Rethinking Stateful Stream Processing with RDMA

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BIFOLD
The Berlin Institute for the Foundations of Learning and Data

What is this talk about?

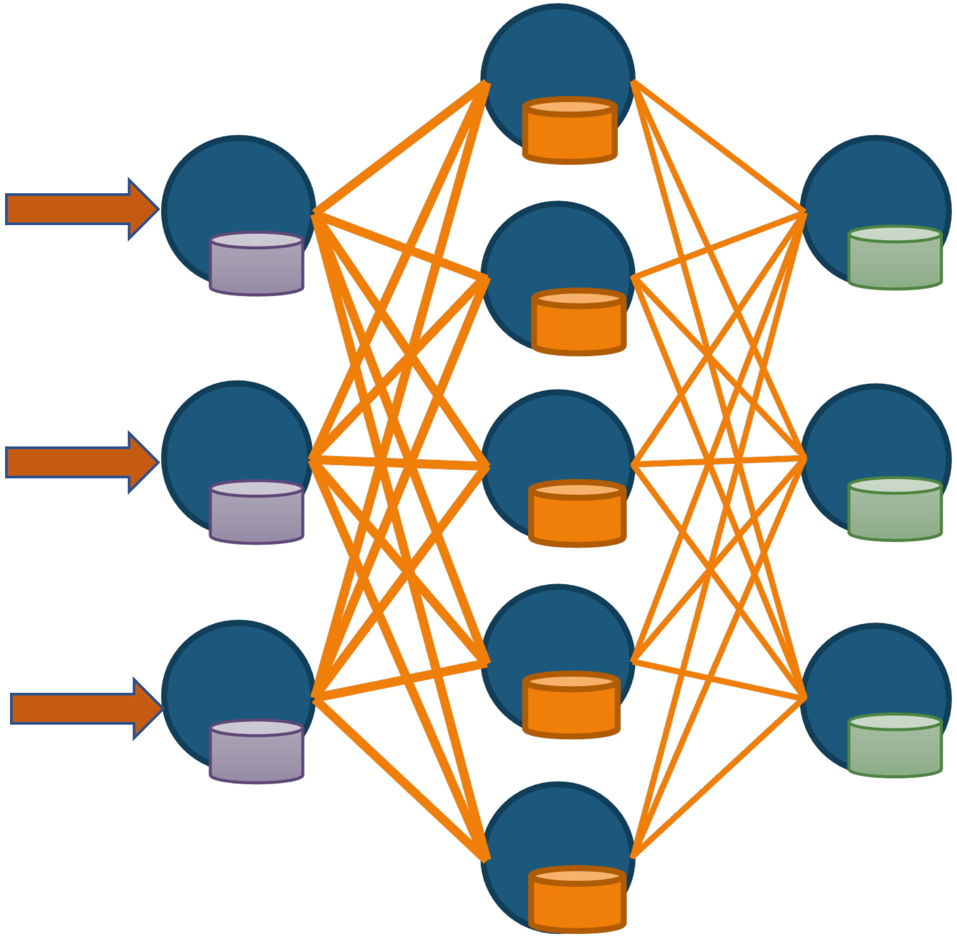
Enable *robust scale-out performance* of
stateful streaming queries using *high-speed networks*

Motivation

Distributed Stream Processing Engines are network-hungry!

Data Repartitioning as primitive for aggregations and joins.

Often the network is a bottleneck!



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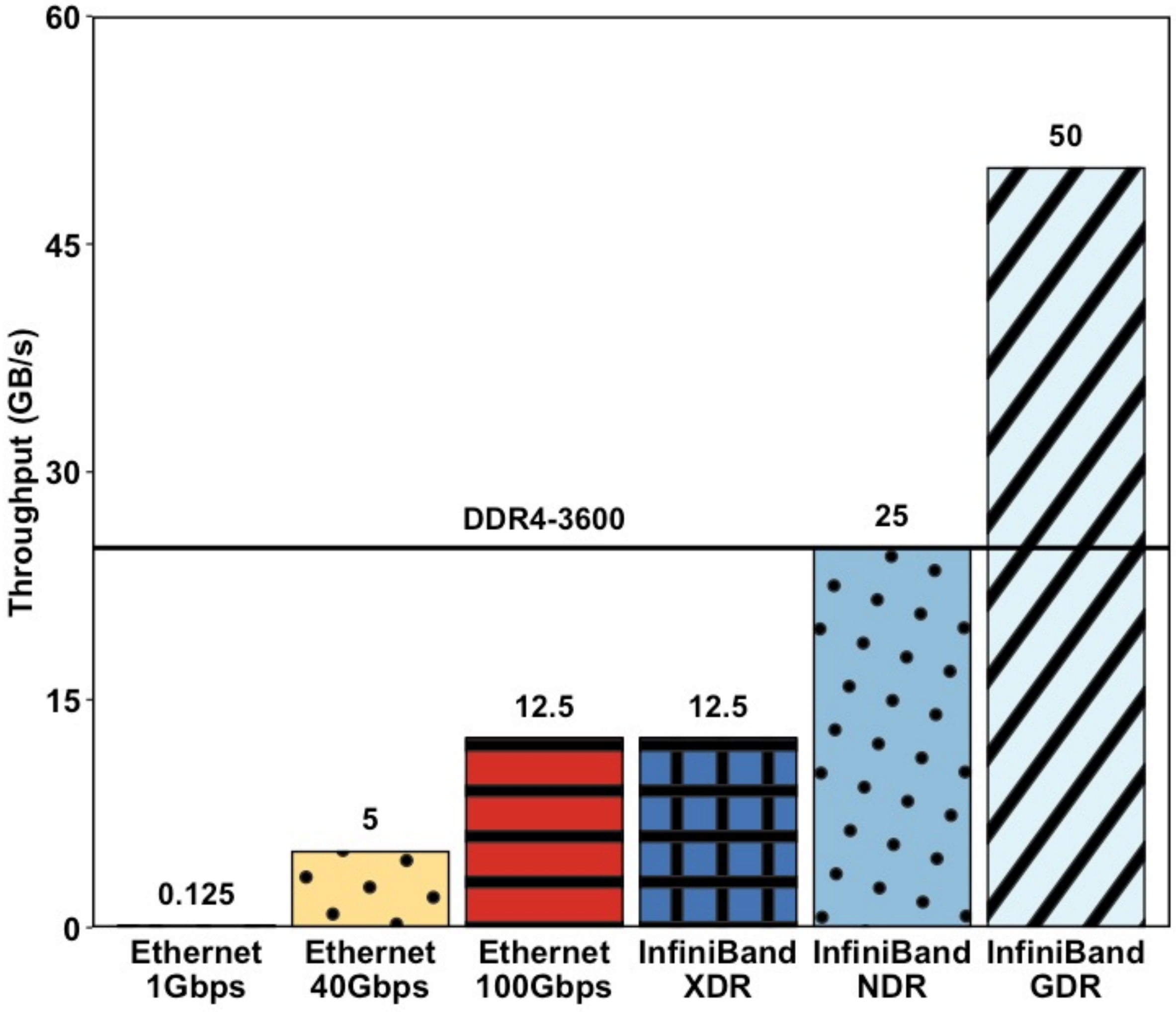
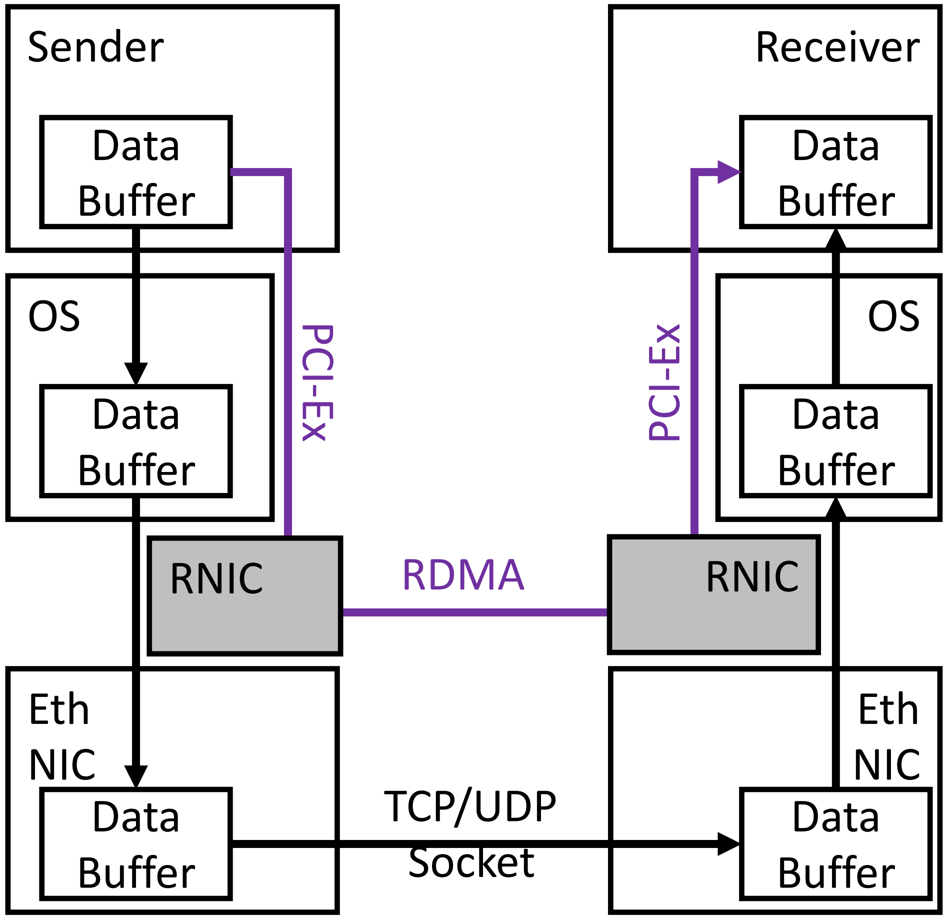


