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Meces: Latency-efficient Rescaling via Prioritized State Migration for Stateful Distributed Stream Processing Systems

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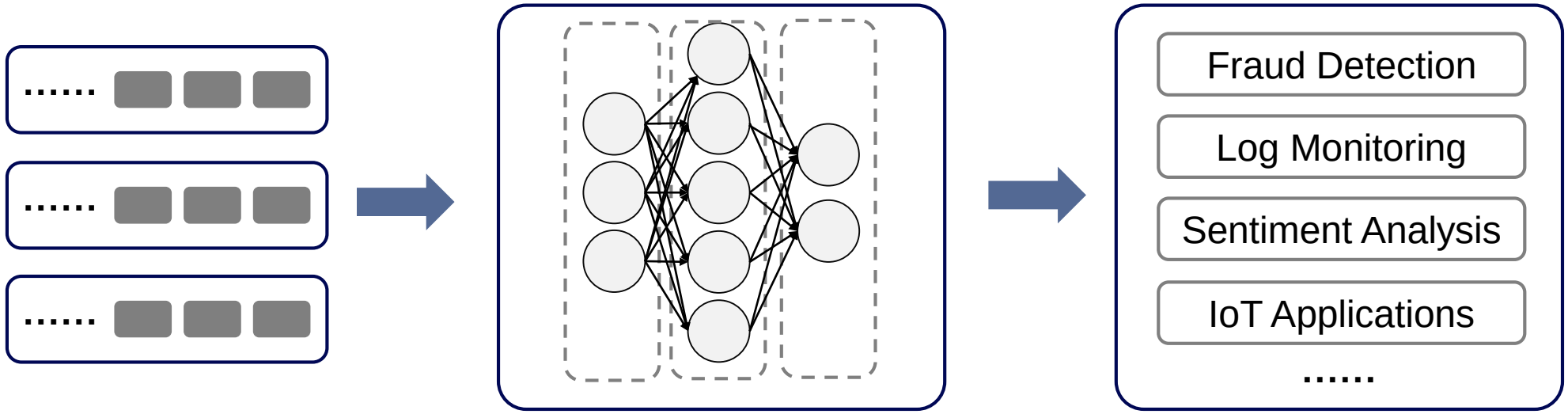
Motivation

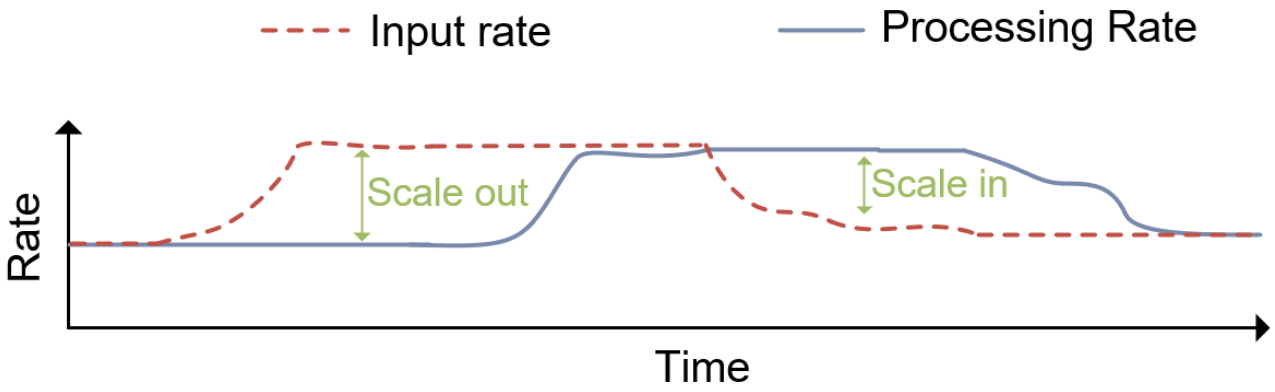
Stream Processing Engines (SPEs) are widely adopted for real-time processing



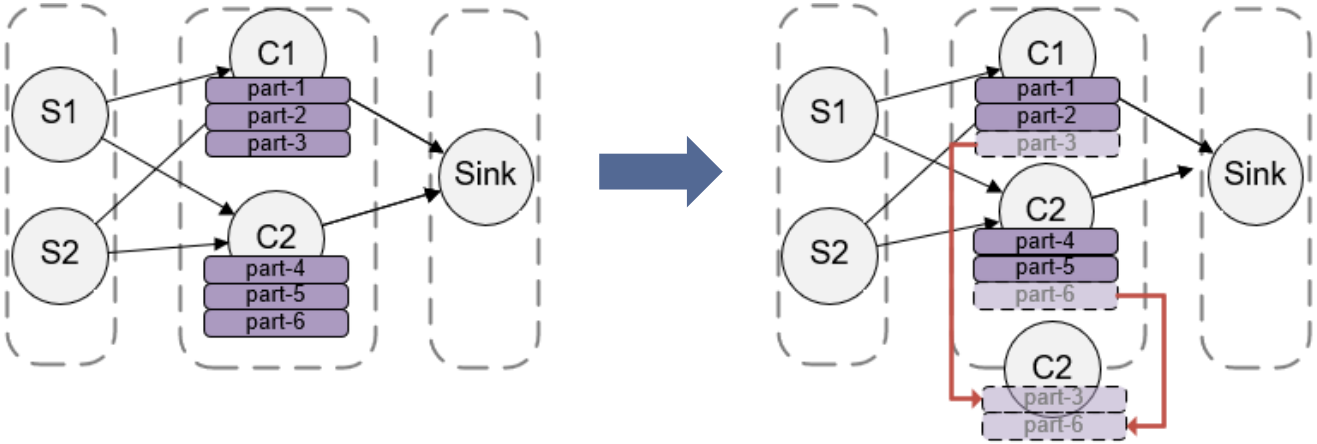
Data Streams SPE Real-time Applications

Motivation

SPEs usually call for dynamic rescaling due to varying workloads[1]



Rescaling in SPEs usually comes with state migration



[1] Vasiliki Kalavri, et al. Three steps is all you need: fast, accurate, automatic scaling decisions for distributed streaming dataflows. OSDI'18.

Related Work

- **① Full Restart & ② Partial Pause**
  - Related works：Spark *(SOSP'13)*, Heron*(SIGMOD'15)*, Flink*(VLDB'17),* Flux*(ICDE'03),* Seep*(SIGMOD'13)*
  - Method: Pauses and resumes whole or part of the task when redistributing states
  - **Shortcomings: blocks processing and causes latency spikes during rescaling**
- **③ Replicated-Dataflow**
  - Related works：ChronoStream*(ICDE'15)*, Gloss*(ASPLOS'18)*
  - Method**:** Executes a new dataflow in parallel with the old one until finishing the state migration
  - **Shortcomings: high resource usage during rescaling**
- **④ Proactive**
  - Related Work：Megaphone*(VLDB'19)*, Rhino*(SIGMOD'20)*
  - Method: Adds extra behavior to non-rescaling periods to relieve the pressure during state migration
  - **Shortcomings: incurs extra overhead to a non-rescaling dataflow**

