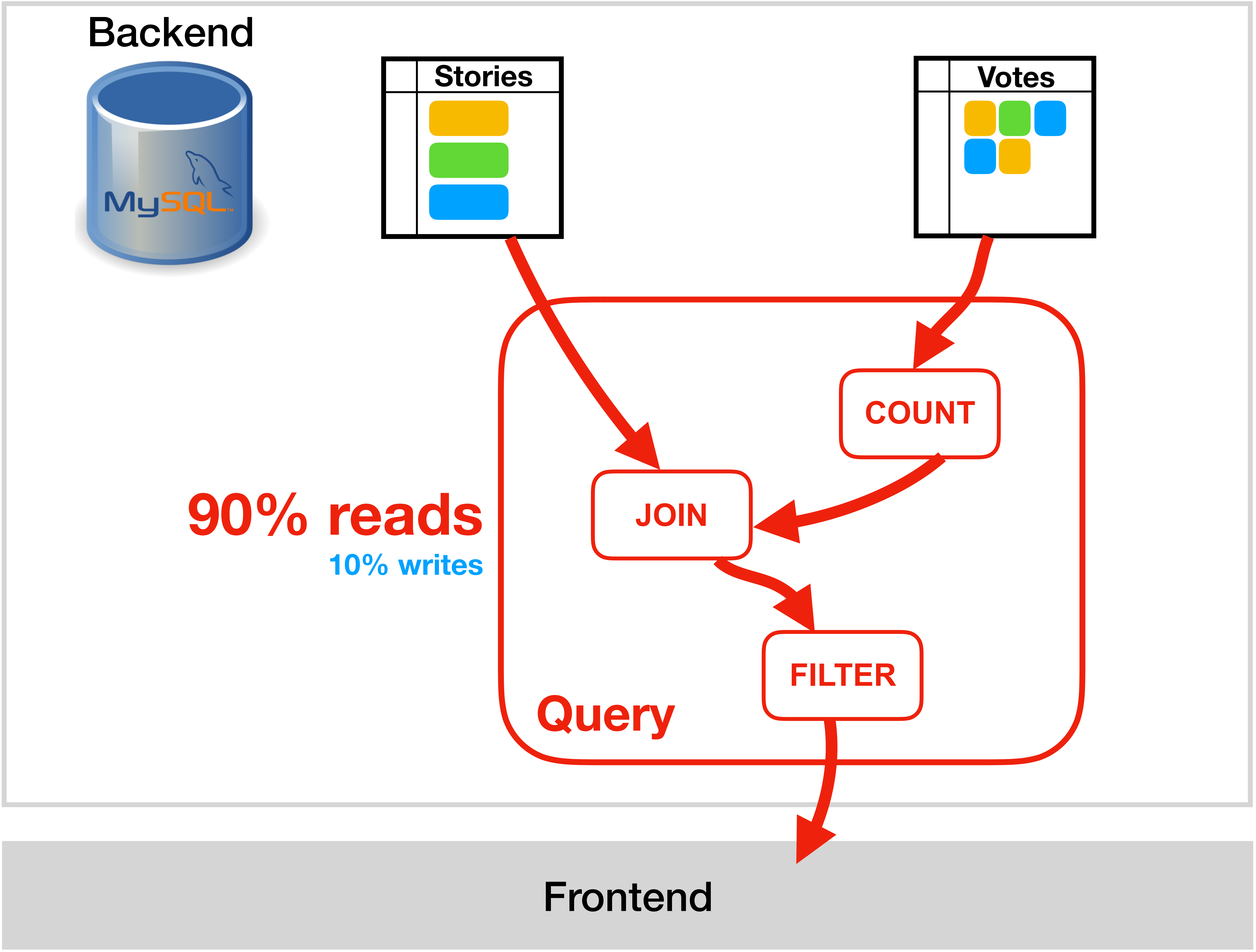


90% reads

10% writes

Slow reads, repeated work!

🙁



Backend

Stories

Votes

COUNT

JOIN

FILTER

Query

90% reads

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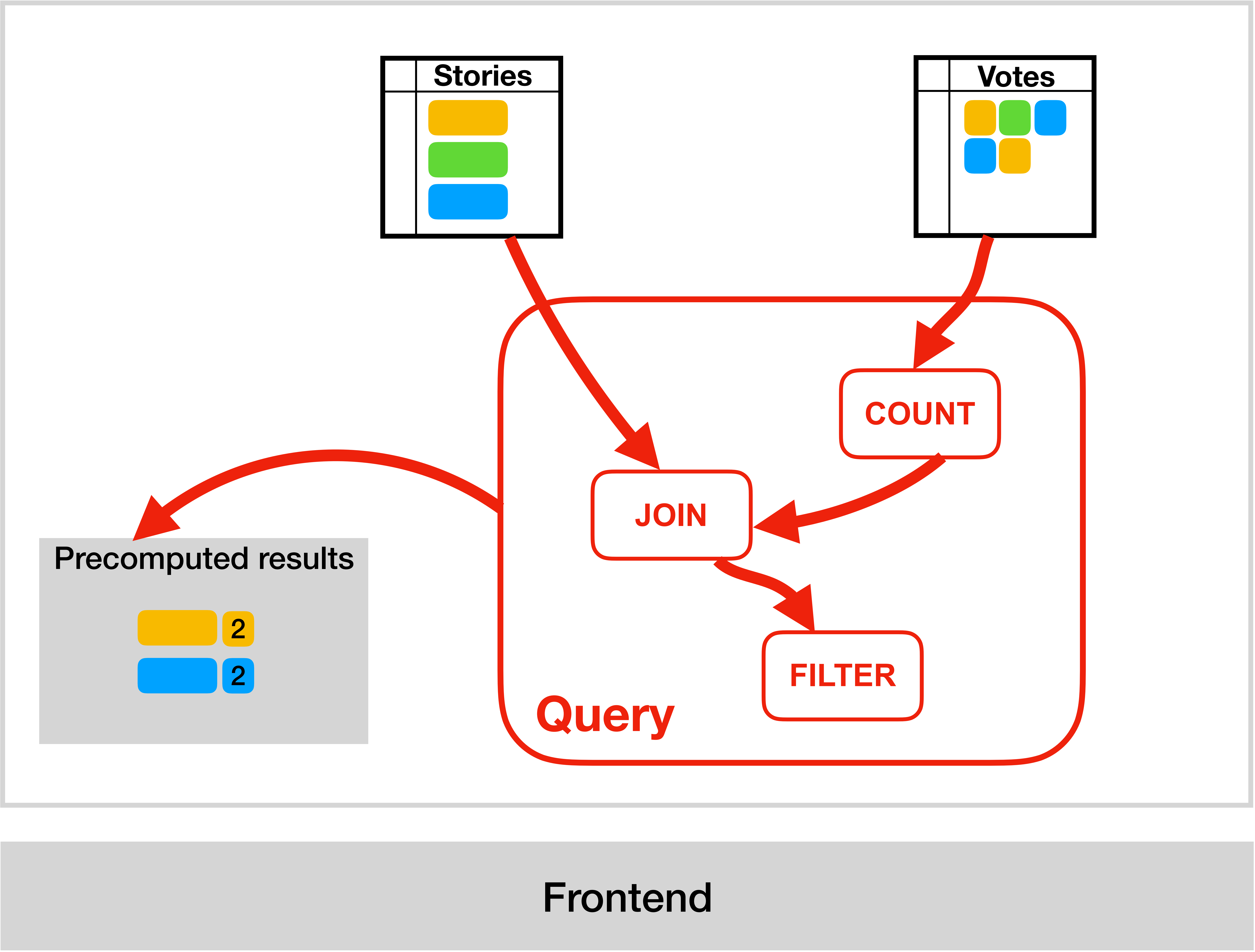
Frontend



Stories

Votes

Query

JOIN

COUNT

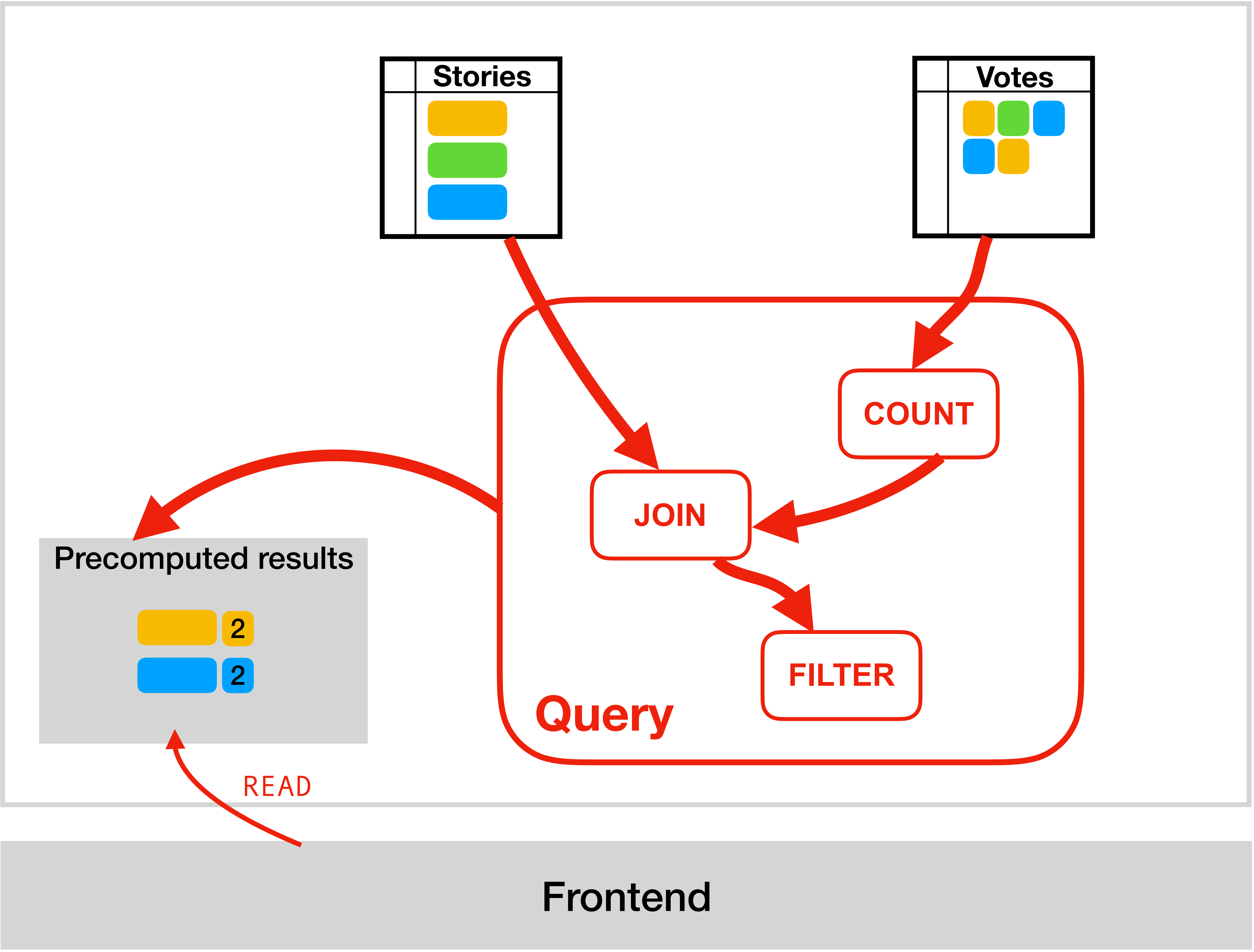
FILTER

Precomputed results

2

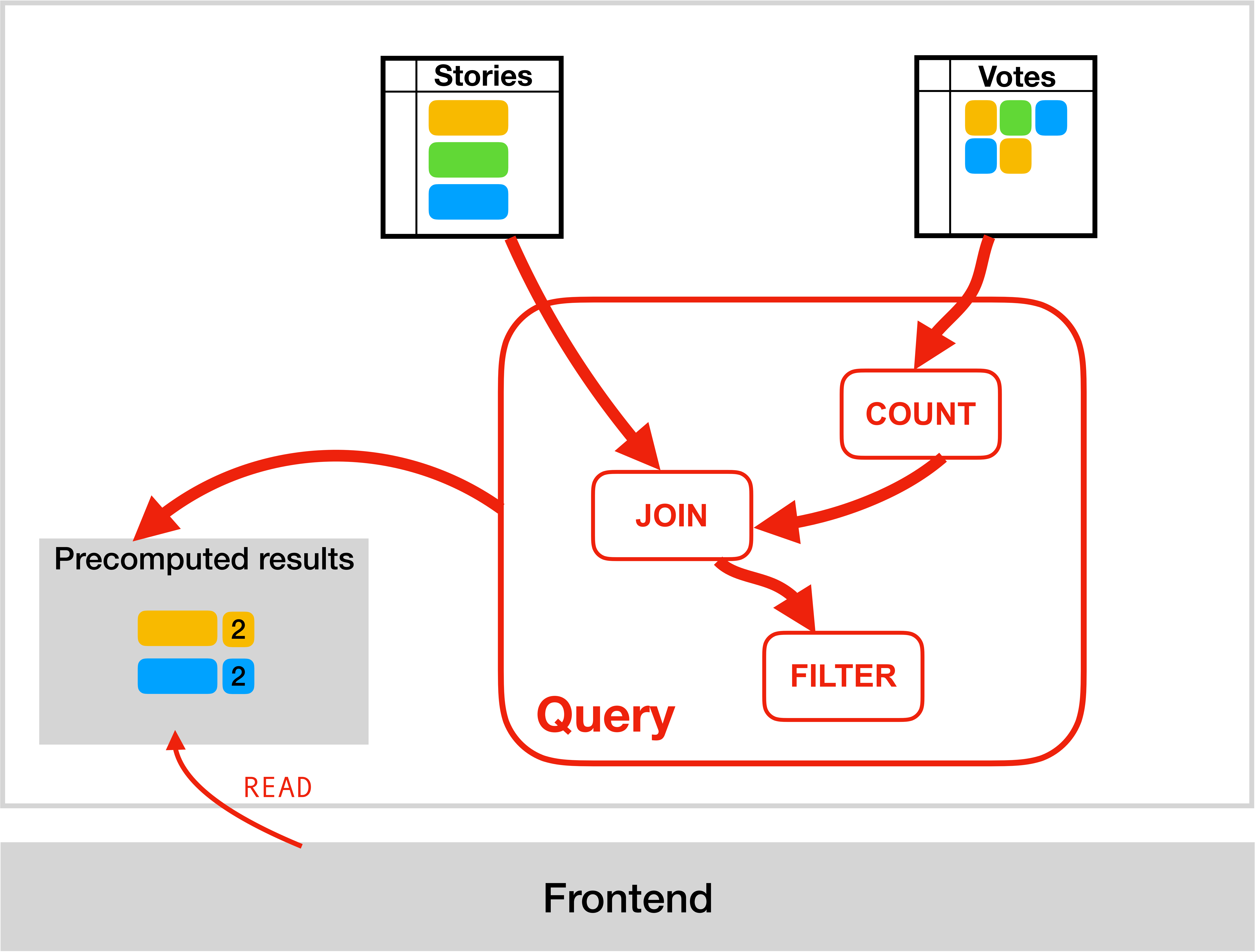
2

Frontend


Stories
Votes
COUNT
JOIN
FILTER
Query
Precomputed results
2
2
READ
Frontend

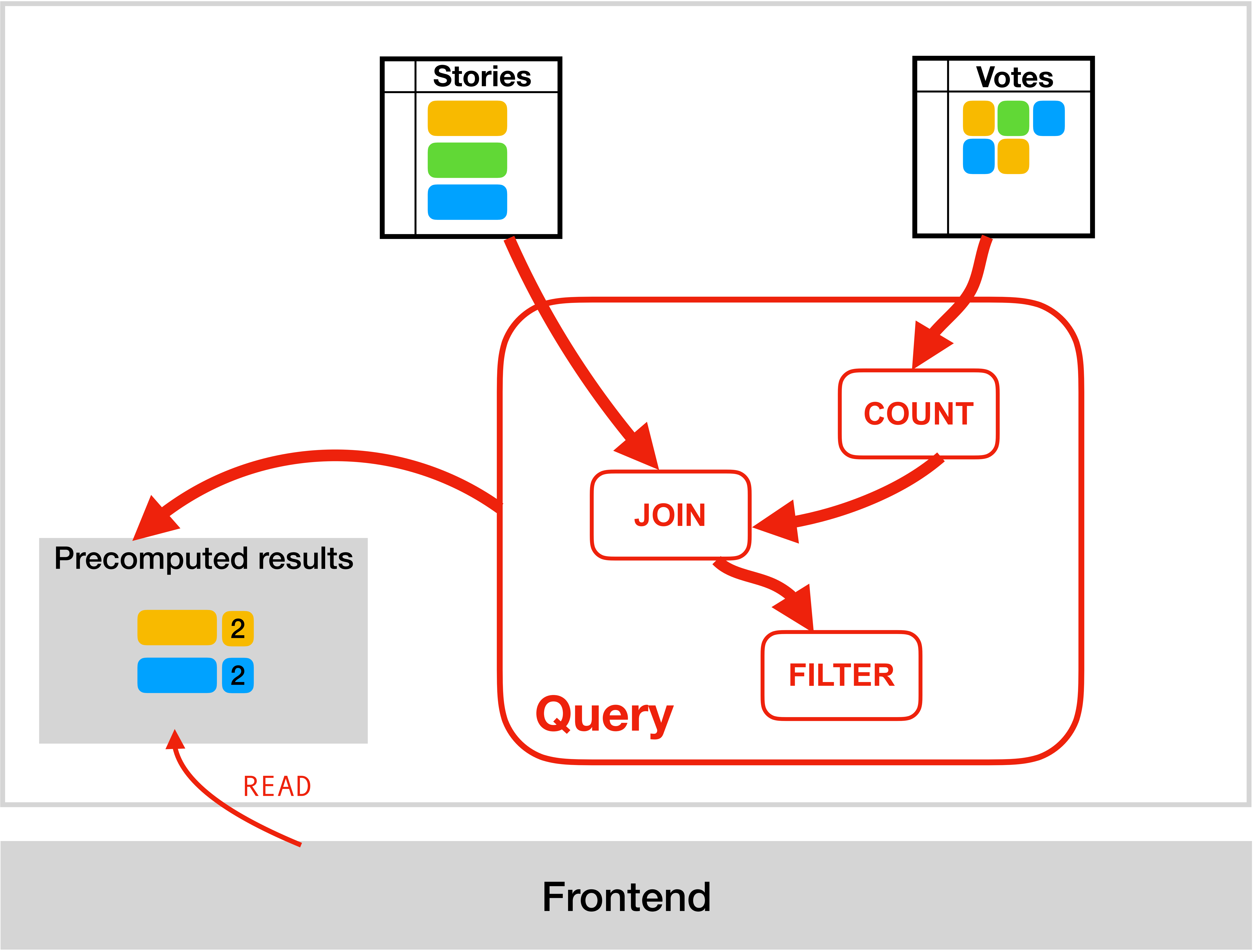
Store in base table?

— manual, slow.



Store in base table?
— **manual, slow**.

memcached?
— **complex** [Facebook NSDI'13].



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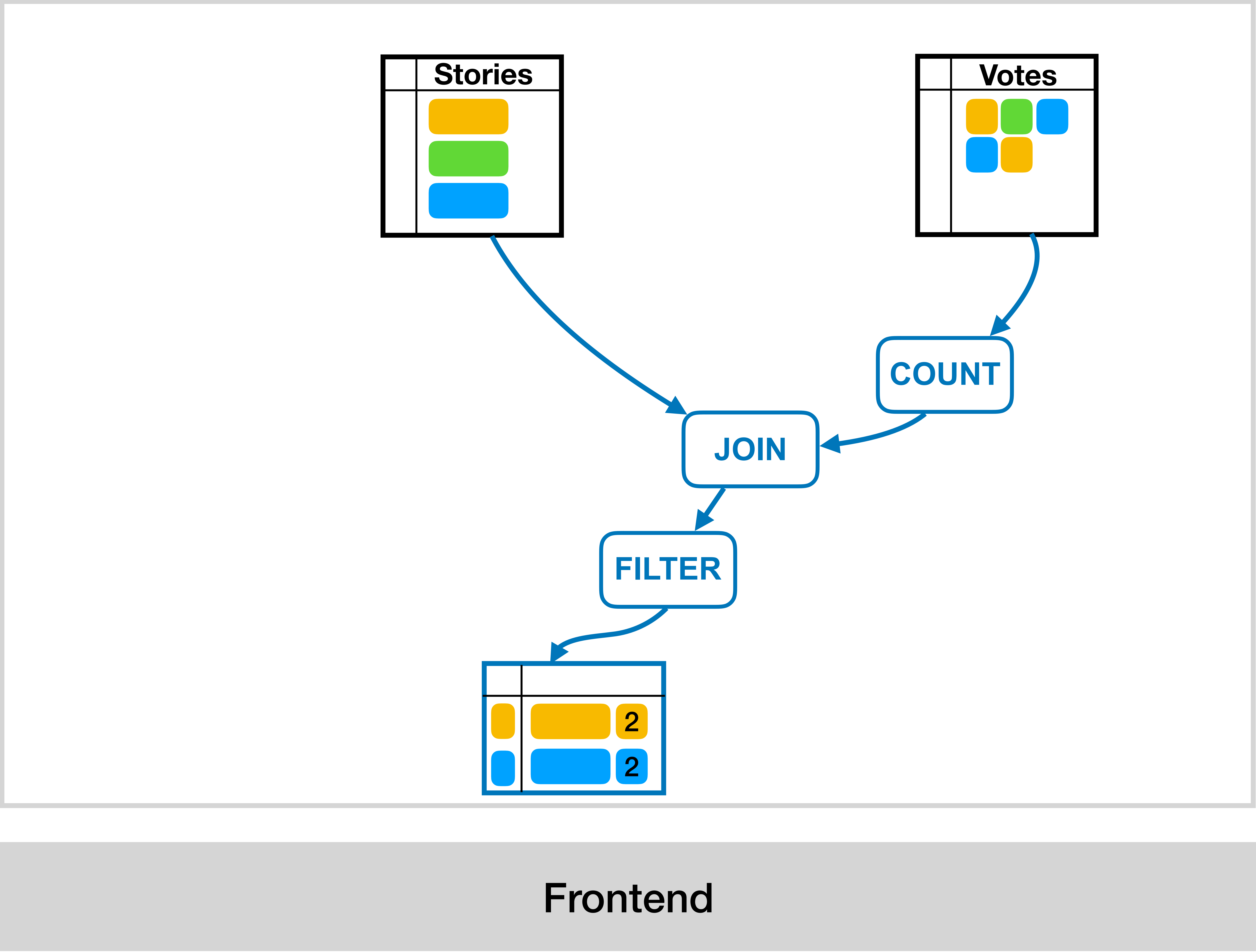
Streaming data-flow?



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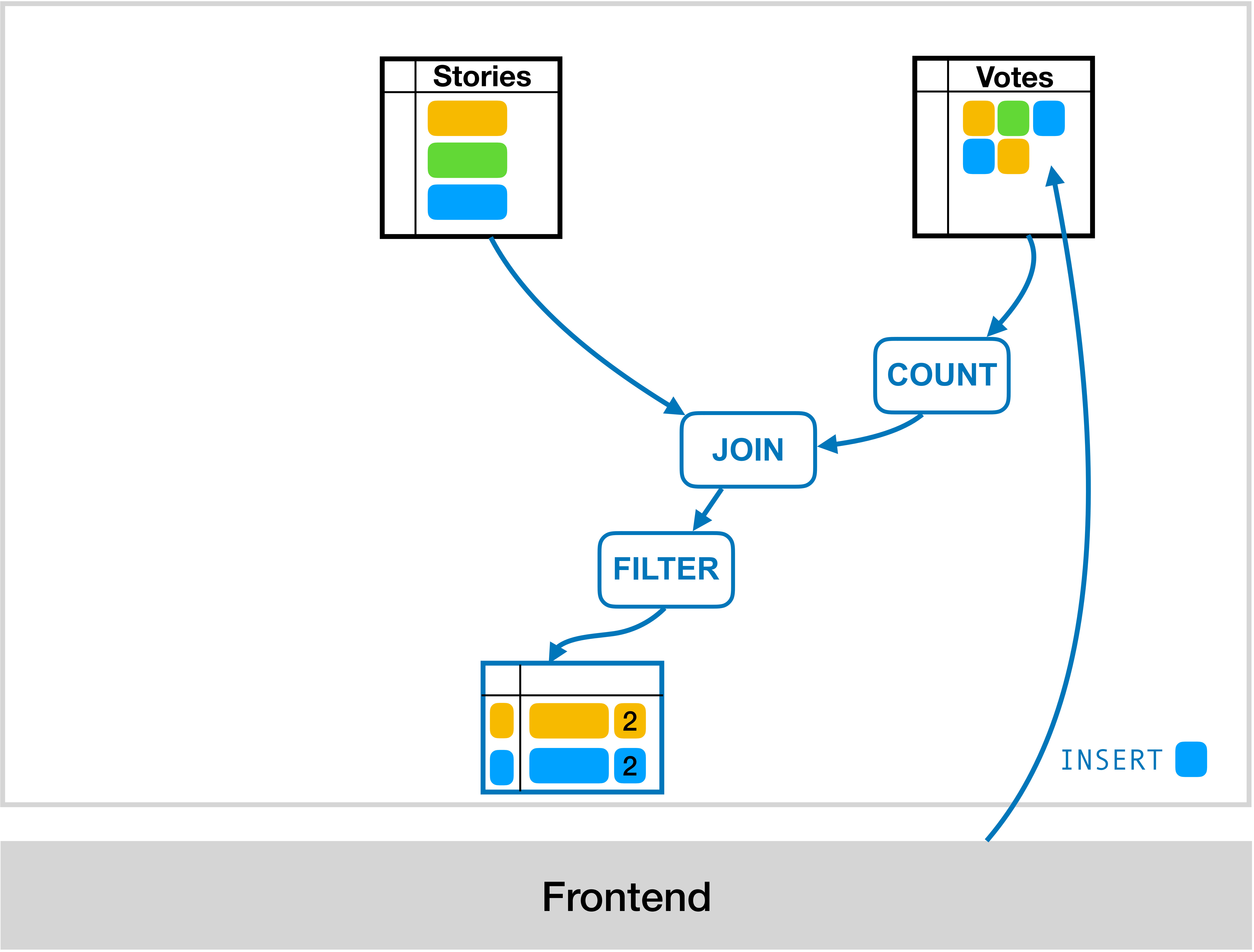

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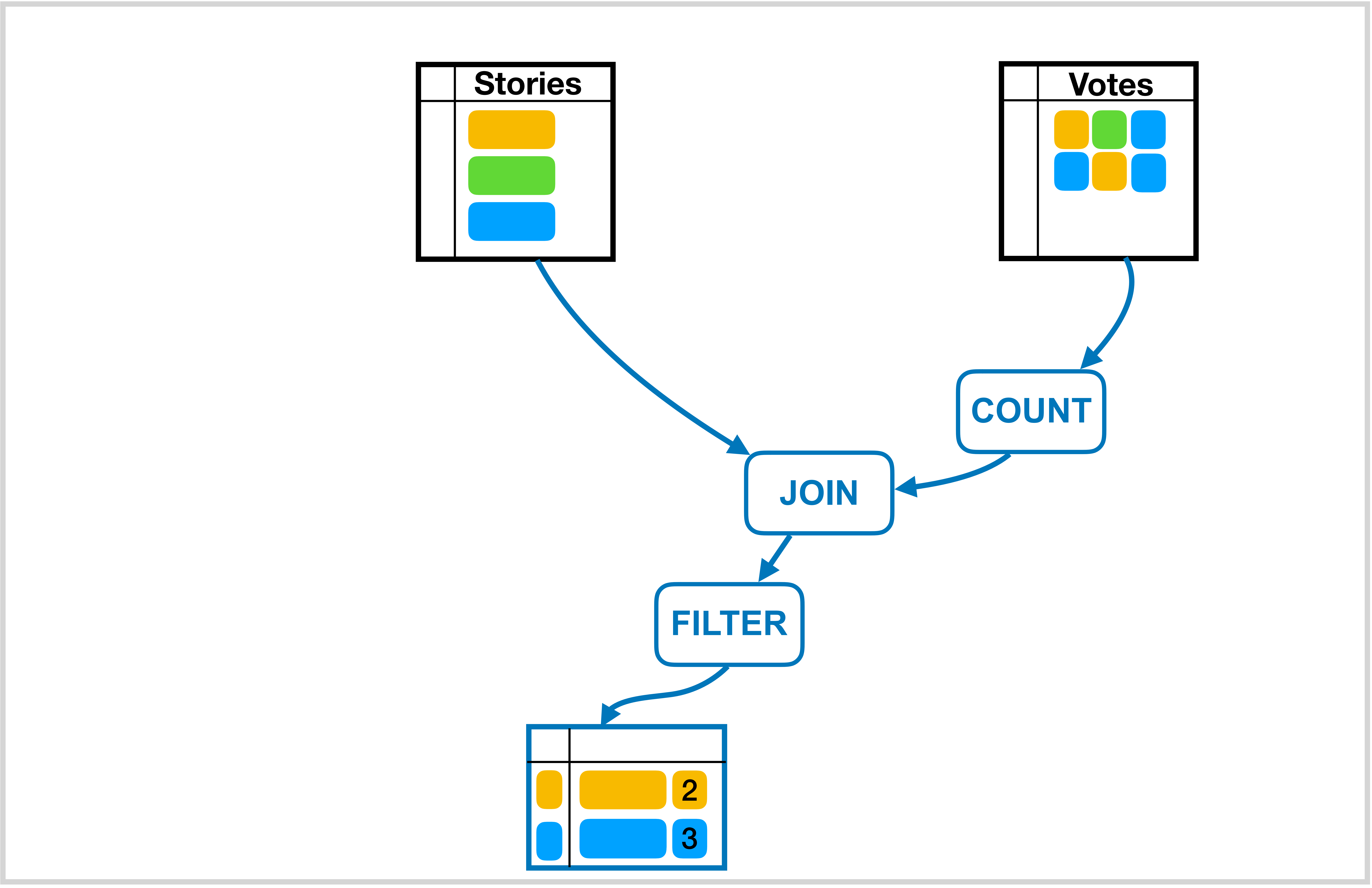
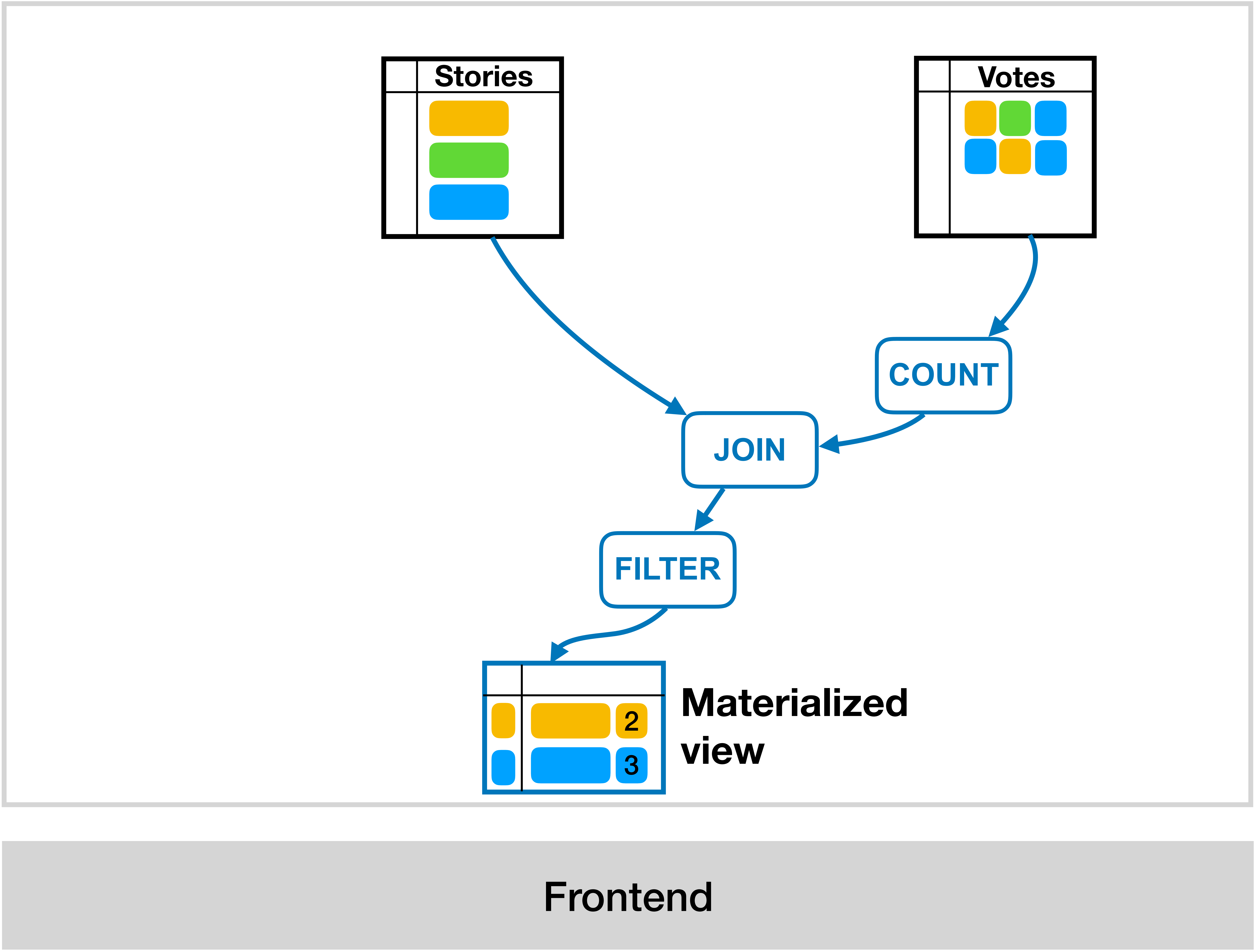


Frontend

Streaming data-flow?



Stories

Votes

COUNT

JOIN

FILTER

2

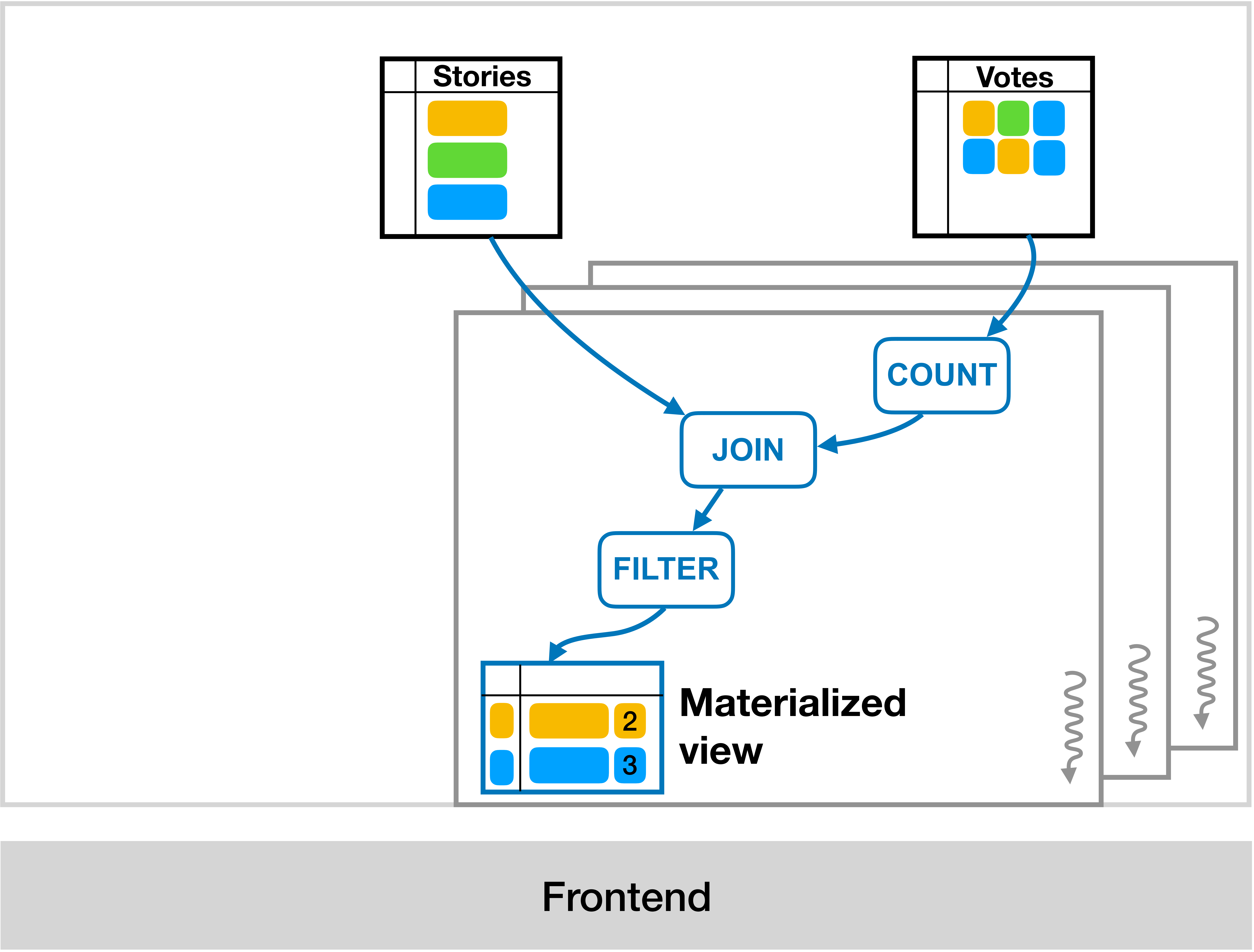
3

Materialized view

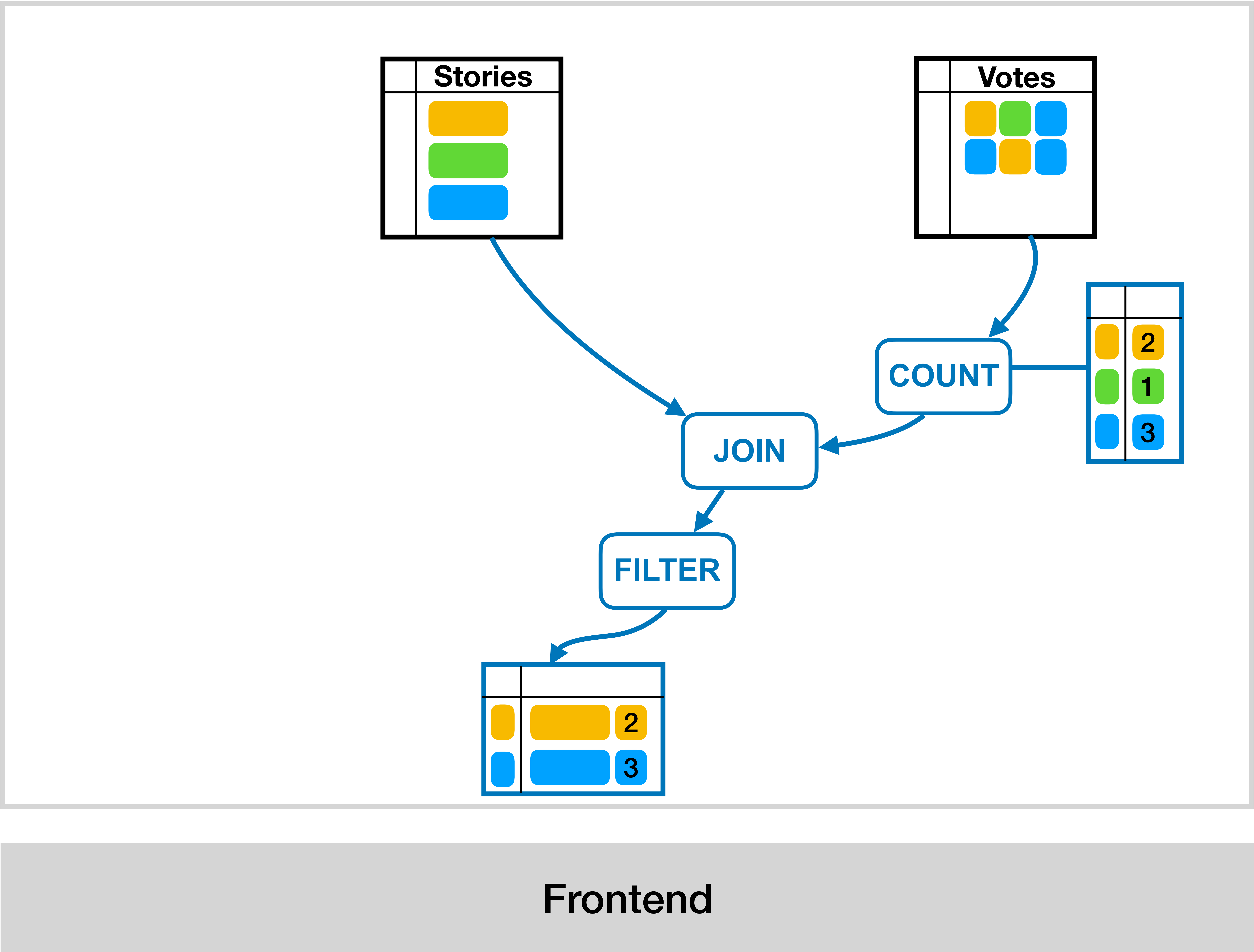
Frontend

Streaming data-flow?