Source: InfiniBandTA

What is RDMA?

- OS kernel stack bypass and zero-copy transfer
- Message-oriented via verbs API
- Current DBMS use RDMA to accelerate batch OLAP and OLTP workloads



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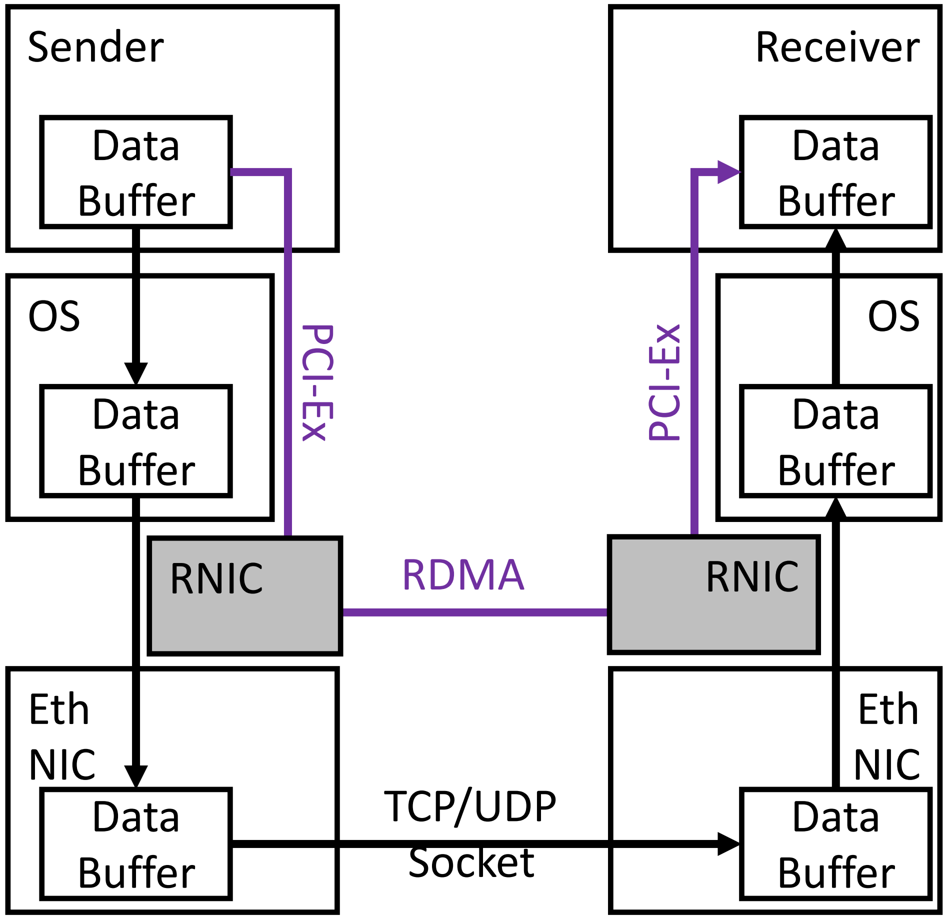
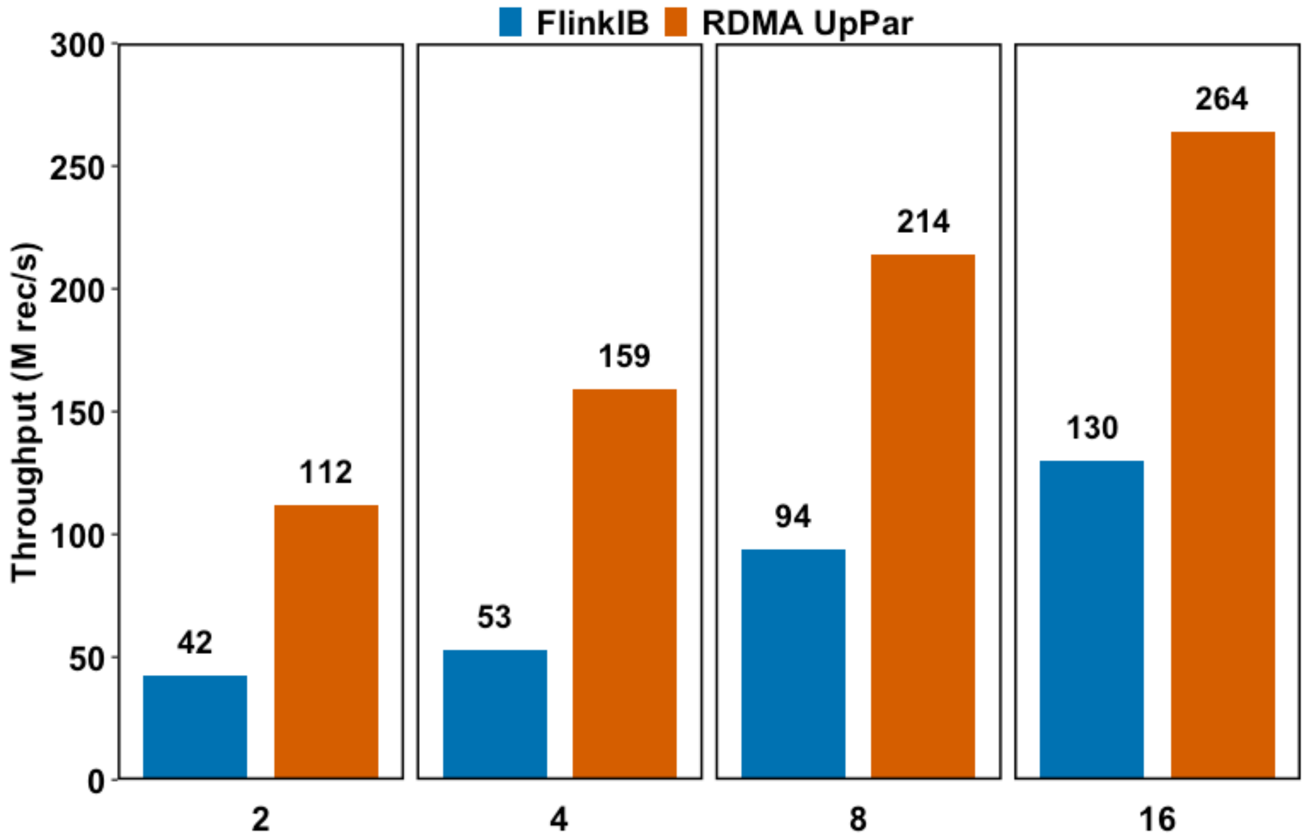


Can I apply RDMA acceleration to Stream Processing Engines (SPEs)?
If SPEs are often network-bound, adding a fast network is a good idea!

Can SPEs benefit from a fast network?