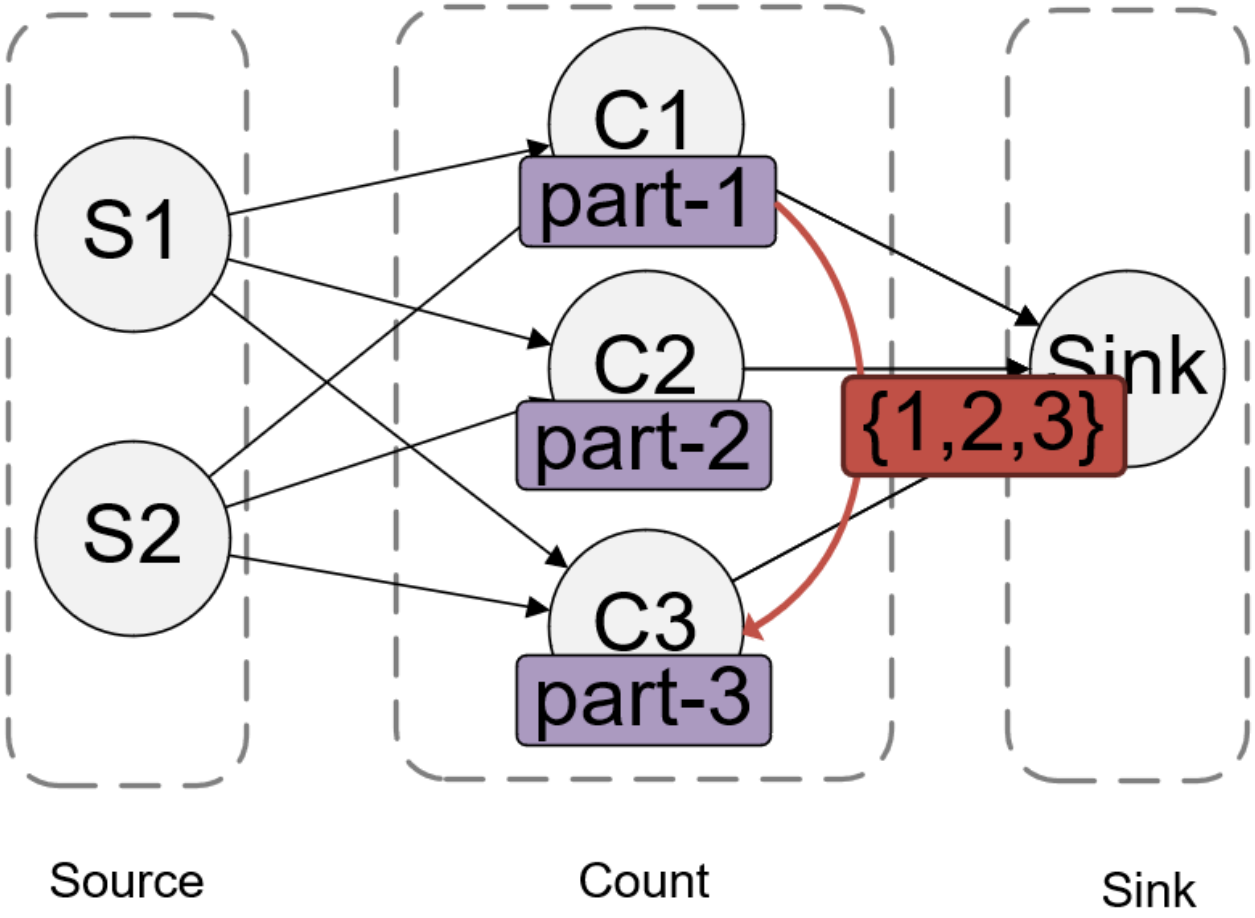
Related Work

Existing state migration approaches suffer from latency spikes, or high resource usage, or major disruptions

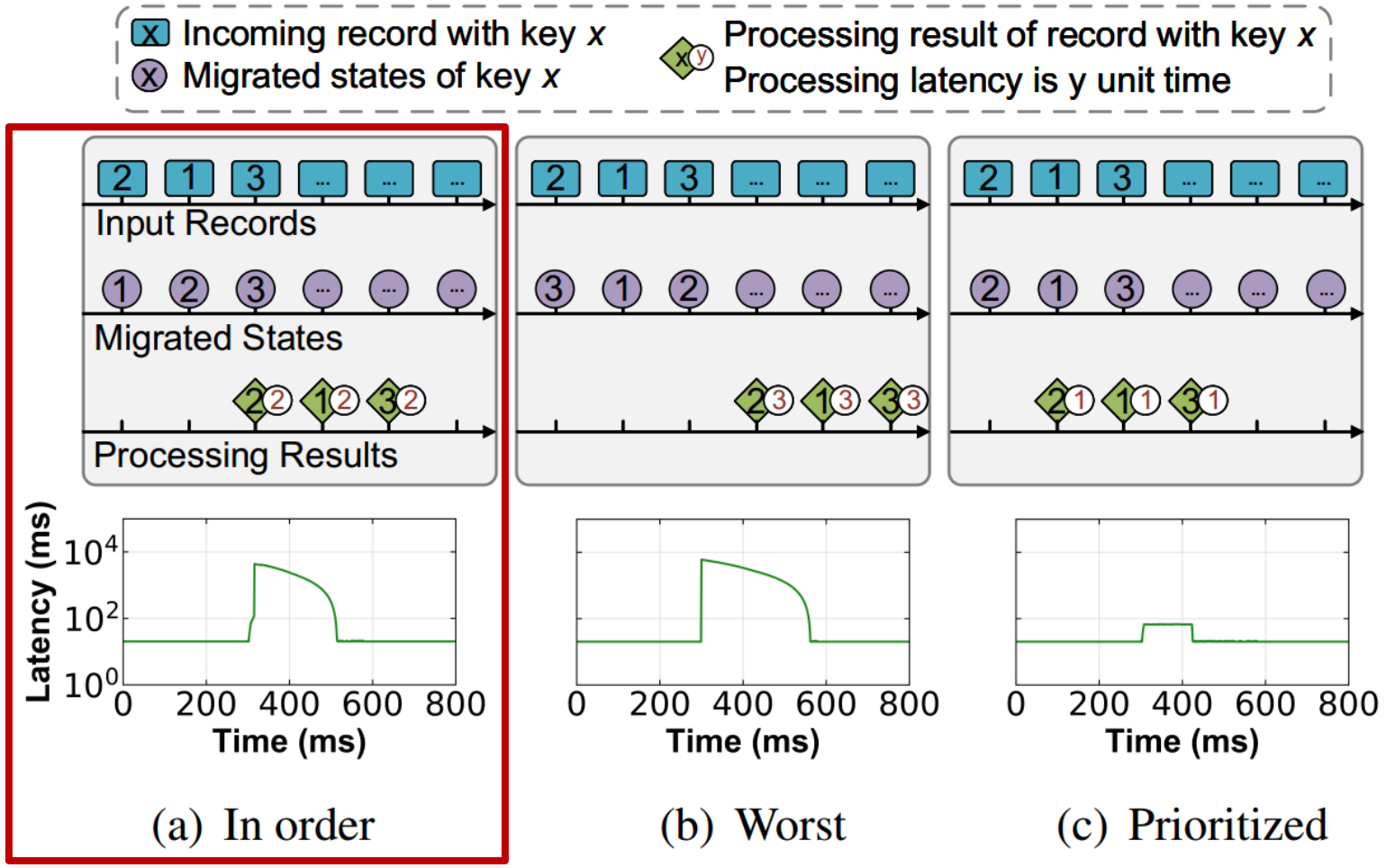
Common limitations: not taking into account the order in which operator state migrates