Fast reads.
Efficient writes.
Parallelizes well.



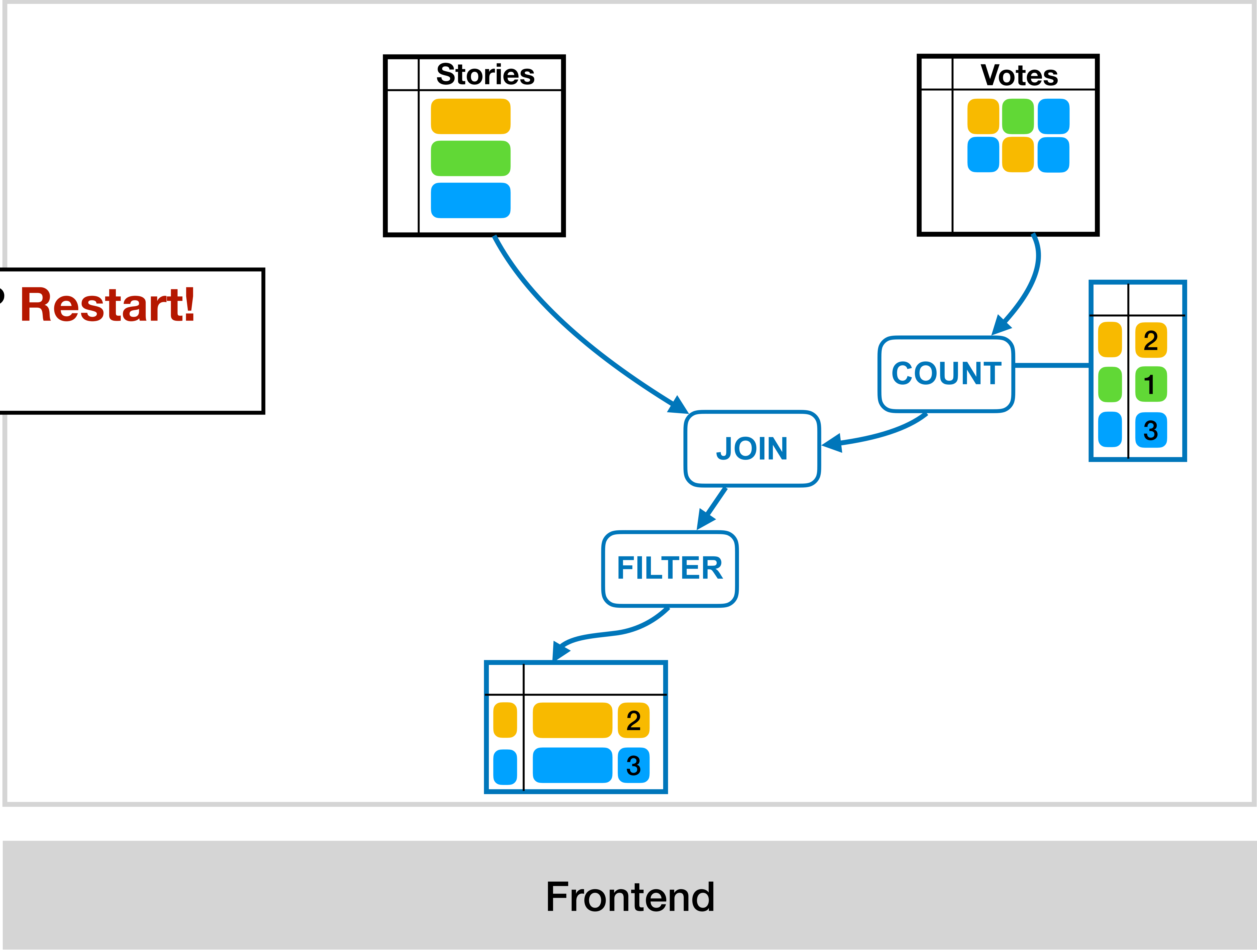
Challenges



Challenges

State-of-the-art data-flow systems:

- **Change queries? Restart!**



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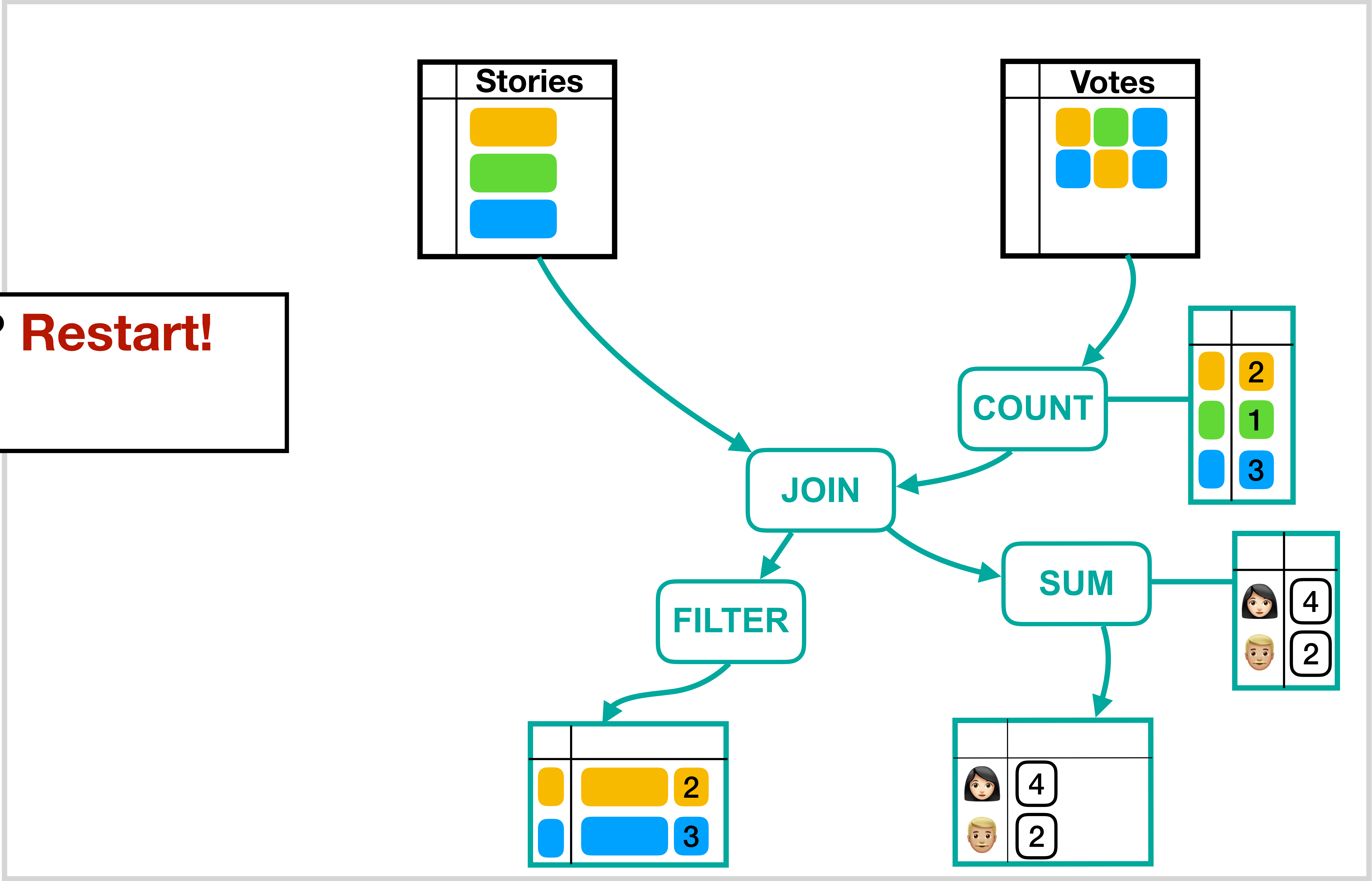
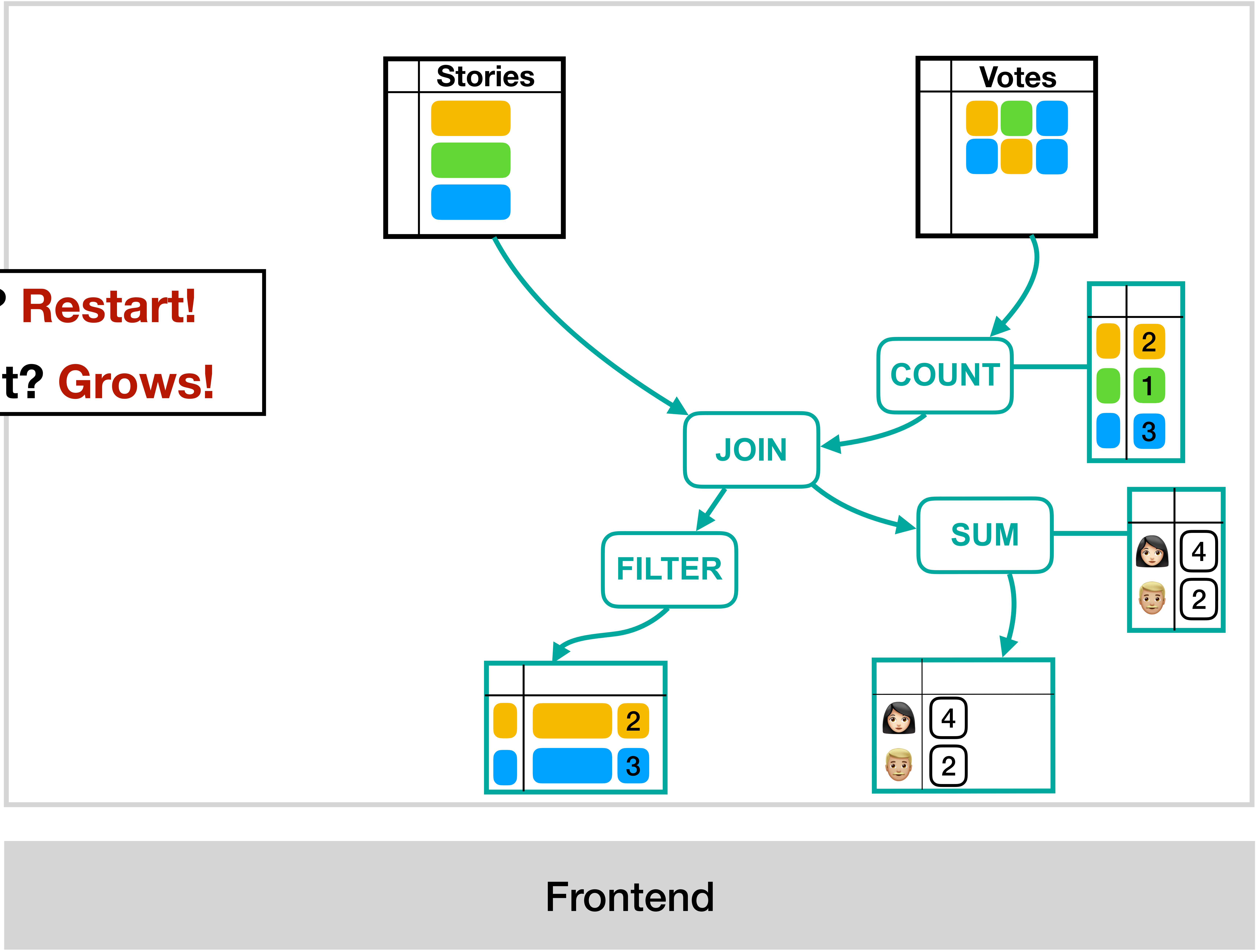


Frontend

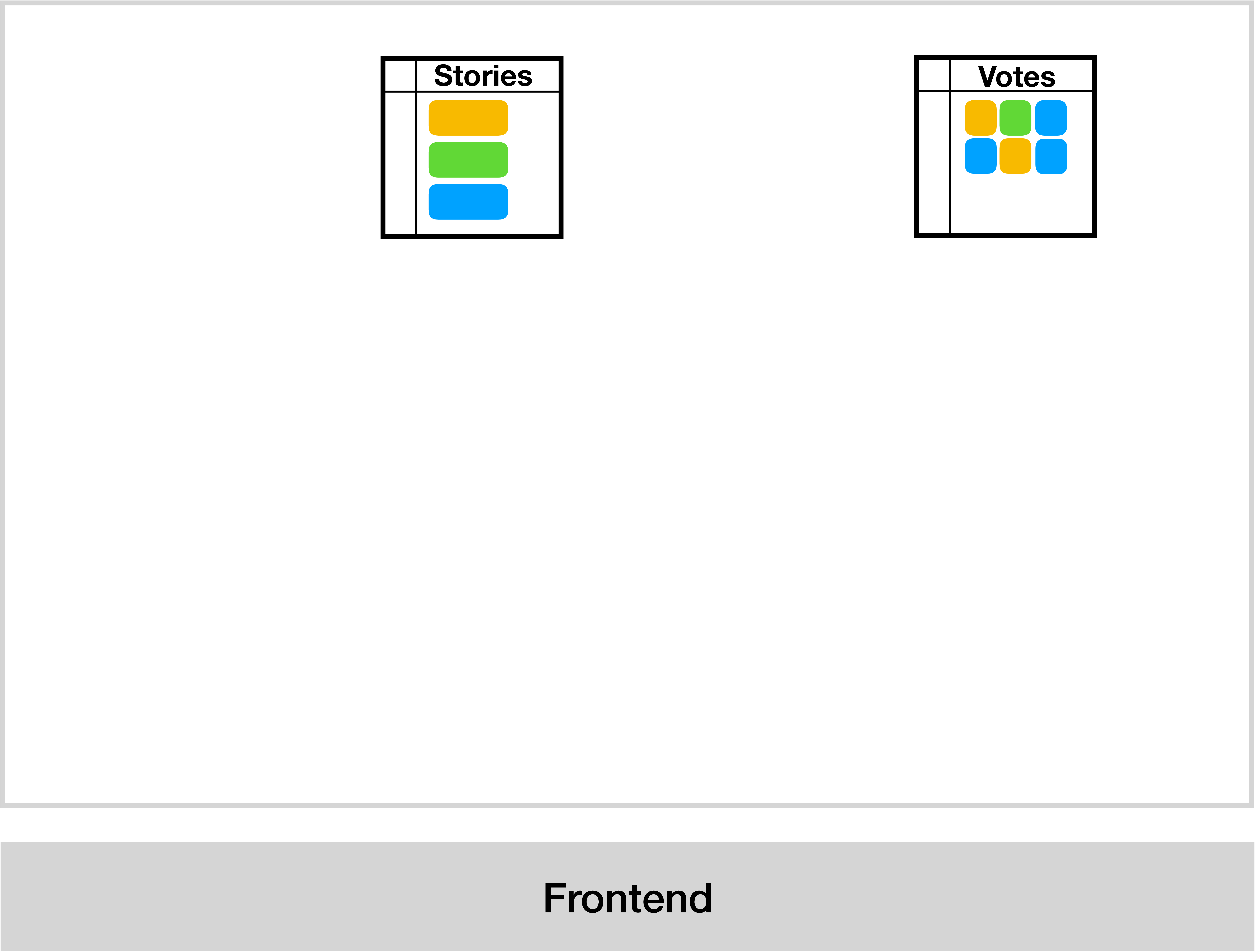
Challenges

State-of-the-art
data-flow systems:

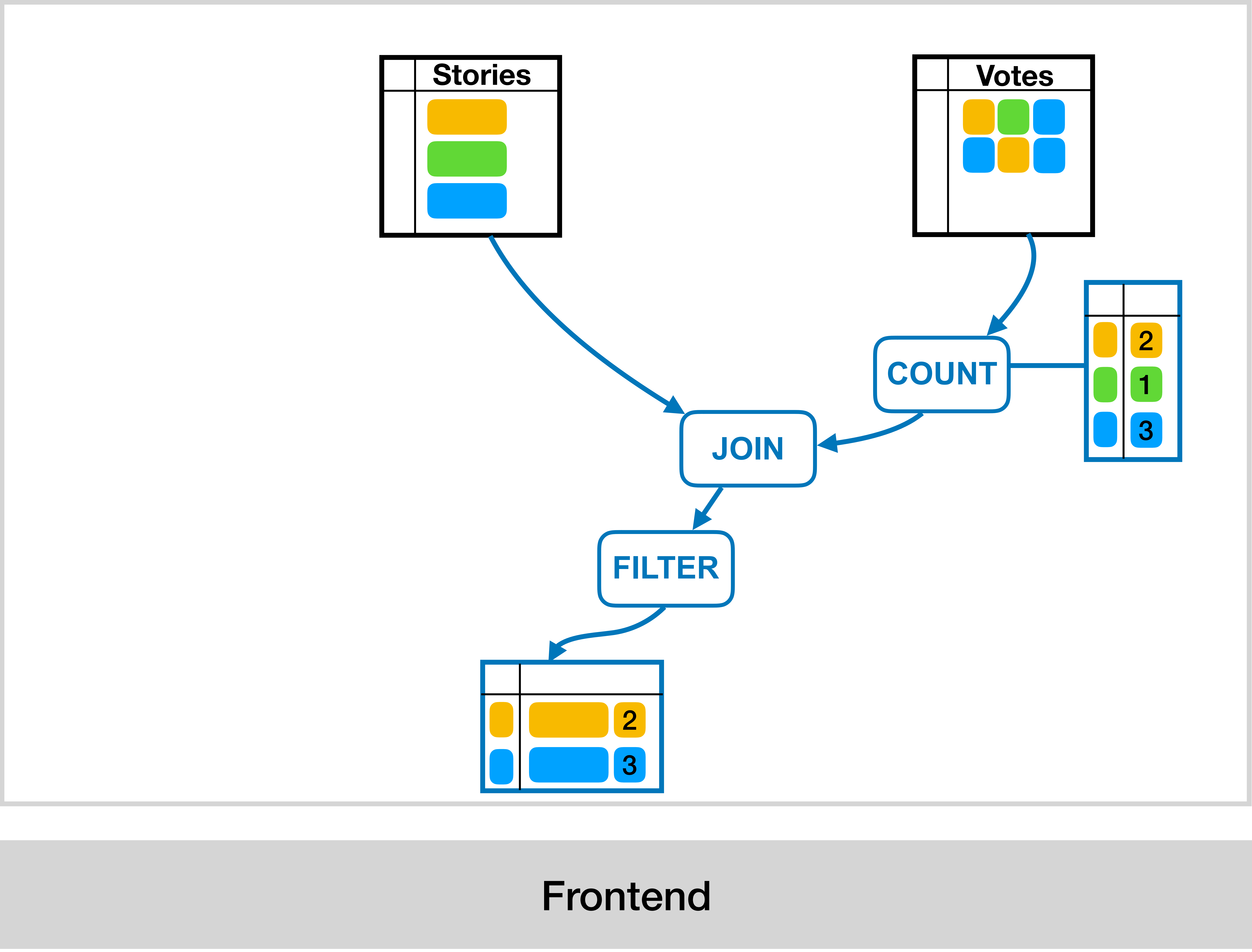
- **Change queries? Restart!**
- **Memory footprint? Grows!**



Noria

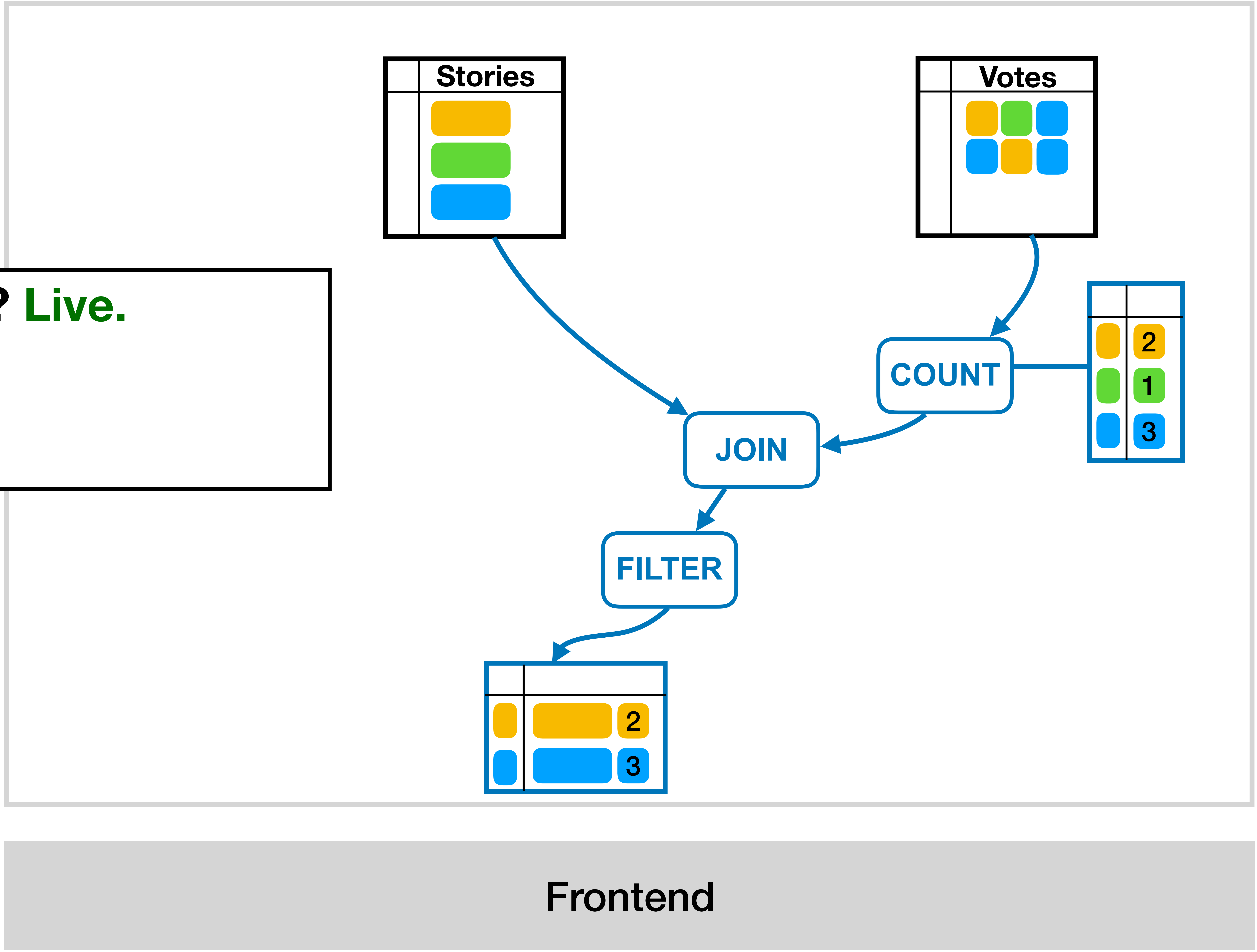


Noria



Noria

- **Change queries? Live.**



Noria

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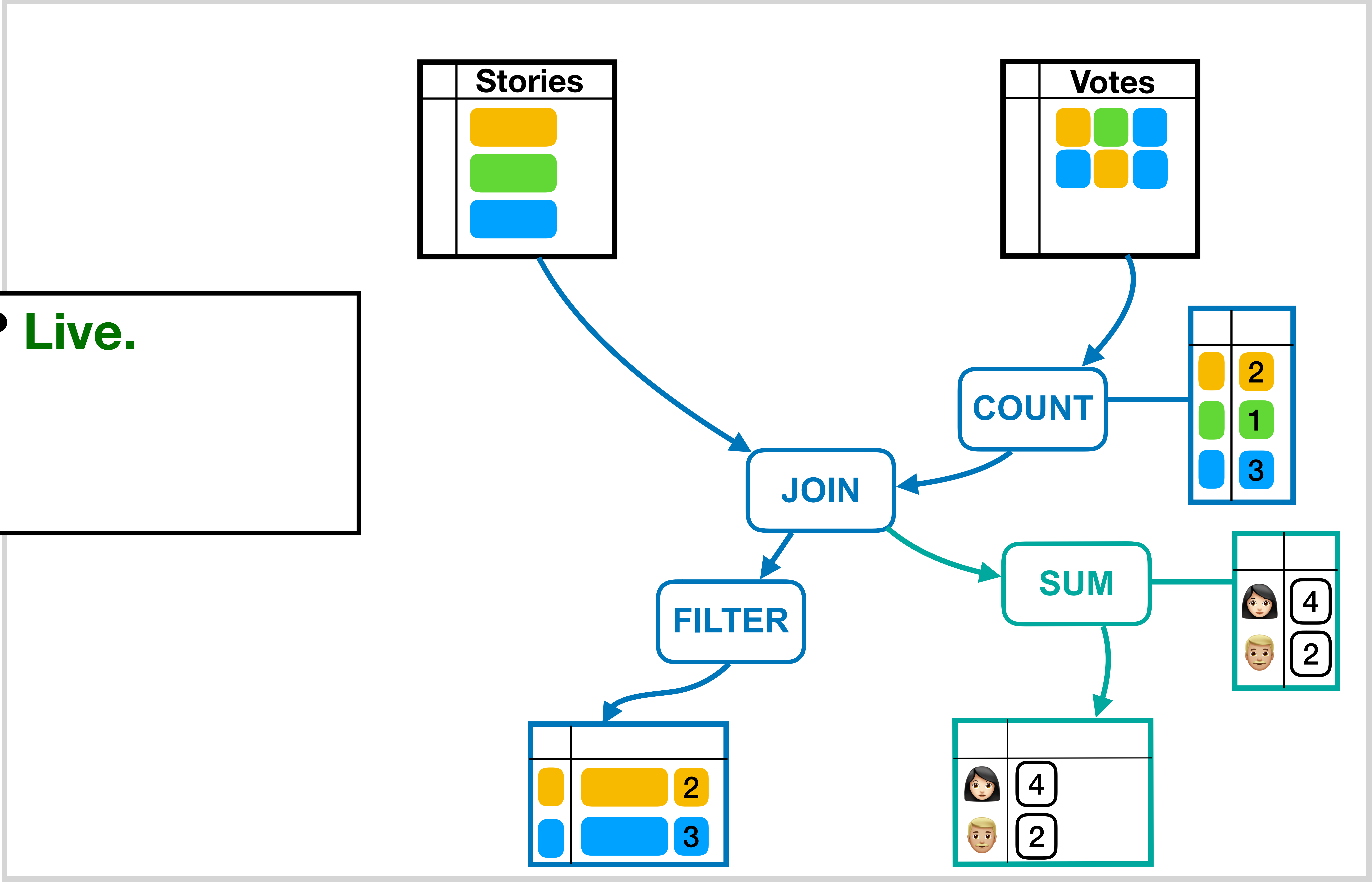
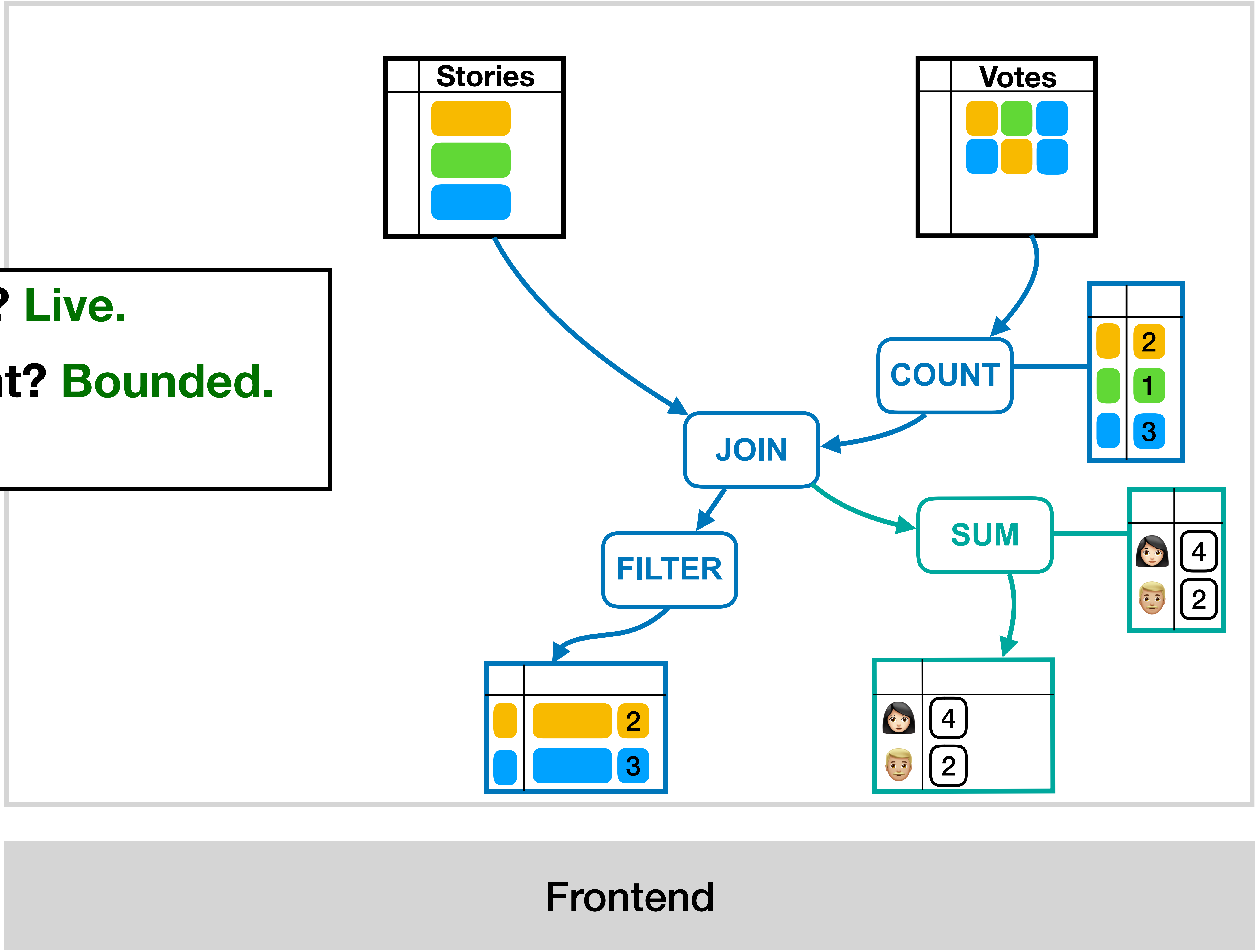


Frontend

Noria

- Change queries? **Live.**
- Memory footprint? **Bounded.**



Noria

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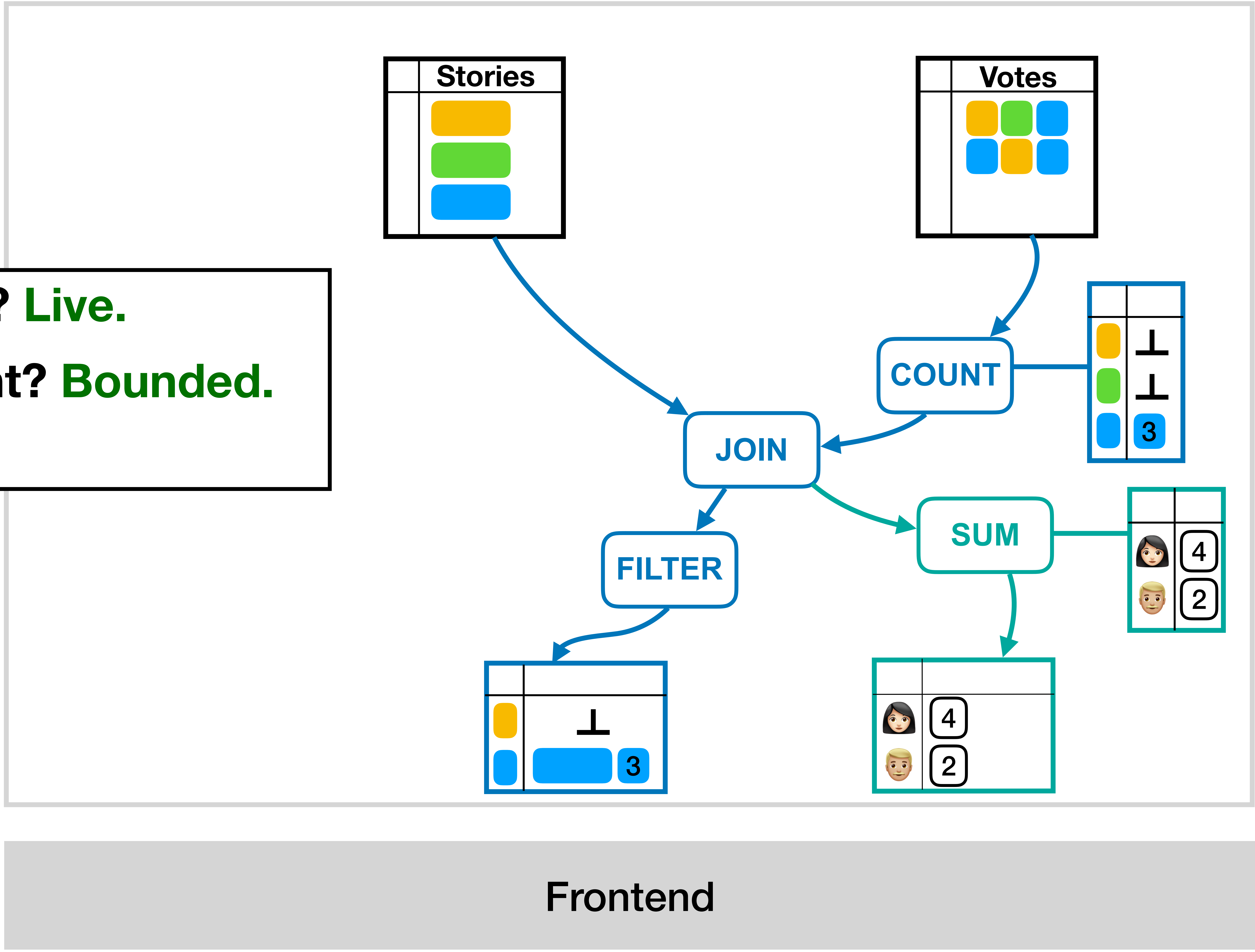
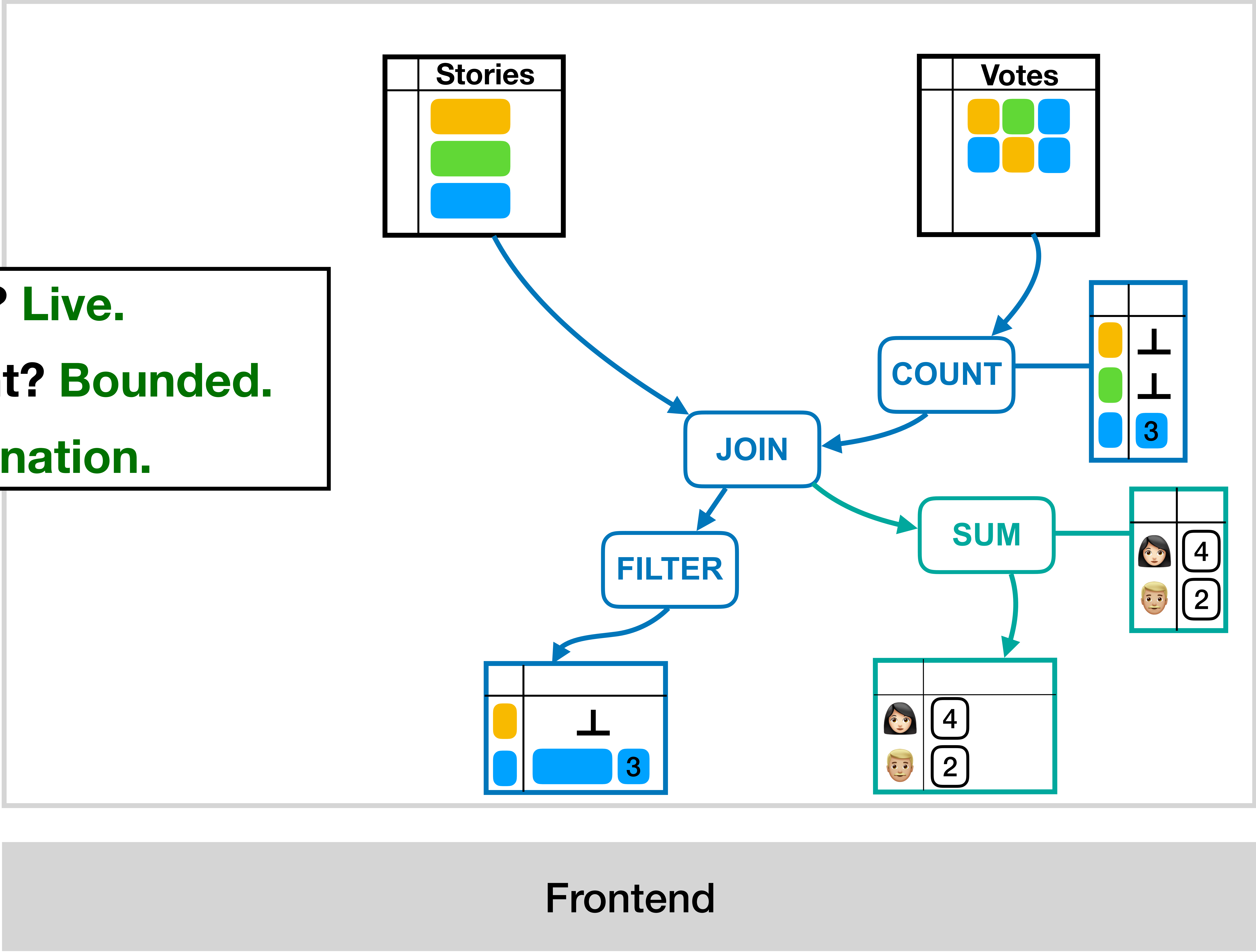