YSB Benchmark on a 16-node cluster with 100 Gbit Mellanox NICs using FlinkIB and RDMA UpPar

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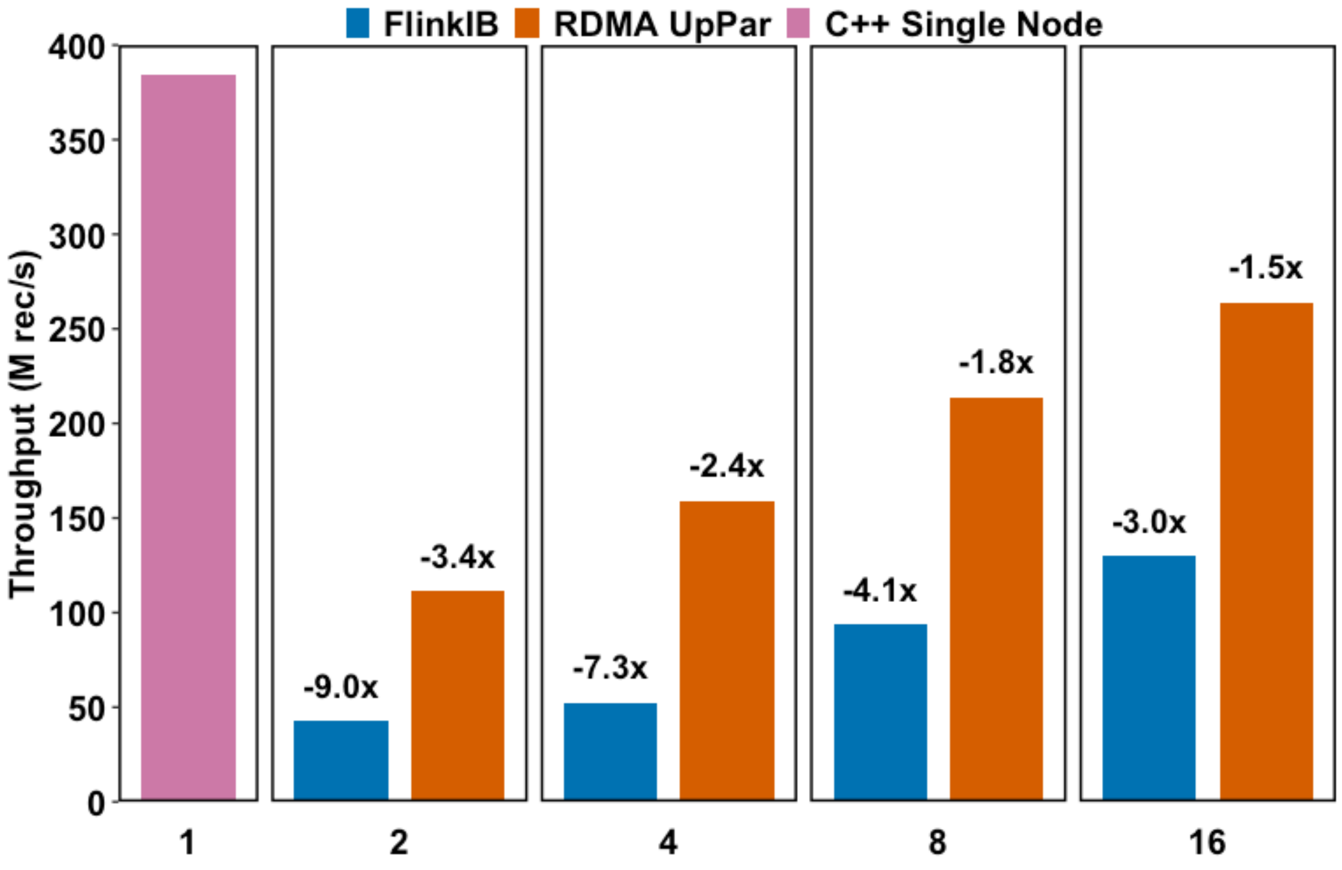
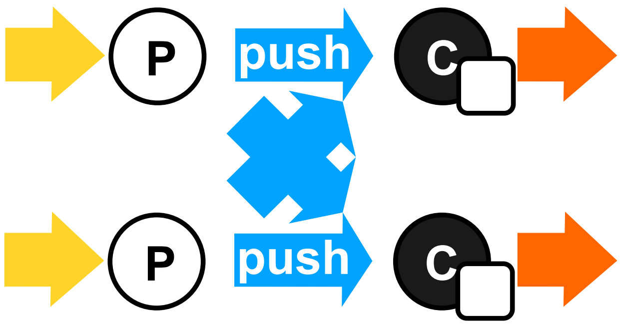


Adding a fast network to an SPE does not generally make it run faster, if execution is CPU-Bound.

Can we reuse any insight from scale-up SPEs?



Upfront
Partitioning

Source: Analyzing efficient stream processing on modern hardware, S. Zeuch, B. Del Monte, et al., VLDB 2019

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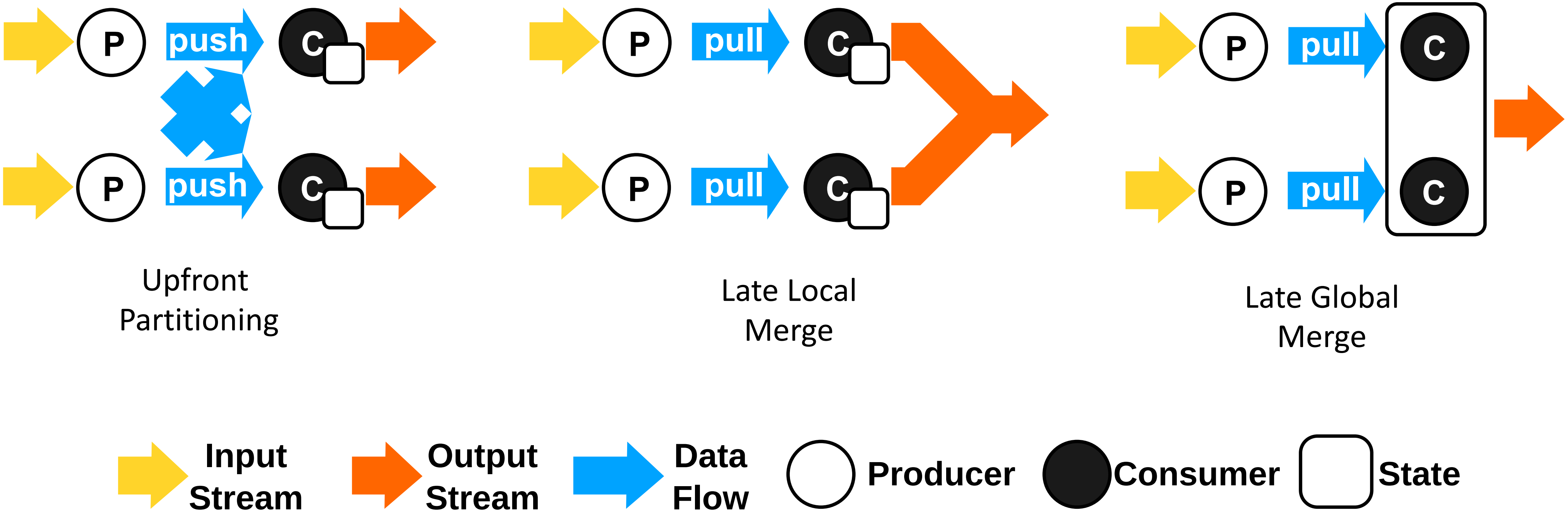