Prioritized Migration

Example: a key-count stream processing job

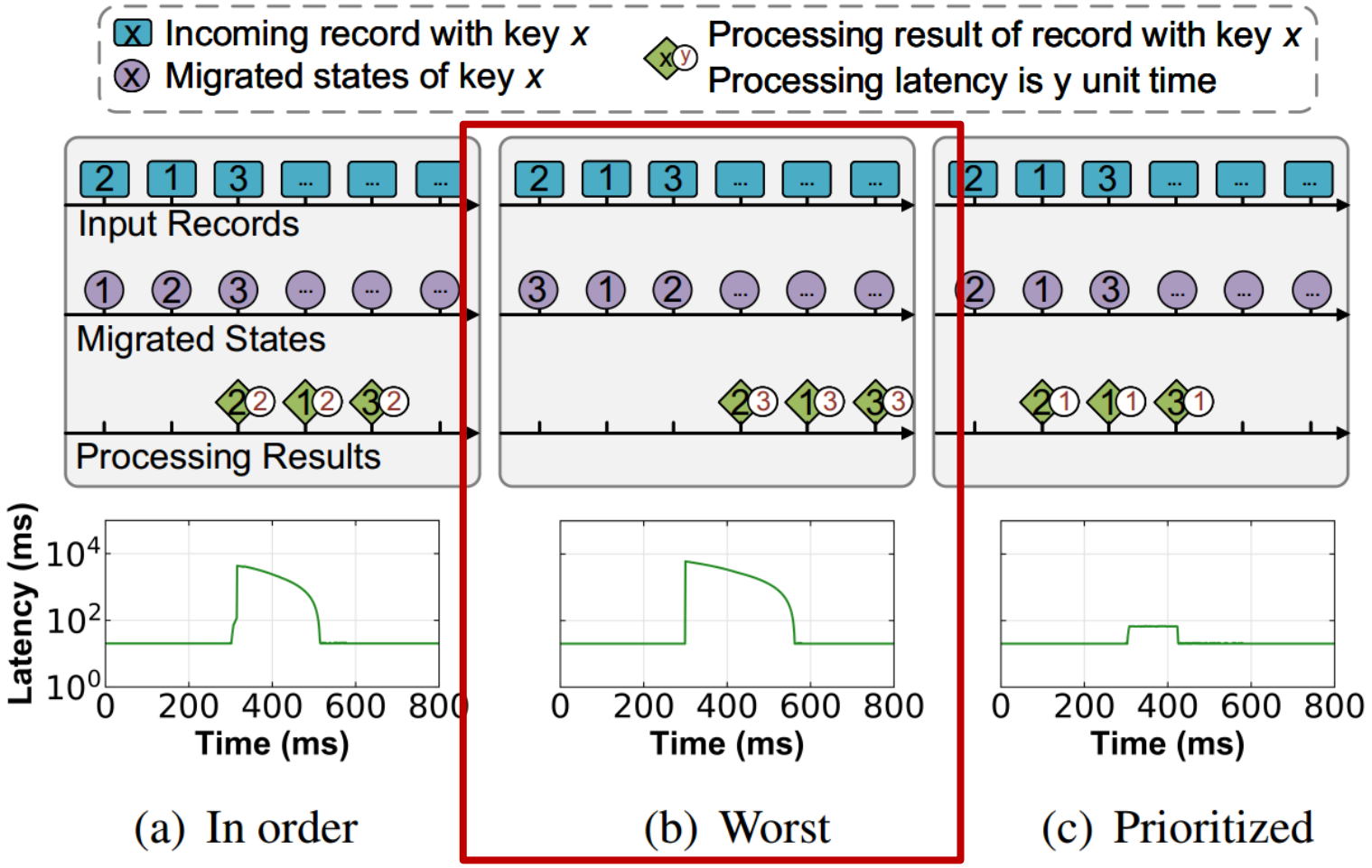


Prioritized Migration



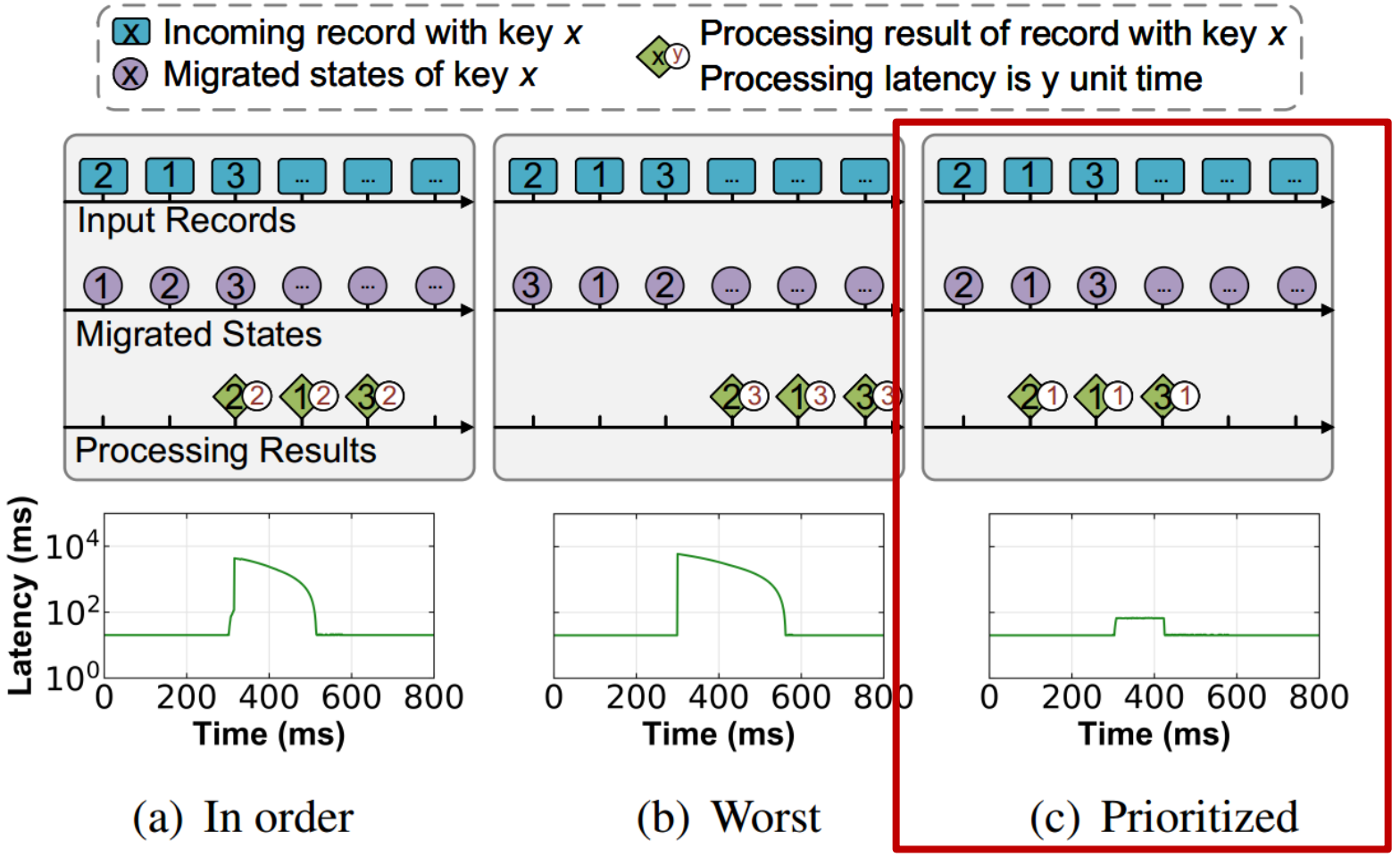
- Wait for the arrival of its corresponding state
- Block subsequent records in the queue

Prioritized Migration



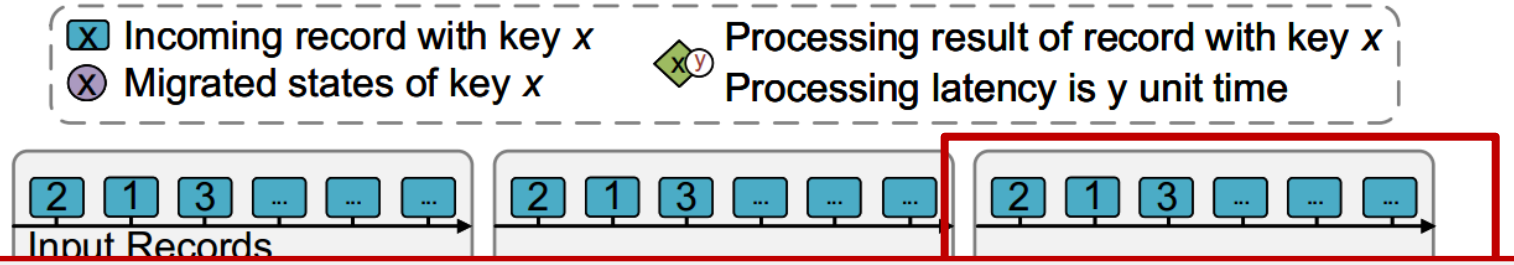
- Block all records until the migration ends

Prioritized Migration



- Minimize the time spent in the waiting queue

Prioritized Migration



Prioritized Migration:

- Hot keys: those being processed or about to be processed by downstream operator tasks
- State of hot keys needs to be prioritized so that the stream processing proceeds without blocking