Noria

- Change queries? **Live.**
- Memory footprint? **Bounded.**
- **No global coordination.**

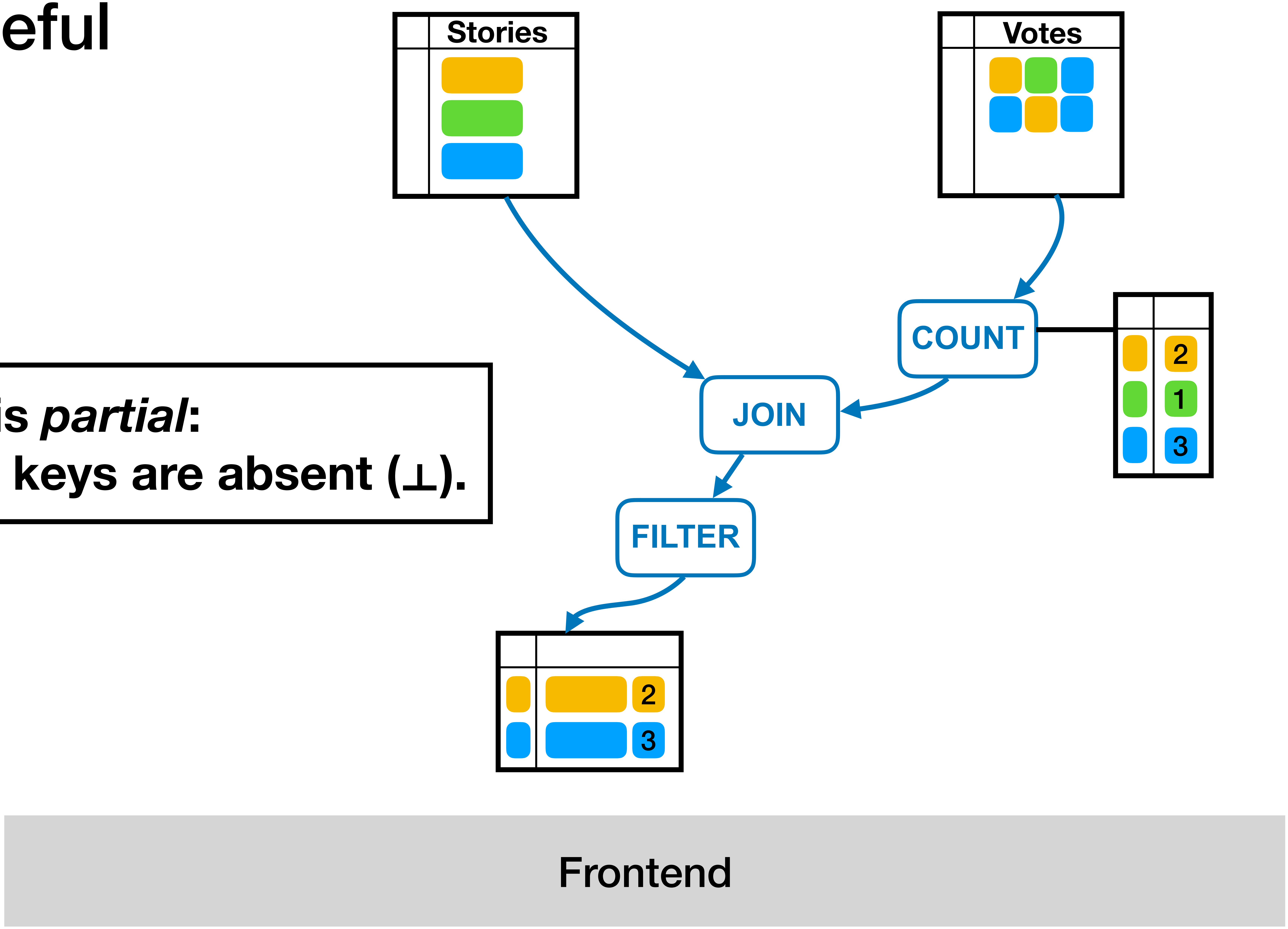


New model:

Partially-stateful data-flow

Partially-stateful data-flow

**Data-flow state is *partial*:
entries for some keys are absent (⊥).**



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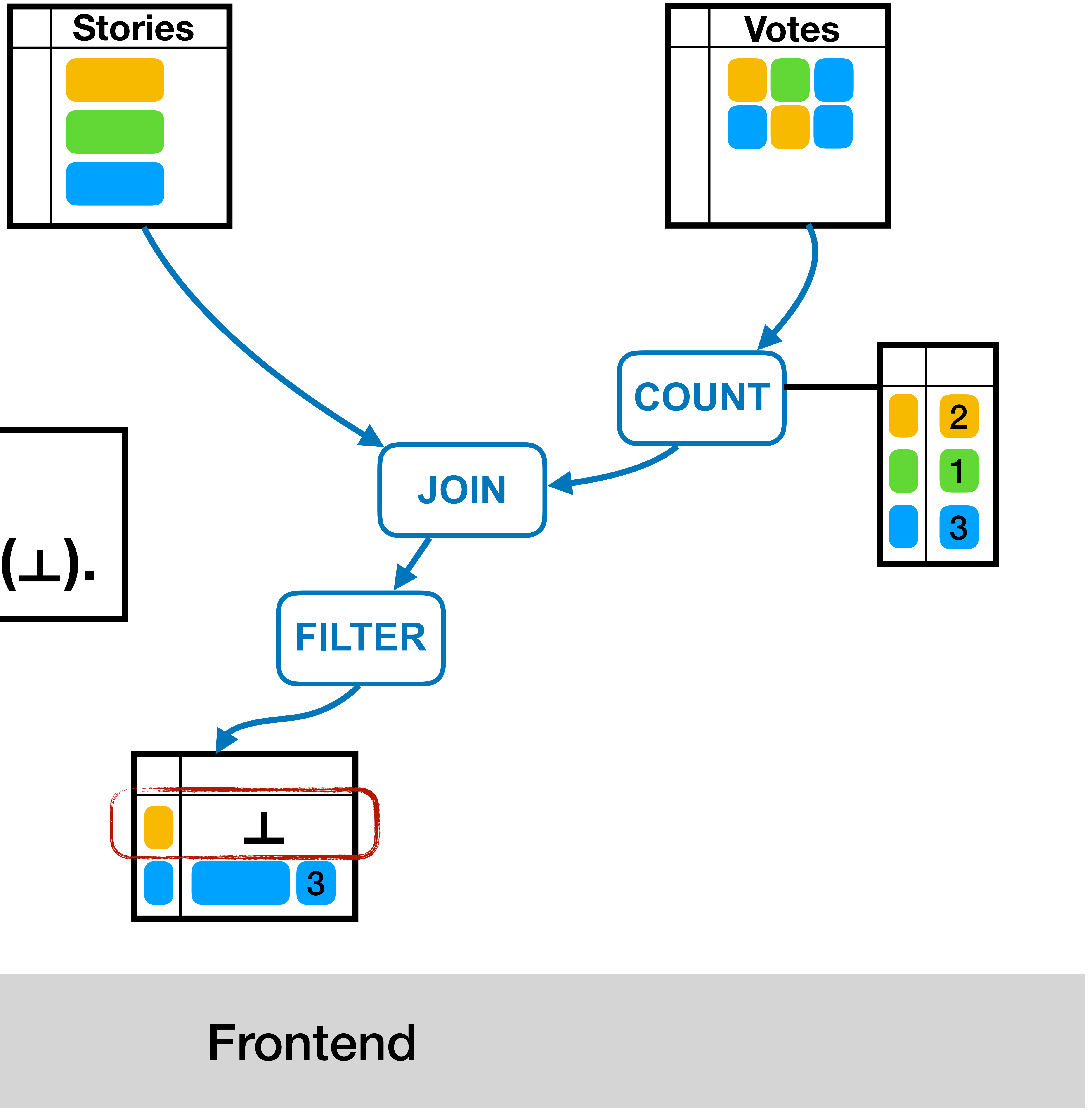

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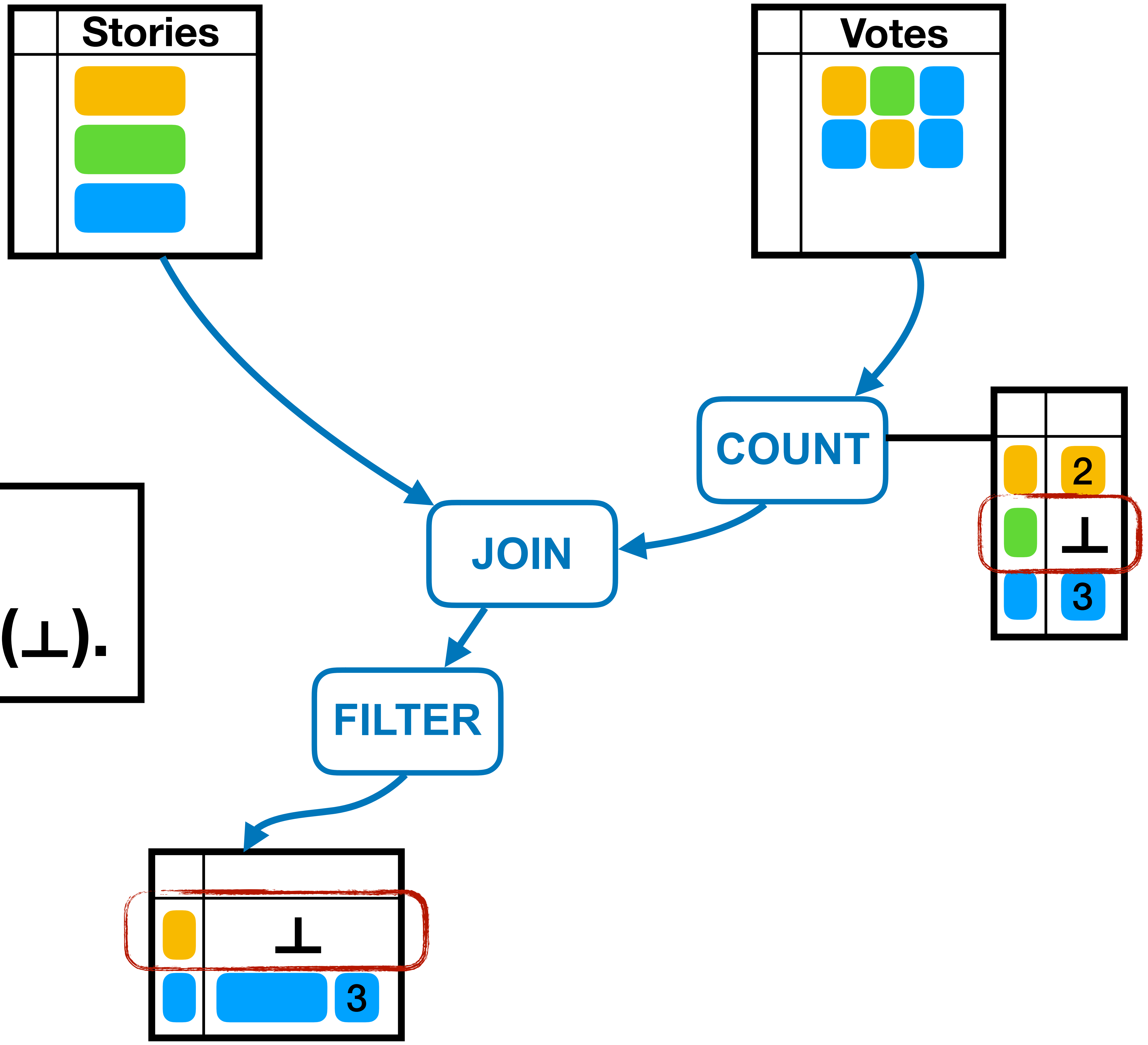

Frontend

Partially-stateful data-flow

Data-flow state is *partial*:
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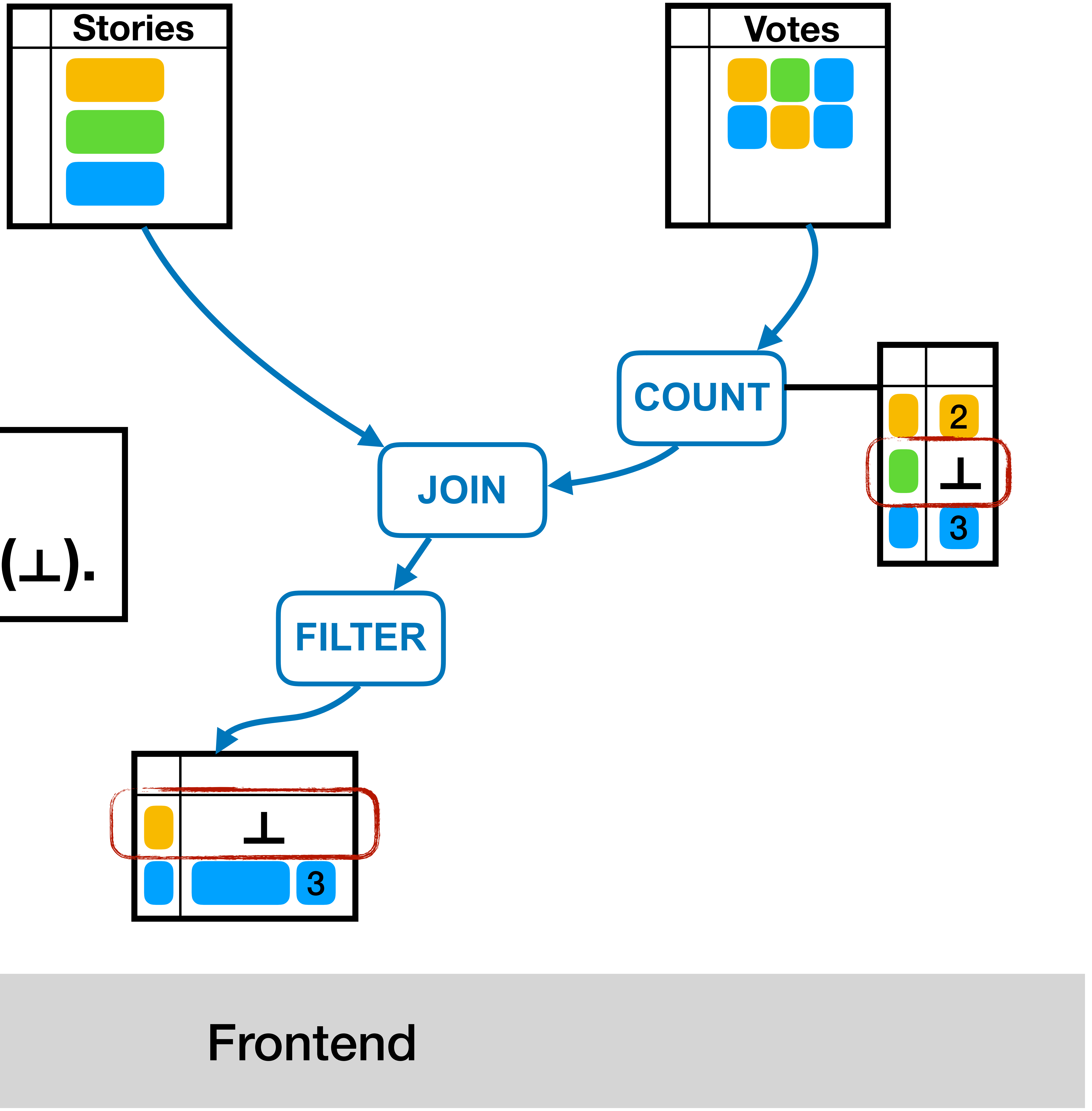
Lower memory footprint.



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Data-flow state is *partial*:
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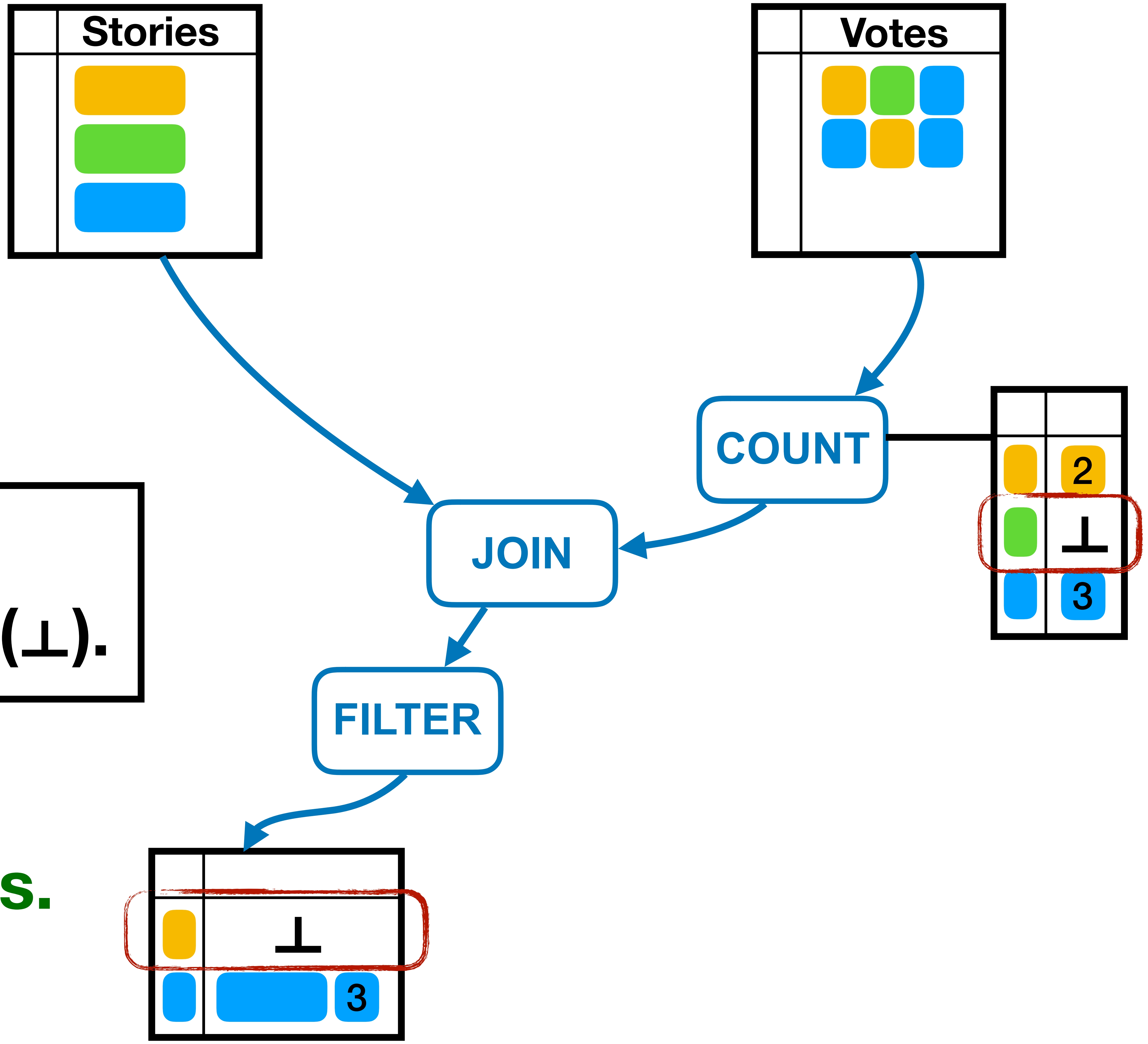
Lower memory footprint.

No need to update absent entries.



Frontend

Partially-stateful data-flow

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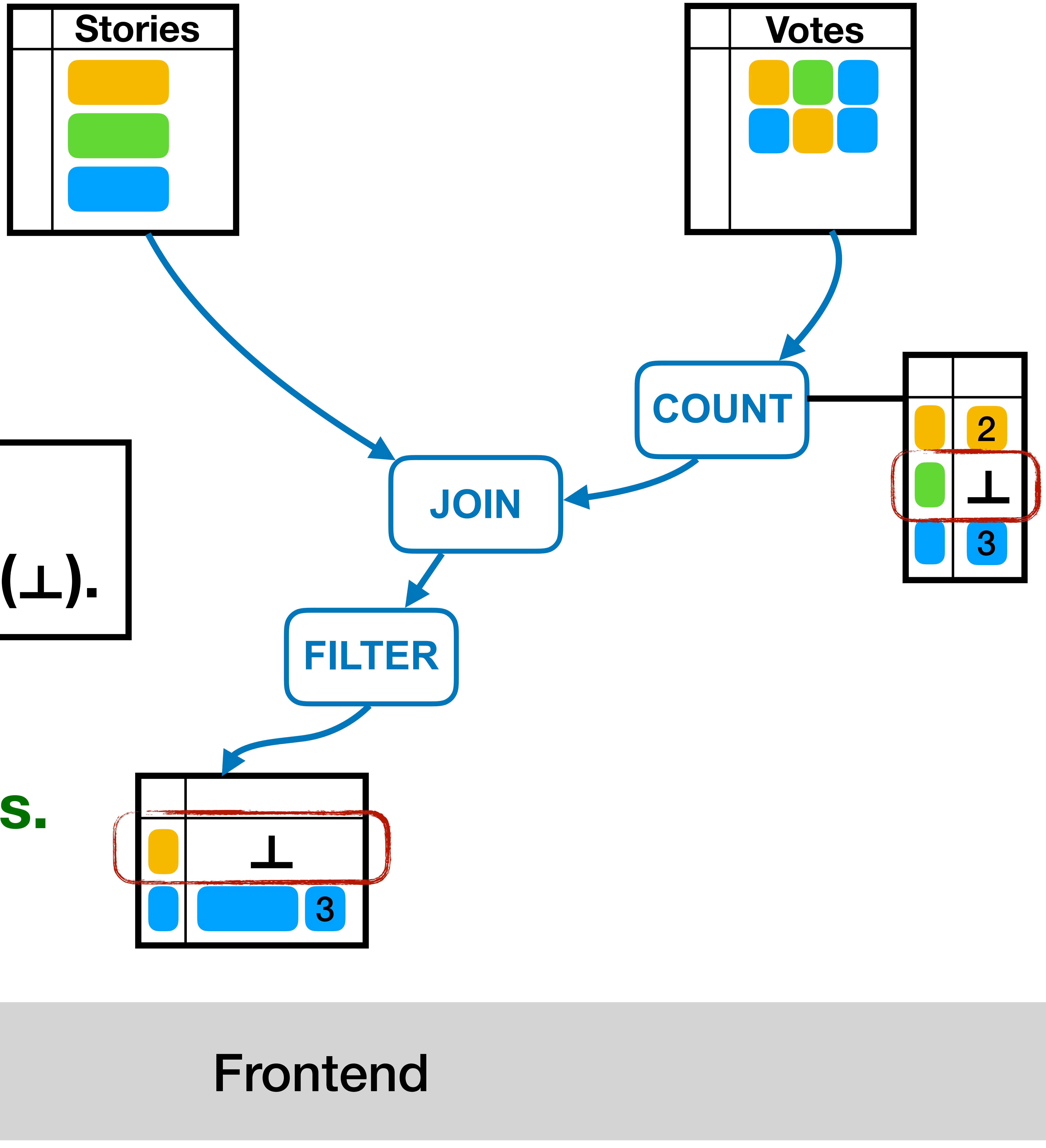
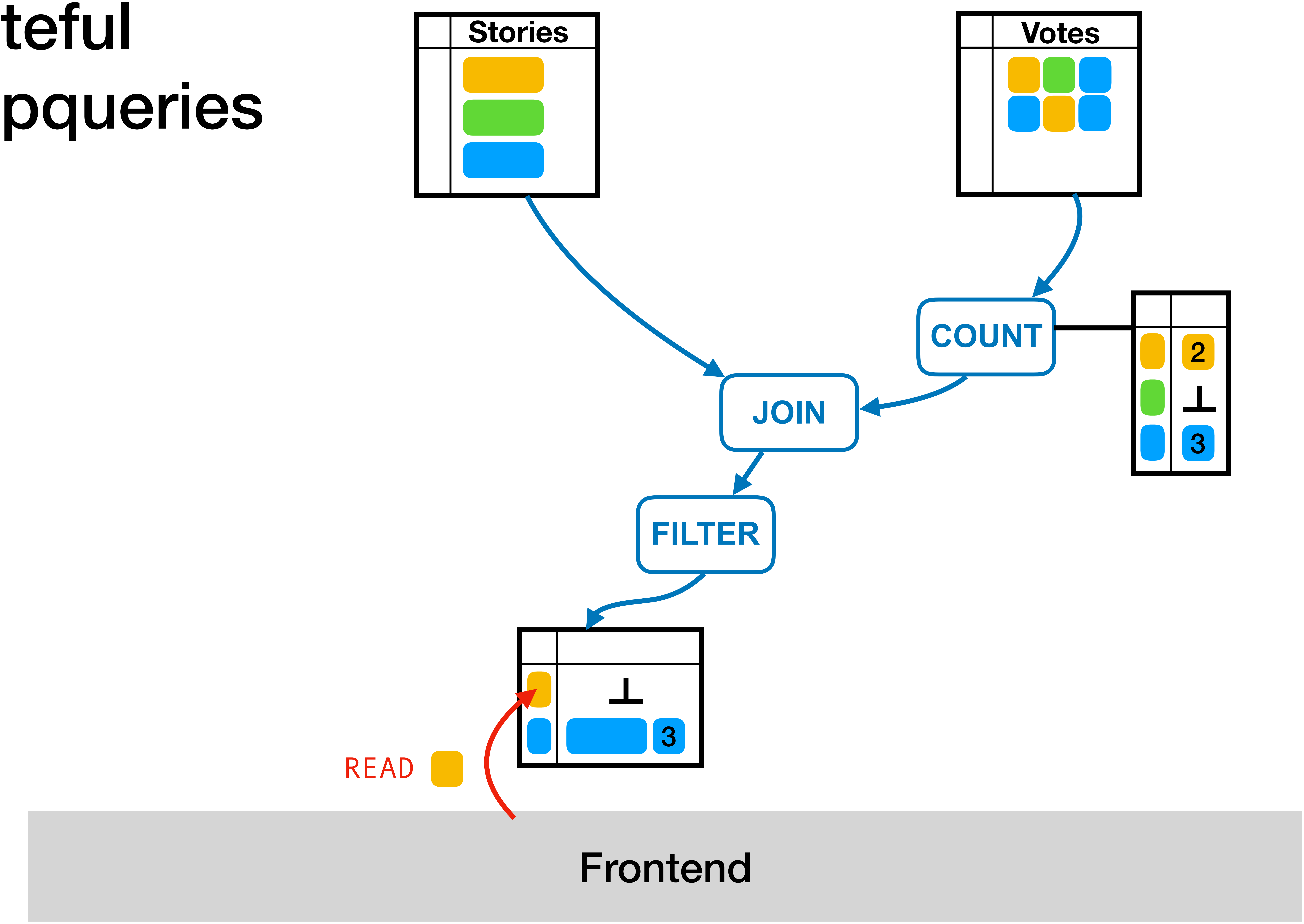
Enables live data-flow changes.



Partially-stateful data-flow: upqueries



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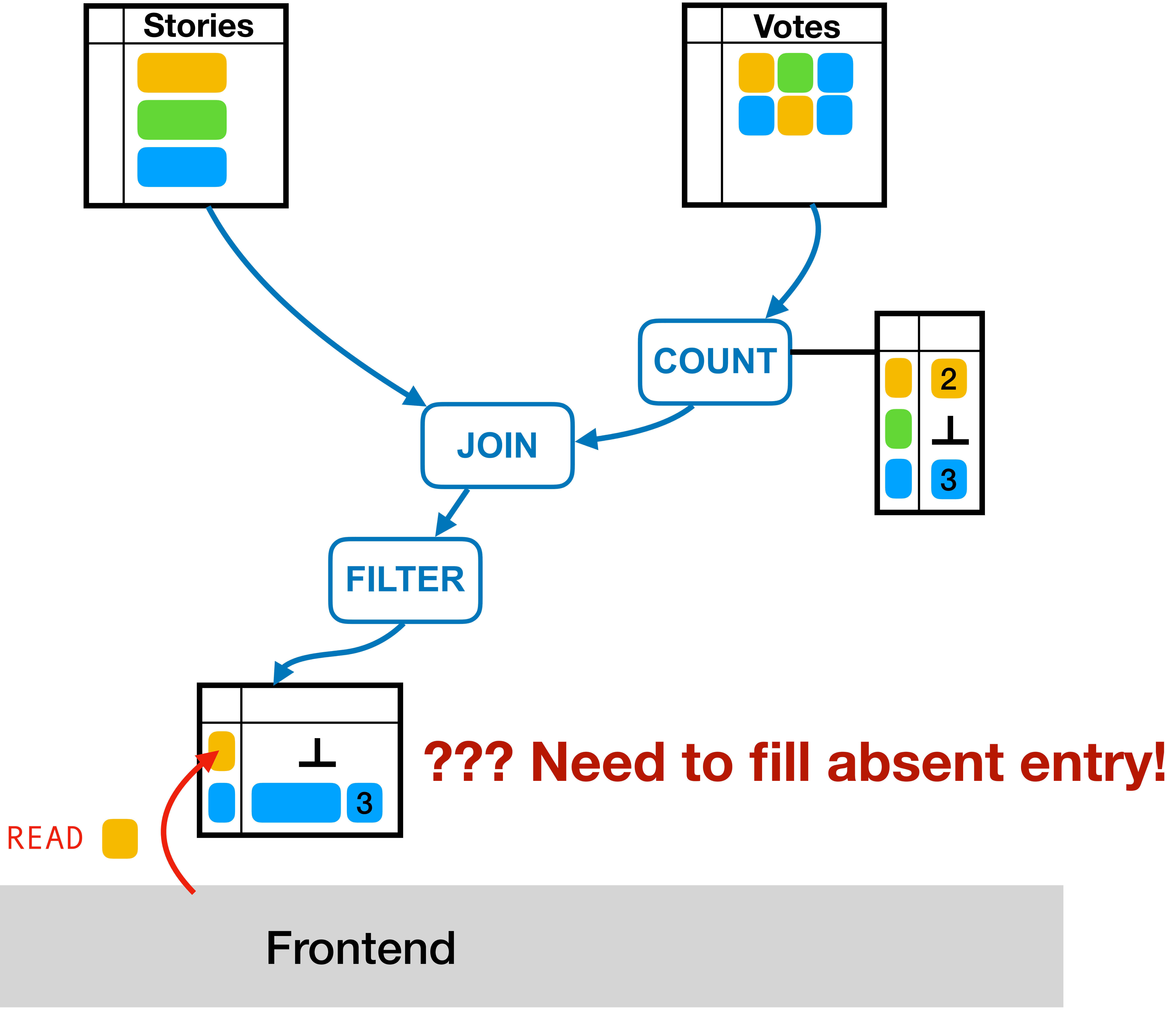
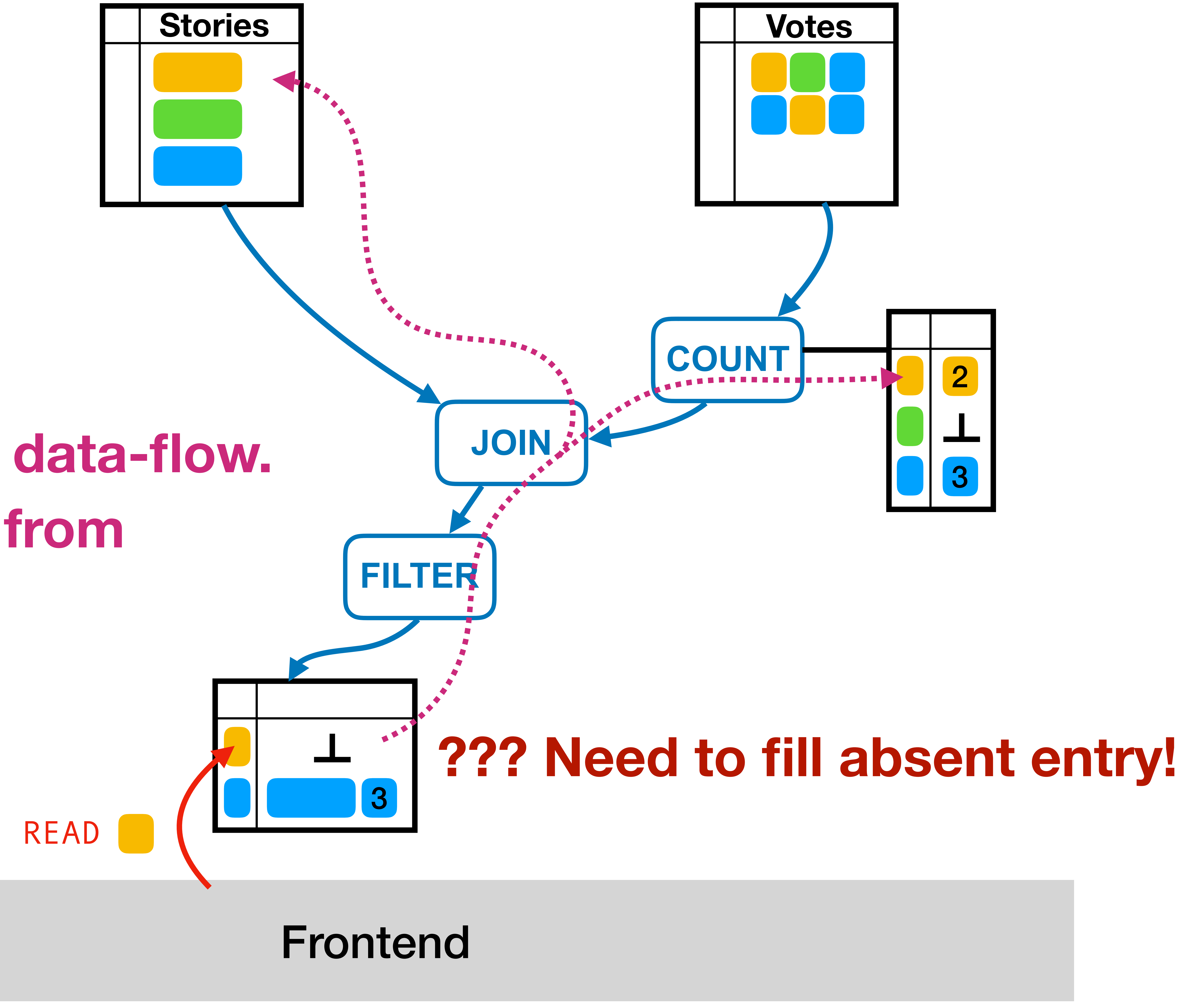


??? Need to fill absent entry!

Partially-stateful data-flow: upqueries



Solution: *upquery* through data-flow.