Upfront Partitioning

Late Local Merge

Late Global Merge

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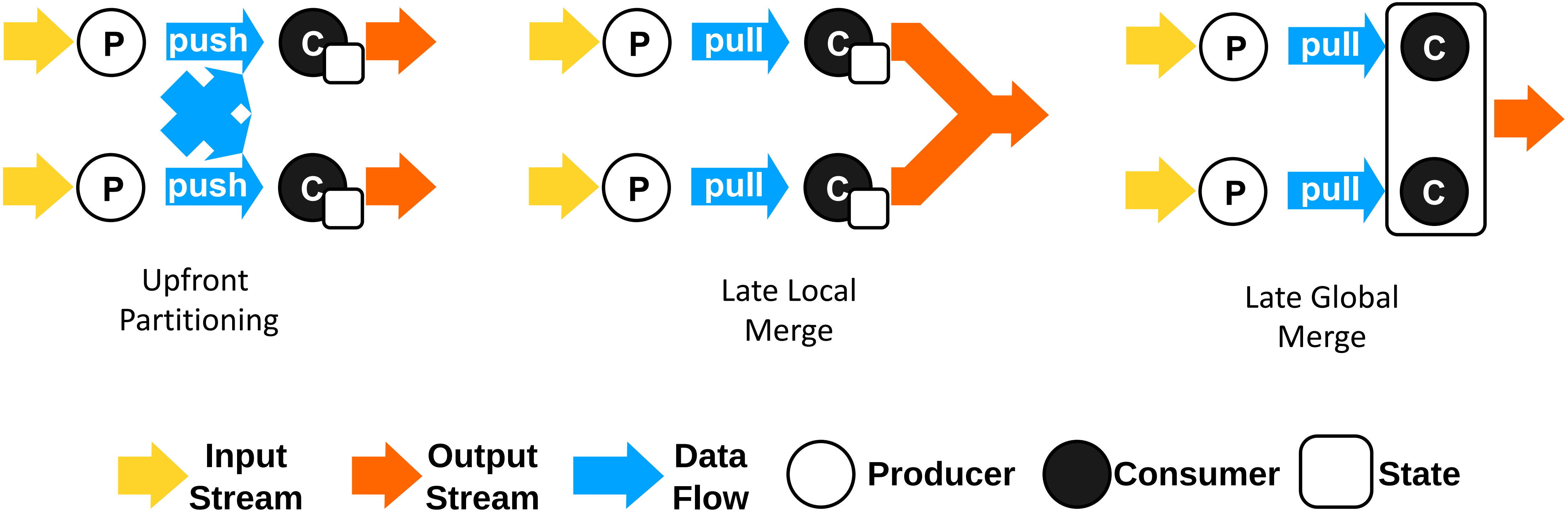

Partitioning makes SPEs CPU-Bound, when processing high-speed data streams.
Use alternative processing model for scale-up SPEs.

Architectural Change: Design Challenges

1. Efficient streaming computations
   - Replace data re-partitioning with RDMA-enabled late merge

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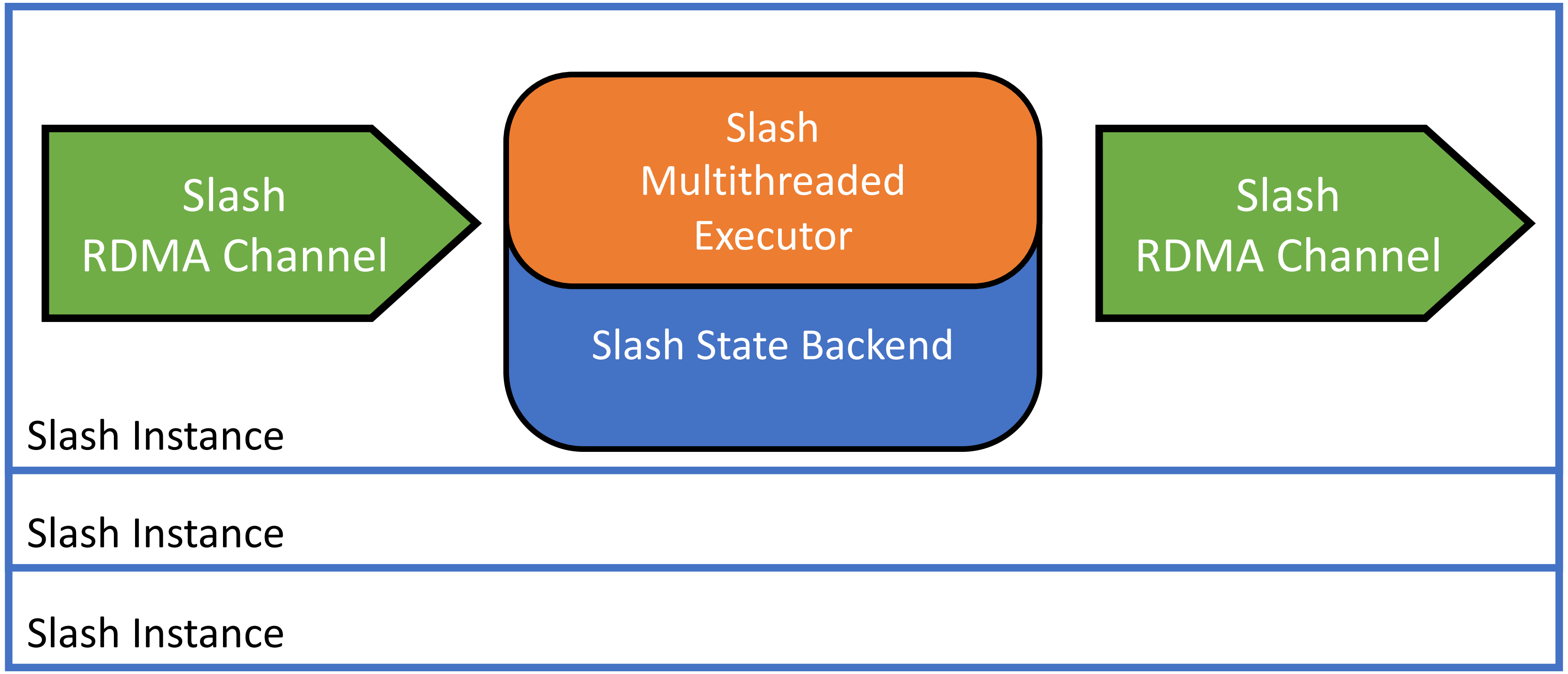
2. Efficient data transfer
   - RDMA performance depends on low-level factors

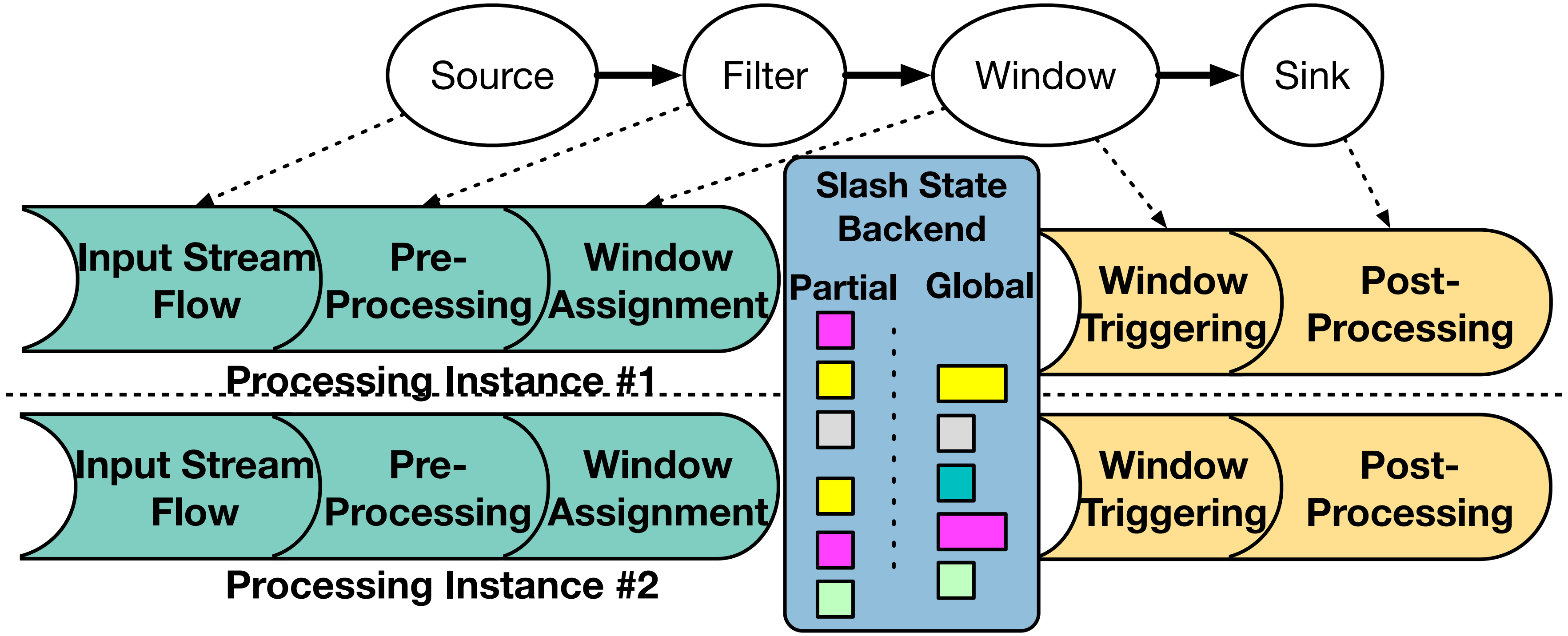
3. Consistent stateful computations
   - Progress tracking and exactly-once state updates