Meces: Design and Mechanisms

Meces: On-the-fly Rescaling via Prioritized State Migration

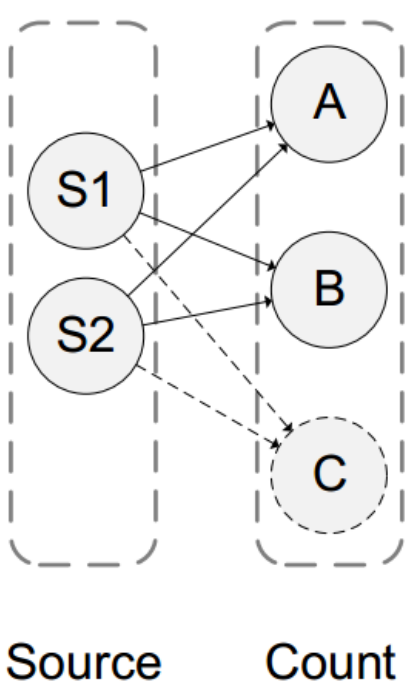
- **Fetch-on-demand state accessing during rescaling**
- **Coordinated by control messages***

* Inspired by previous works:

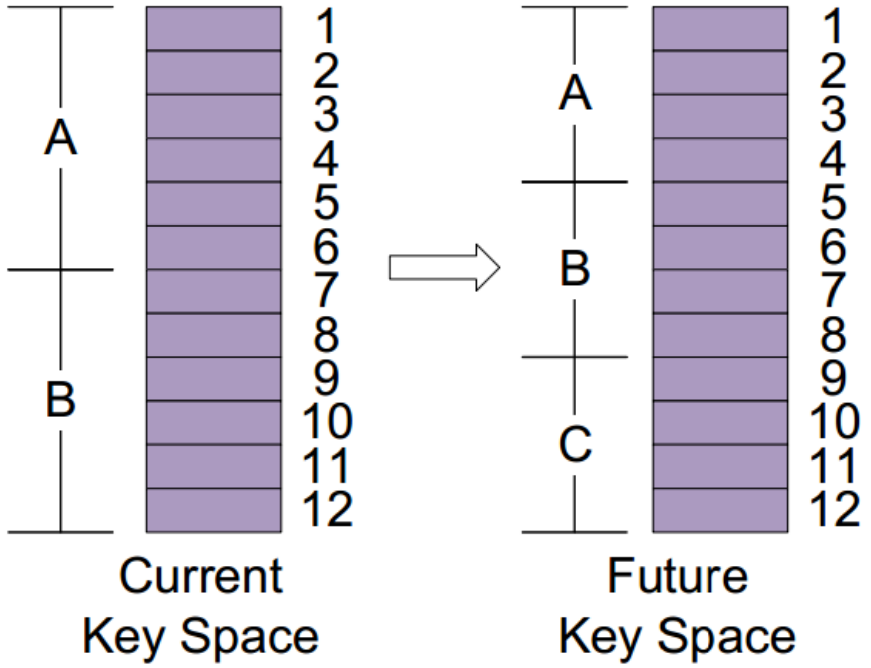
[1] Paris Carbone, et al. Lightweight asynchronous snapshots for distributed dataflows. arXiv preprint arXiv:1506.08603, 2015.
[2] Luo Mai, et al. Chi: A scalable and programmable control plane for distributed stream processing systems. PVLDB ’18
[3] Bonaventura Del Monte, et al. Rhino: Effcient management of very large distributed state for stream processing engines. SIGMOD ’20