- **Compute missing entry from upstream state**

Partially-stateful data-flow: upqueries

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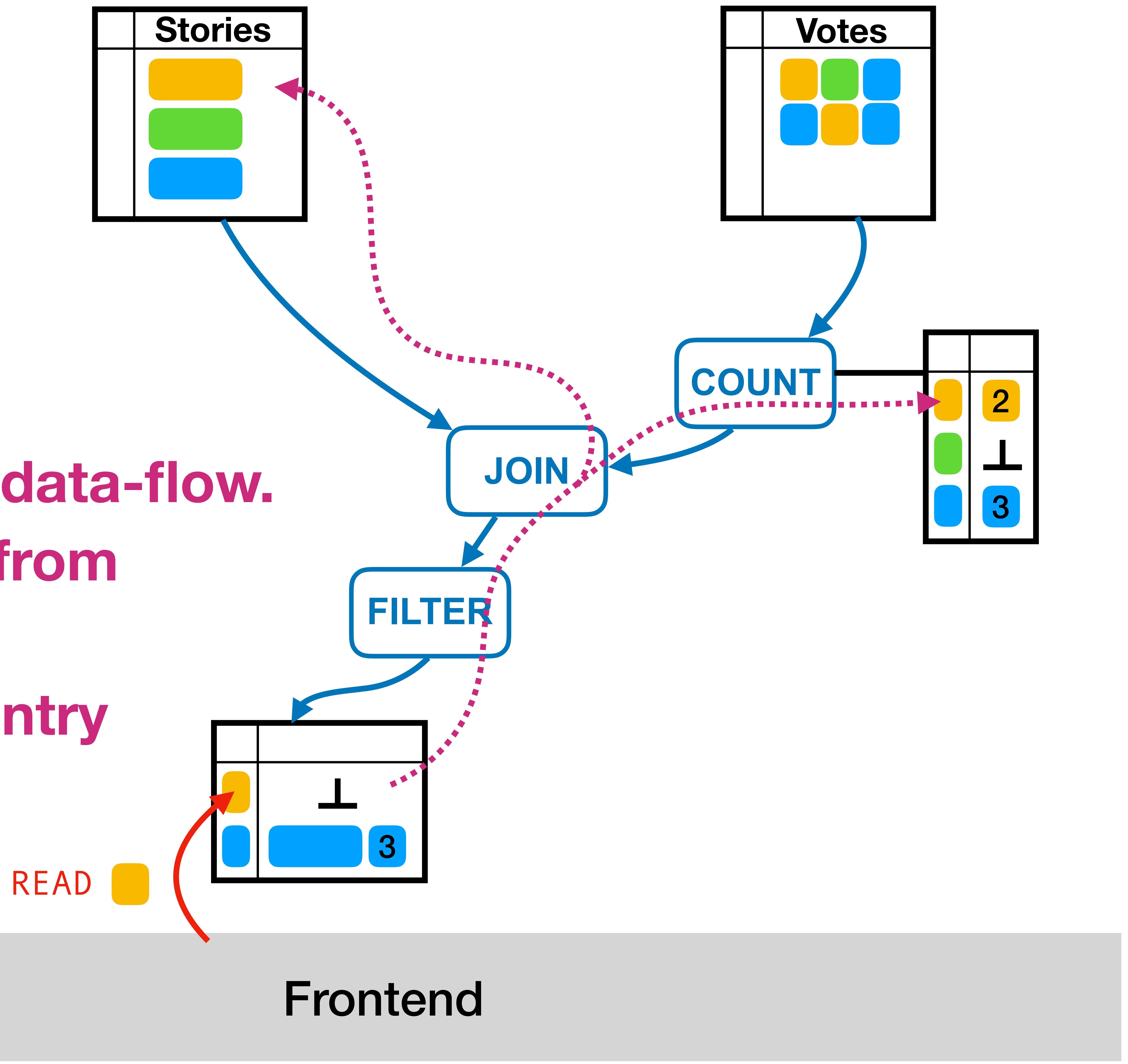
- Compute missing entry from upstream state
- Response fills missing entry



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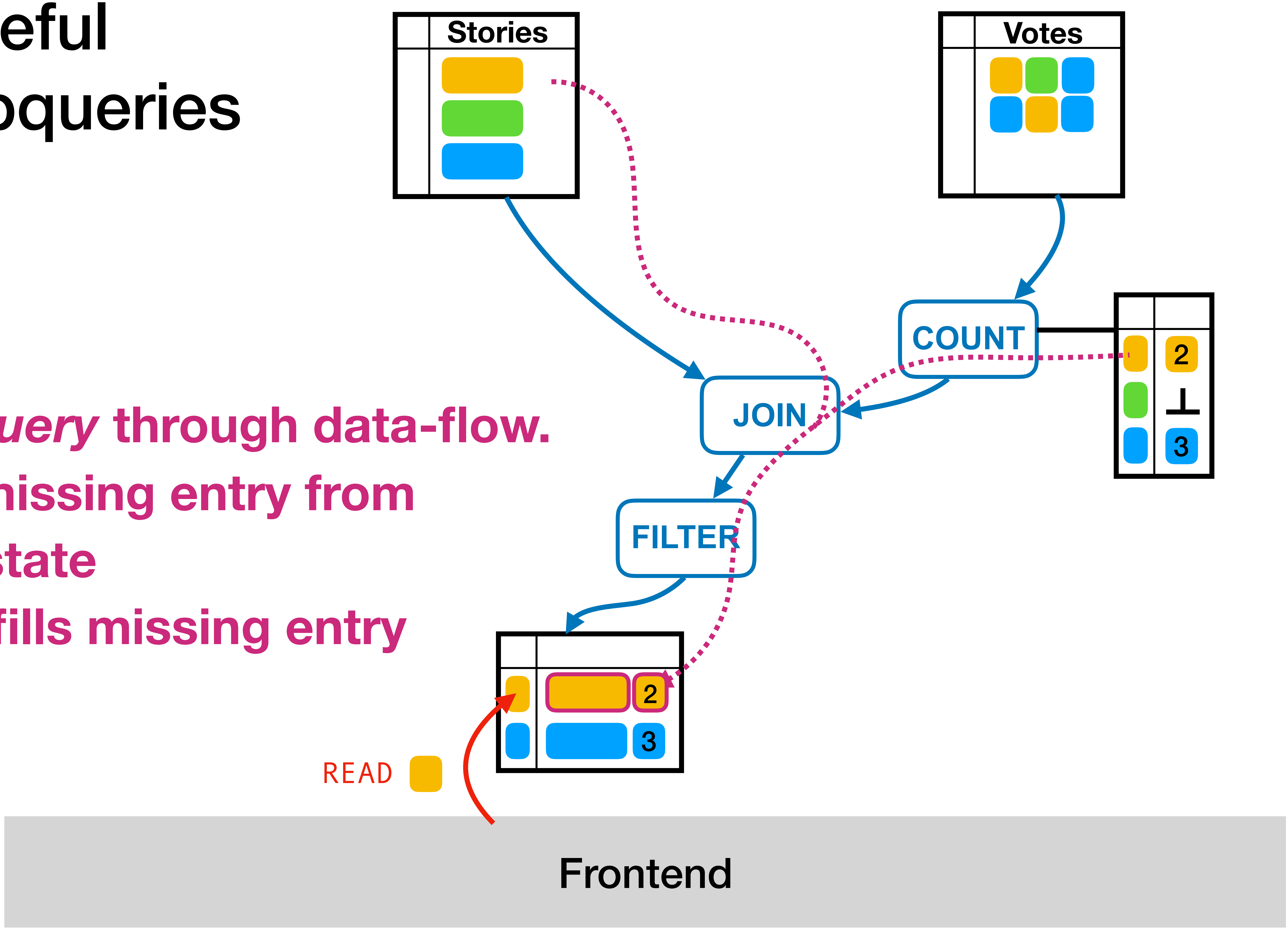
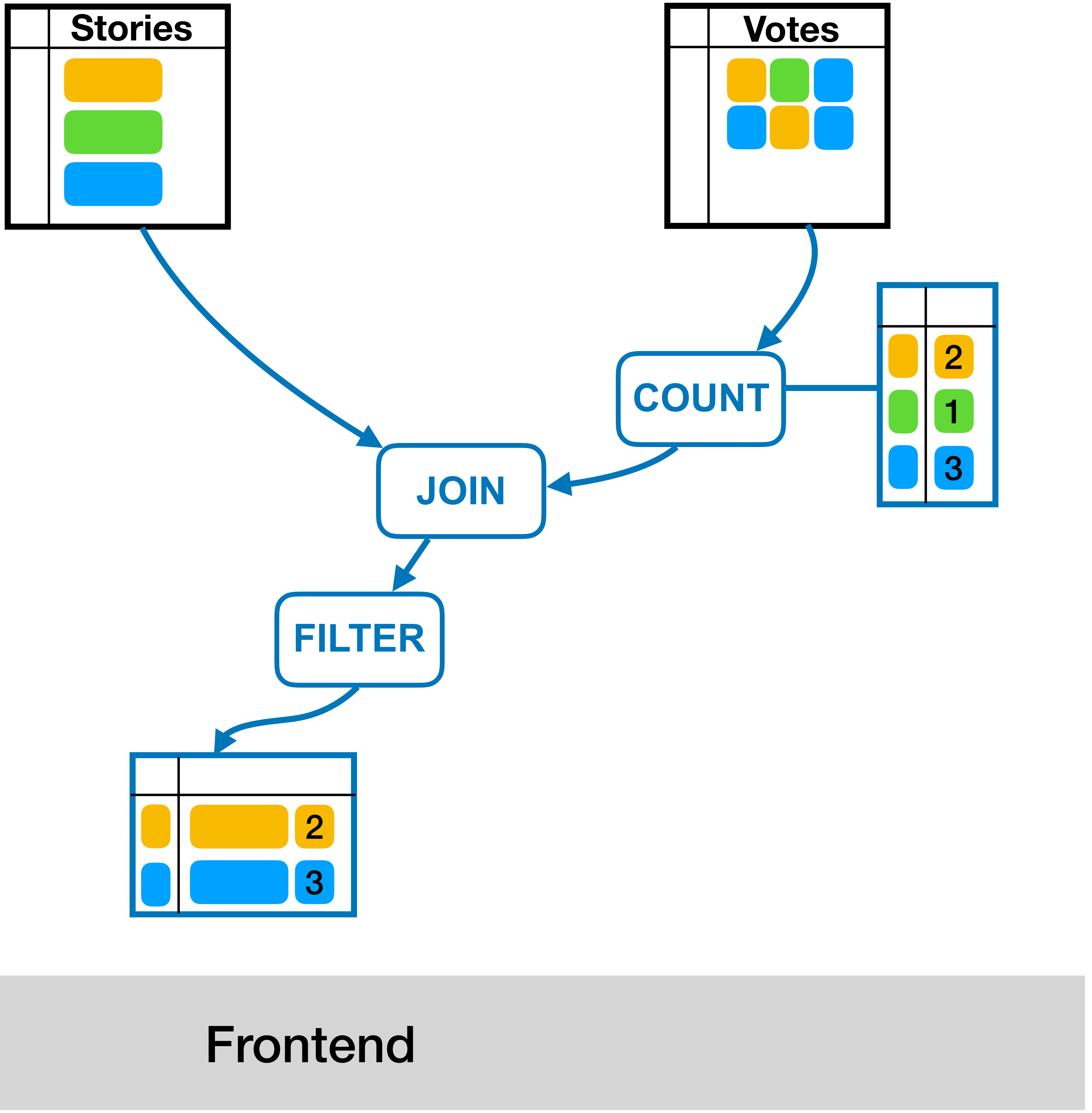


Partial state enables live data-flow changes

Start new views and operator state **empty**, **fill via** upqueries.



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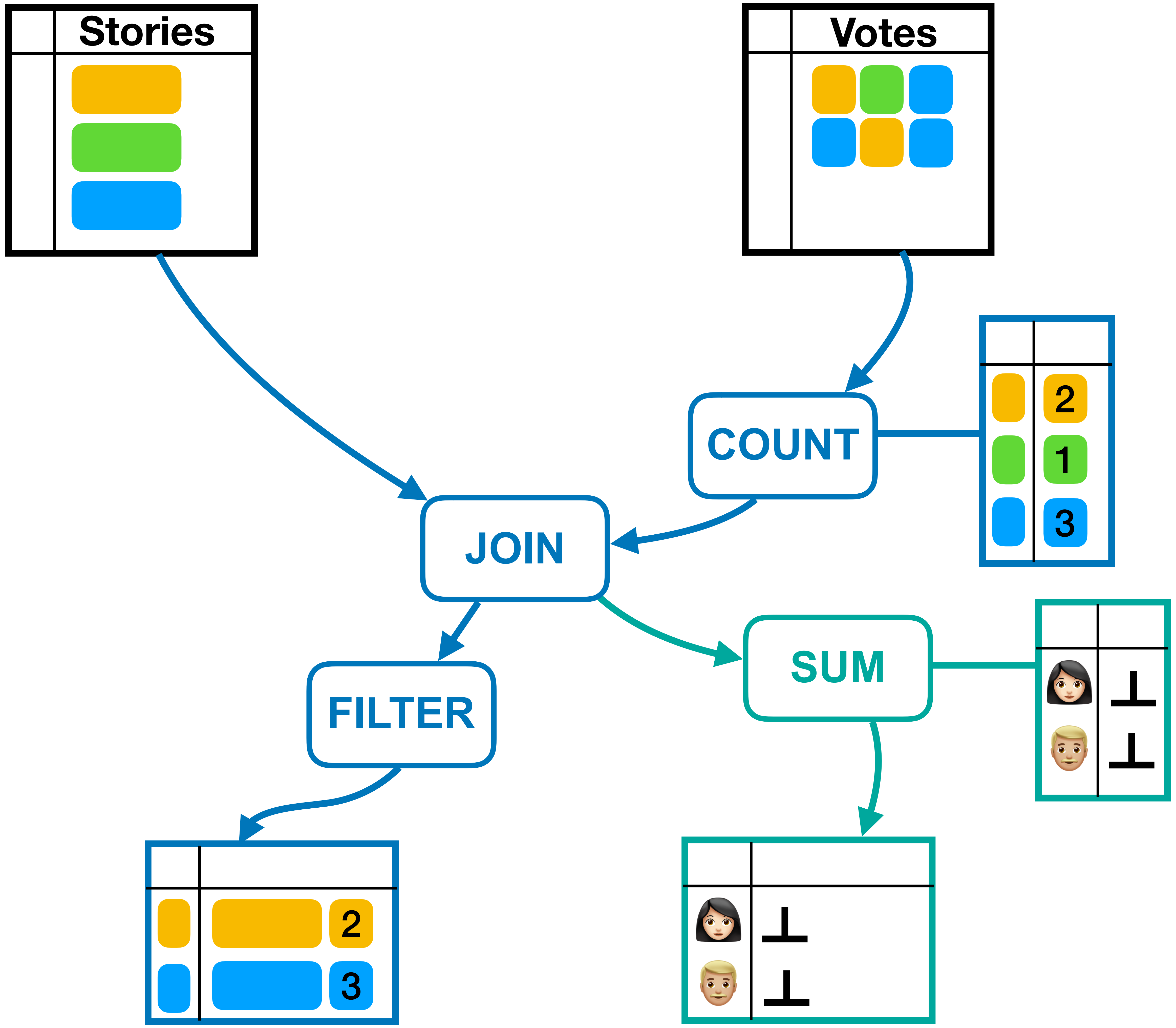

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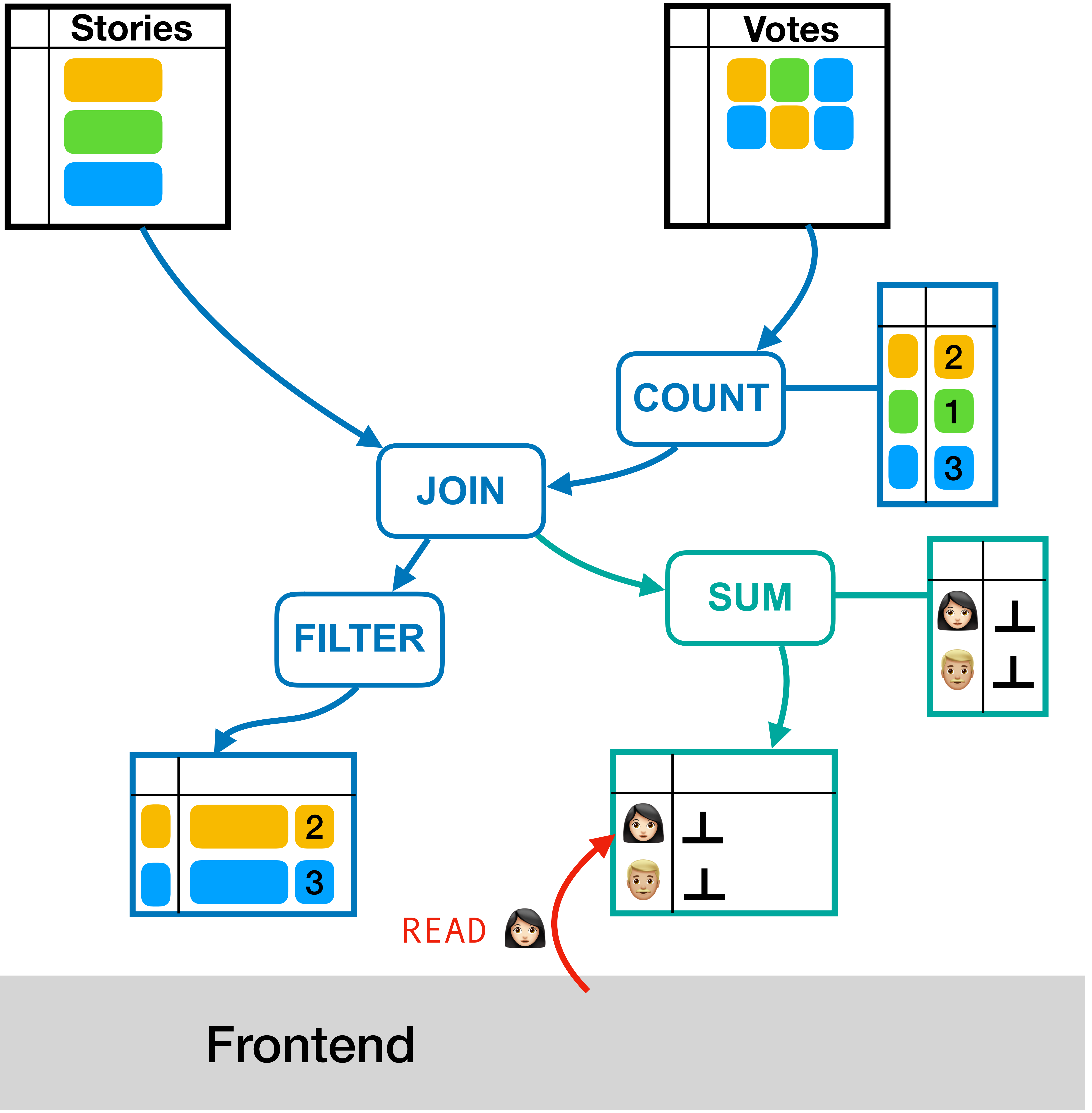

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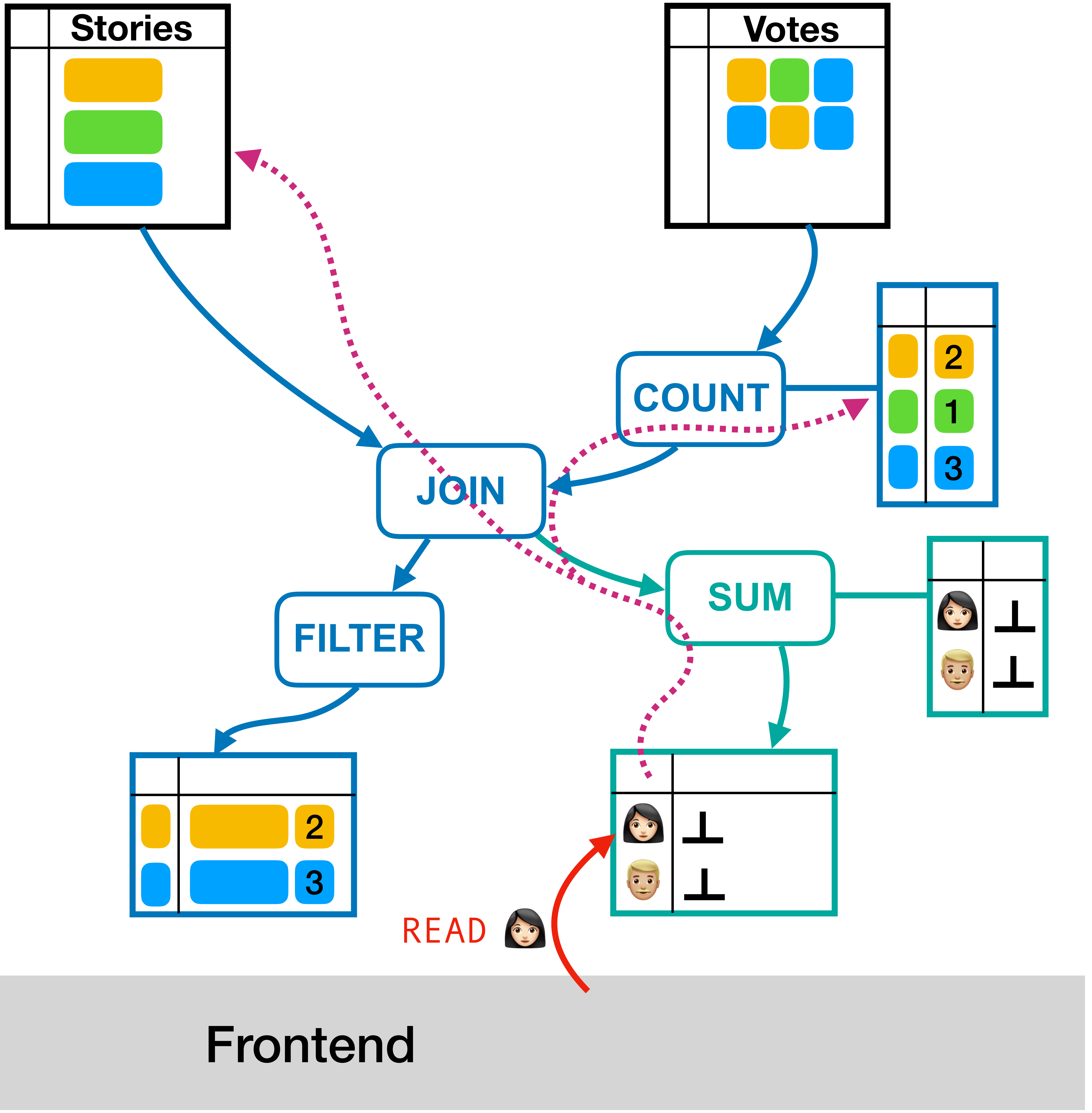

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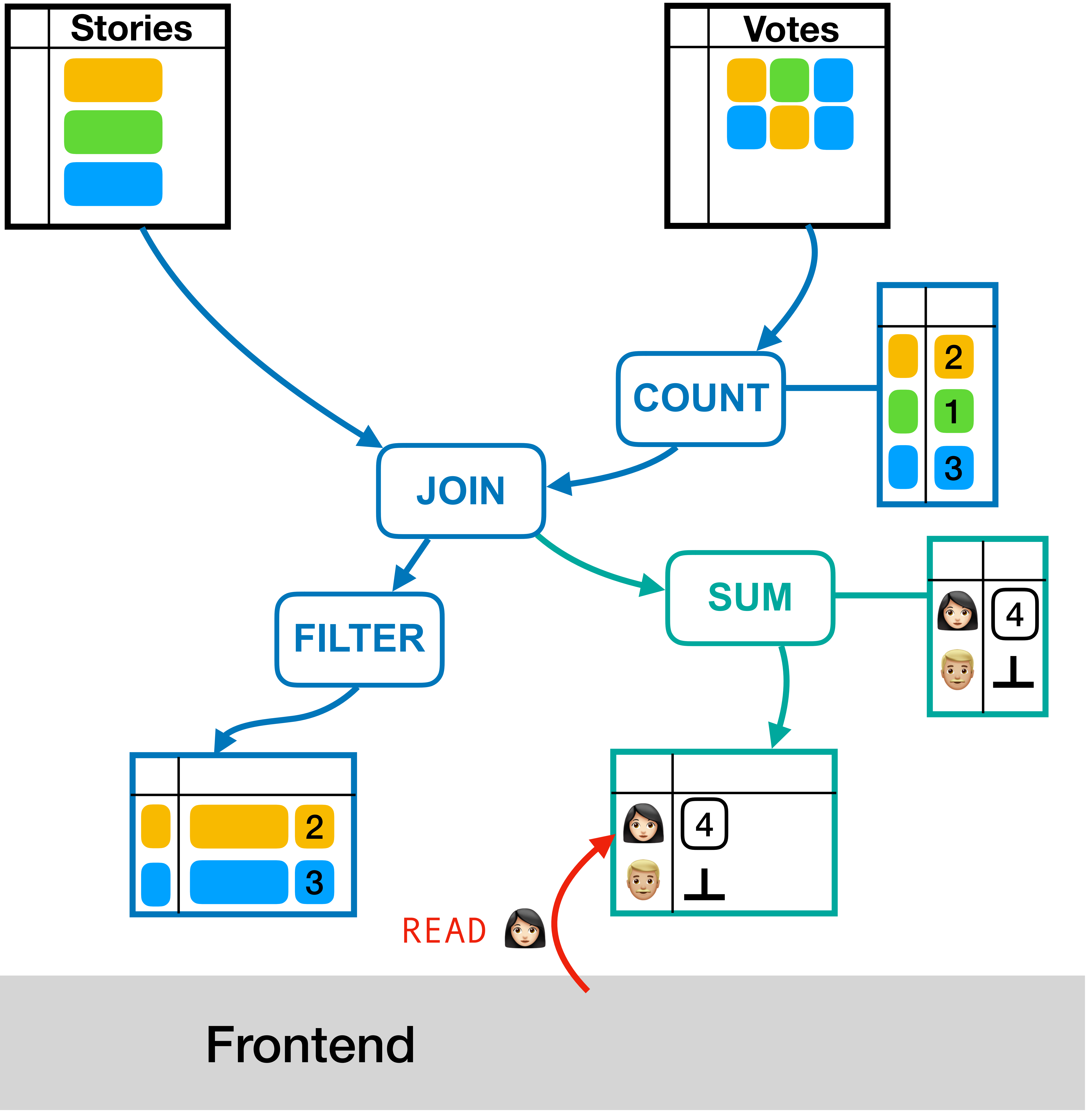
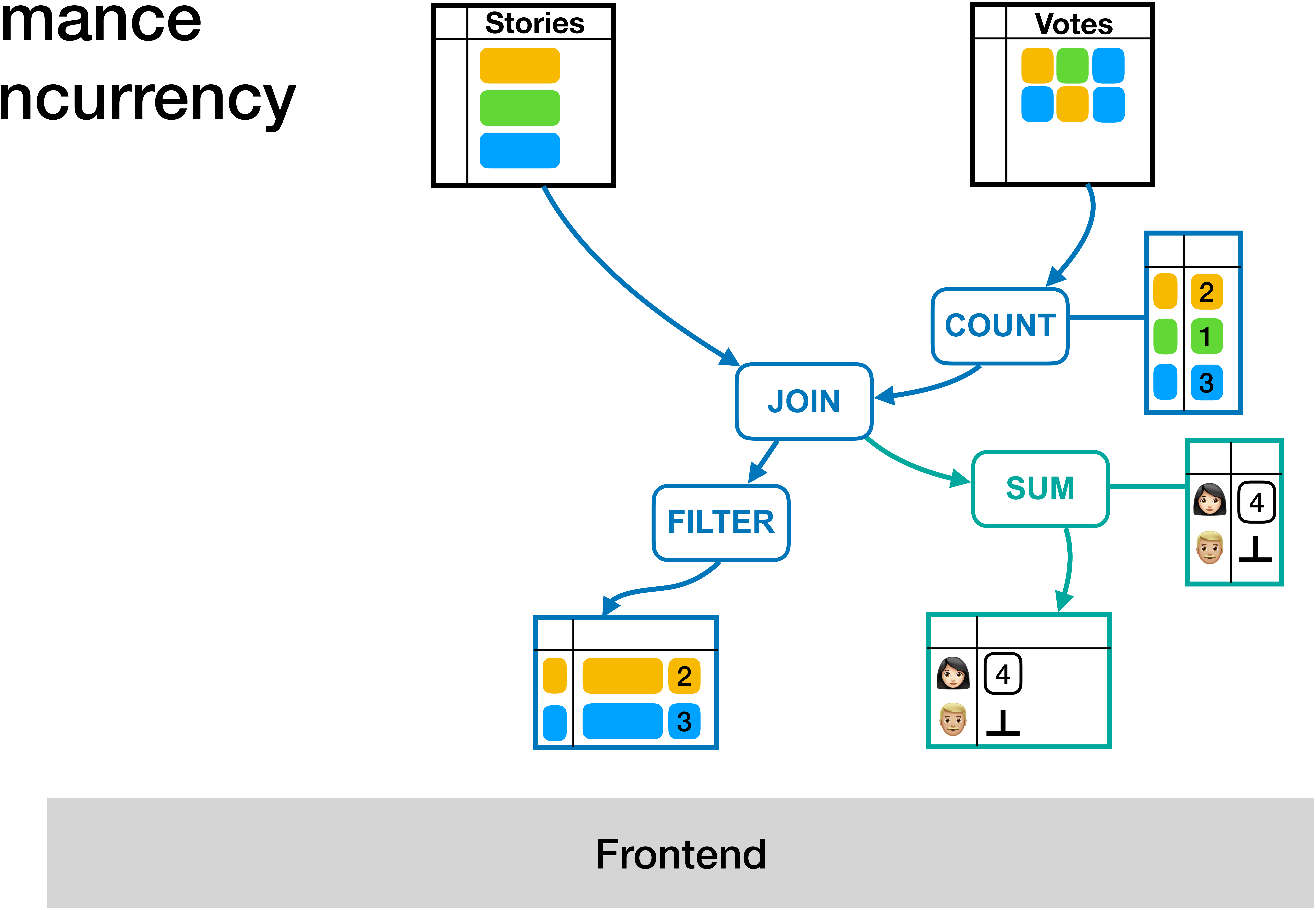


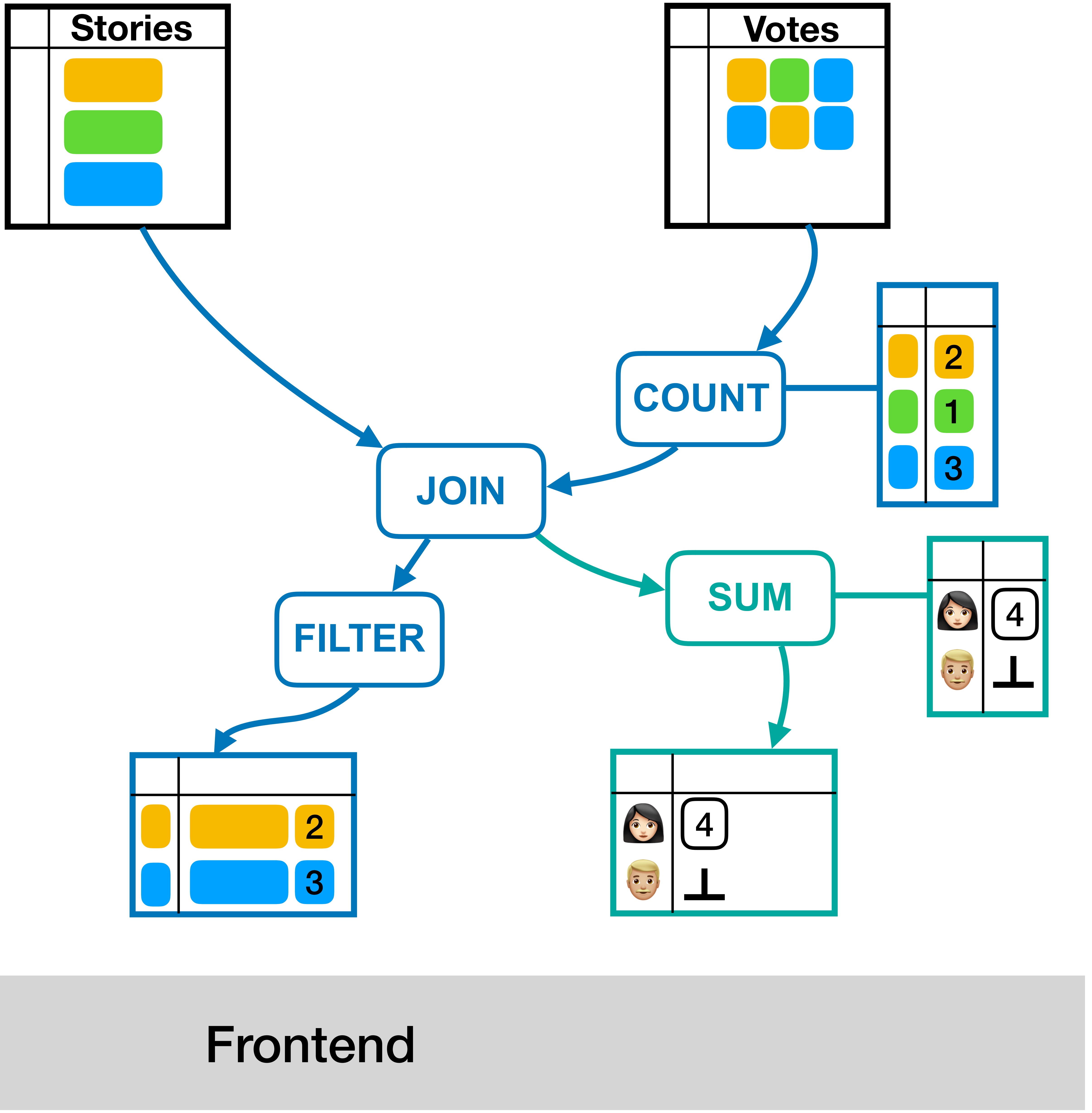
High performance requires concurrency



High performance requires concurrency

Process operators concurrently.
Read from views concurrently.
Process shards concurrently.

Without global coordination!



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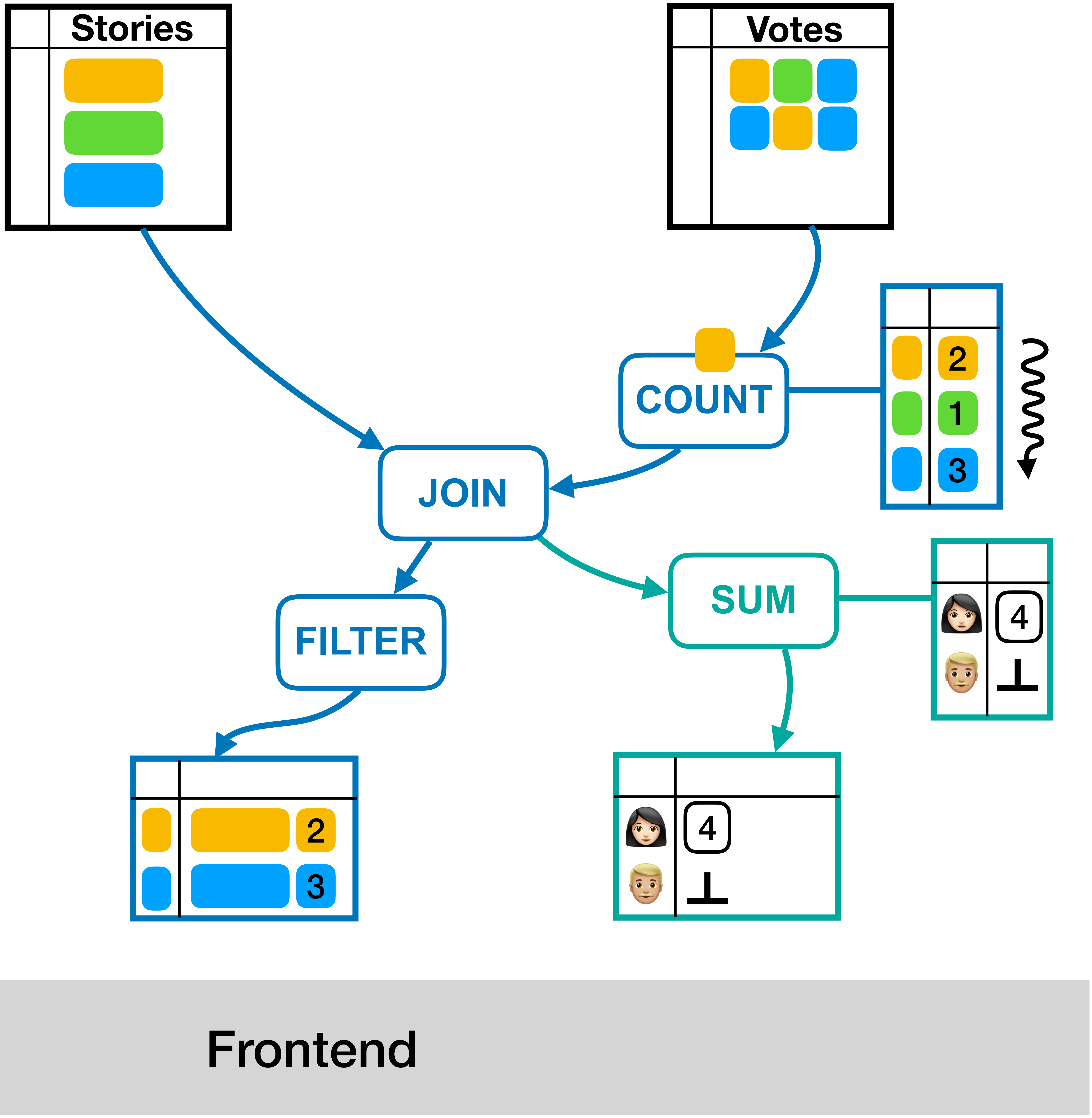

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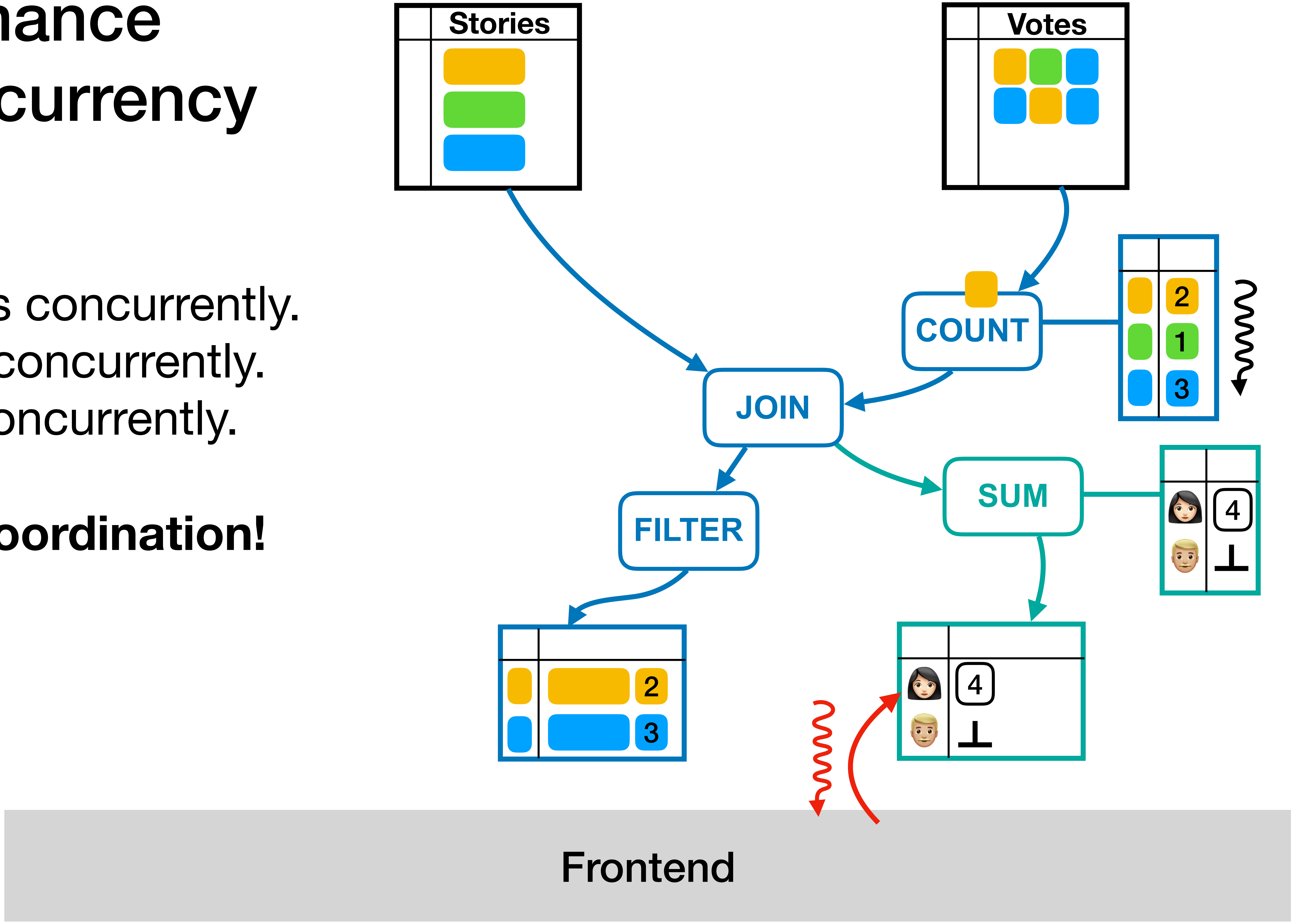

Challenges implementing partially-stateful data-flow

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1. Concurrent upqueries and forward processing — races!

Must maintain **correctness** under concurrency!