Our prototype: Slash



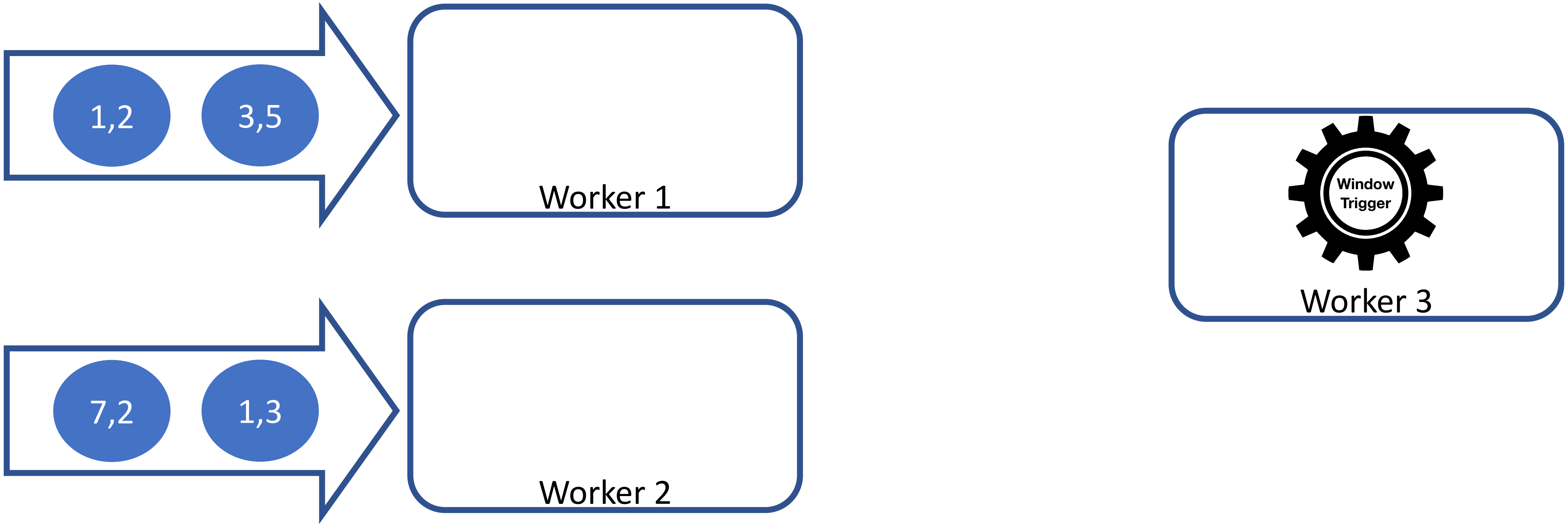
Slash’s design principle: make the common case fast

Slash: Stateful Query Execution



Eager computation of partial states followed by
lazy late merging of partial states in a consistent state

Slash in action: Window Aggregation



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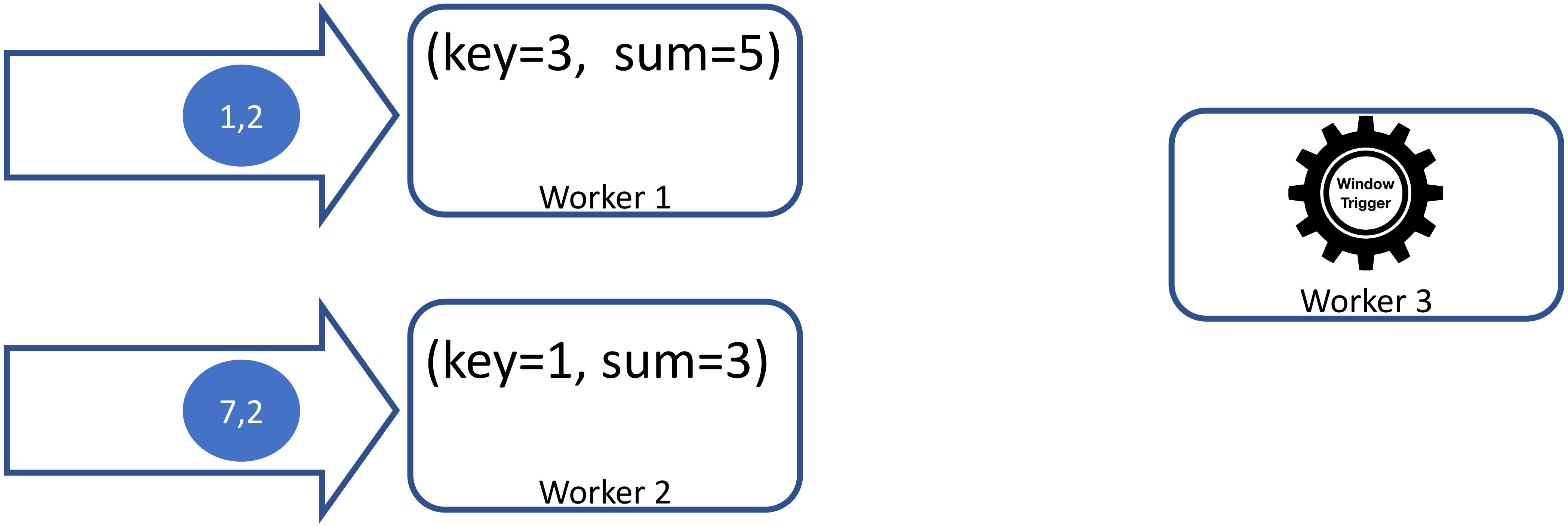