Meces: Design and Mechanisms

Fetch-on-demand State Accessing



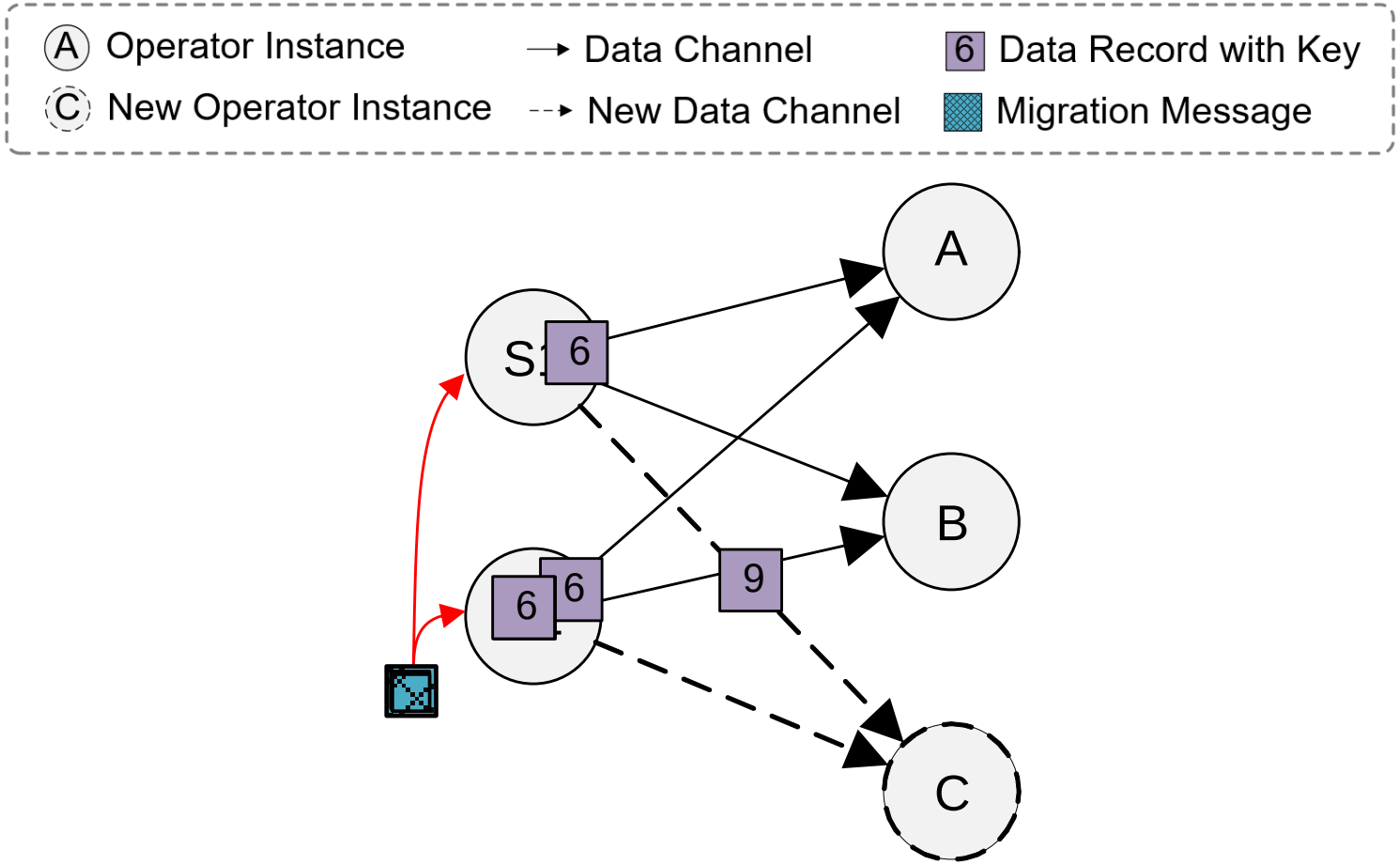
(a) Instances rescaling



(b) Key space redistribution

Meces: Design and Mechanisms

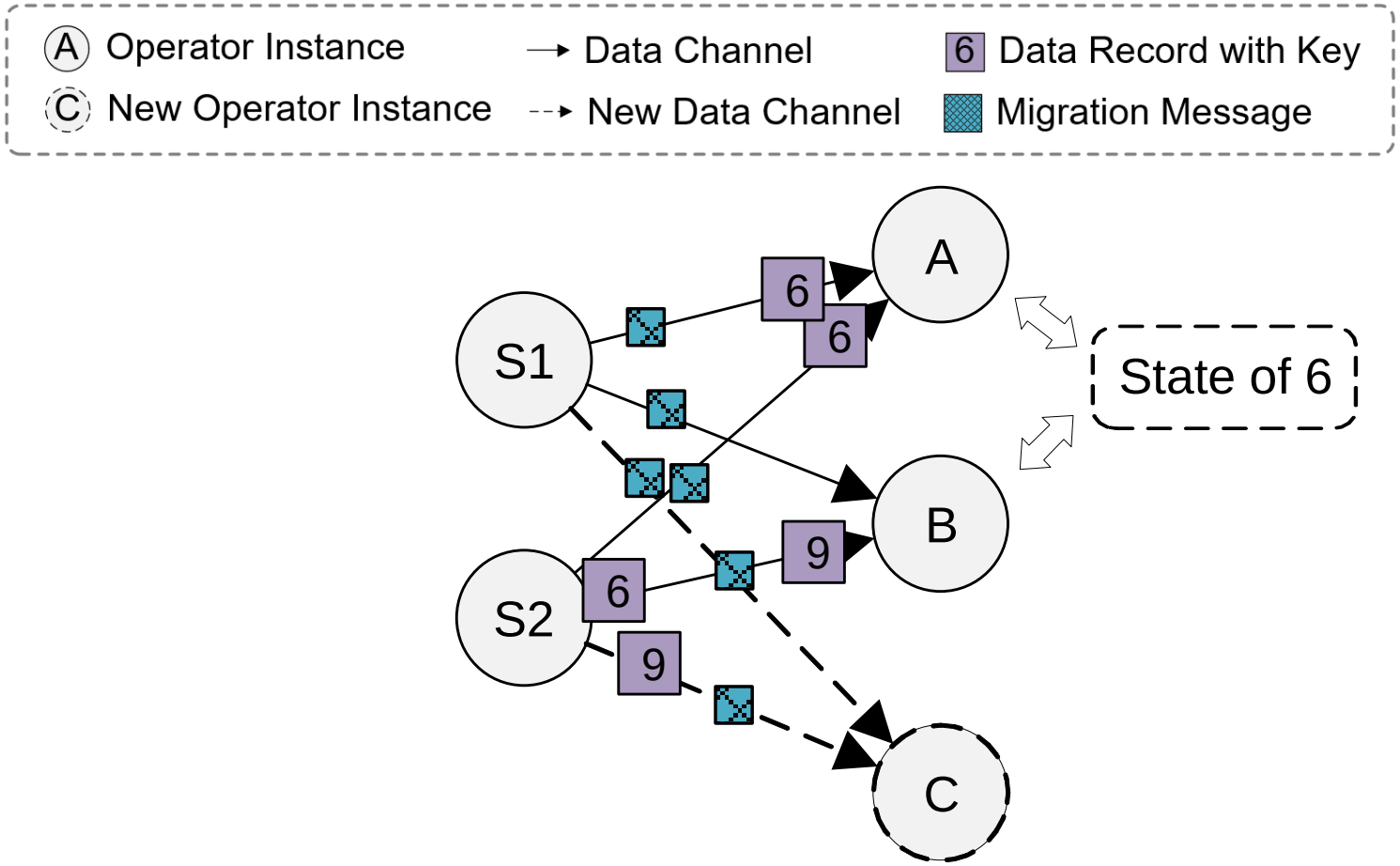
Fetch-on-demand State Accessing



(1) Triggering controlling messages

Meces: Design and Mechanisms

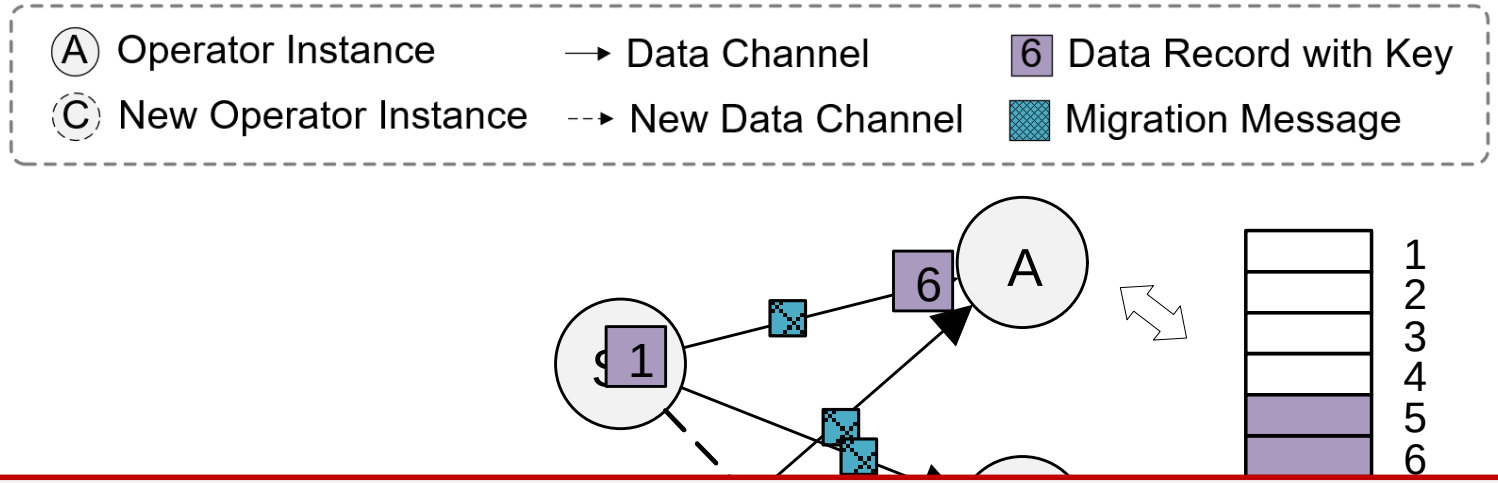
Fetch-on-demand State Accessing



(2) Aligning phase

Meces: Design and Mechanisms

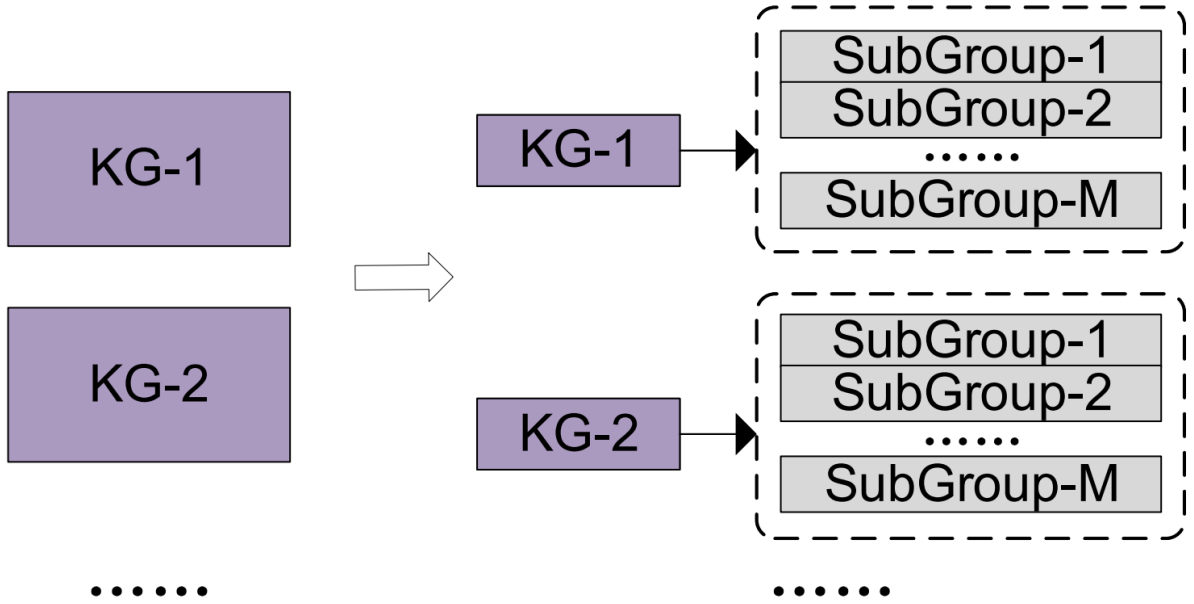
Fetch-on-demand State Accessing



Maintaining Exactly-once Semantics during the Migration Stage.