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Correctness under concurrency

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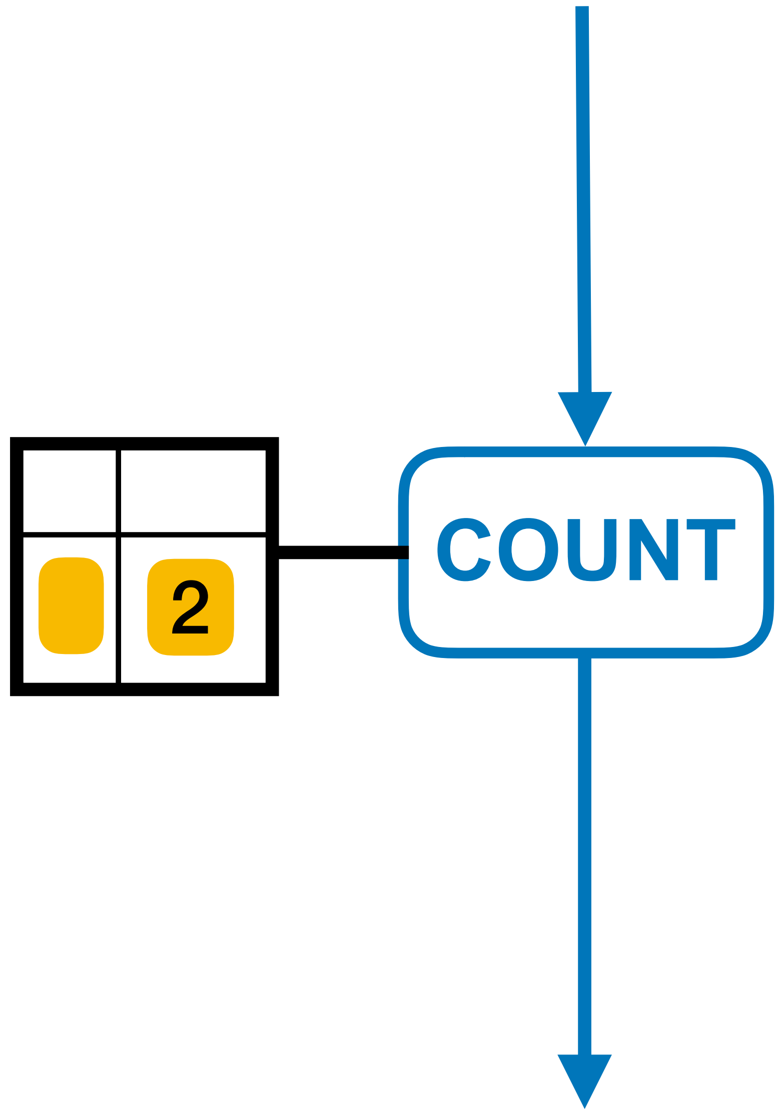

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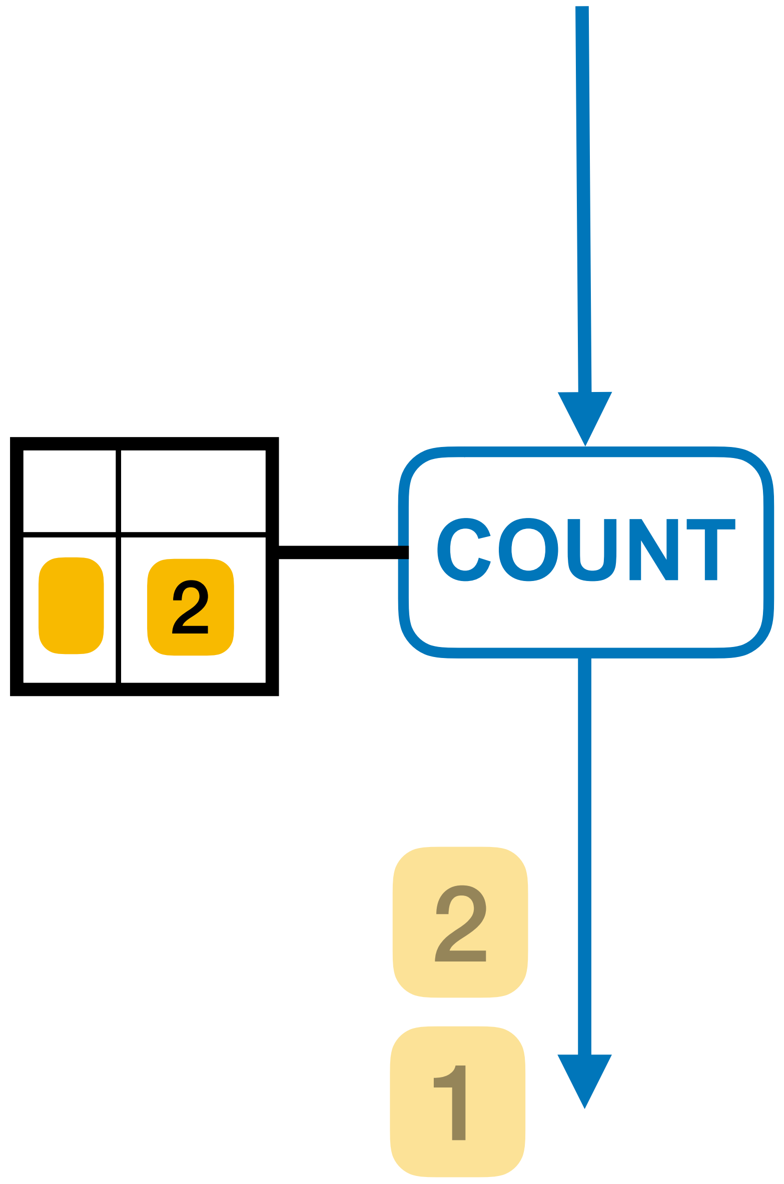

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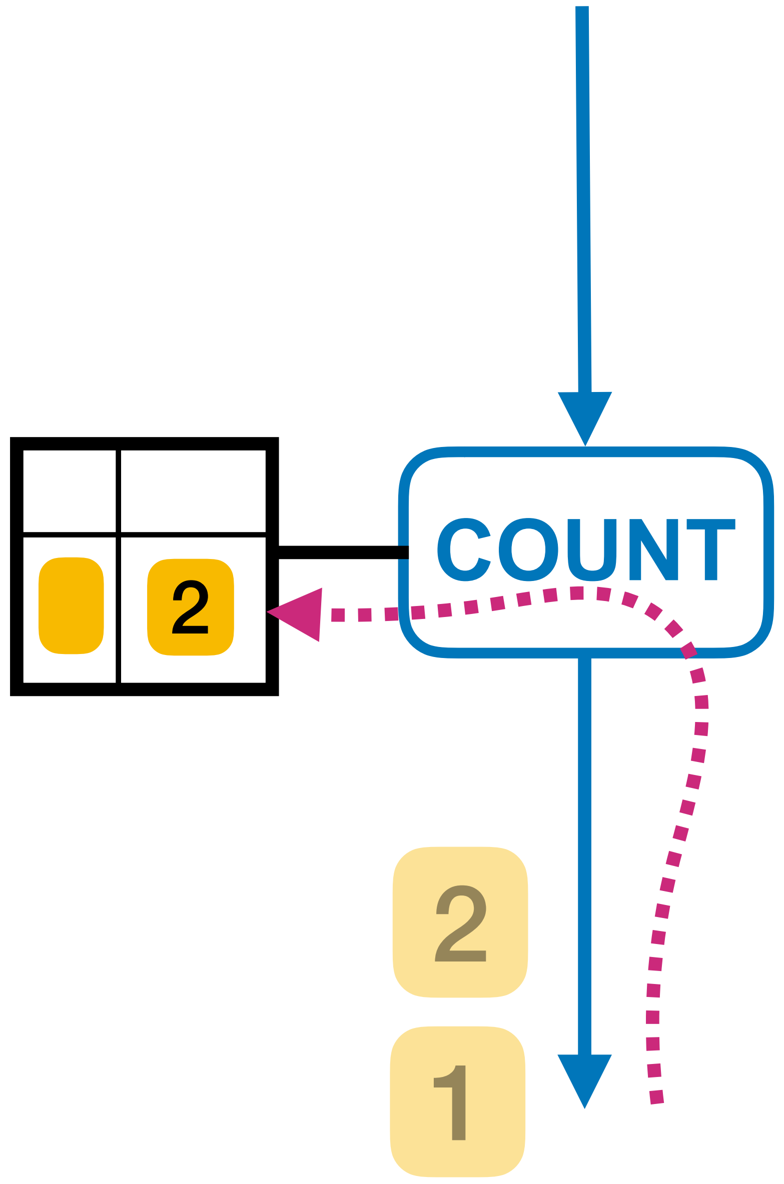

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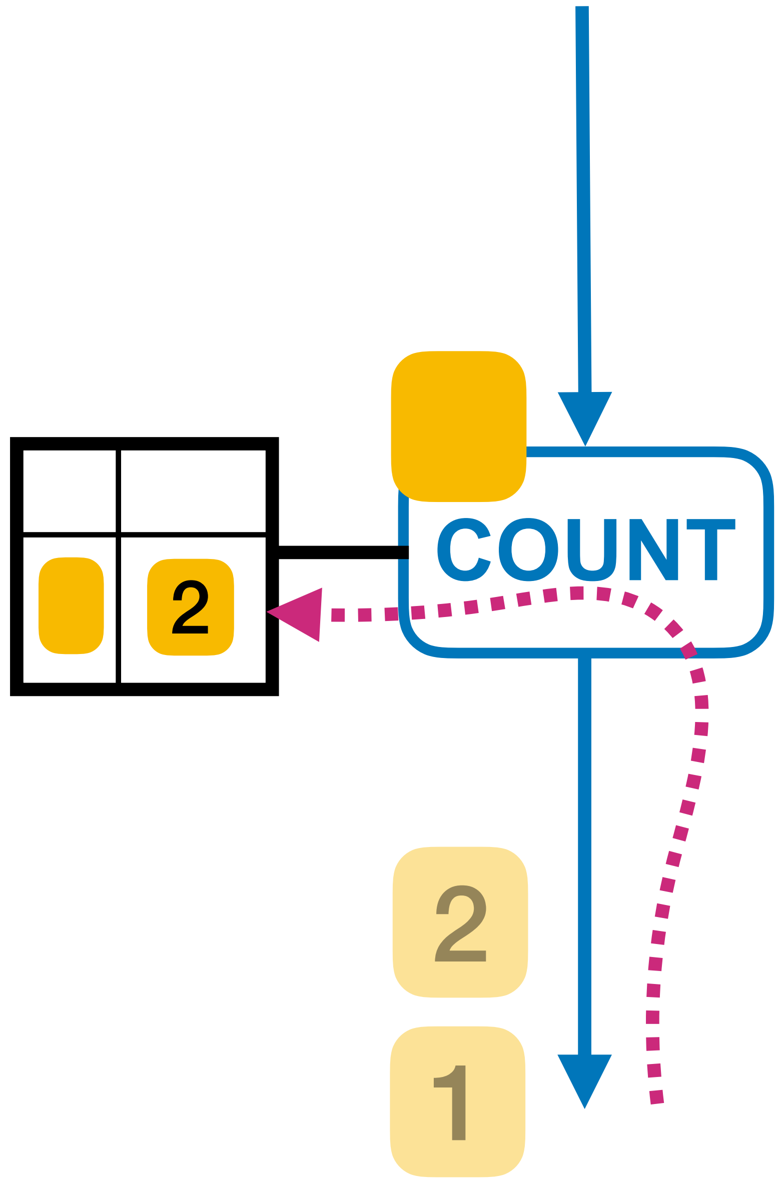

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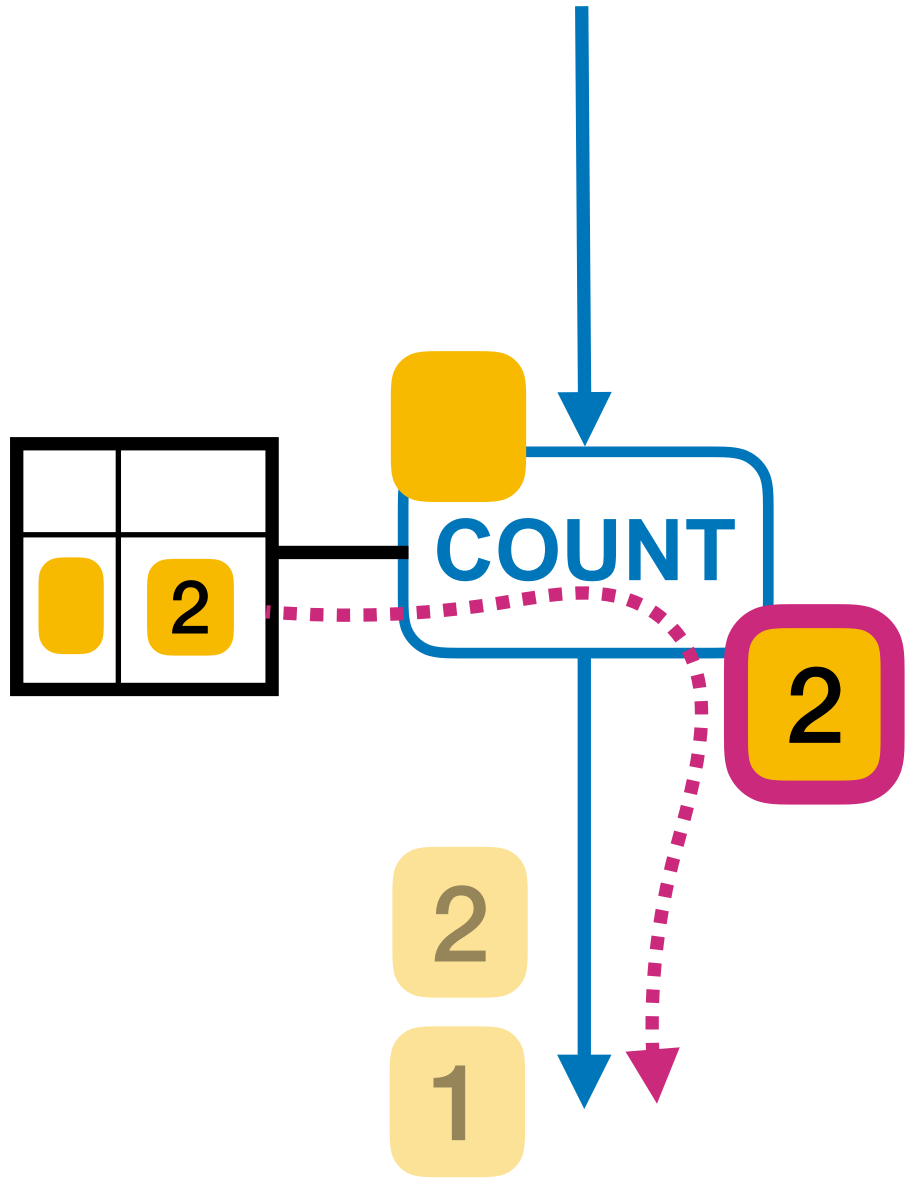

Upquery response is a **snapshot** of state

Correctness under concurrency

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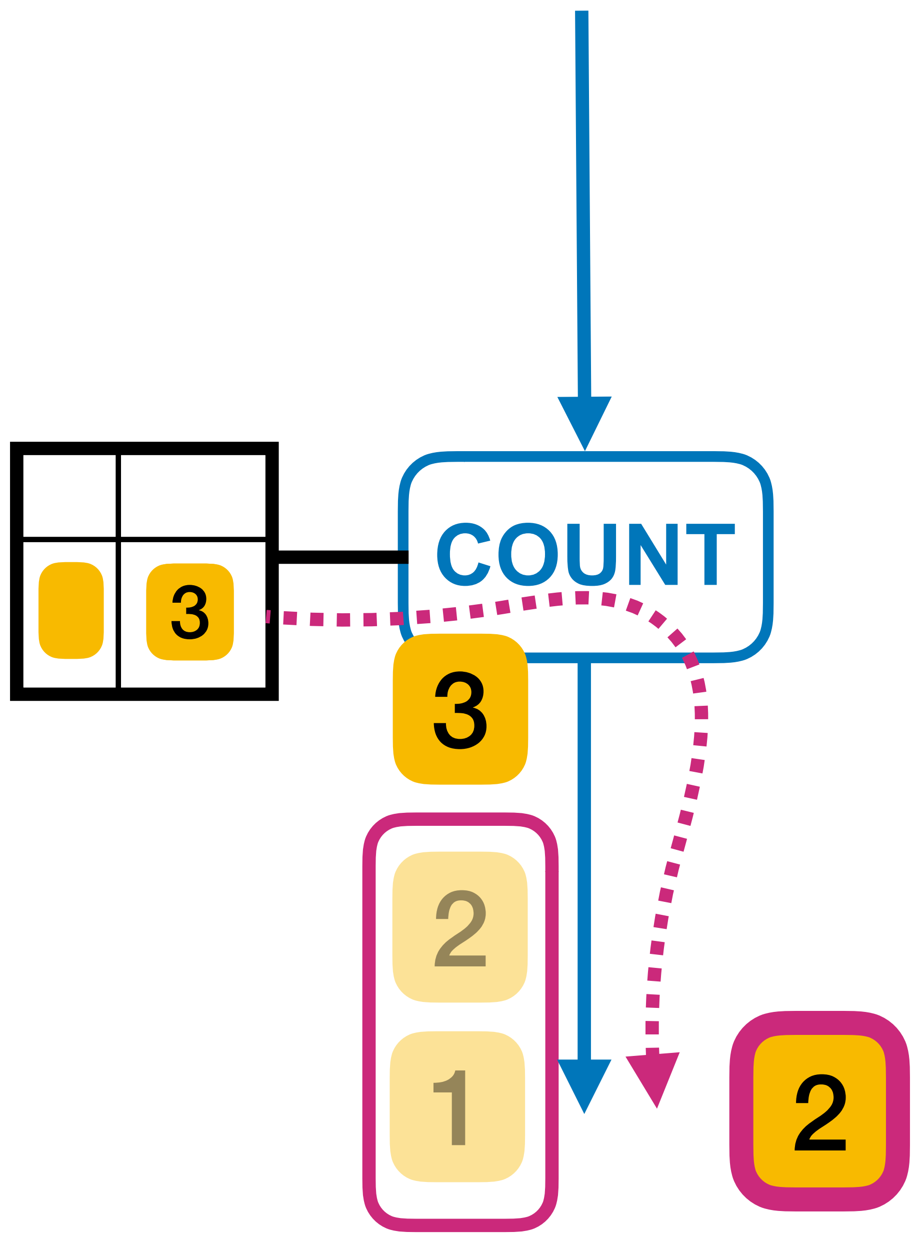

Upquery response is a **snapshot** of state

includes 2 1

does **not** include 🟨

Correctness under concurrency

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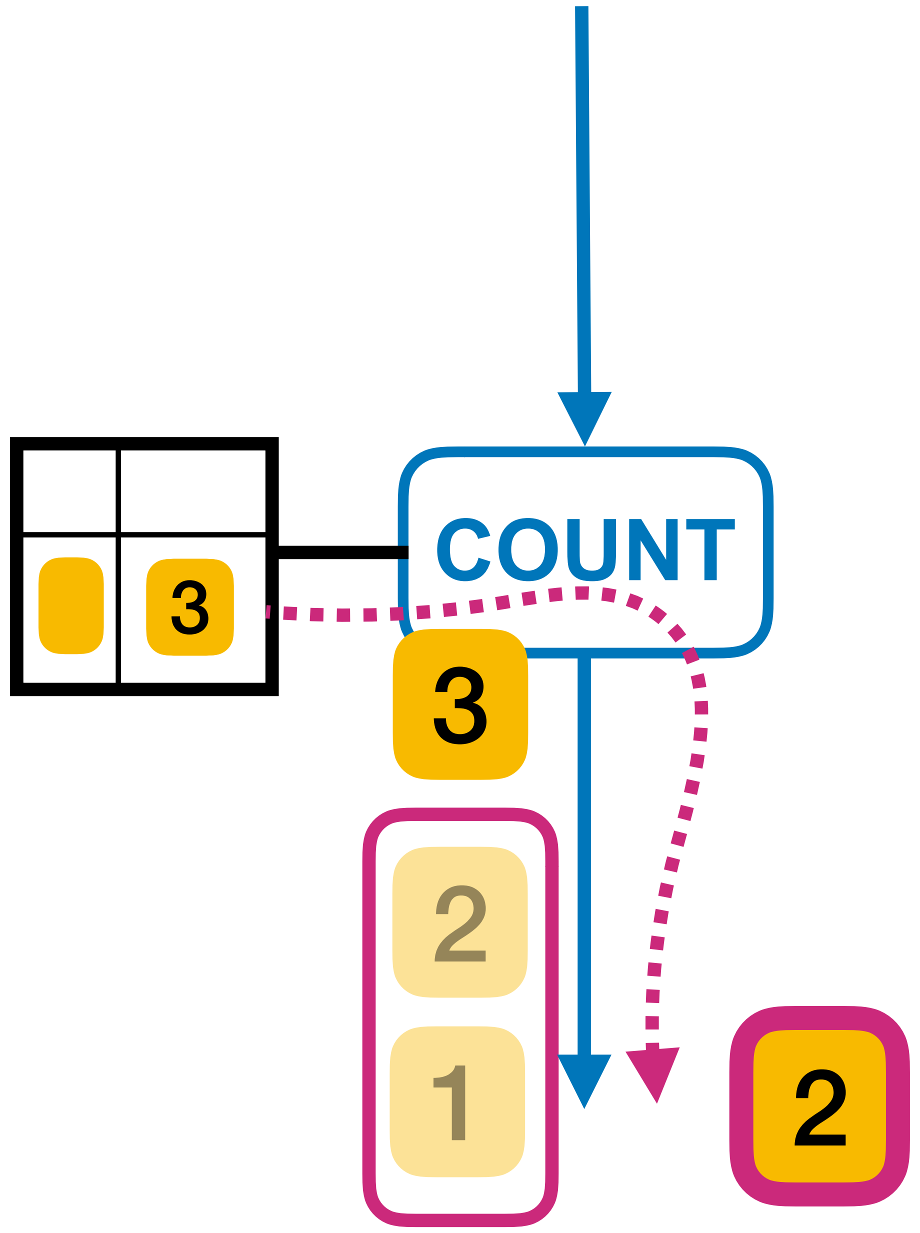

Upquery response is a **snapshot** of state

includes 2 1

does **not** include 🟨

Solution: Maintain **order** of upquery response and surrounding updates, despite lack of global coordination.

Upquery responses in total order with updates

Goal: upquery restores state as if present all along.

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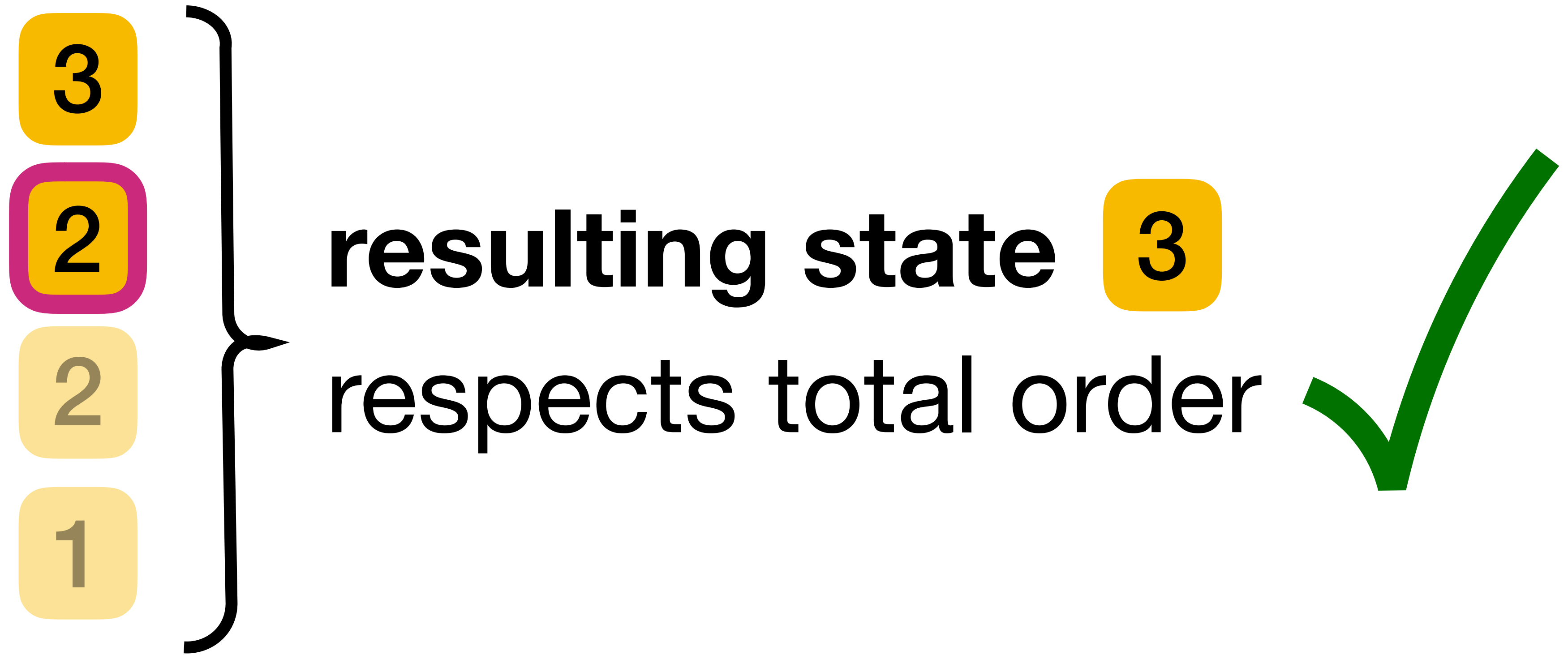

resulting state 3
respects total order ✓

Upquery responses in total order with updates

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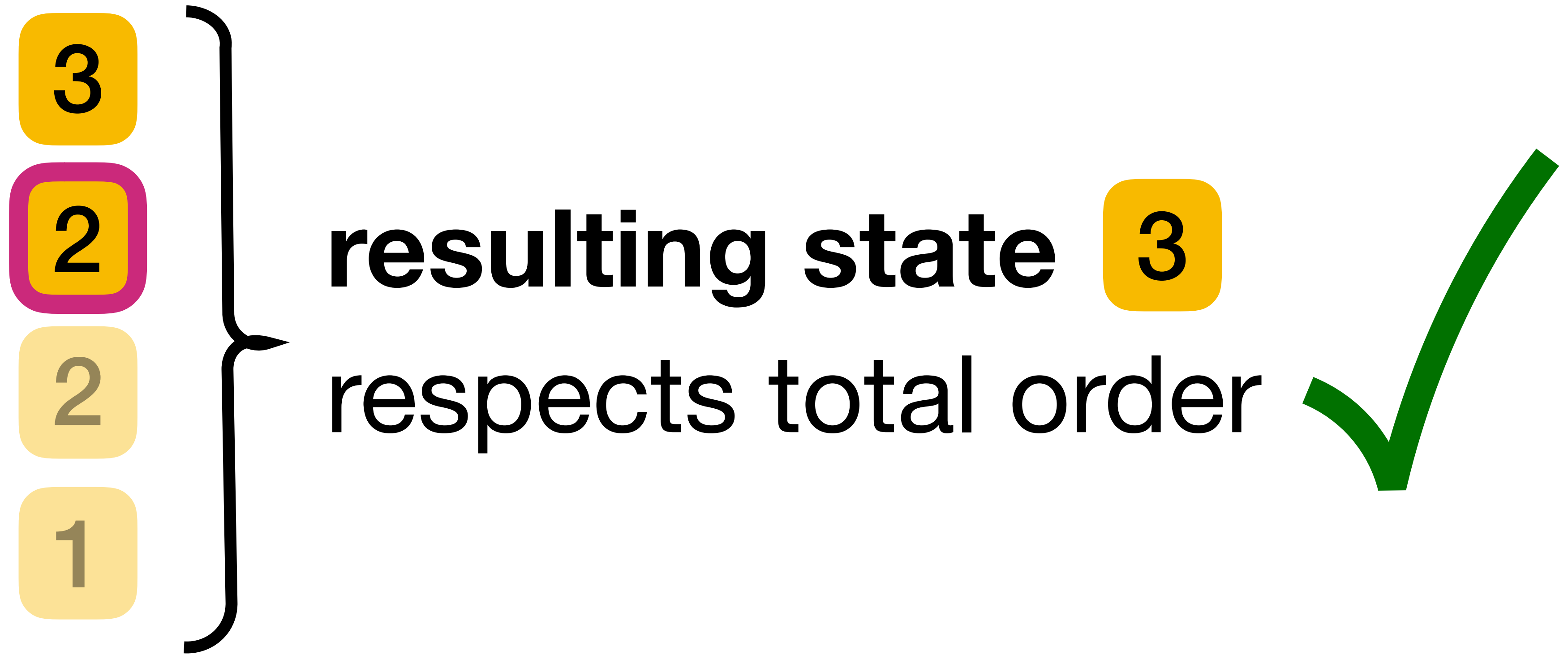

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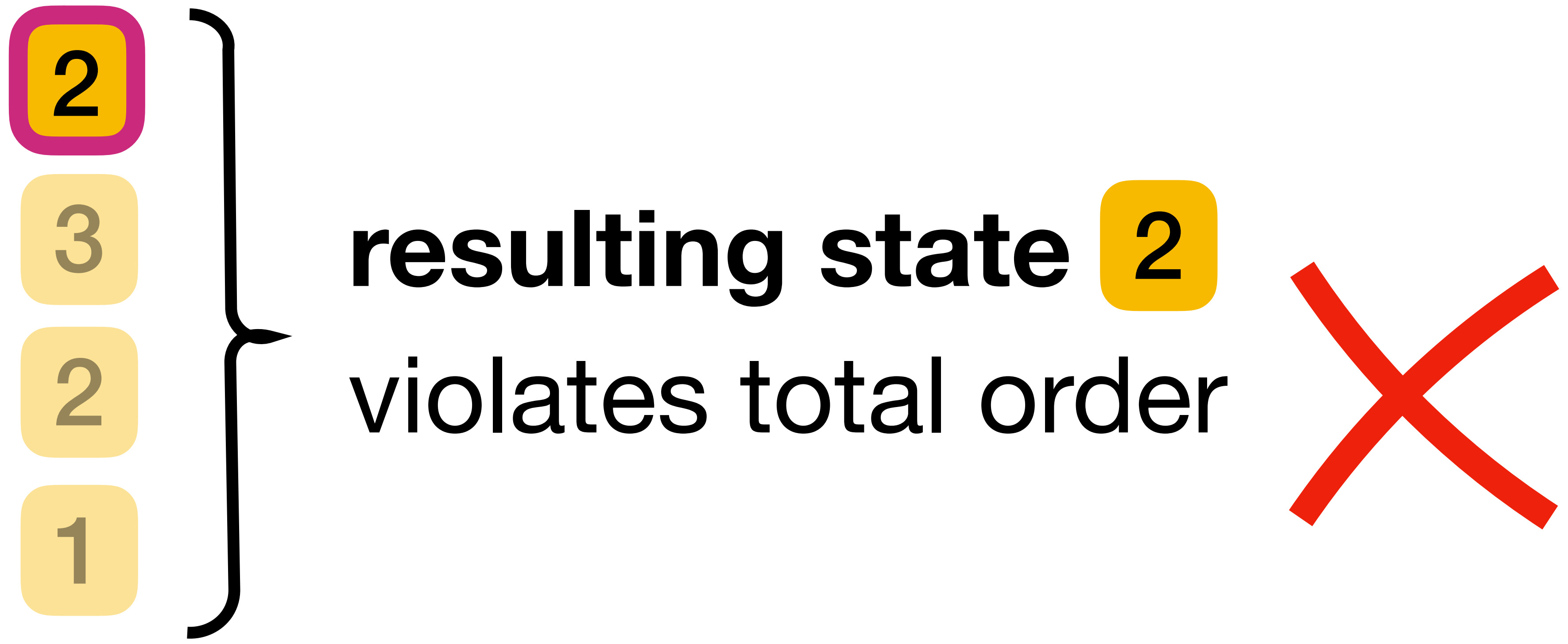

resulting state 2
violates total order ✗

Upquery responses in total order with updates

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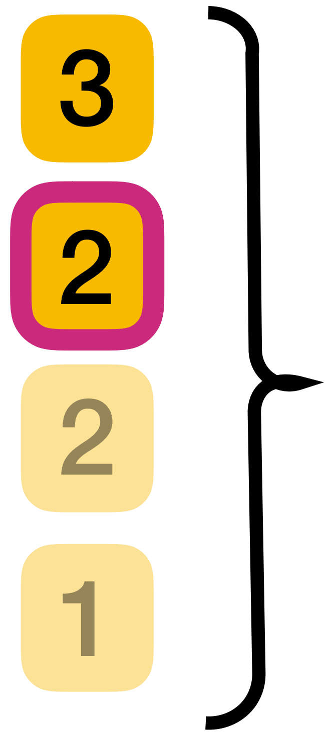
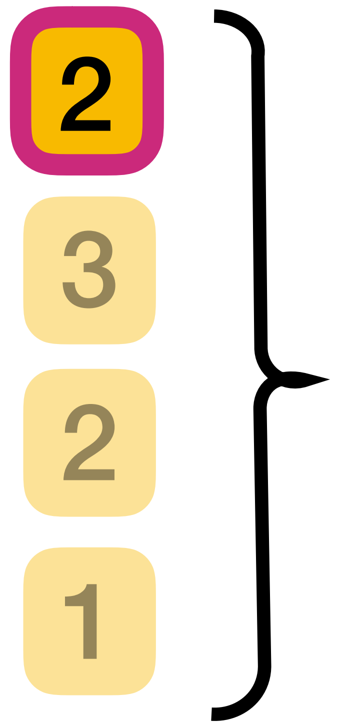


resulting state 3

respects total order ✓



resulting state 2

violates total order ✗

More complex cases: merged upquery responses, evictions (**Paper**).

Challenges implementing partially-stateful data-flow

1. Concurrent upqueries and forward processing — races!

Must maintain **correctness** under concurrency!

2. Update processing may require absent state

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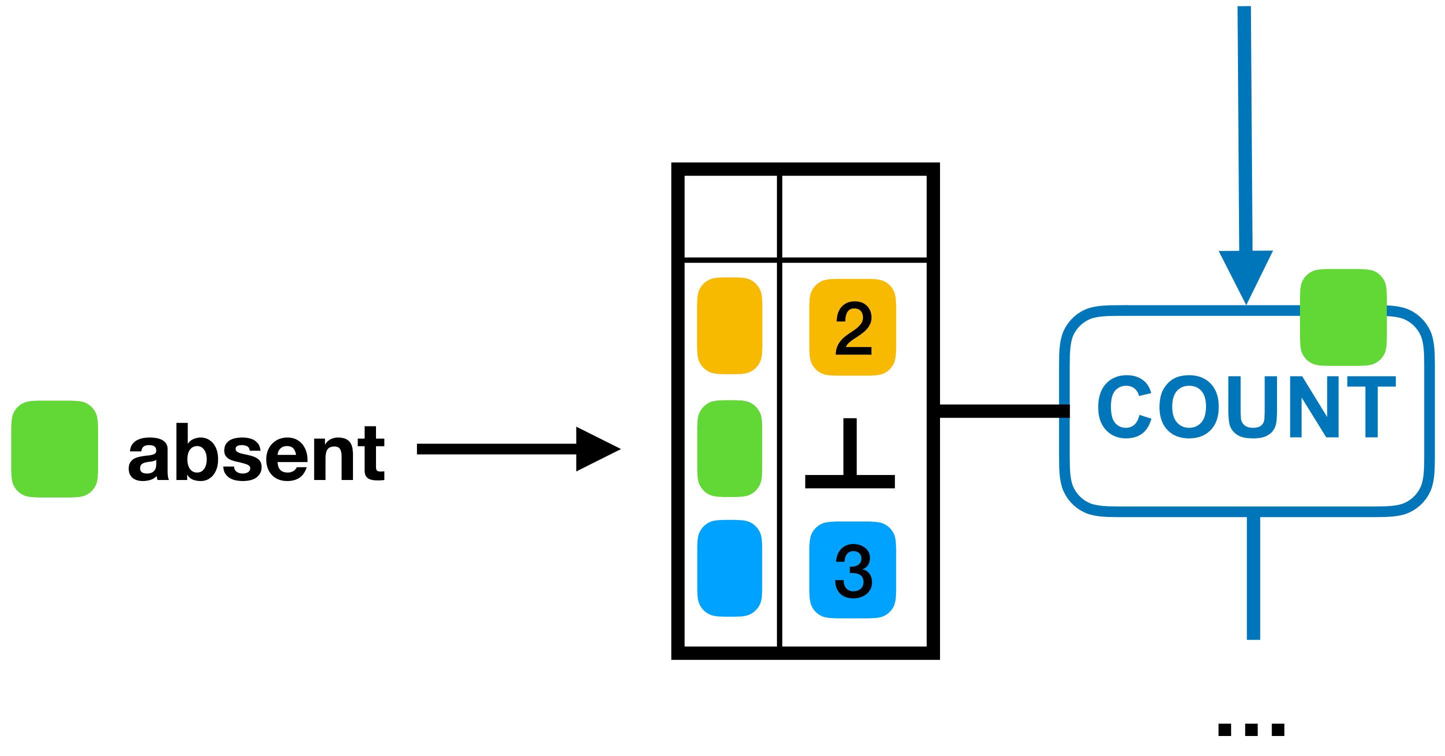

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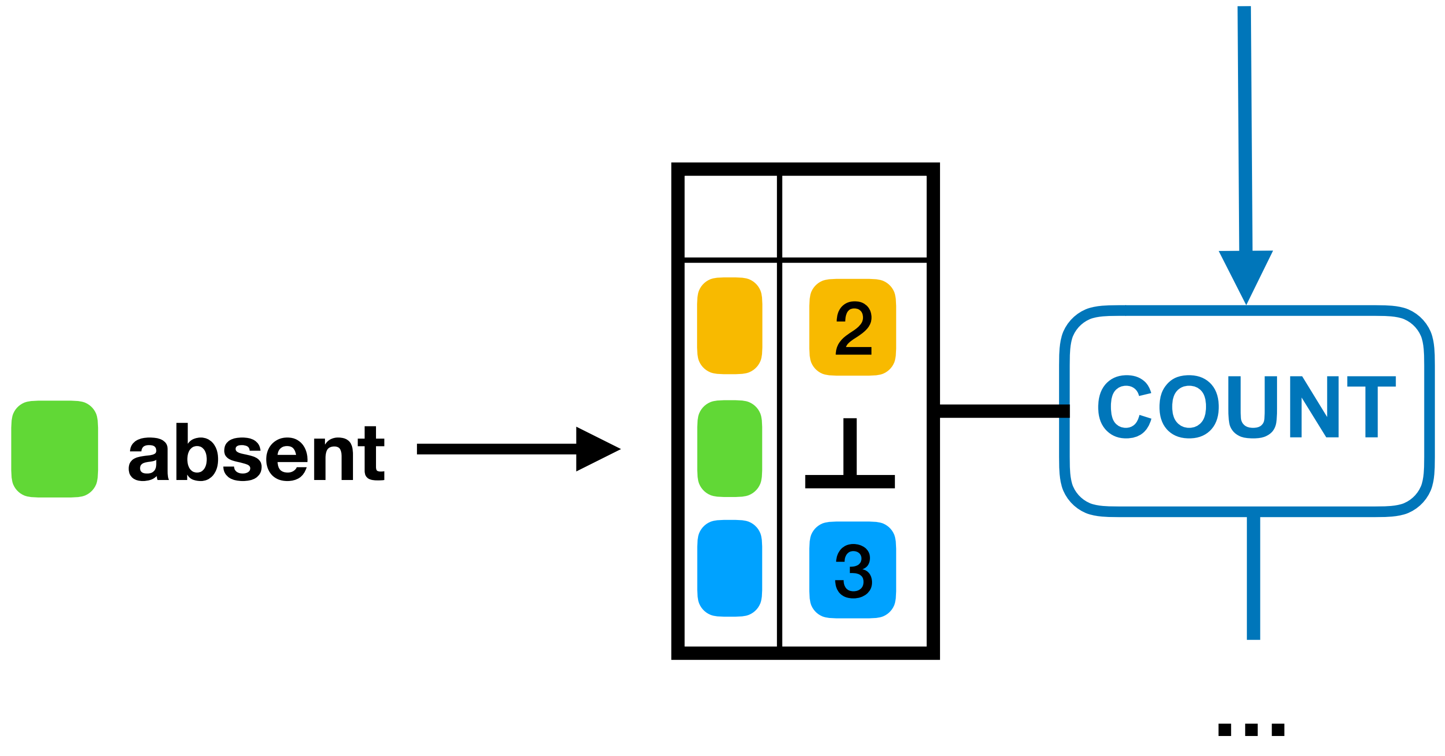

Drop updates that touch absent state, future upquery repeats them.