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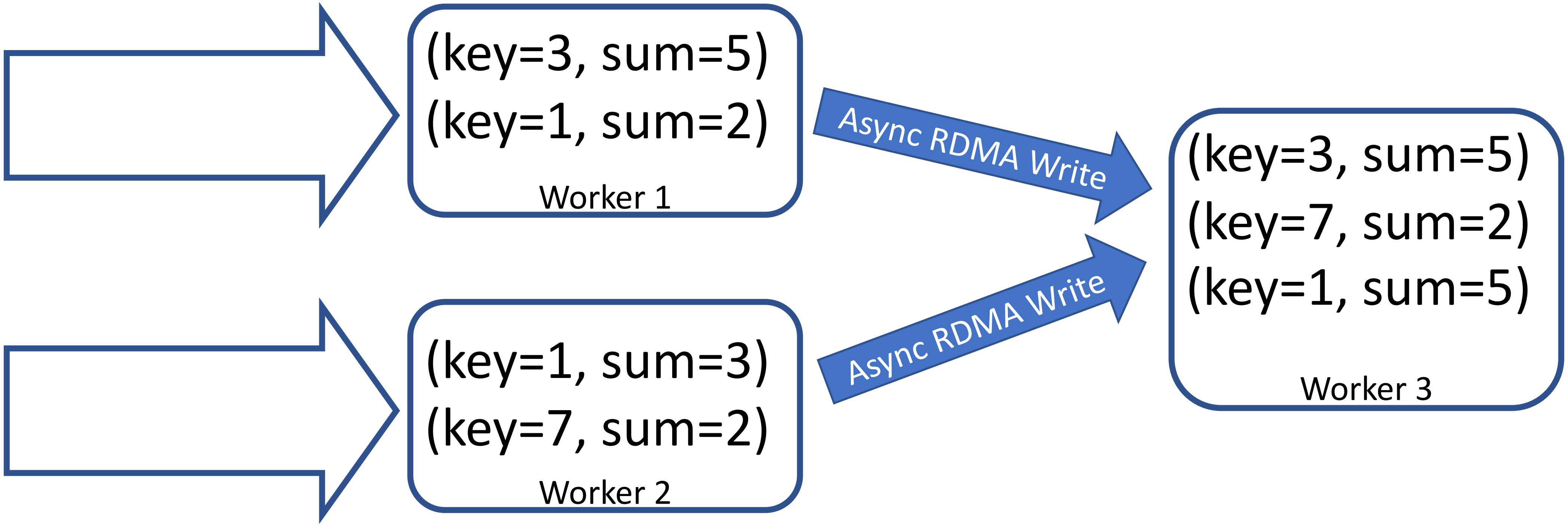
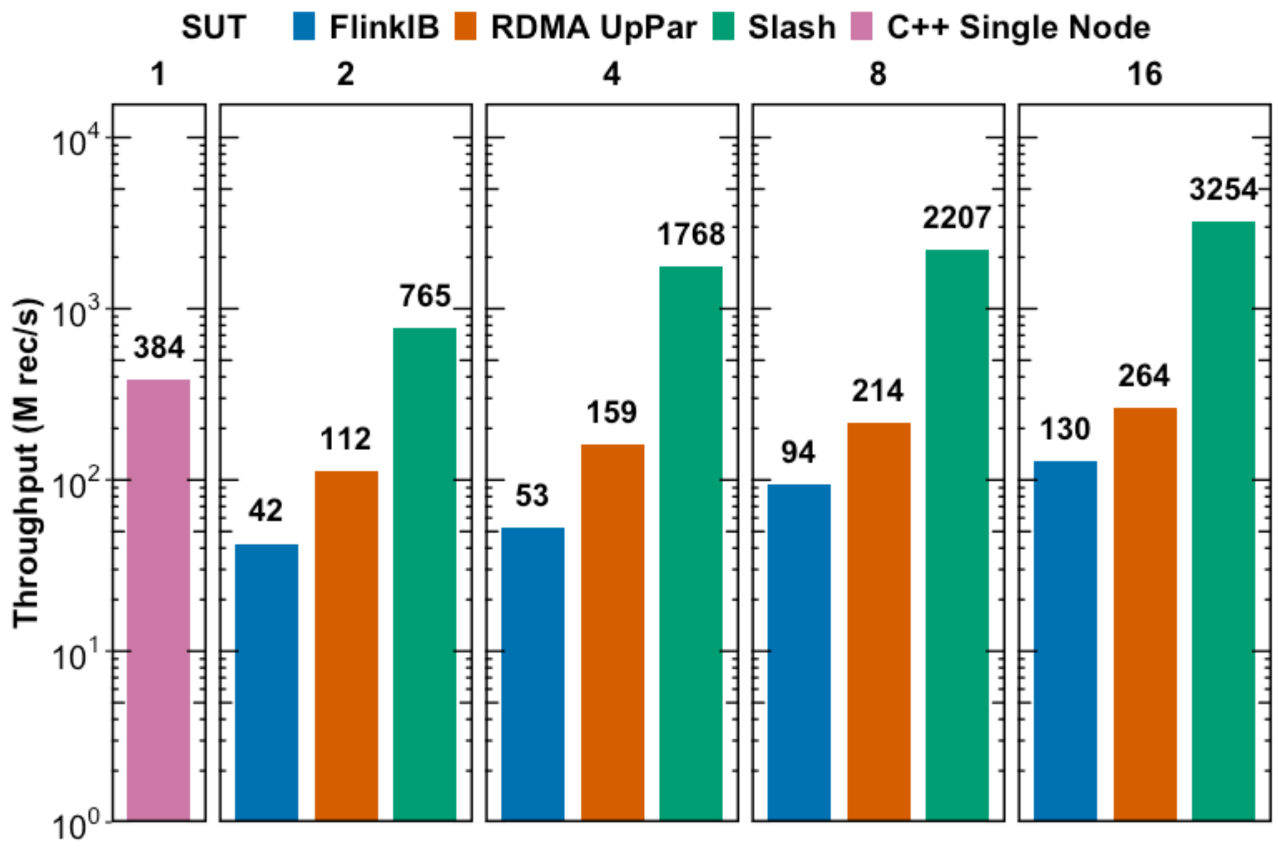


Slash relies on log-structured storage, epoch-based synchronization, and CRDT for late lazy merging.

Performance Evaluation



Slash outperforms the baselines by a factor up to 25x.

Performance gain explained

	IPC	Instr./ Rec.	Cyc./ Rec.
RDMA UpPar	0.6	166	274
	0.4	78	276
Slash	0.9	42	53

- RDMA UpPar needs to execute partitioning logic on every record. Next, it computes a thread-local result on pre-partitioned data.
- Slash computes thread-local results that lazily merges (less data moved around).

Slash requires less instructions and cycles to process a single record.
Partitioning for RDMA UpPar is an expensive operation.

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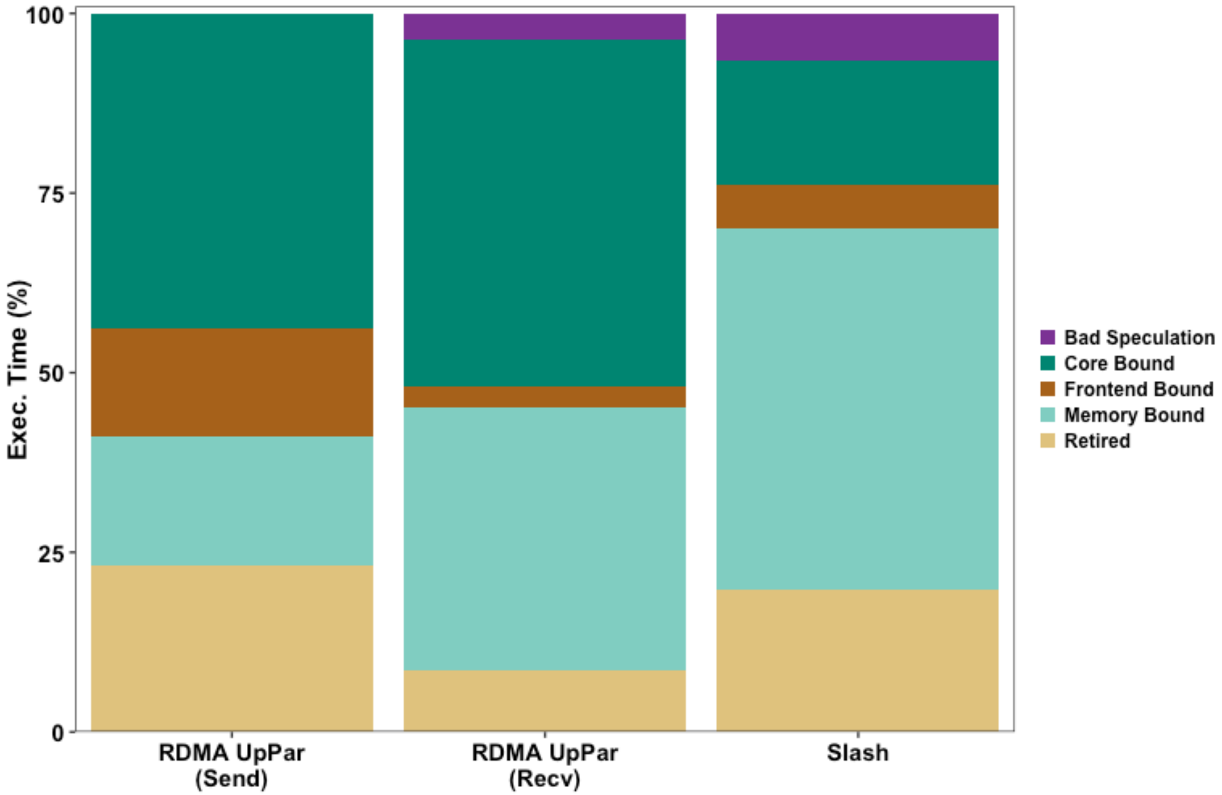