Meces: Design and Mechanisms

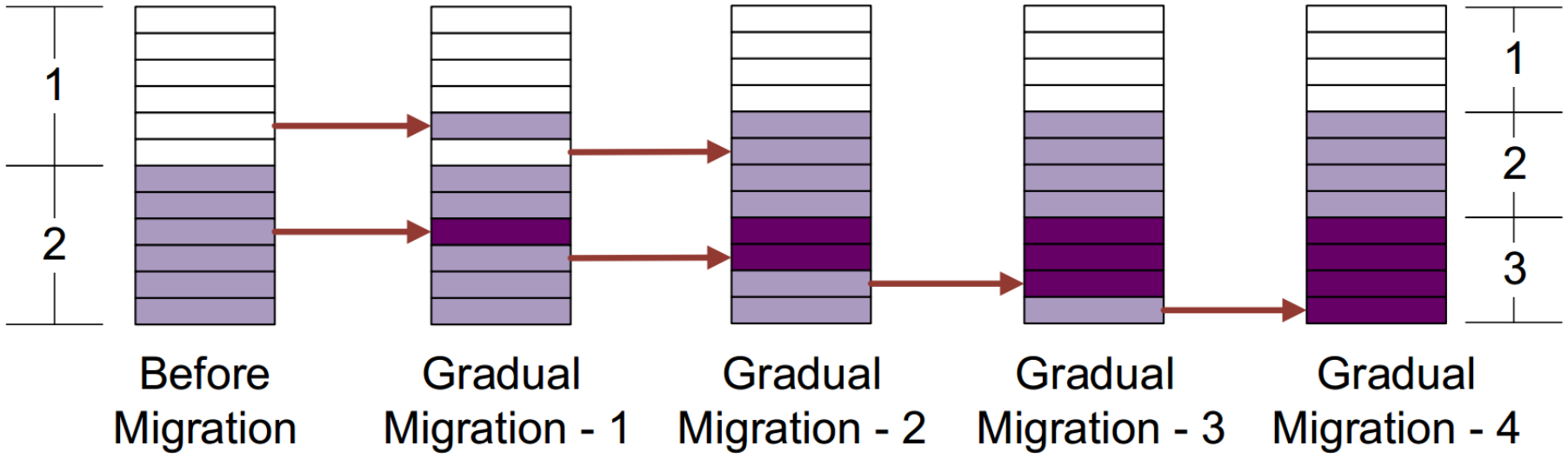
Finer Granularity of State Migration



Split Key-groups into Sub-groups

Meces: Design and Mechanisms

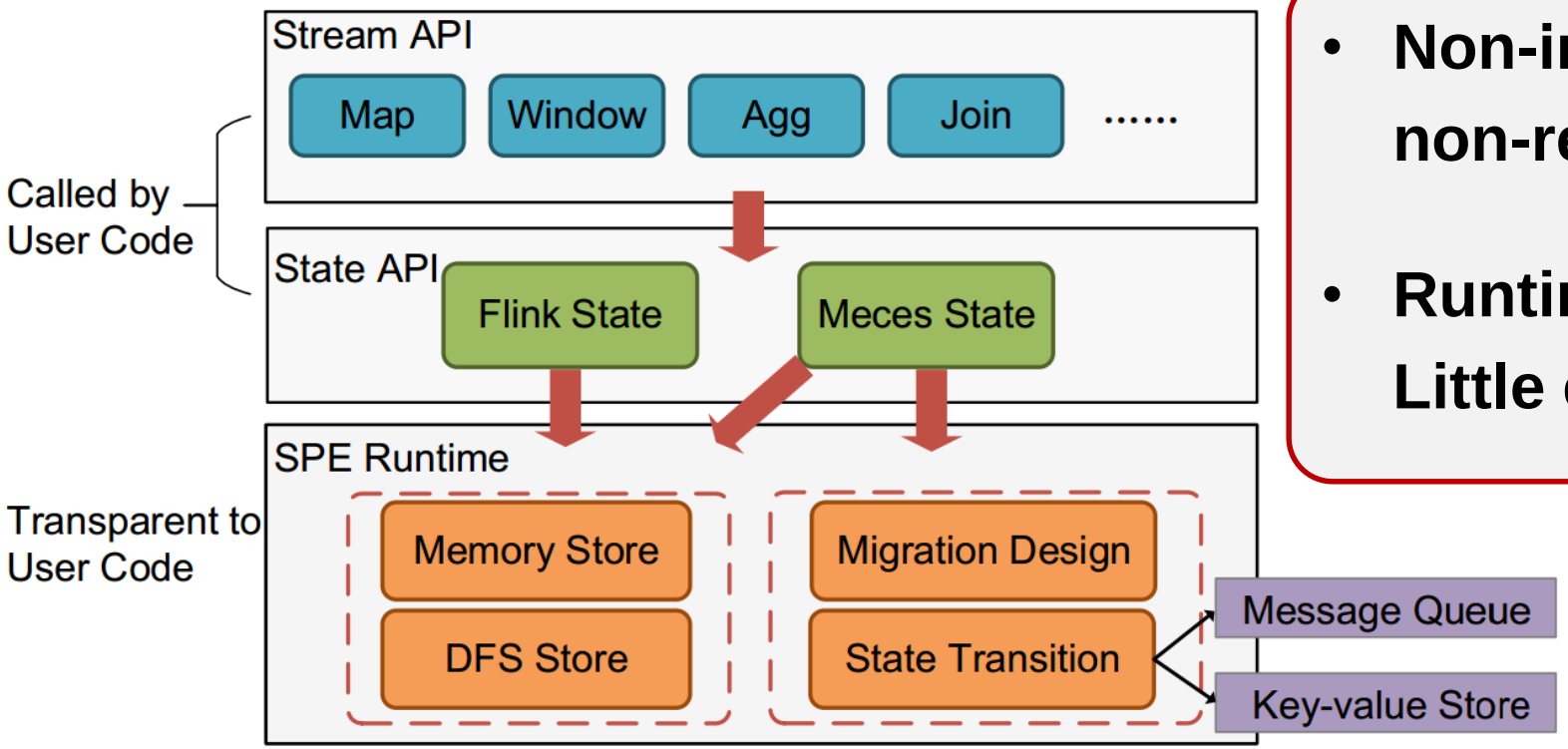
Finer Granularity of State Migration



Split one Migration stage into Gradual-Fetch steps

Meces: Design and Mechanisms

Meces System Architecture



- **Non-intrusive design: Not affecting non-rescaling periods**
- **Runtime code transparent to users: Little effort for code migration**

Evaluation

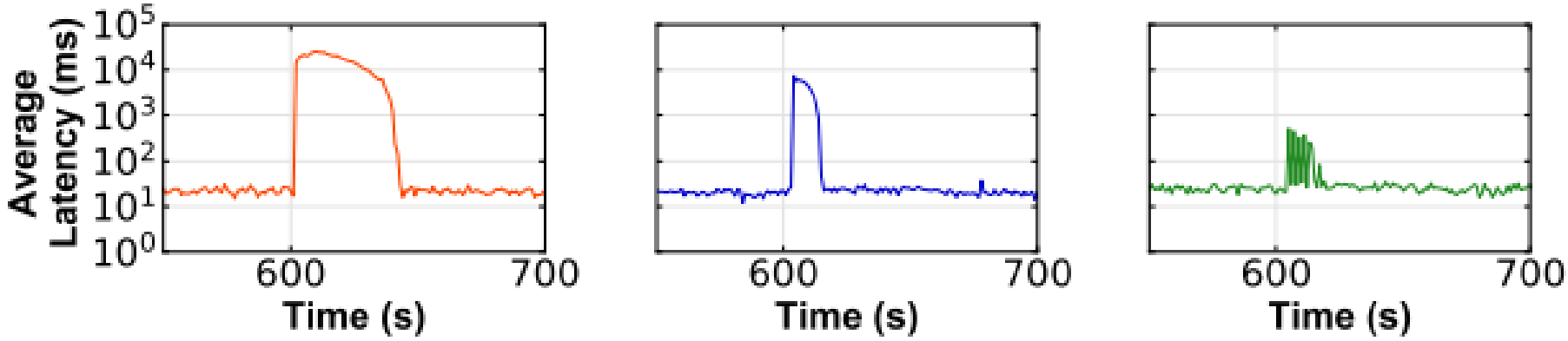
Latency Performance during Rescaling

Compared Systems

- **Flink (stopping the whole job when rescaling)**
- **Order-Unaware (online block-based state migration without order prioritization)**