Challenges implementing partially-stateful data-flow

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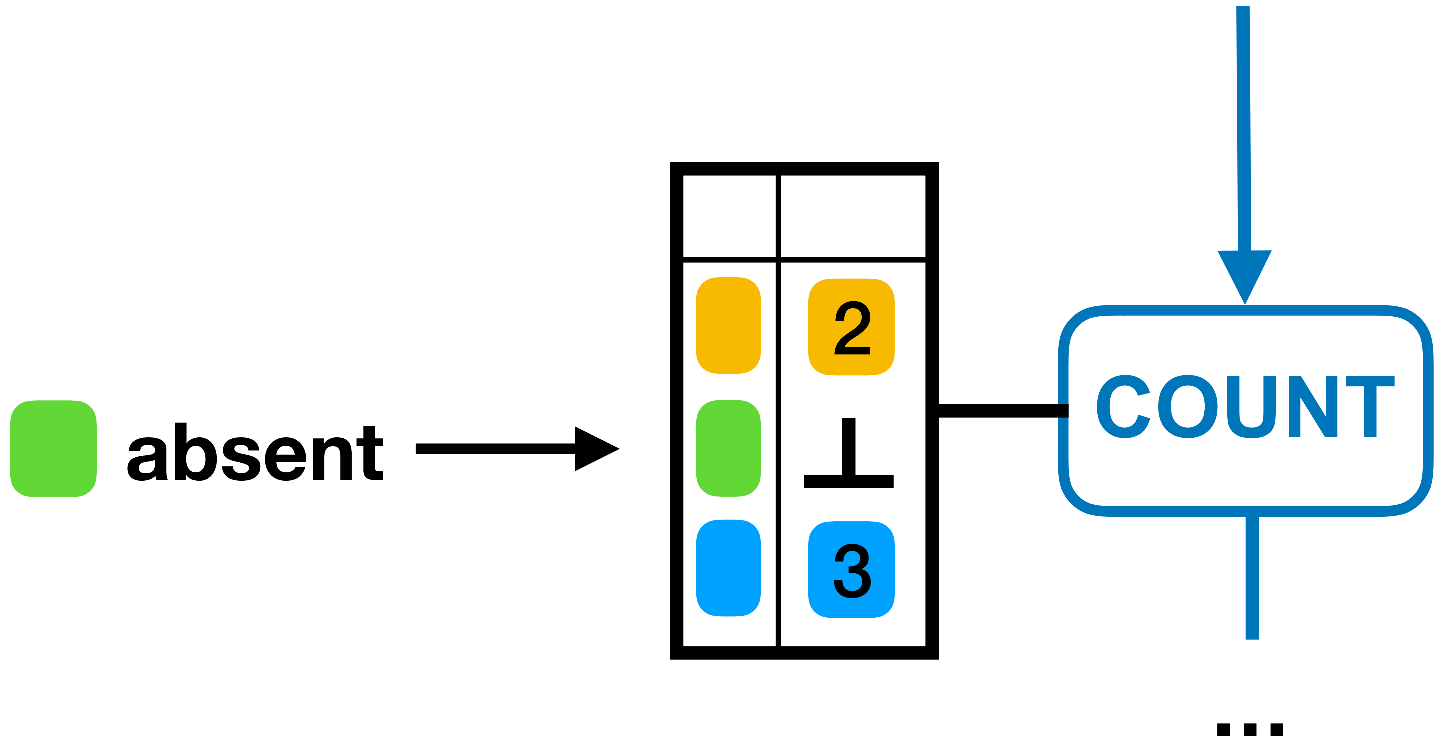

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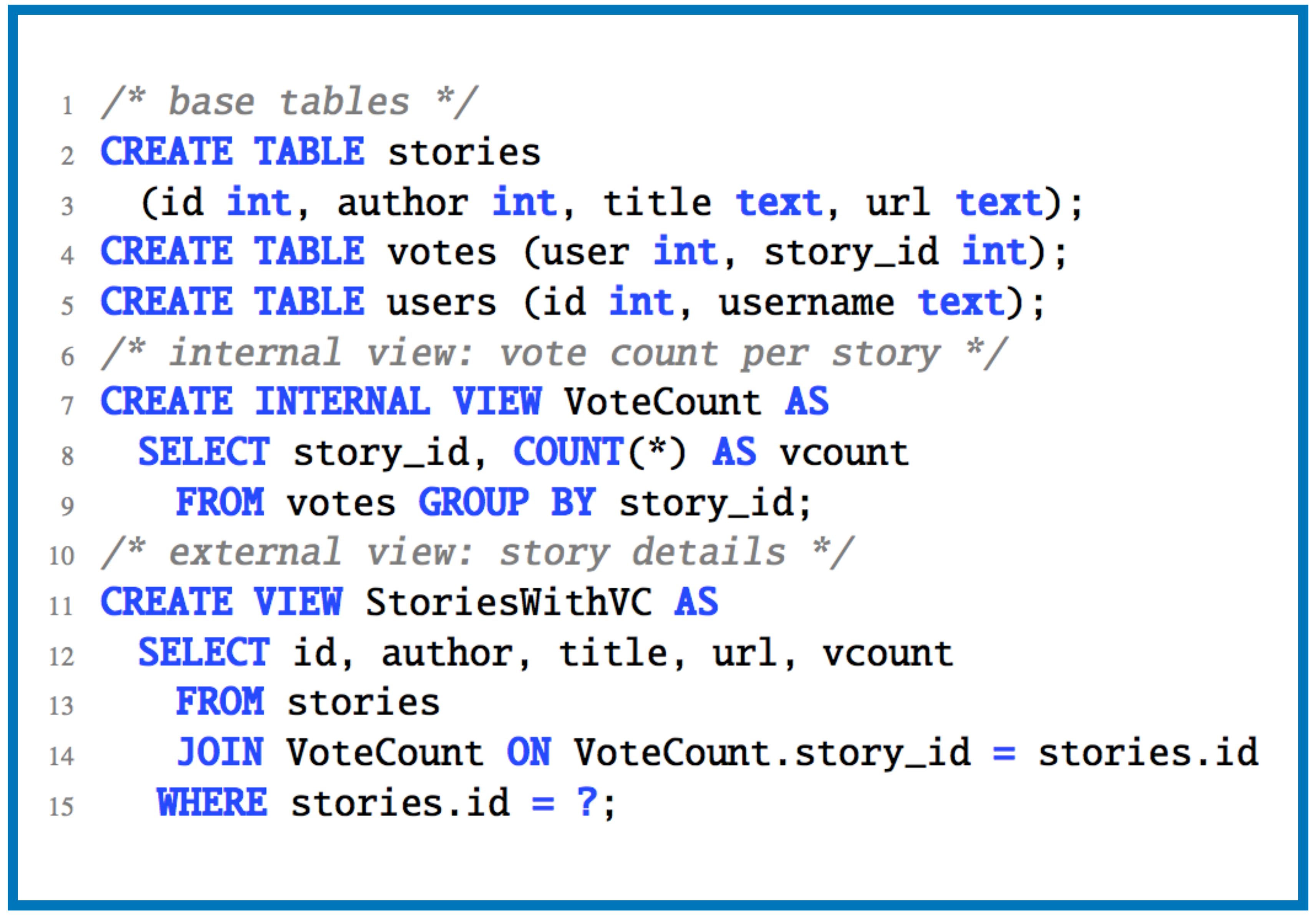
Noria implementation