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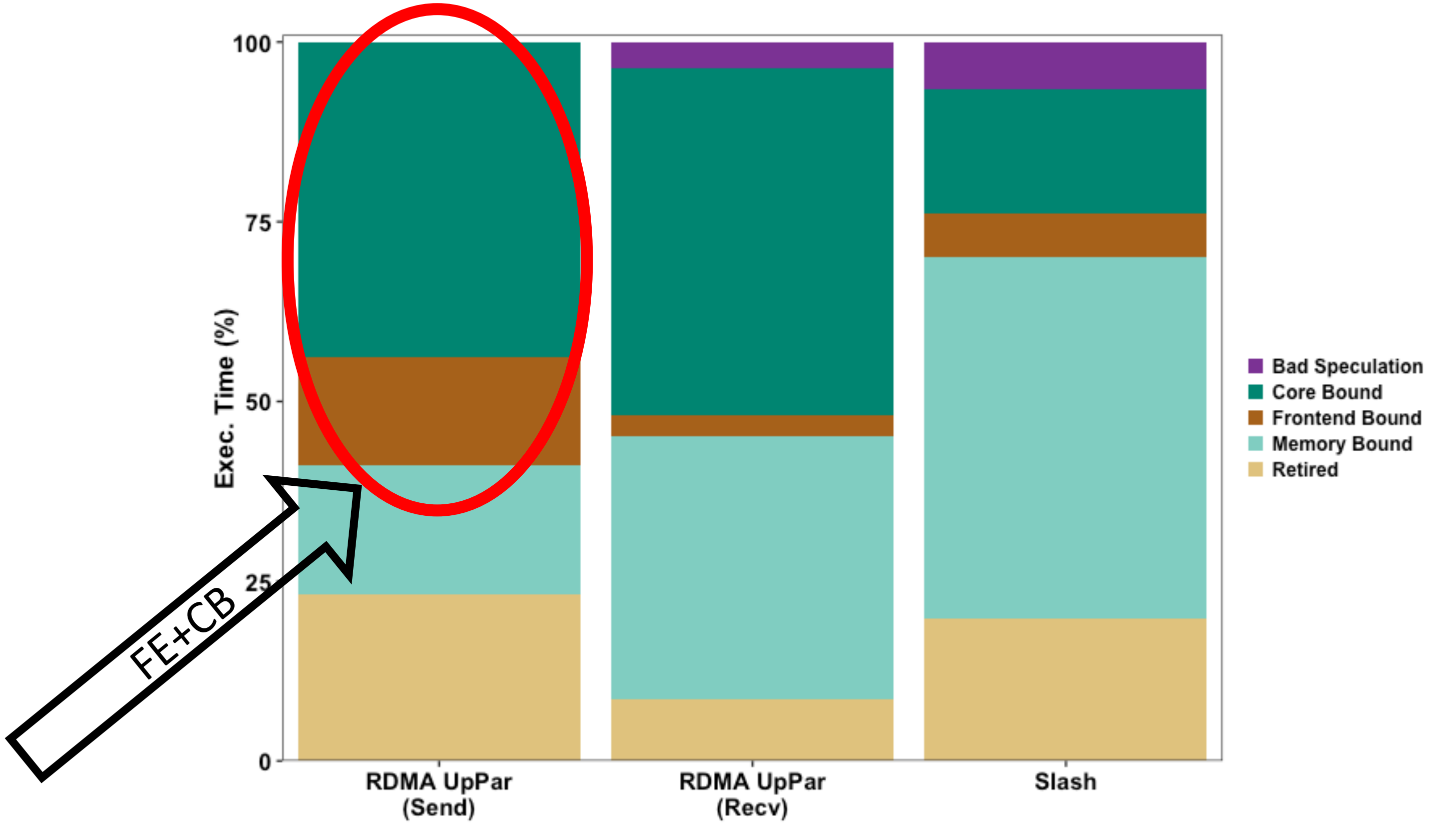

Execution of RDMA UpPar's sender suffers from complex code and spin waiting.
Reason: data partitioning.

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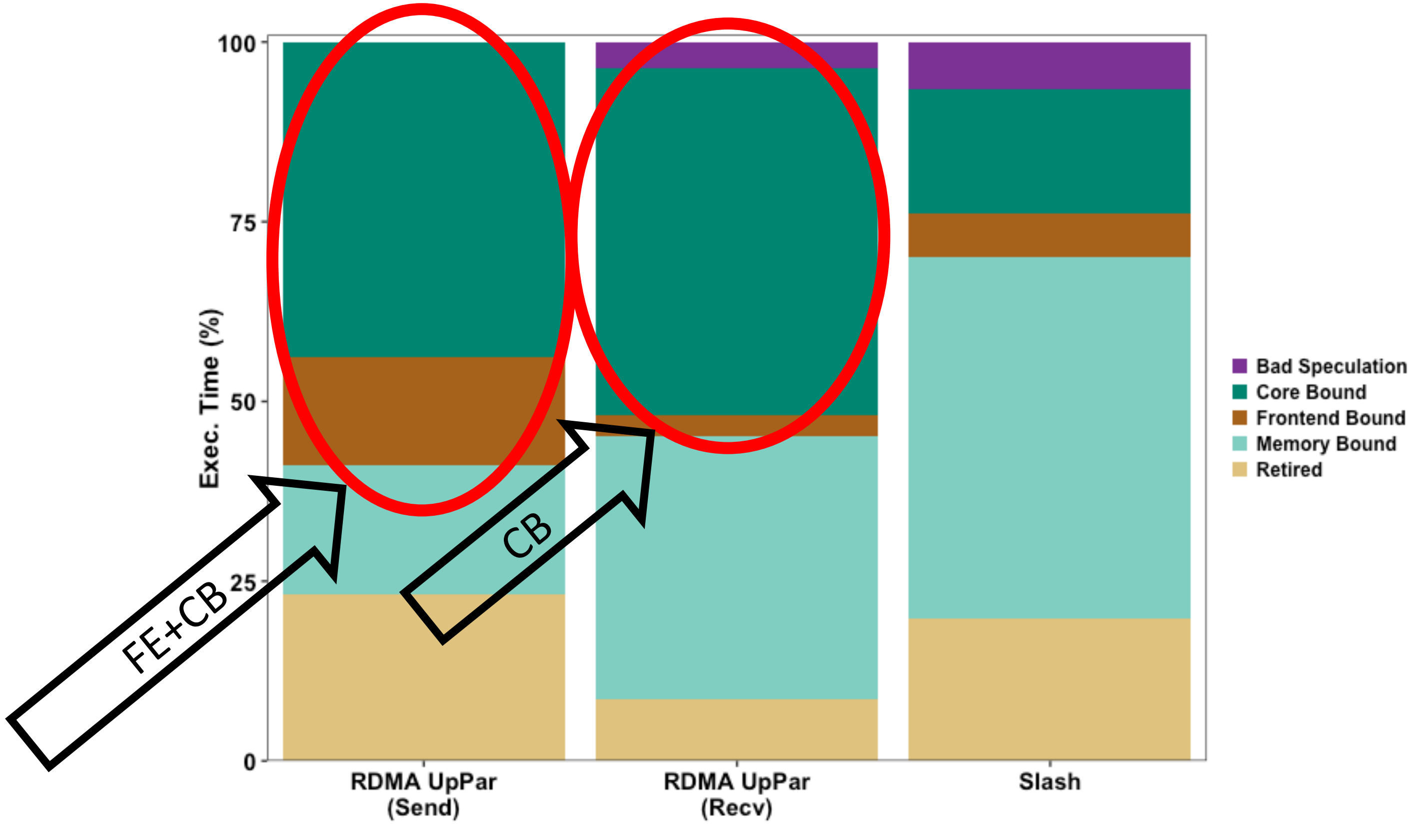

The execution of RDMA UpPar's receiver stalls due to spin waiting on sender.
RDMA UpPar is bound by partitioning speed (CPU).