Scenario

- **Key-count job**
- **Scale out after running for 600s**



(a) Native Flink (b) Order-Unaware (c) Meces

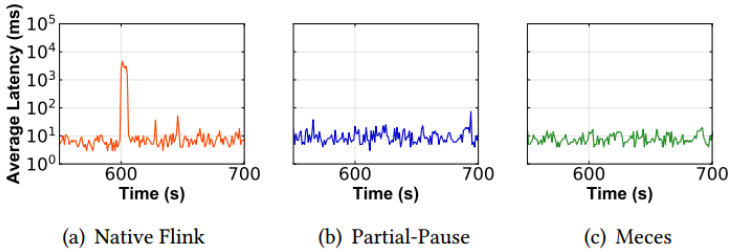
The latency peak of Meces is significantly lower.

Evaluation

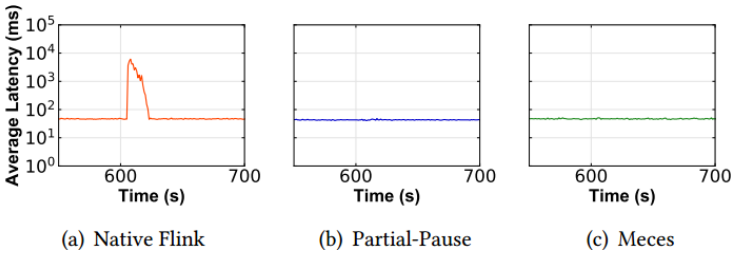
Latency Performance during Rescaling

Workload

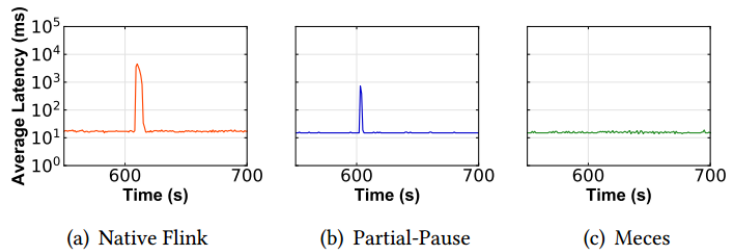
- **NEXMark Q1~Q8**



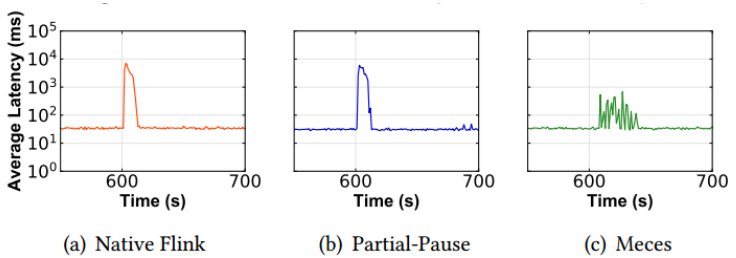
NEXMark Q1



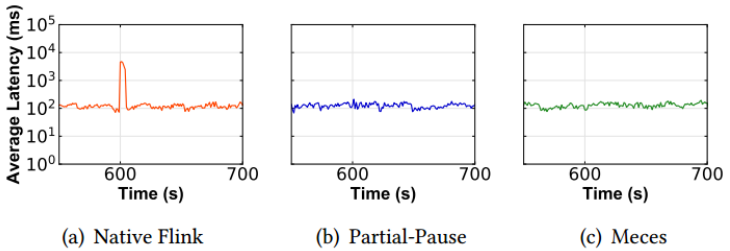
NEXMark Q2



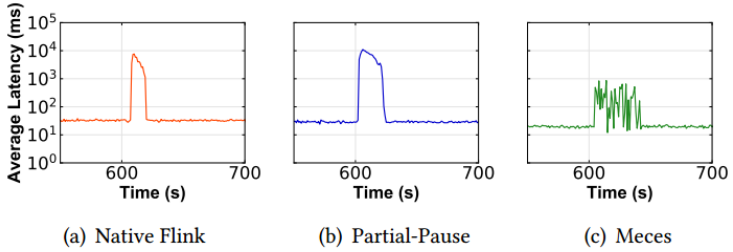
NEXMark Q3



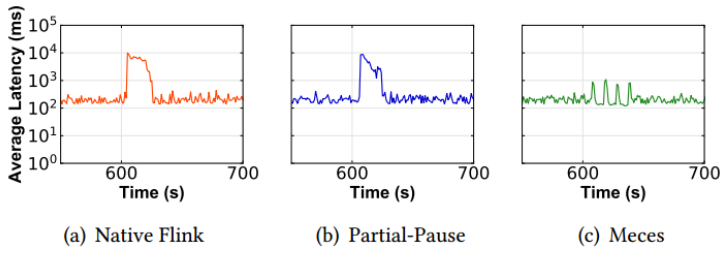
NEXMark Q4



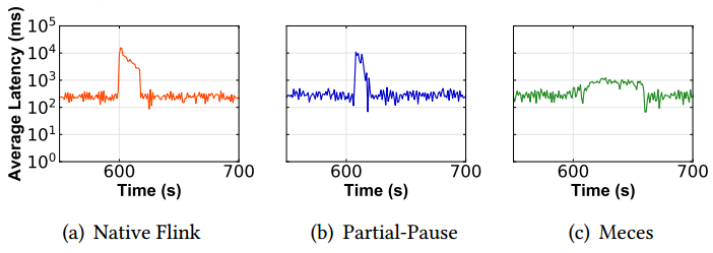
NEXMark Q5



NEXMark Q6



NEXMark Q7



NEXMark Q8

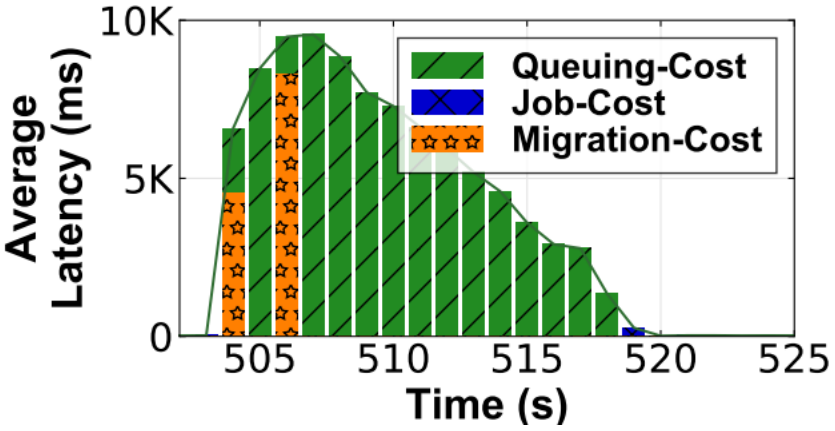
Meces lowers the latency peak by orders of magnitude.