Noria implementation



```
/* base tables */
CREATE TABLE stories
  (id int, author int, title text, url text);
CREATE TABLE votes (user int, story_id int);
CREATE TABLE users (id int, username text);
/* internal view: vote count per story */
CREATE INTERNAL VIEW VoteCount AS
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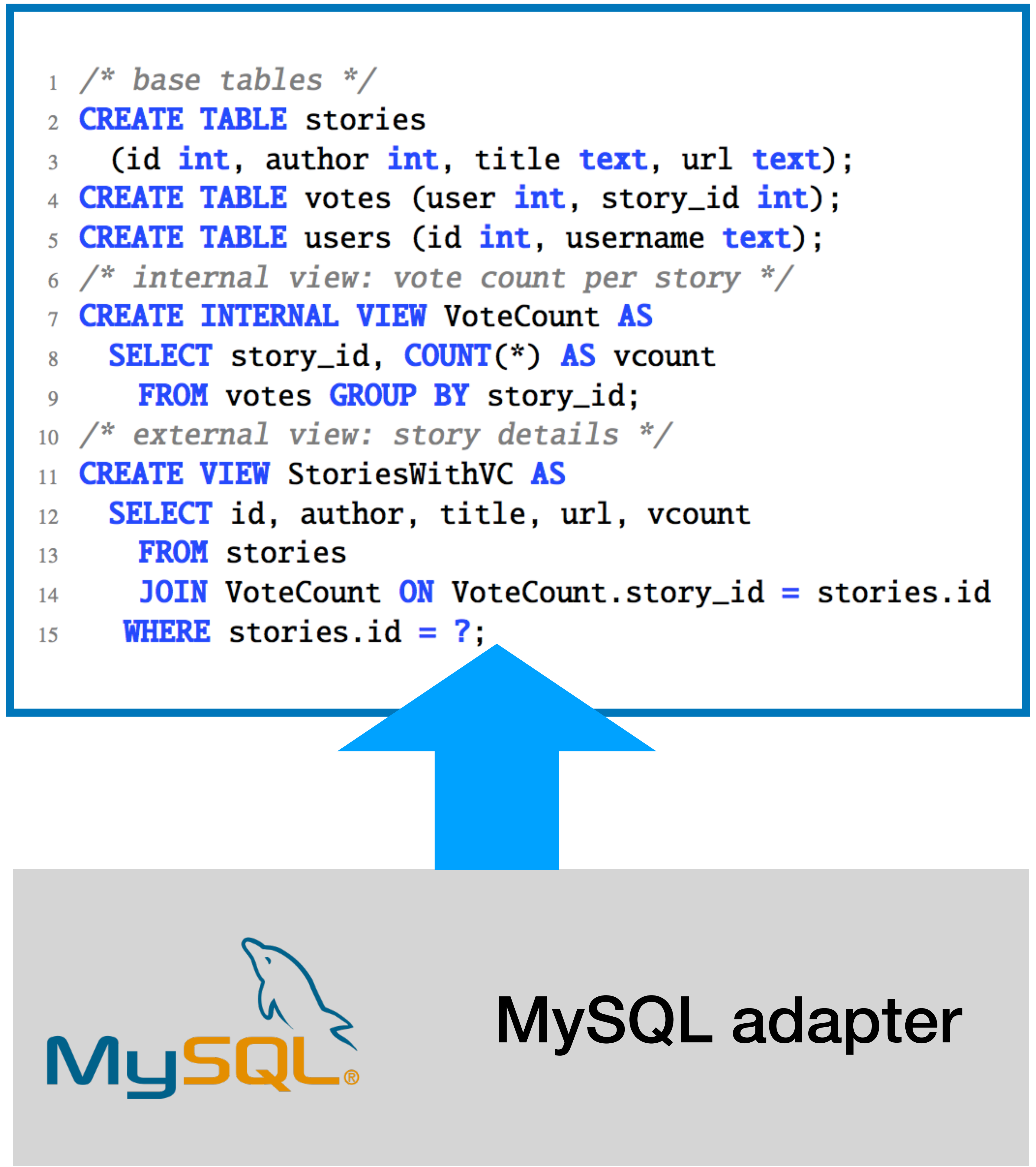

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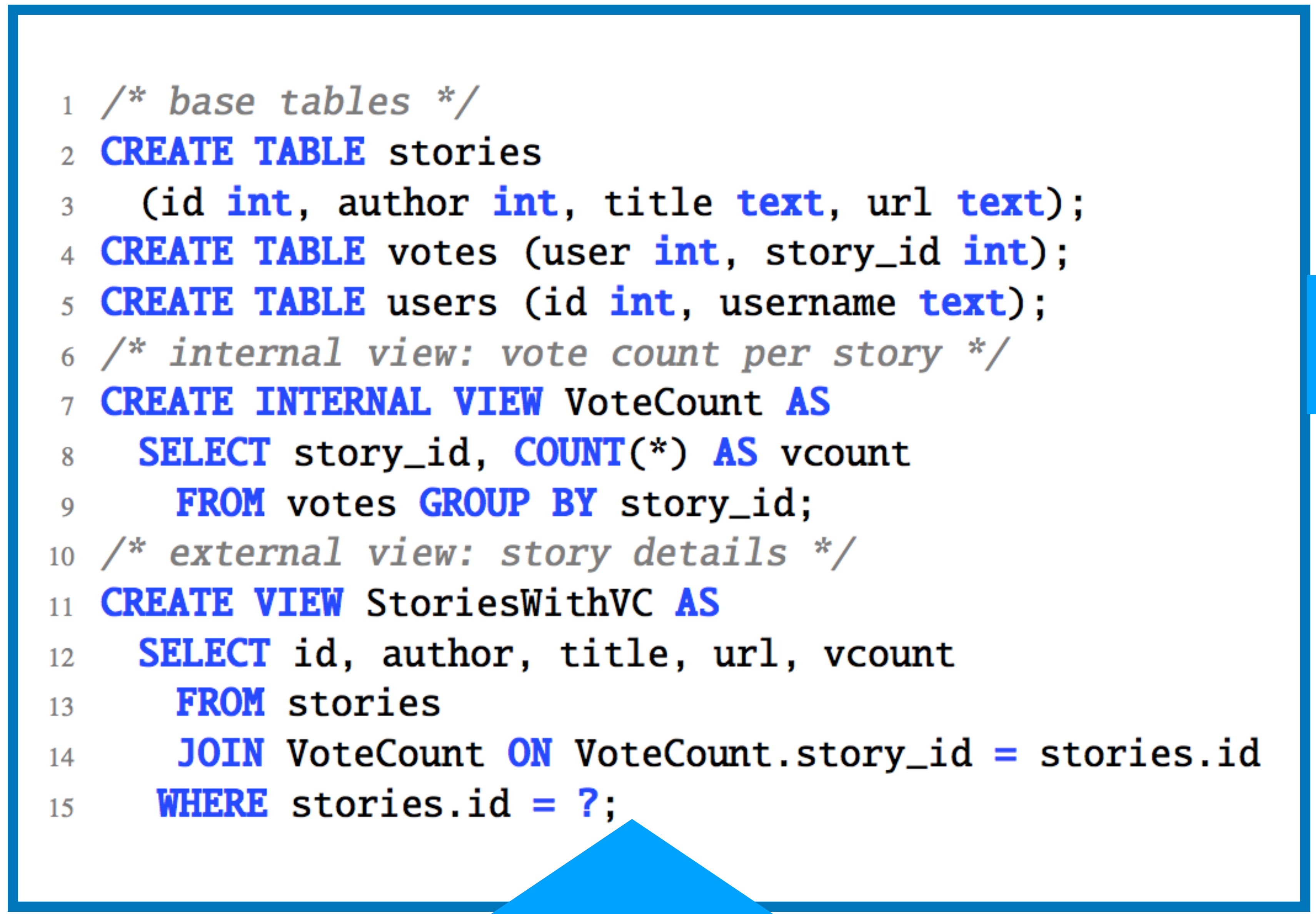

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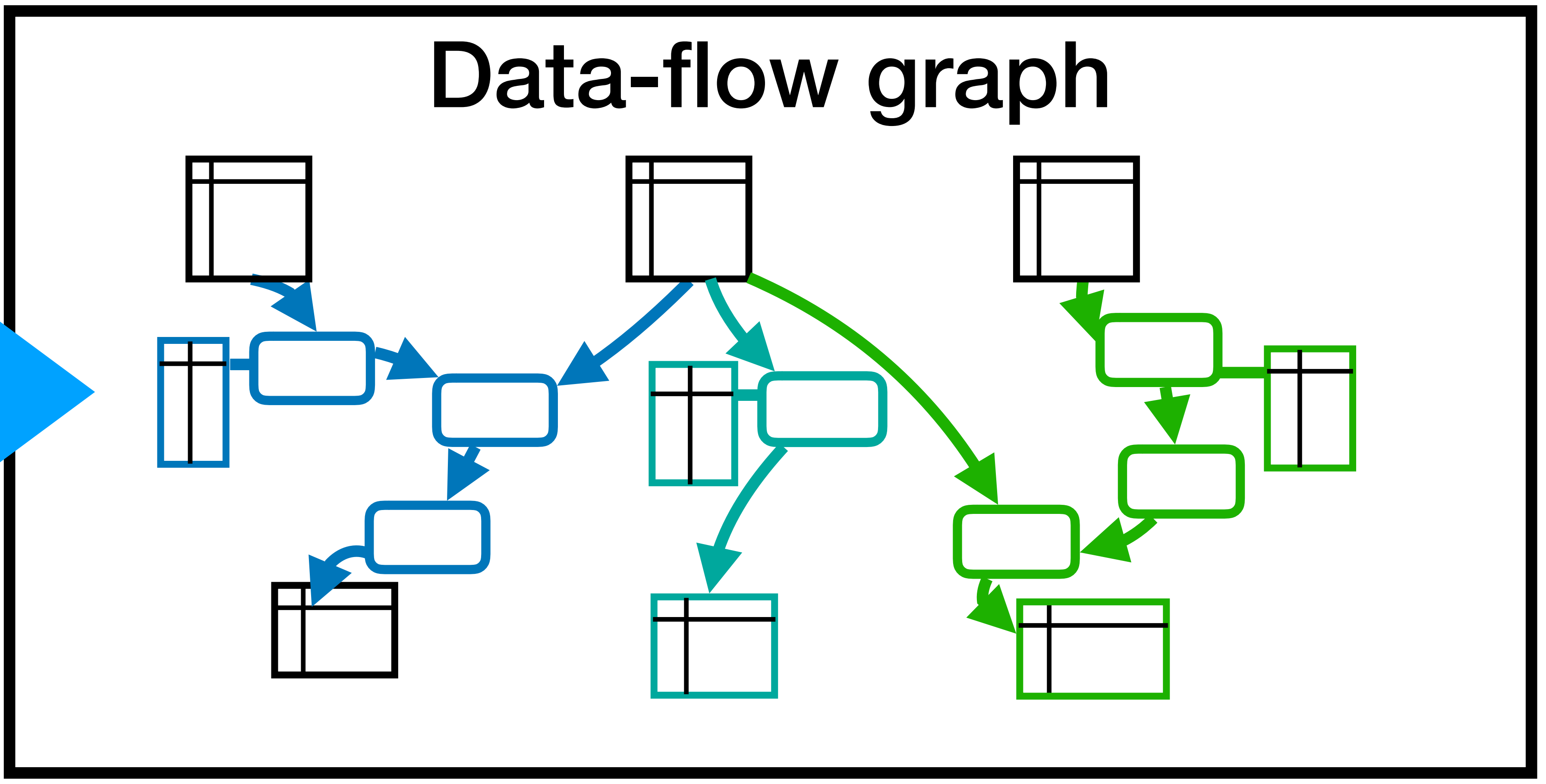
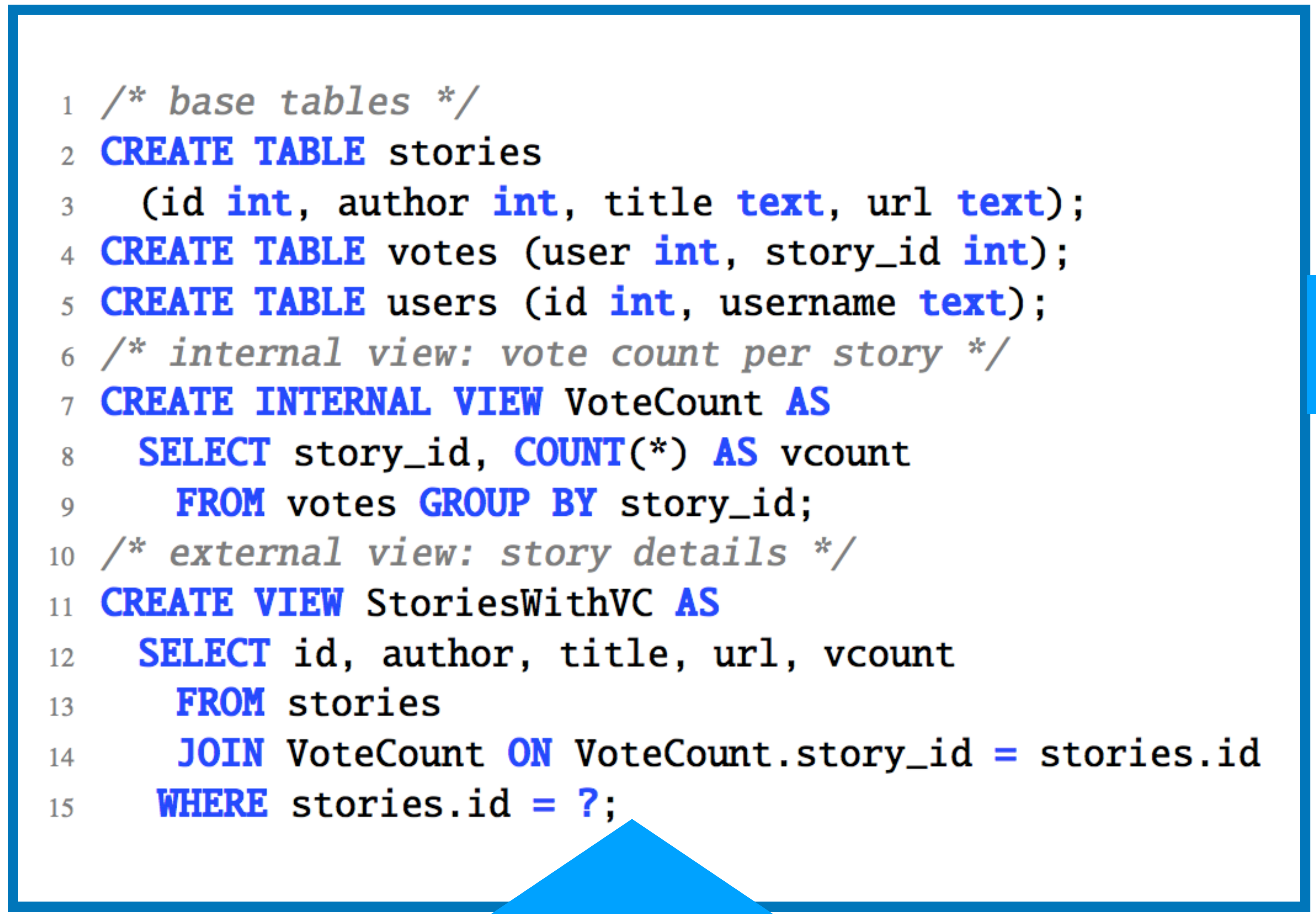
Transform



MySQL adapter

Noria implementation



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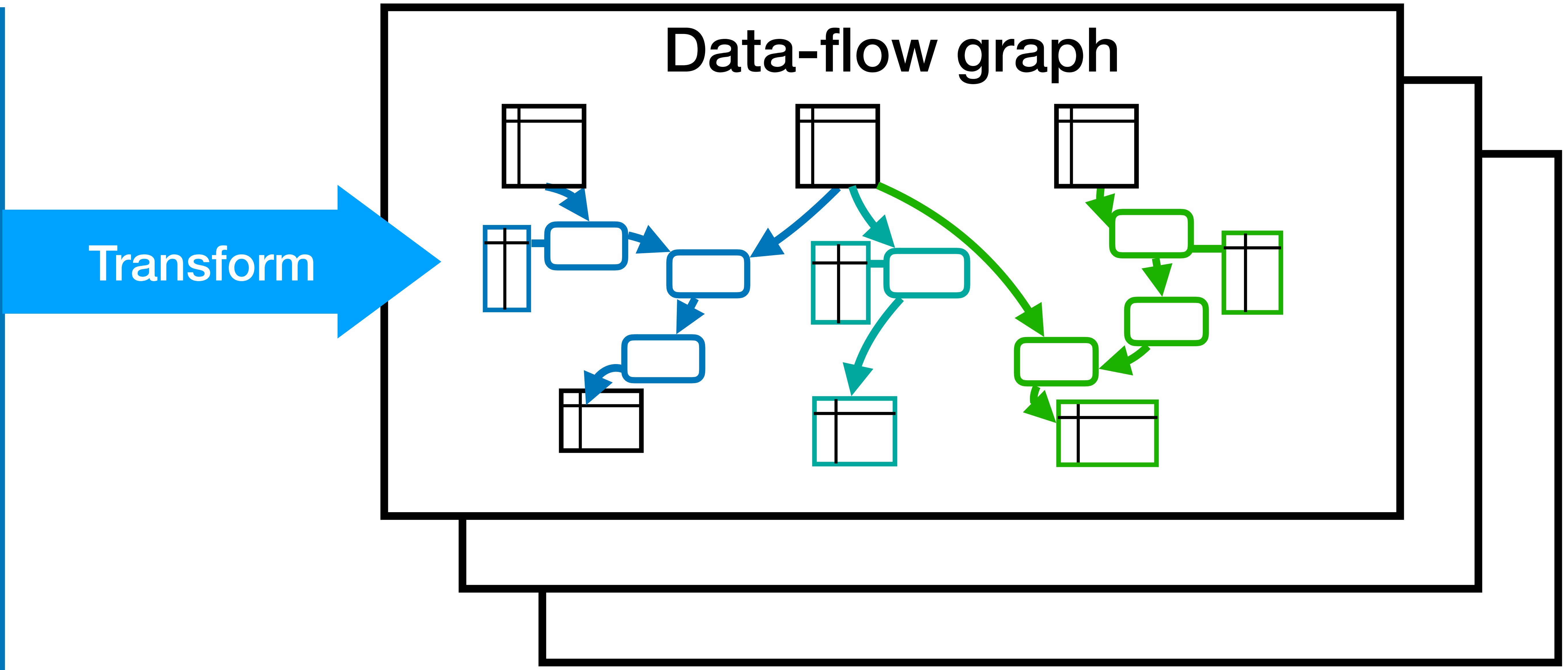

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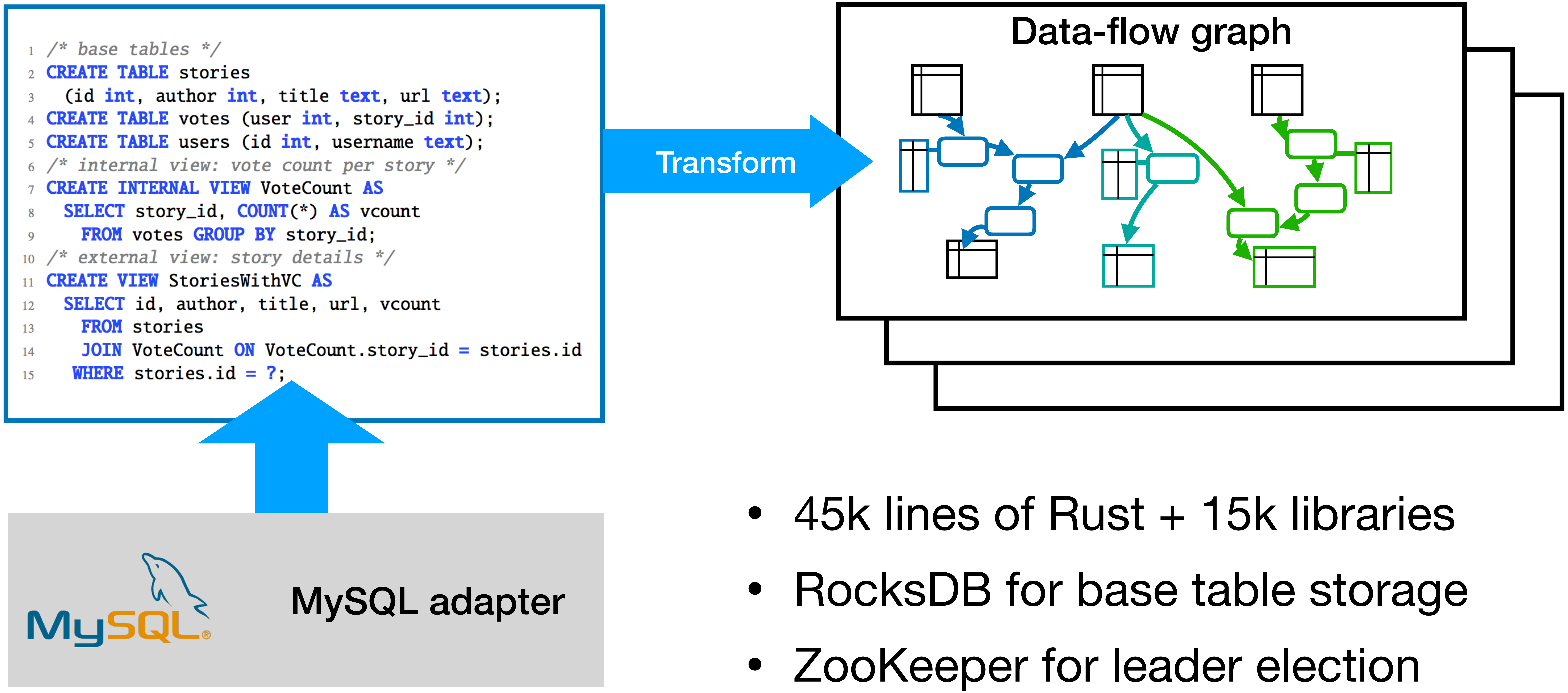

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Transform

Data-flow graph

MySQL adapter

- 45k lines of Rust + 15k libraries
- RocksDB for base table storage
- ZooKeeper for leader election

Evaluation

1. Can Noria improve a real web application’s performance?

2. How does Noria compare to alternative approaches?

3. Can Noria change queries without downtime?

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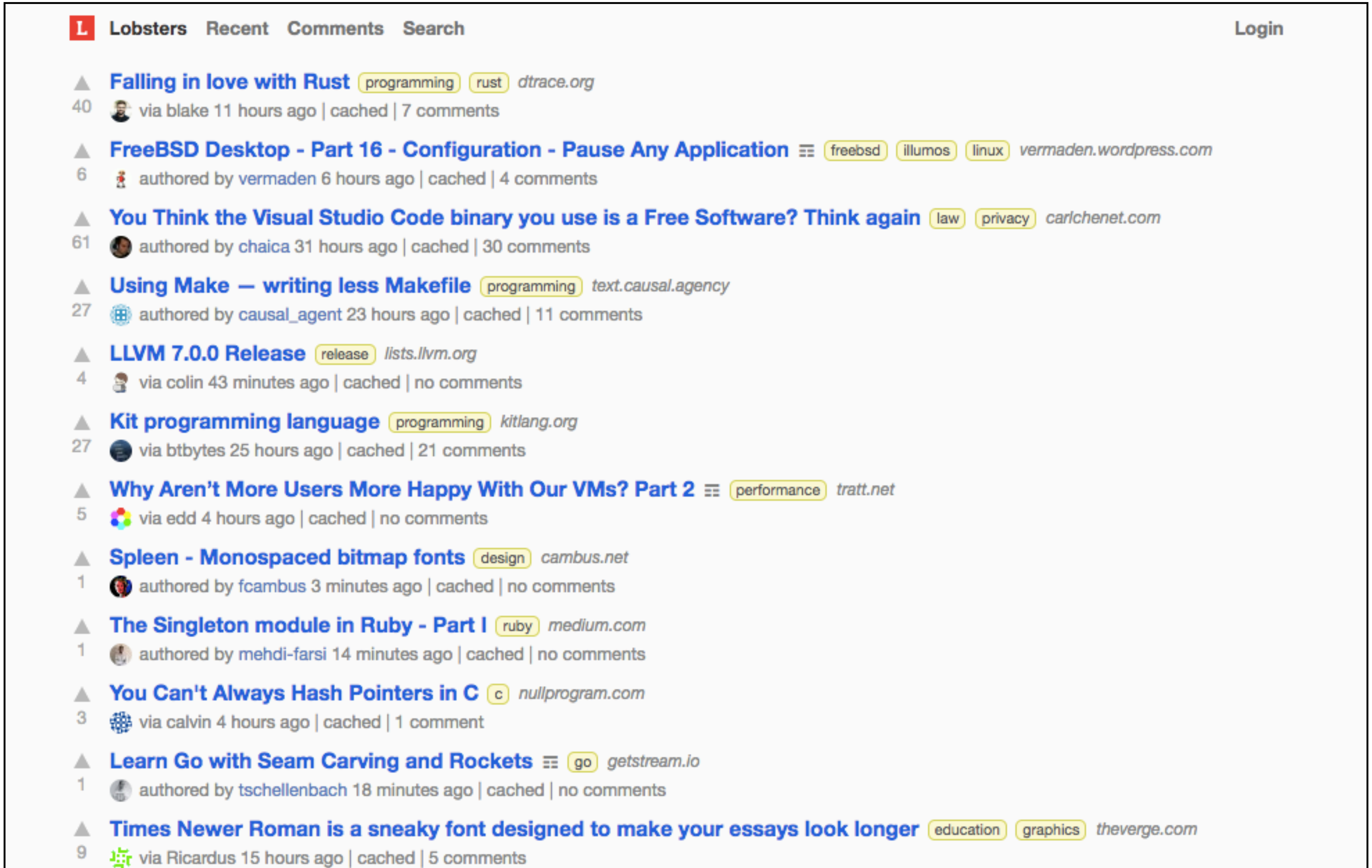
Open-loop clients, measuring latency & throughput

multi-machine experiments
comparison with differential dataflow } **see Paper**

Case study: Lobsters (http://lobste.rs)



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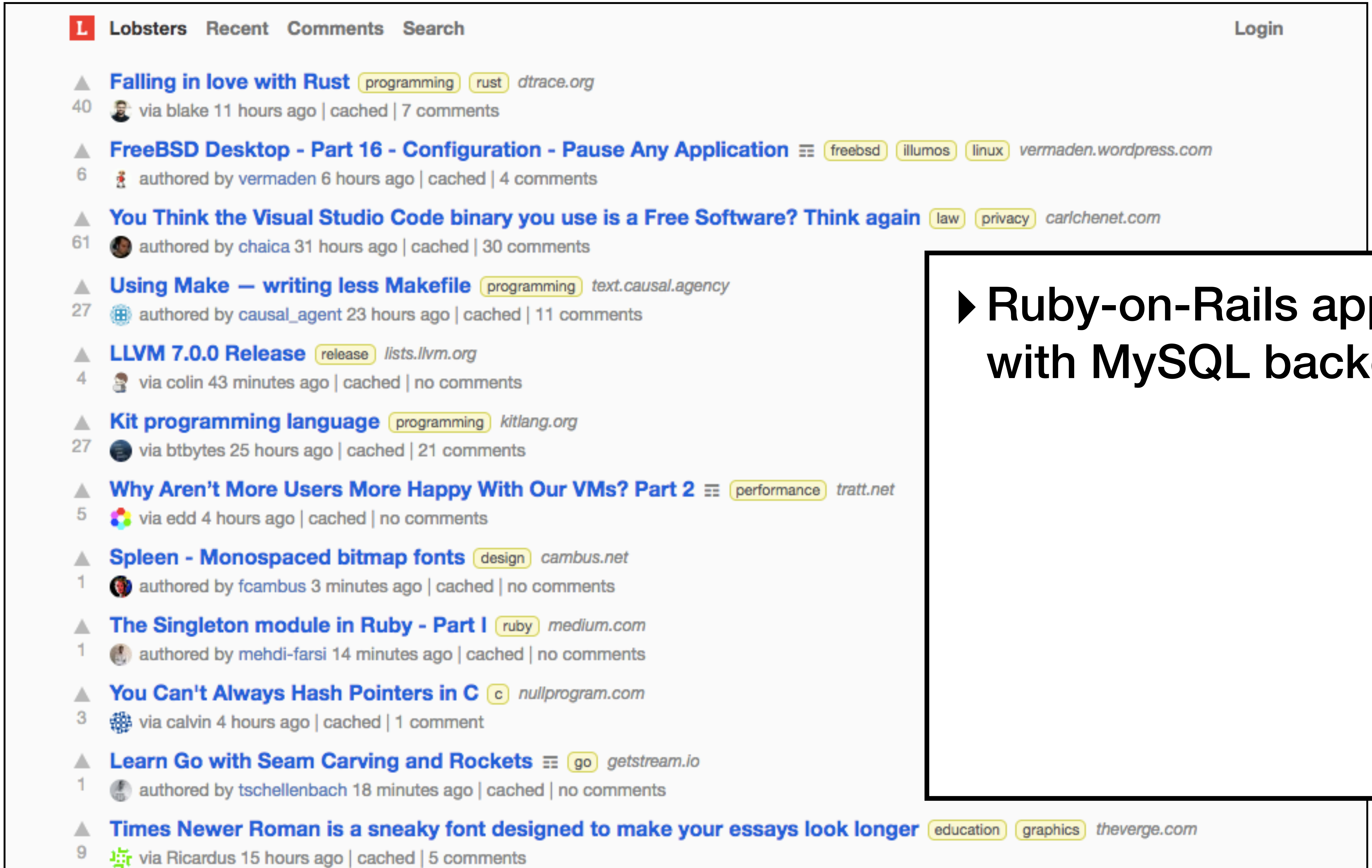

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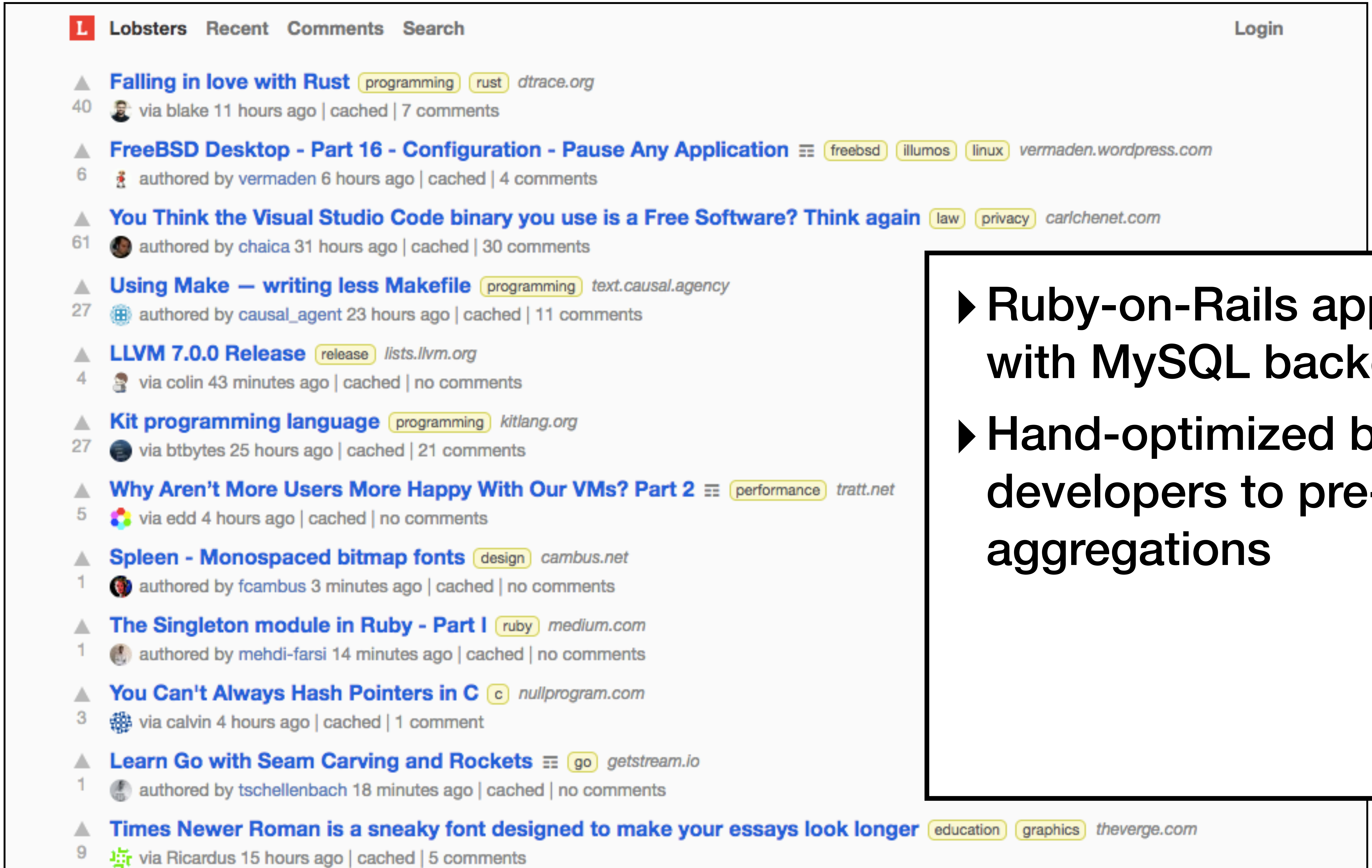

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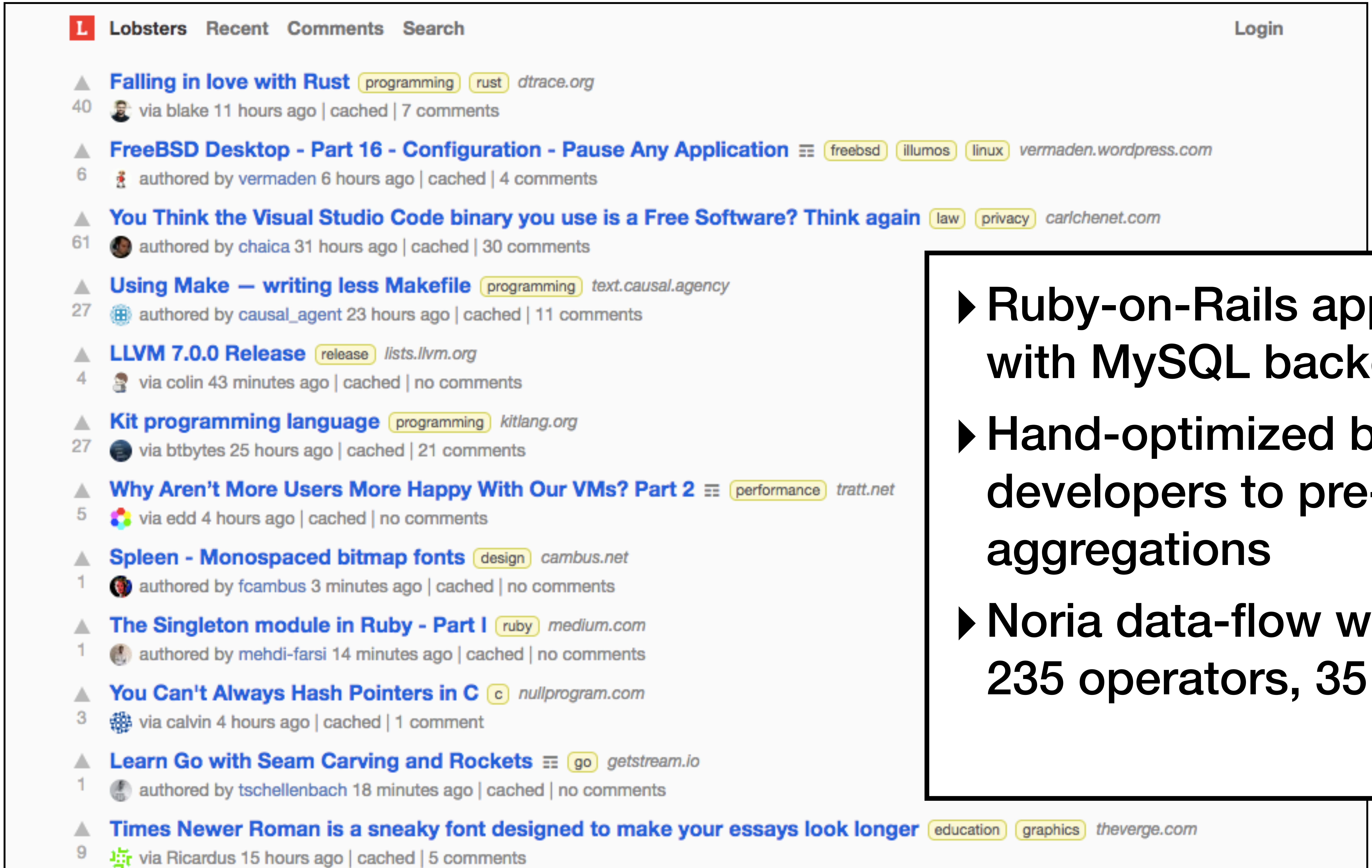

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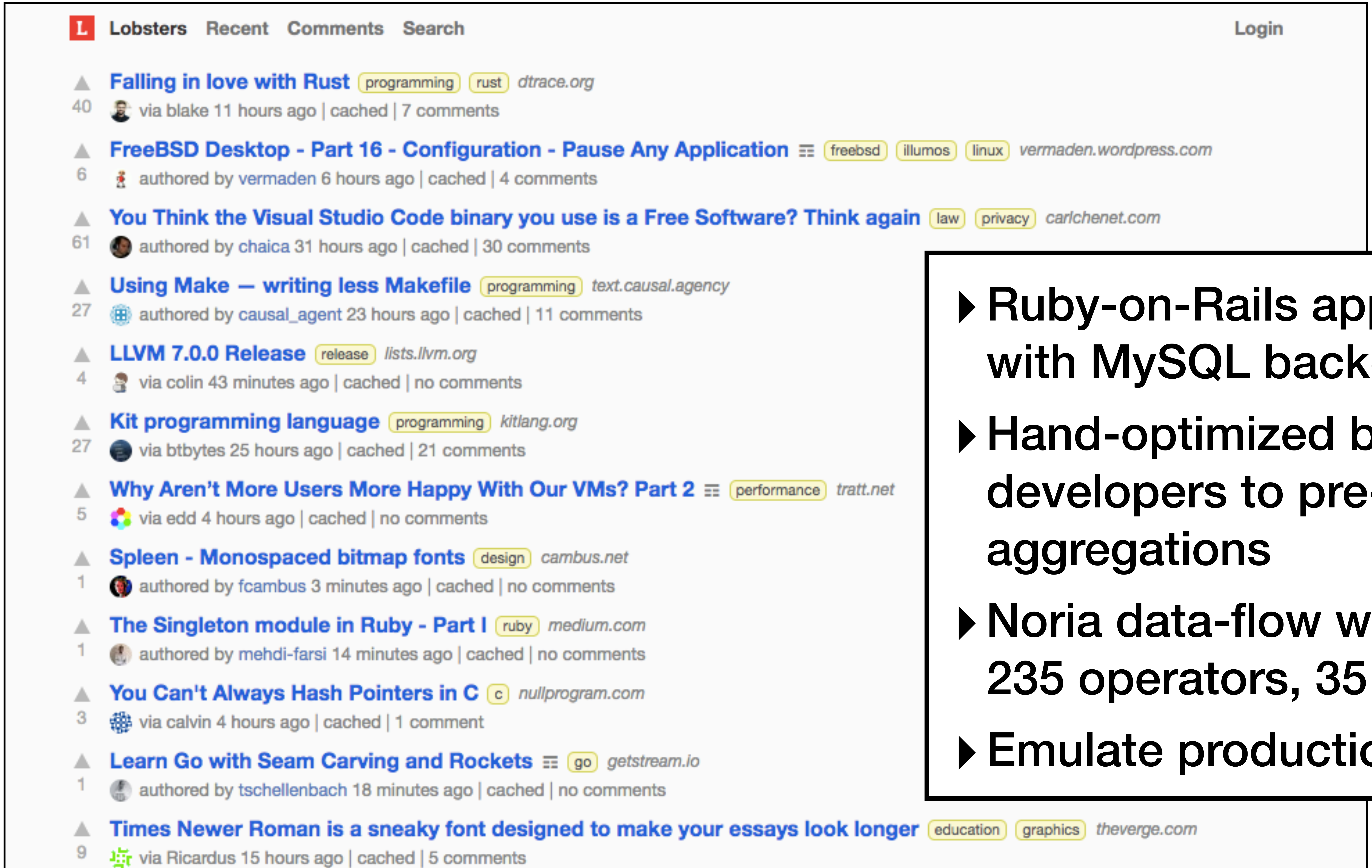

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- Ruby-on-Rails application with MySQL backend
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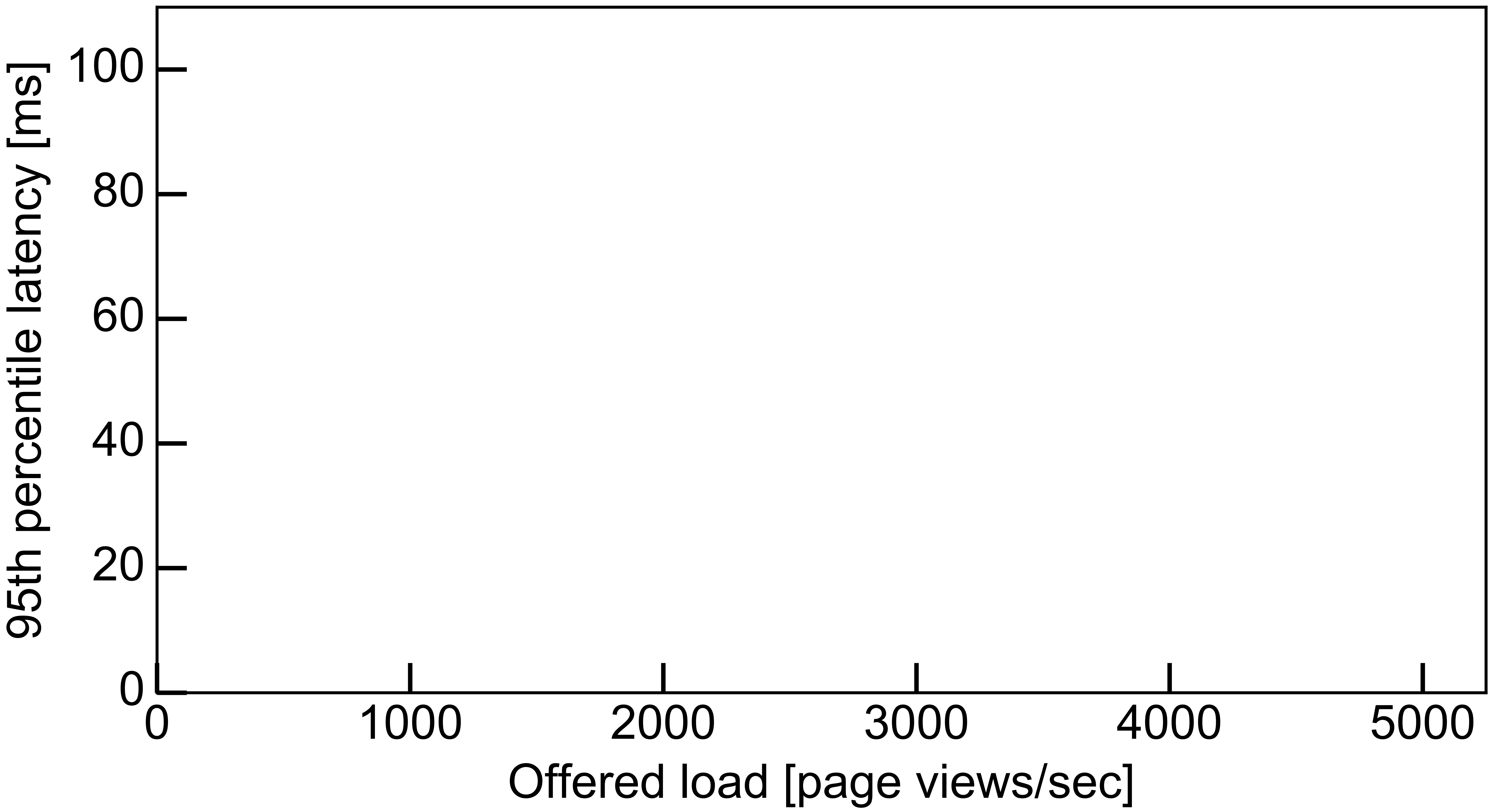
- Noria data-flow with 235 operators, 35 views
- Emulate production load

Can Noria improve Lobsters' performance?



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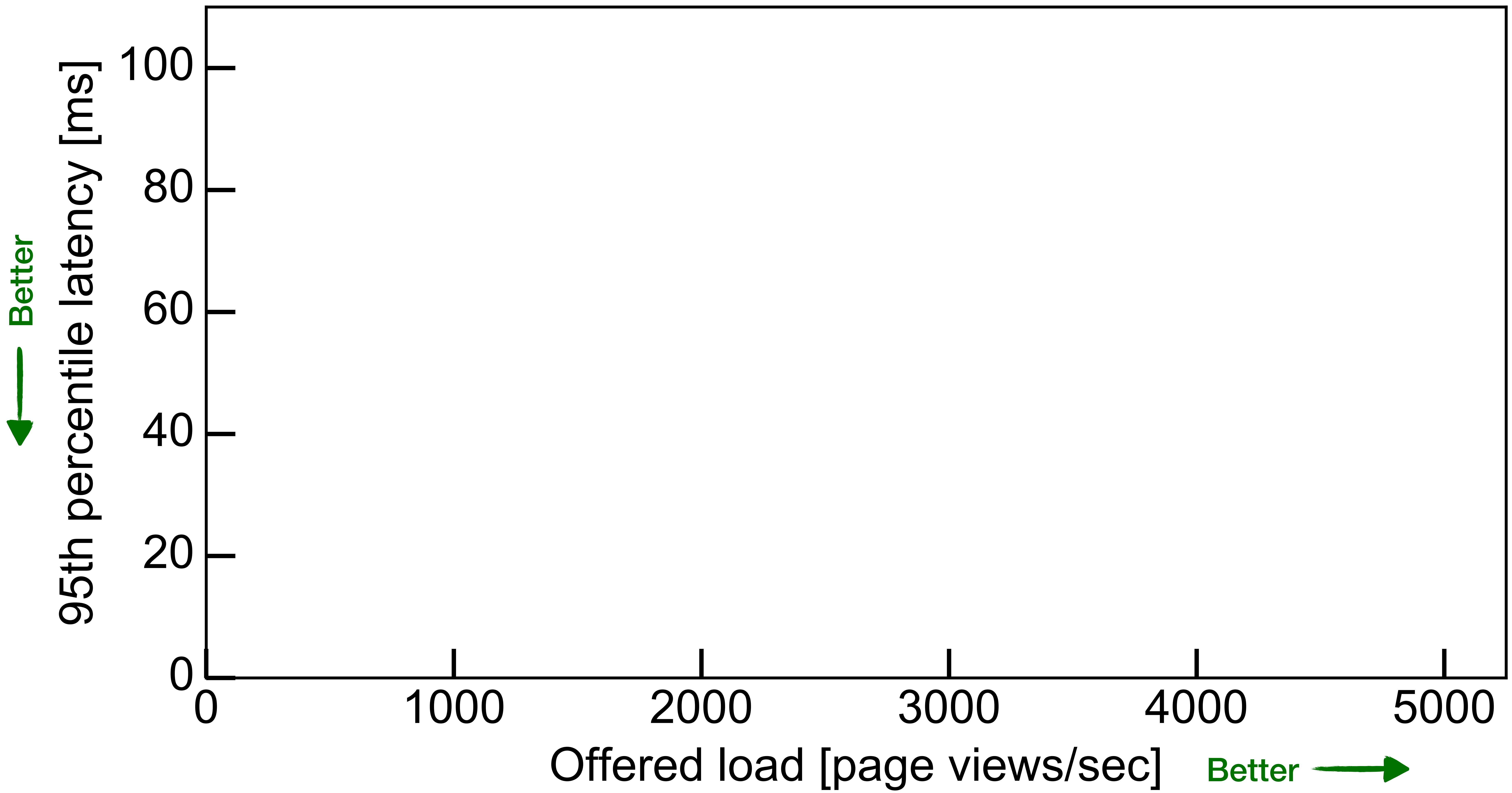

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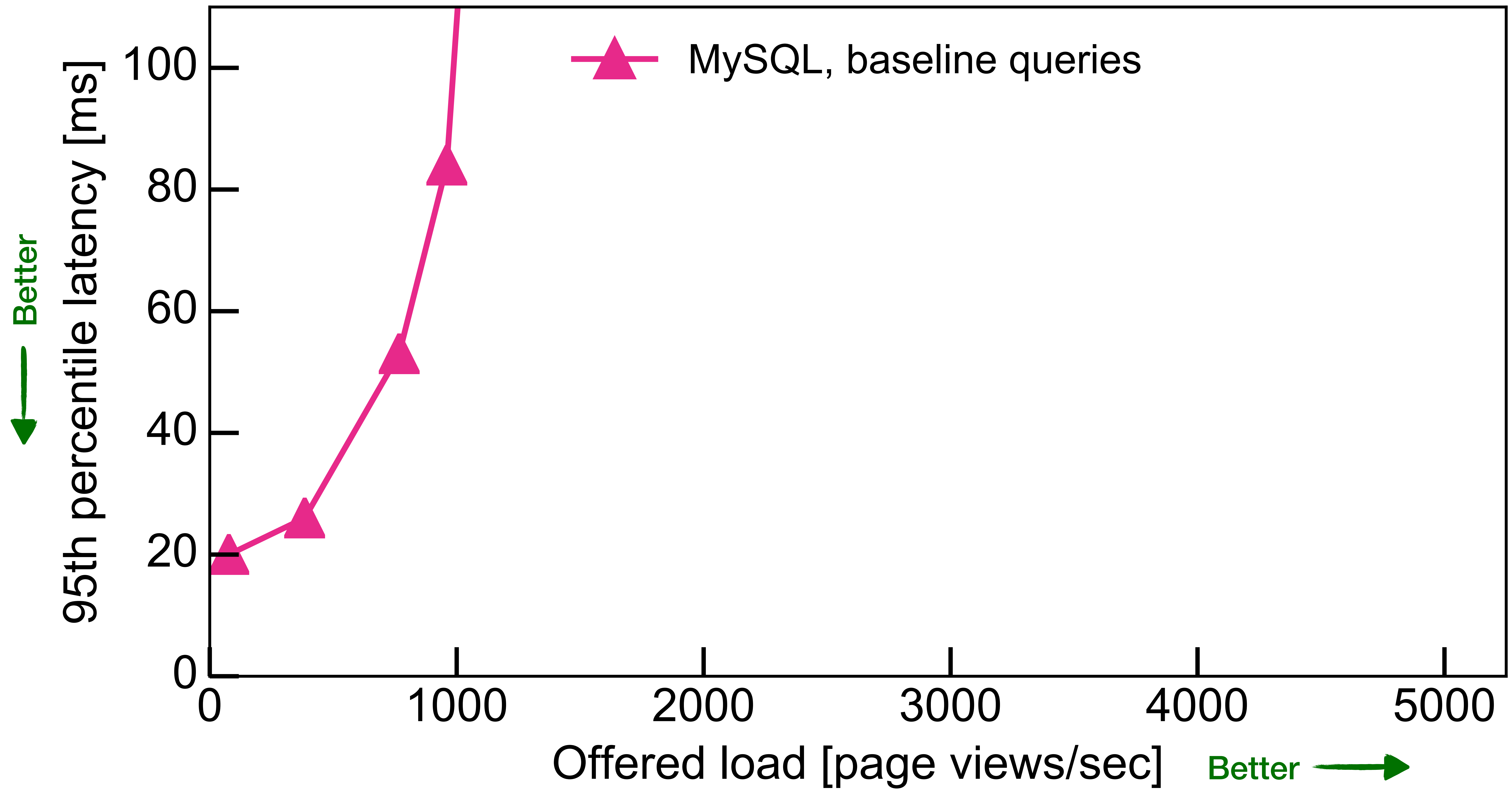

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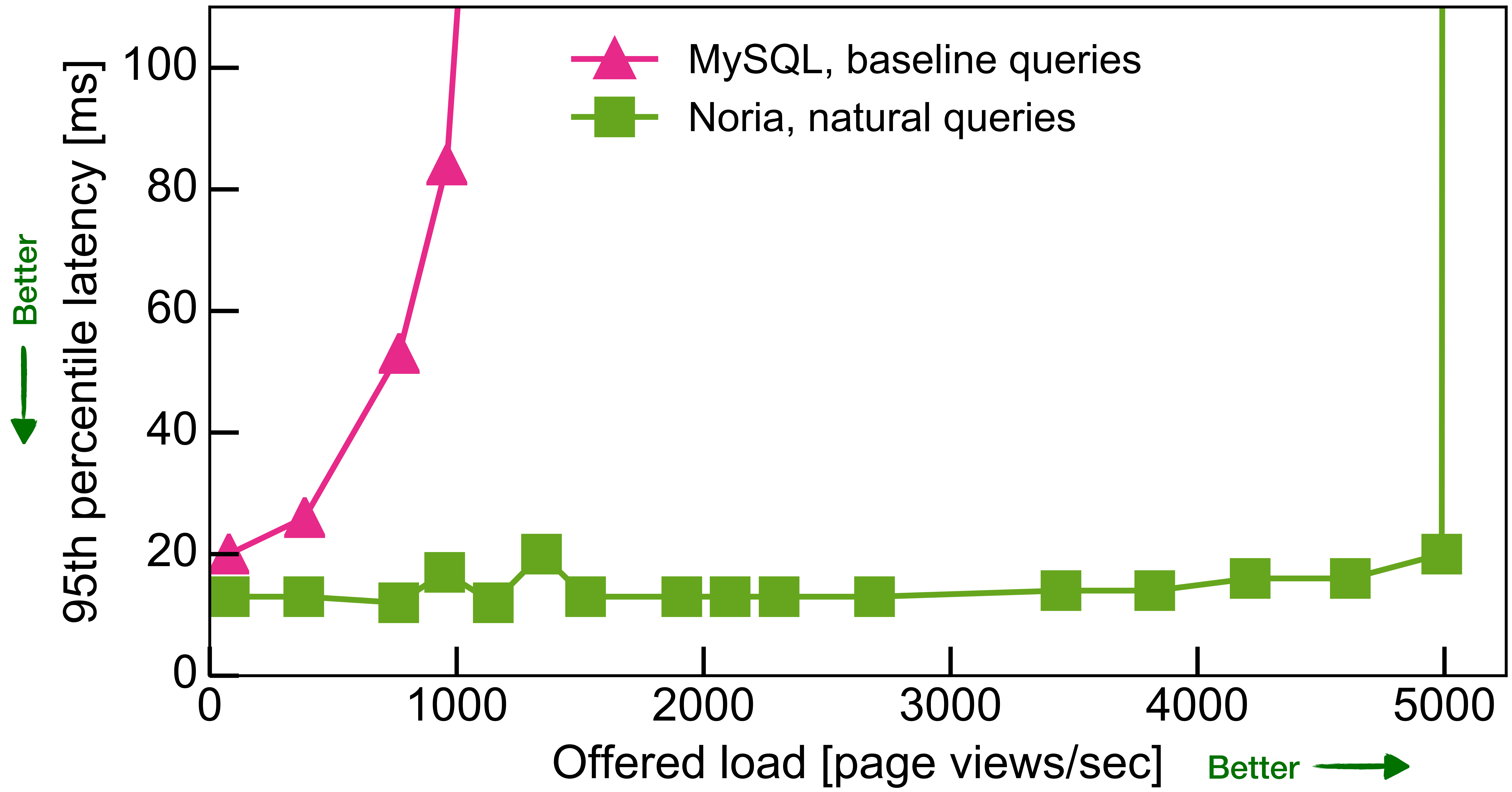

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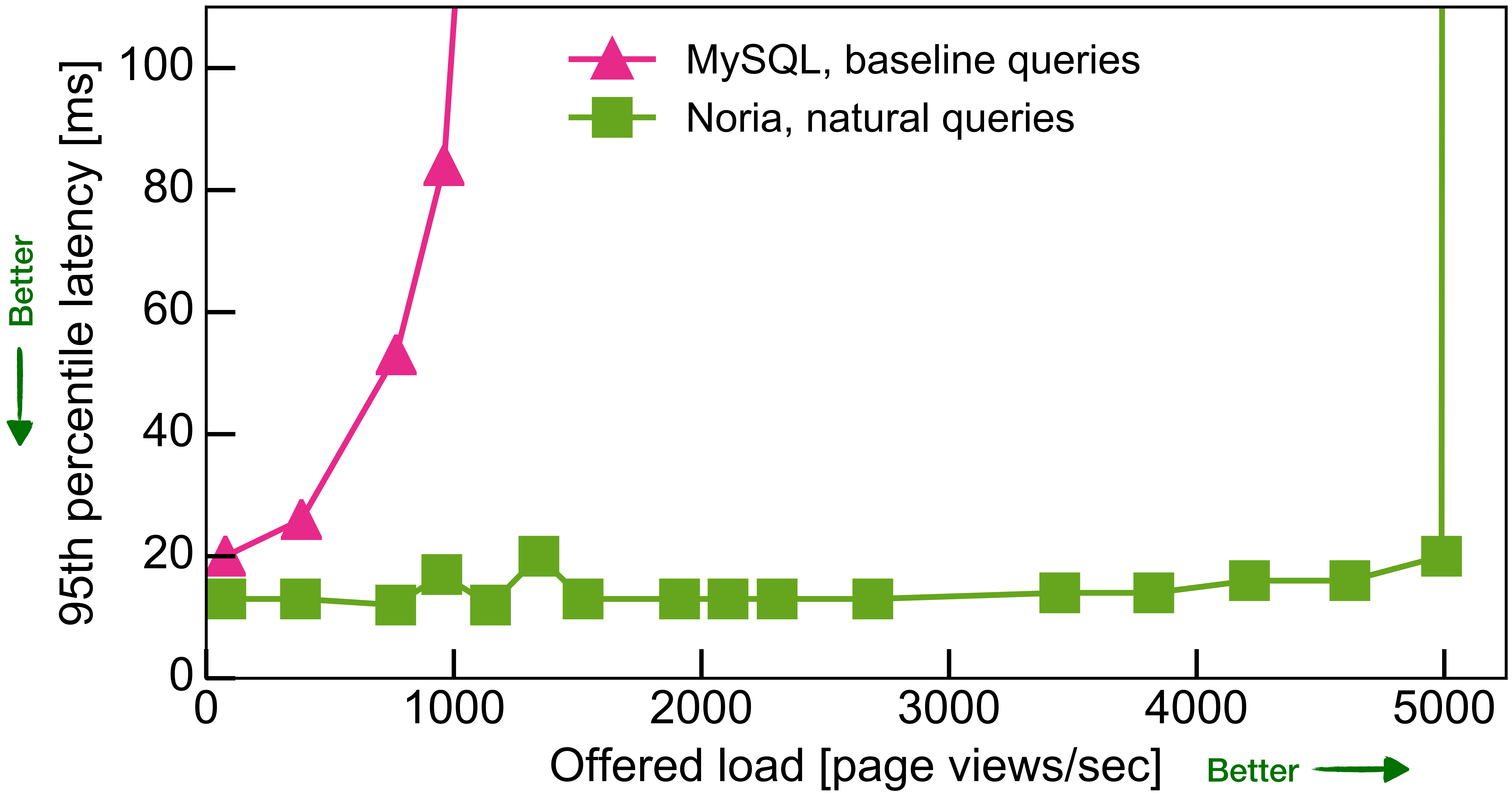