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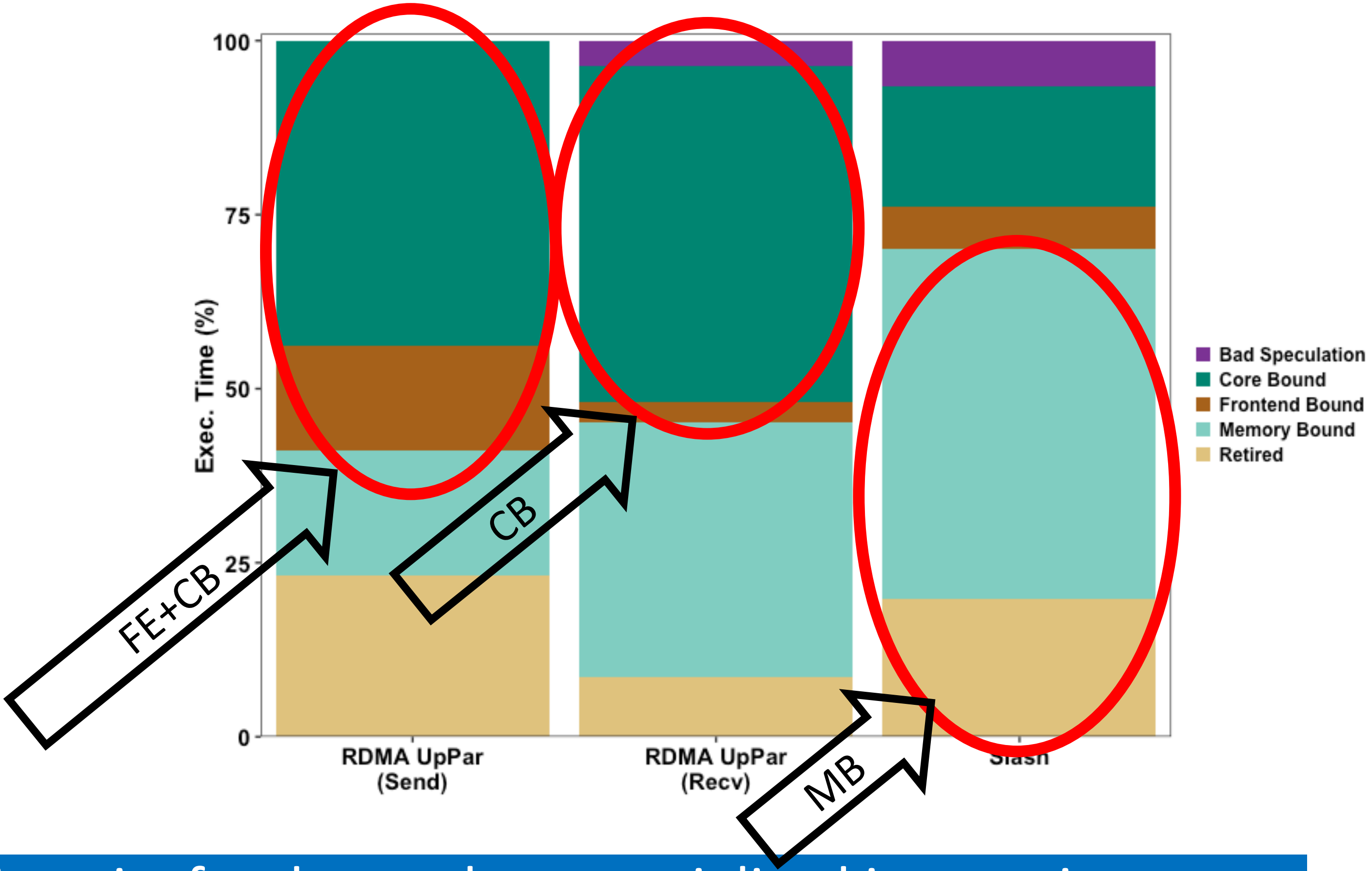


Slash is memory-bound: it waits for data to be materialized into registers.
Slash is ultimately bound by memory speed.

Lesson learned

- Apply RDMA native acceleration and redesign internal data structures

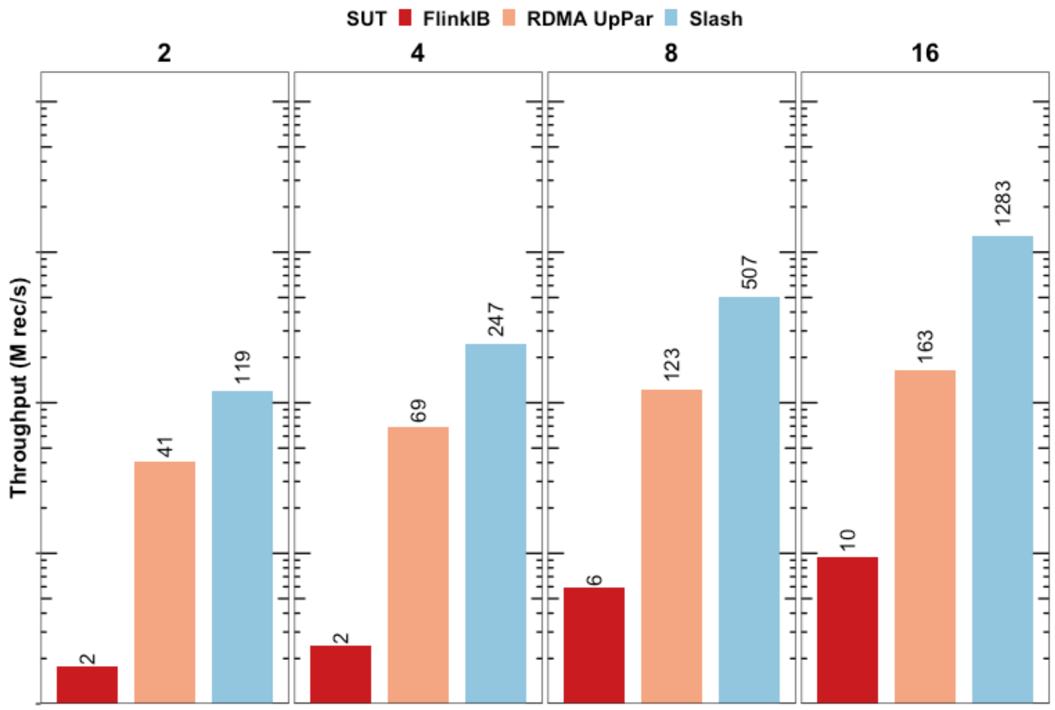
- Avoid data-repartitioning: it induces performance issues!

- Use instead lazy merging of eagerly computed partial state/results

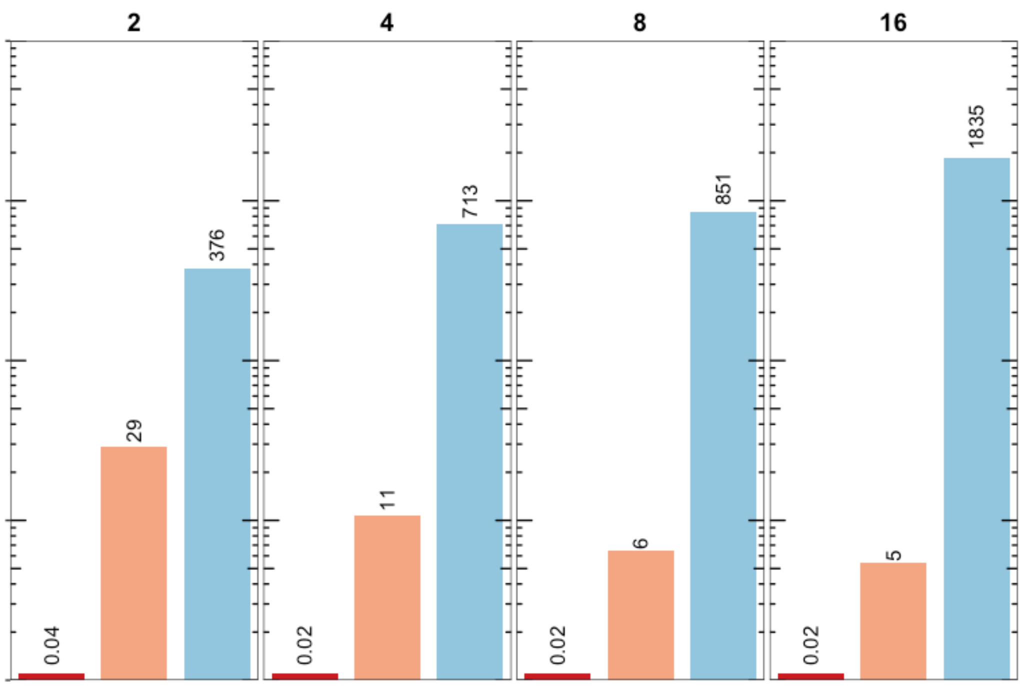
Summary and take-home

- We provide a **new system design** for RDMA-accelerated stateful stream processing.
- Slash attains up to a **factor of 25 increment** in throughput compared to the strongest baseline.
- Our drill-down analysis shows that **Slash is mainly memory-bound**, whereas **our strongest baseline is limited by partitioning speed**.

Show us more numbers



Nexmark Query 8



Google Cluster Monitoring

Slash outperforms baseline executing join operators and real-world workloads