Evaluation

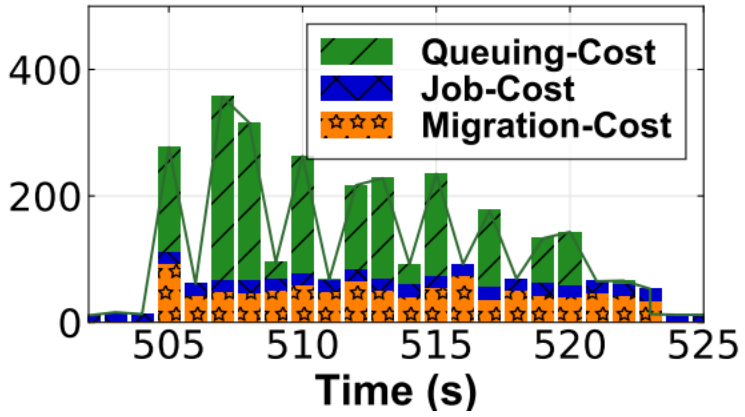
Time breakdown during Rescaling

Workload

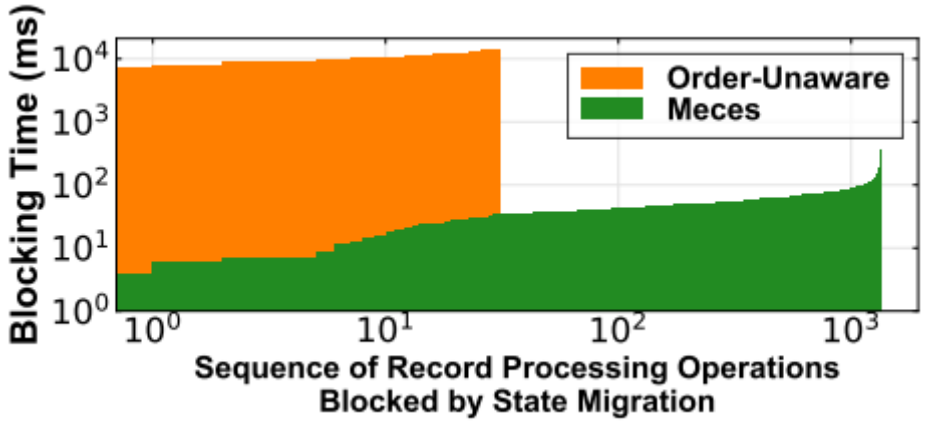
- **Key-count Job**



(a) Order-Unaware



(b) Meces



(c) Distribution of Migration-Cost

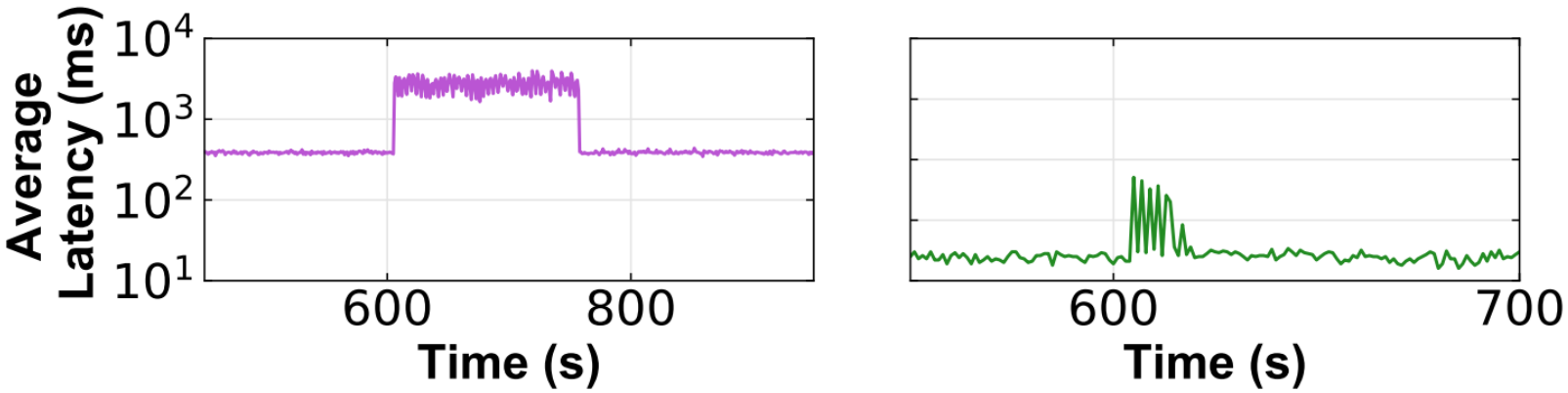
- **Long-duration blocks are converted into short-duration fetch operations.**
- **Reducing the queuing cost for subsequent records.**

Evaluation

Comparison with Megaphone[VLDB'19]

Workload

- **Key-count Job**



(a) Megaphone on Flink

(b) Meces

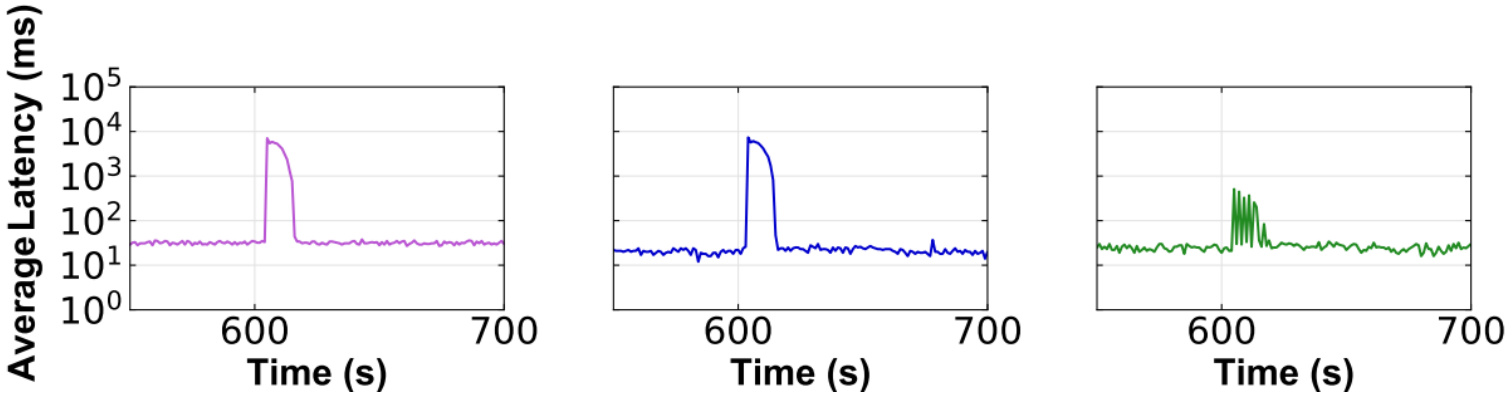
- **Meces incurs no overhead during non-rescaling**
- **Meces reduces latency peak significantly during rescaling**

Evaluation

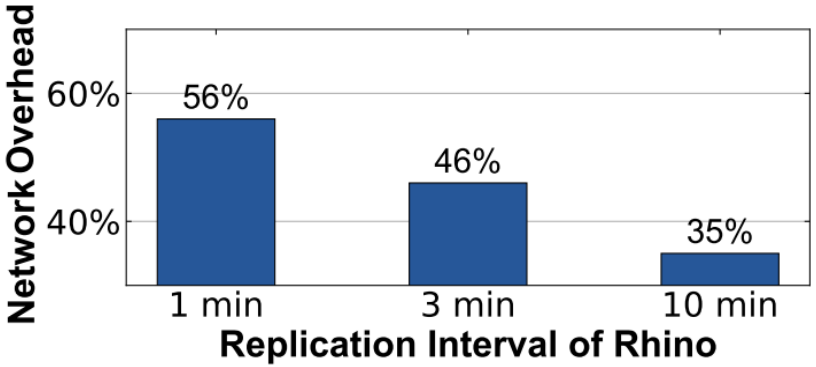
Comparison with Rhino[SIGMOD'20]

Workload

- **Key-count Job**



(a) Rhino on Flink (b) Order-Unaware (c) Meces



Network overhead of Rhino

- **Meces reduces latency peak by one magnitude during rescaling**
- **Meces incurs no network overhead during non-rescaling**

Conclusion

- **Meces: an on-the-fly rescaling mechanism for stateful distributed stream processing engines**
  - Prioritized migration of hot states
  - Coordination protocol based on control messages
  - A hierarchical state data organization and a gradual state migration
  - Implemented on top of Apache Flink

Thank You!

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