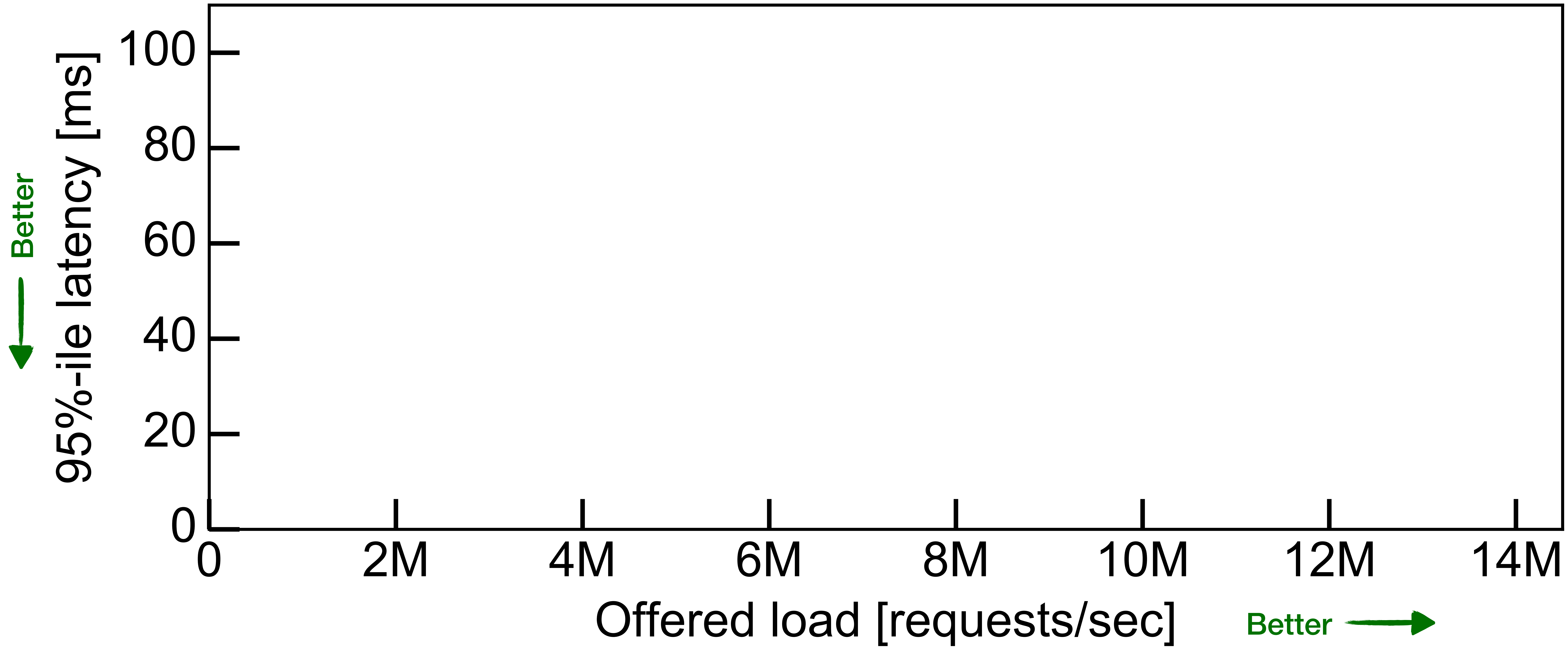


Noria with **natural queries** supports **5x** MySQL's throughput.

How does Noria compare to alternatives?



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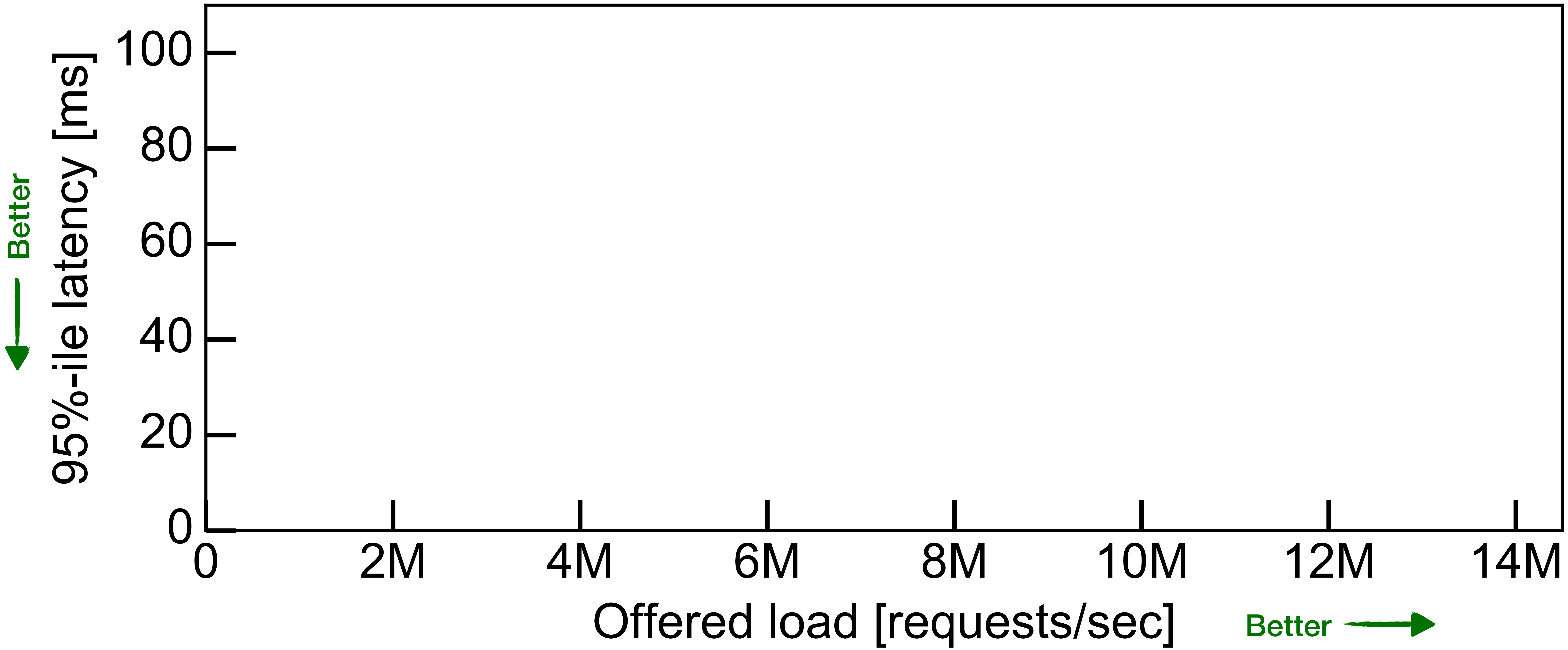

- Zipf-distributed story ID, 95% reads, 5% writes
- No TX, all in-memory

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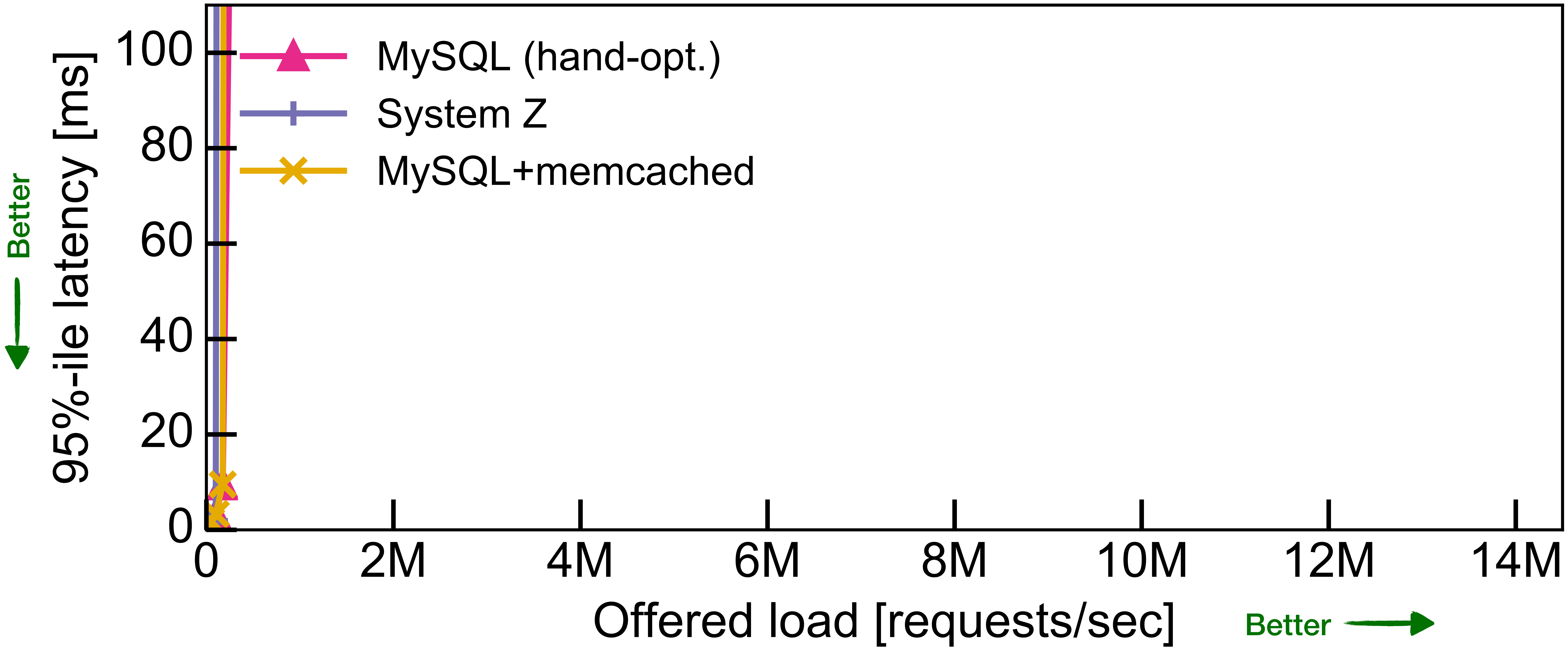

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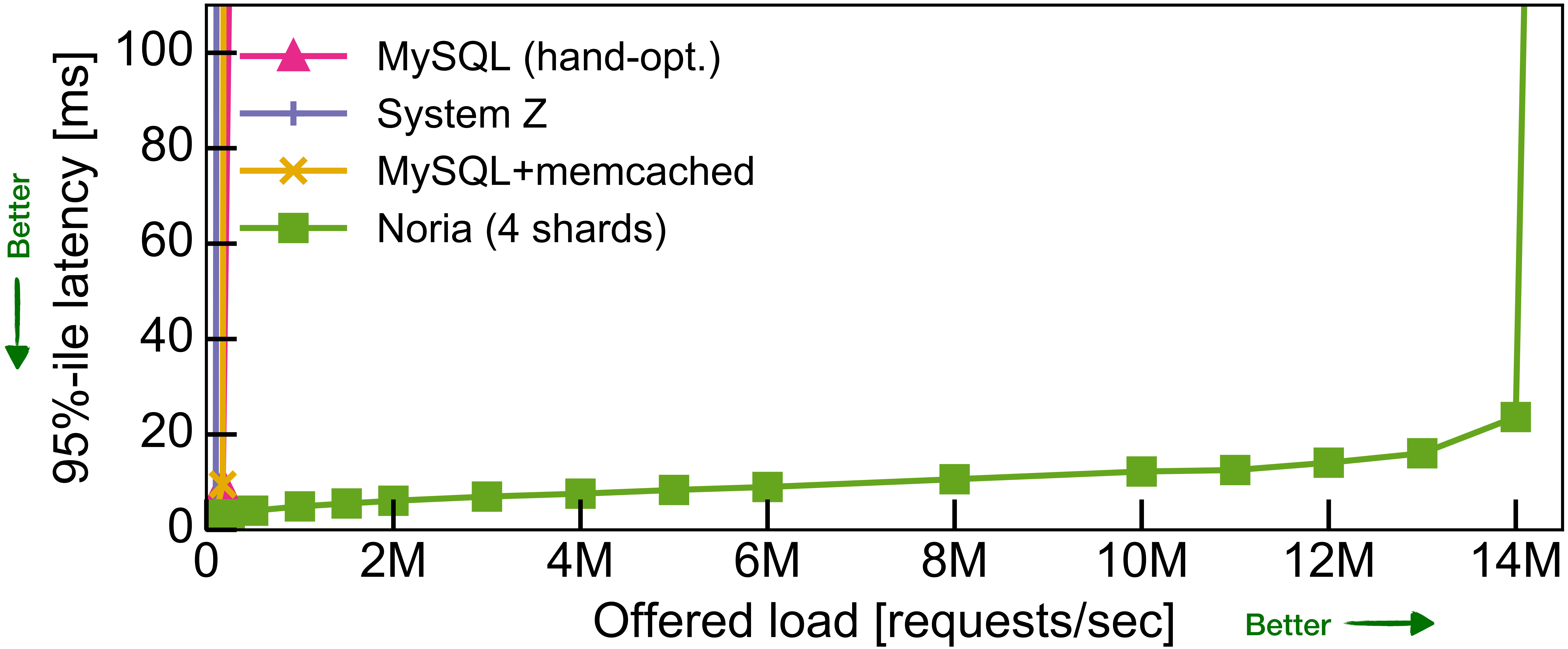

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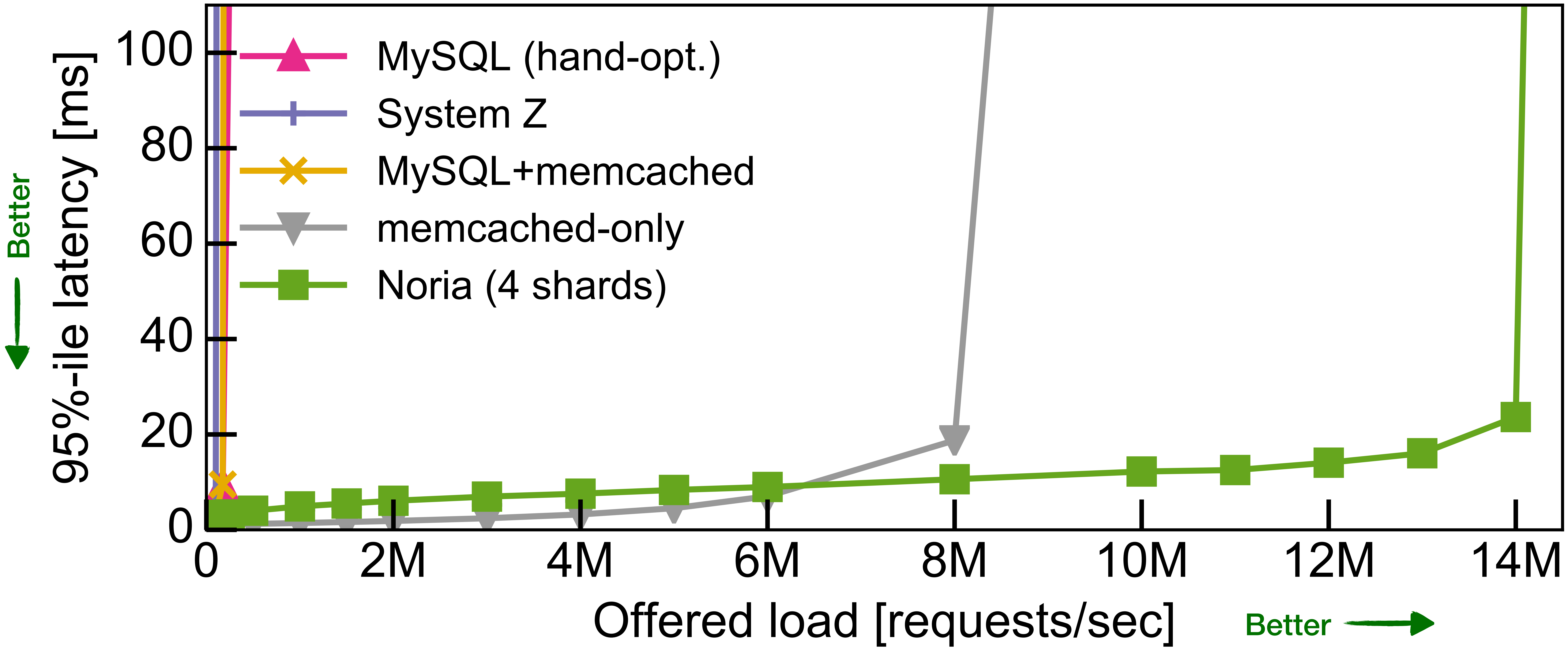

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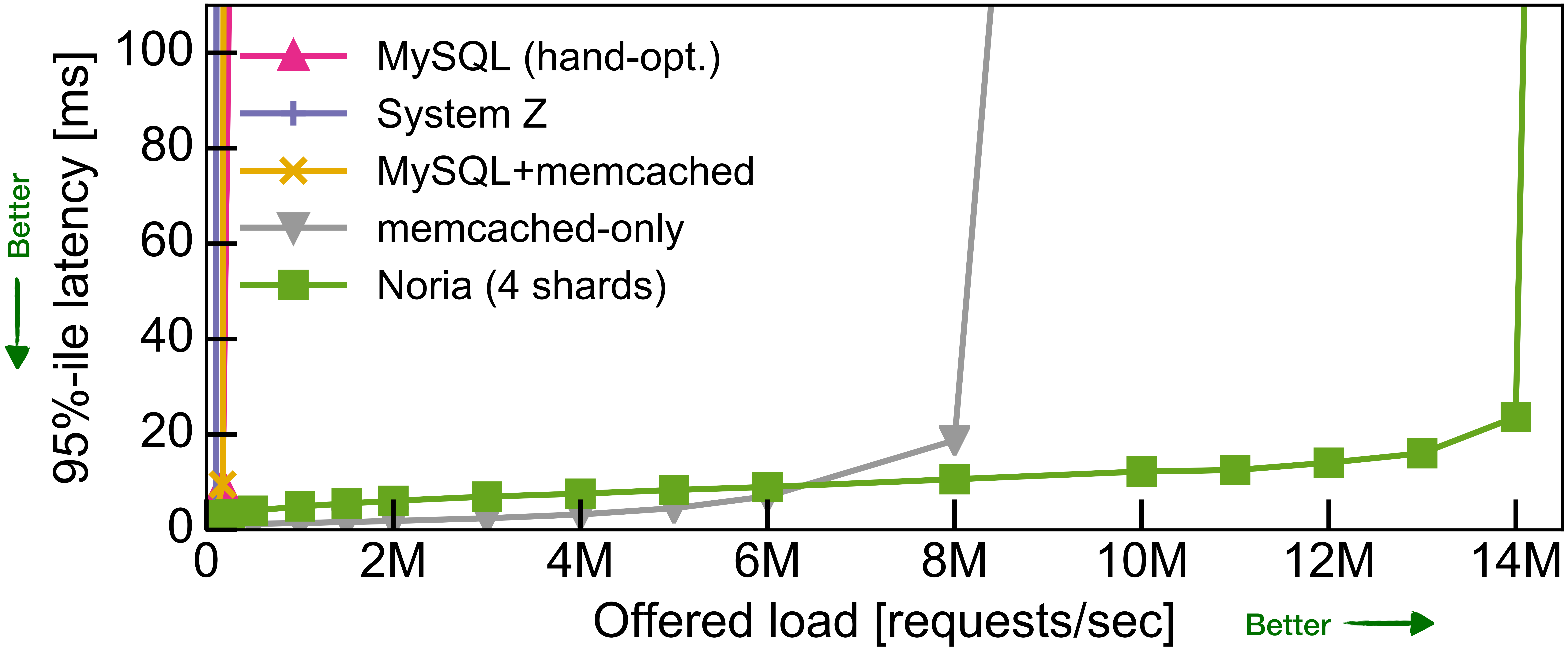

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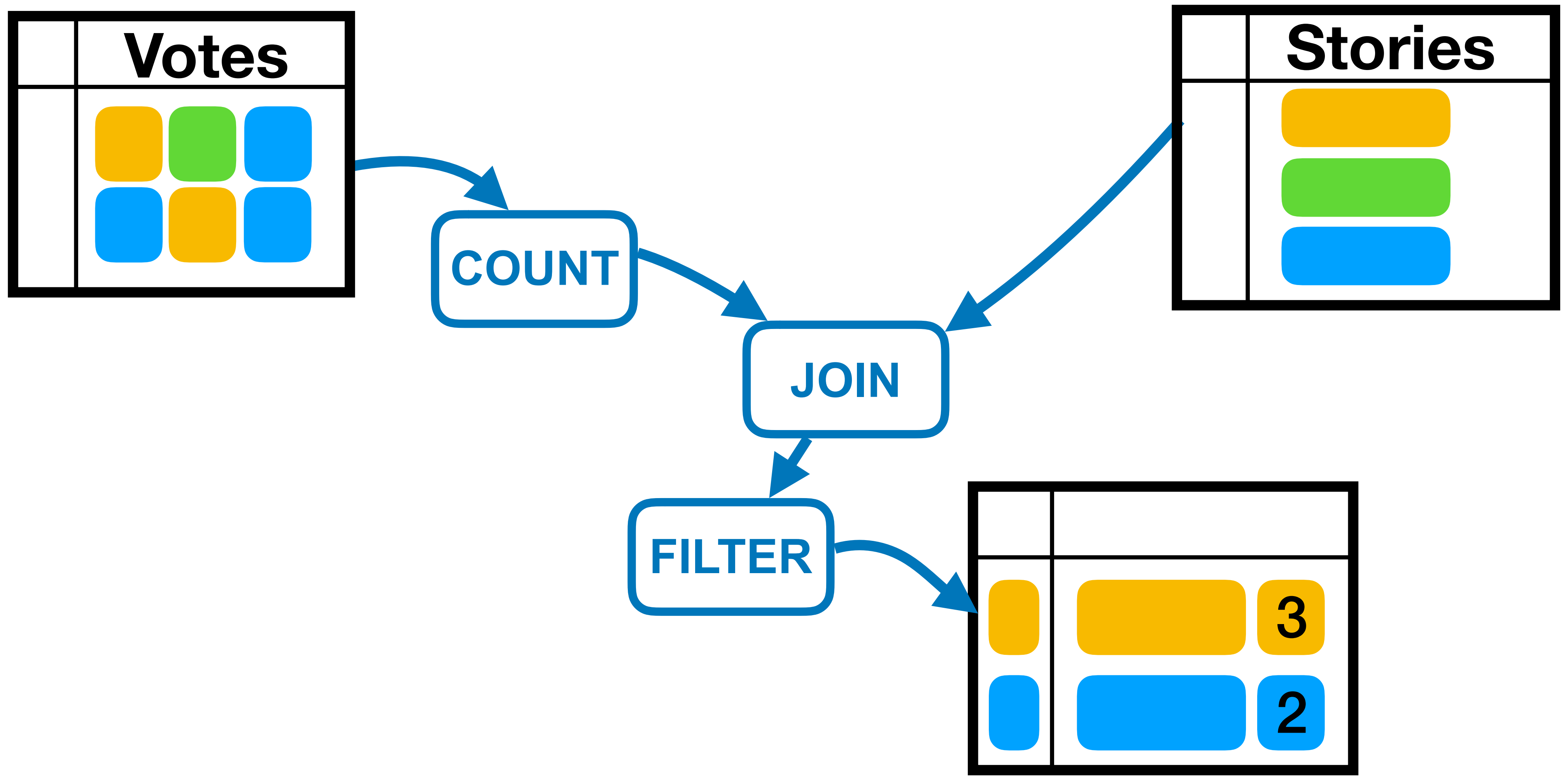
Noria outperforms an **in-memory key-value store** and simplifies its interface.

Can Noria change queries without downtime?



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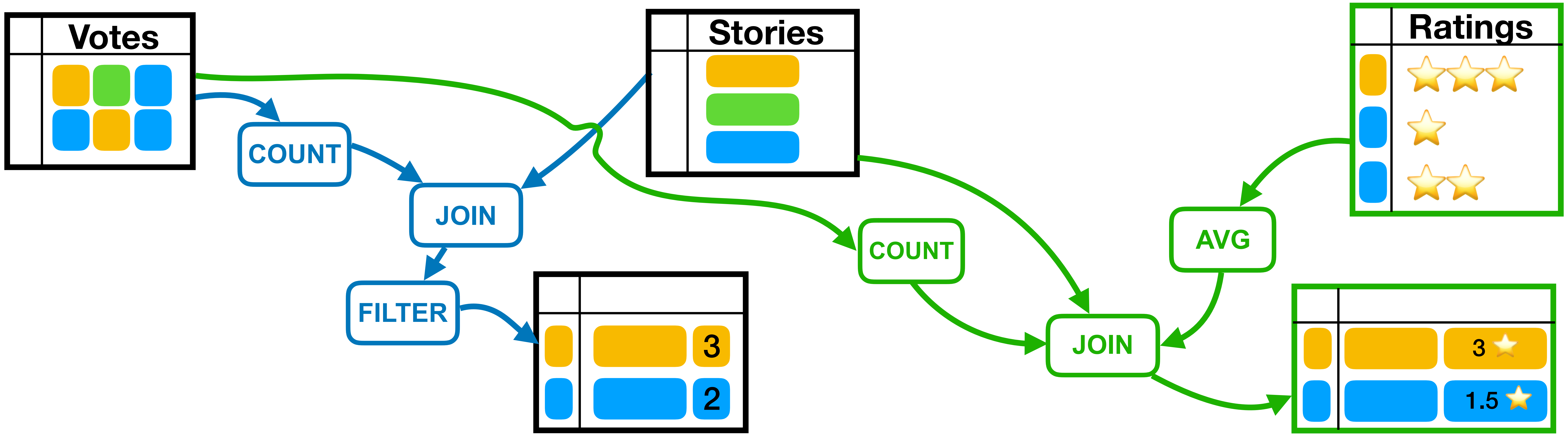

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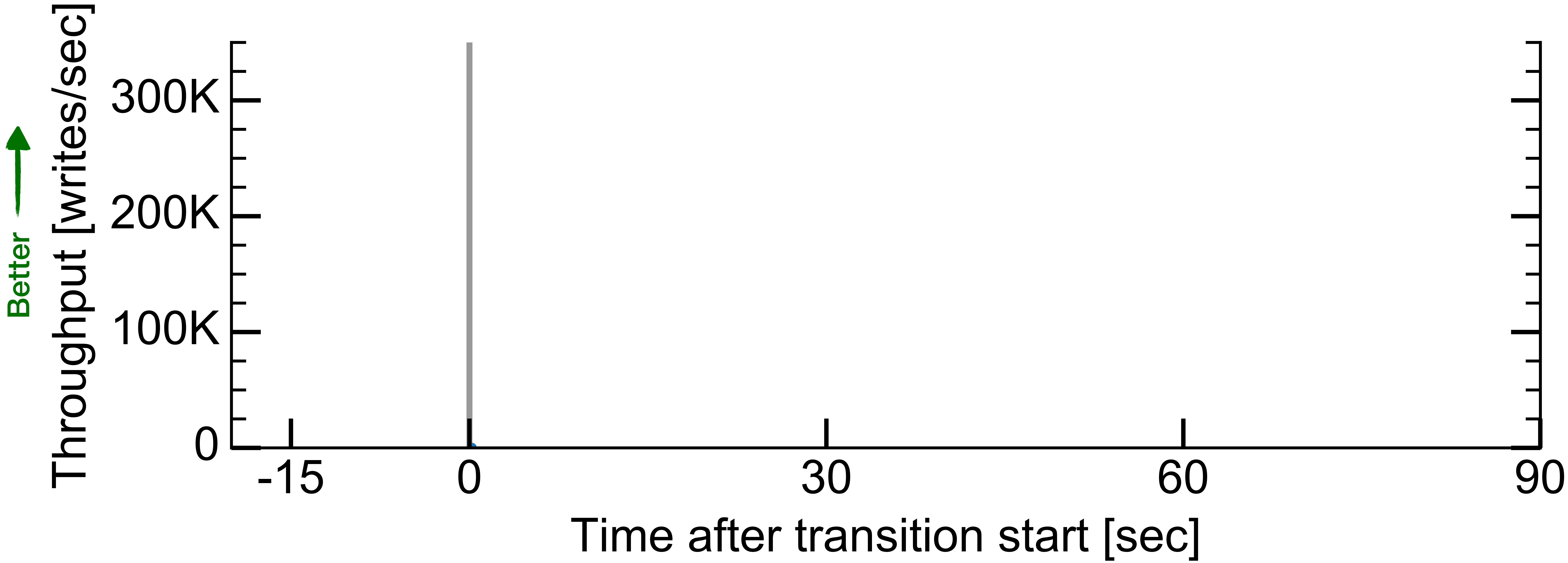

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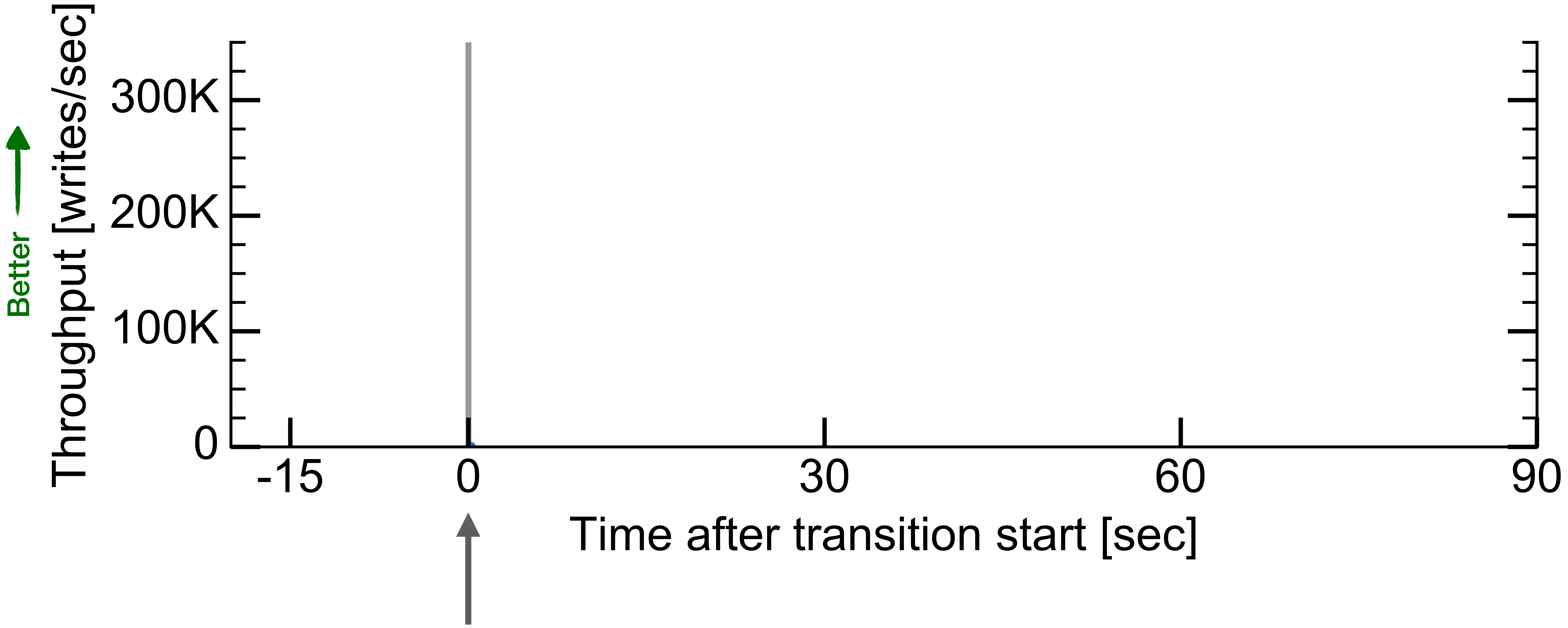

new table & query added

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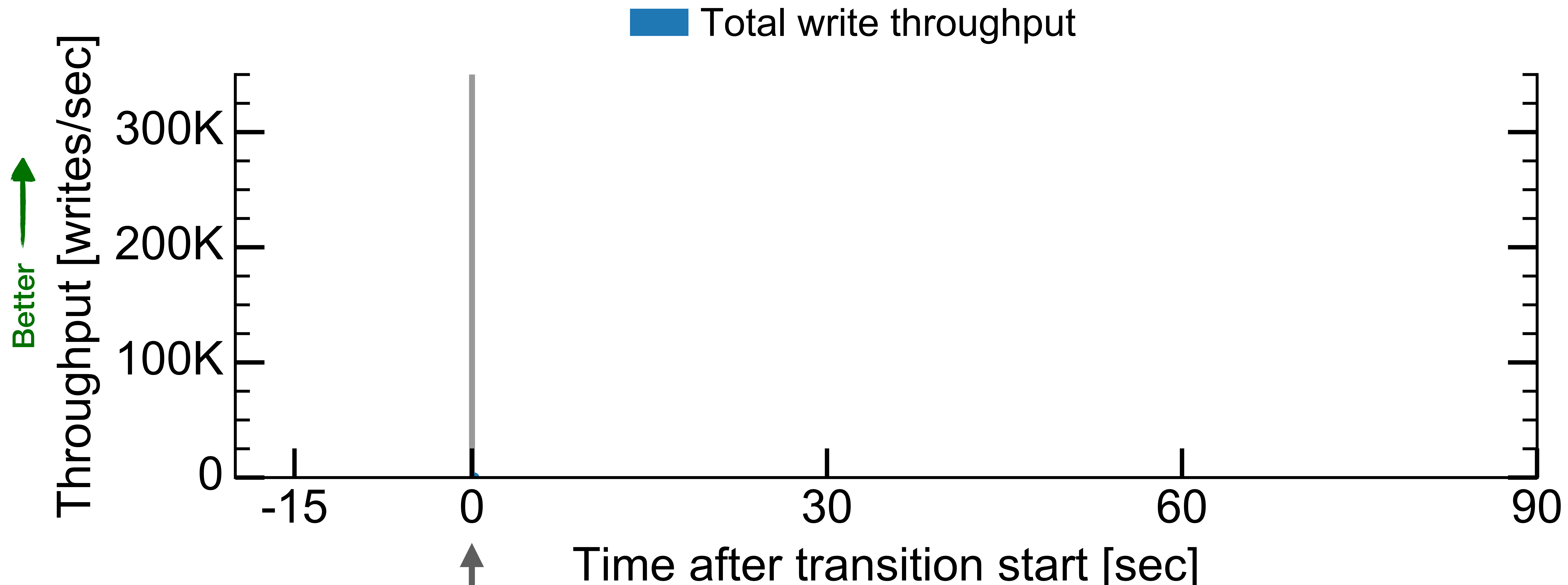

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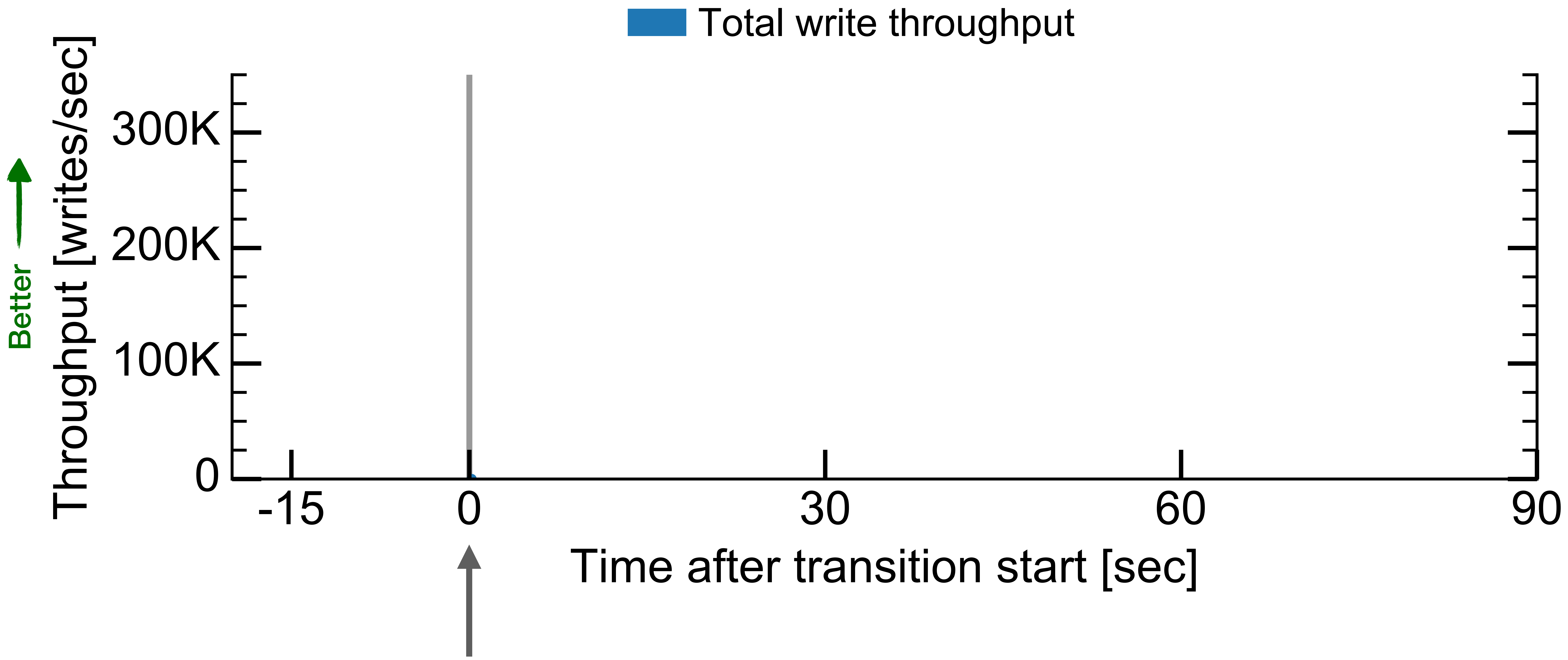

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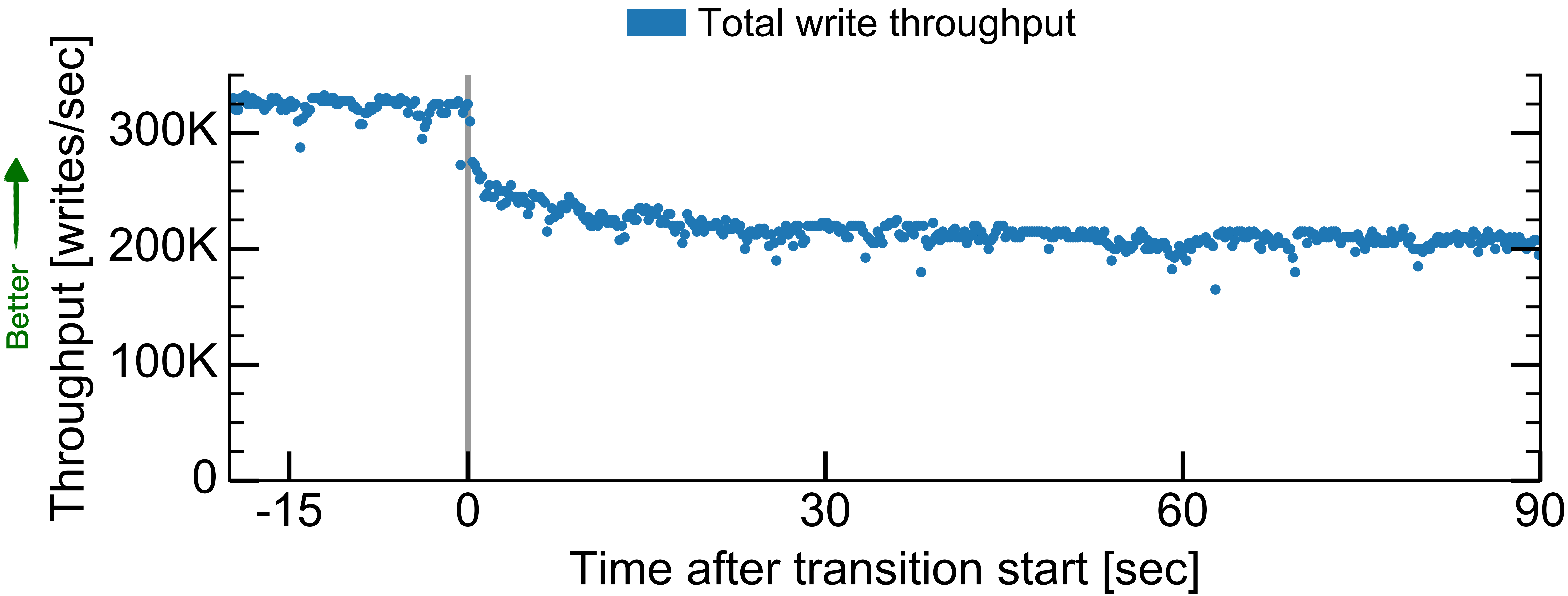

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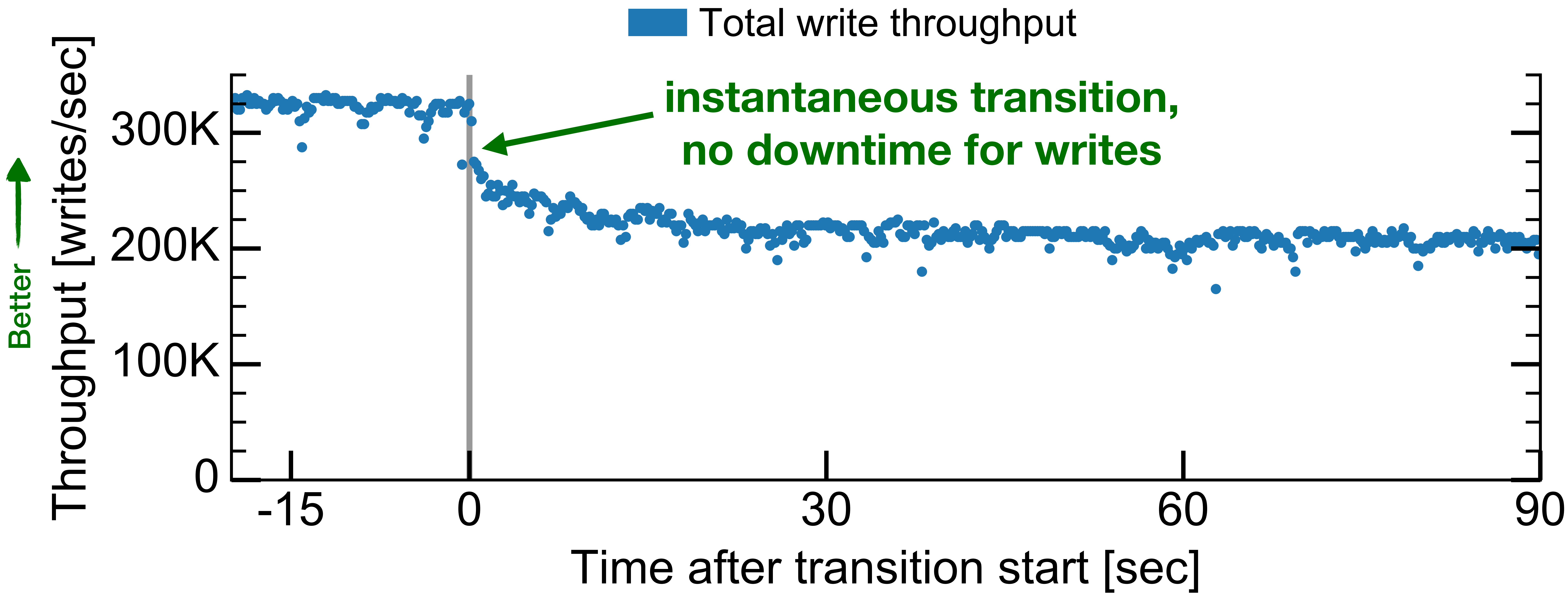

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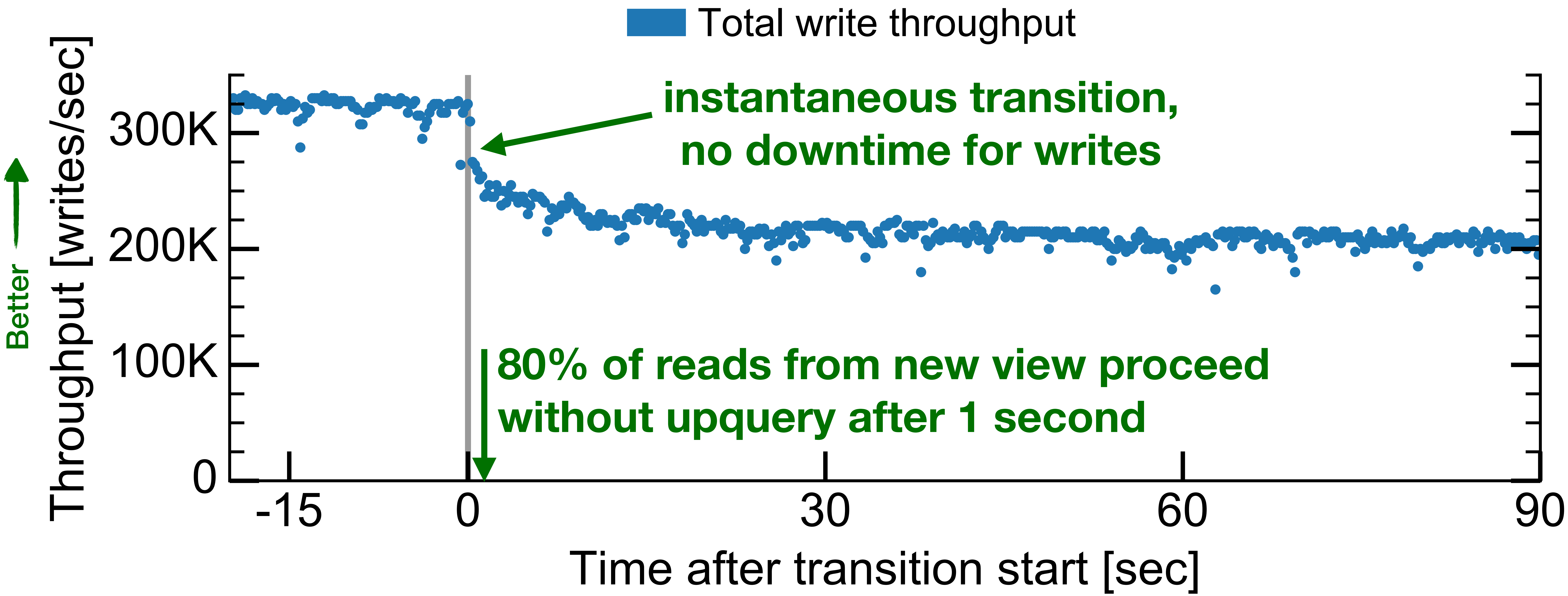
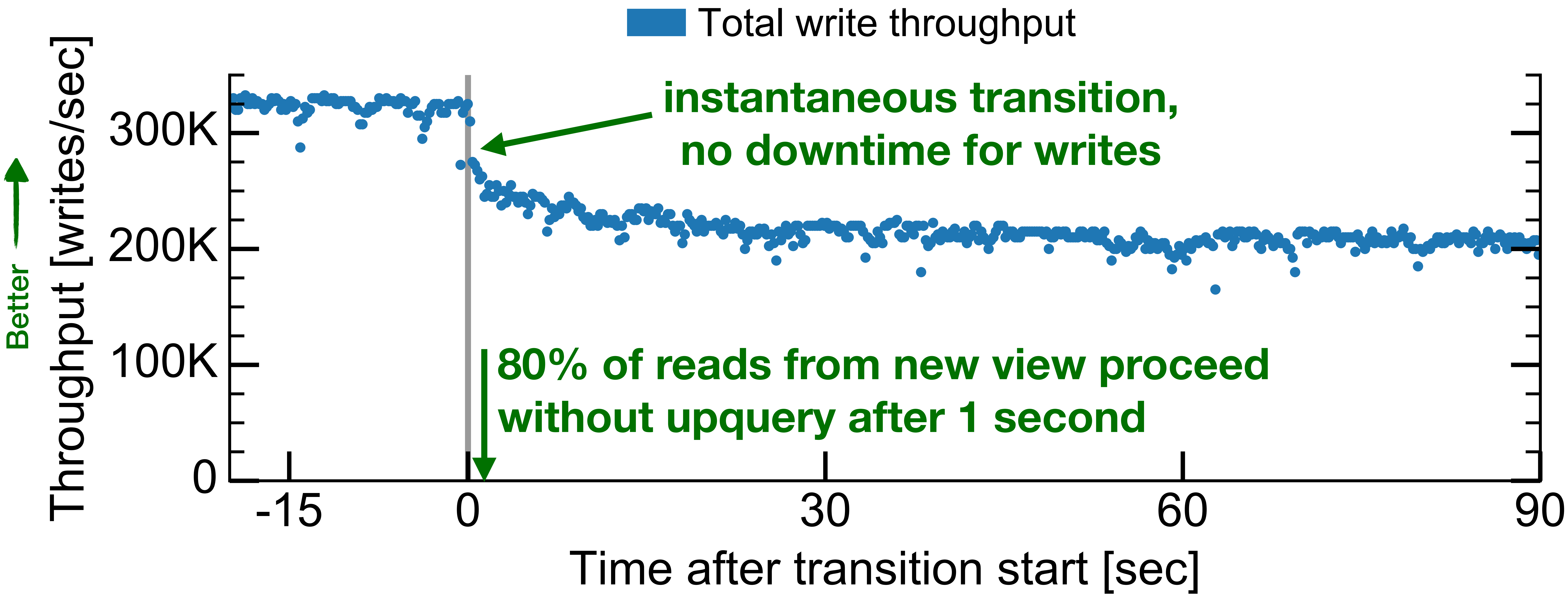


instantaneous transition, no downtime for writes

80% of reads from new view proceed without upquery after 1 second

- Zipf-distributed story ID, 95% reads; 2M existing votes at transition
- Old view reads are live throughout

Can Noria change queries without downtime?



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Noria **achieves downtime-free query change** with partial state.

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Noria — Summary

- New partially-stateful data-flow model.
- Noria: new web application backend based on data-flow.
- Partial state saves space and allows live change.
- Supports high throughput on one or more machines.
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`https://pdos.csail.mit.edu/noria`

(see our demo at poster #37 today!)