Distributed Systems Reading Group - Session 2 - Klas Segeljakt
Snapshotting Protocols in Distributed Stream Processing Systems

Structured Streaming: A Declarative API for Real-Time Applications in Apache Spark

Michael Armbrust[†], Tathagata Das[†], Joseph Torres[†], Burak Yavuz[†], Shixiong Zhu[†], Reynold Xin[†], Ali Ghodsi[†], Ion Stoica[†], Matei Zaharia[†‡]
[†]Databricks Inc., [‡]Stanford University

Consistent Regions: Guaranteed Tuple Processing in IBM Streams

Gabriela Jacques-Silva[♠], Fang Zheng[♠], Daniel Debrunner[‡], Kun-Lung Wu[♠], Victor Dogaru[‡], Eric Johnson[‡], Michael Spicer[‡], Ahmet Erdem Sarıyüce[◇†]
[♠]IBM T. J. Watson Research Center, [‡]IBM Analytics Platform, [◇]Sandia National Labs

State Management in Apache Flink®

Consistent Stateful Distributed Stream Processing

Paris Carbone[†] Stephan Ewen[‡] Gyula Fóra[⋆]
Seif Haridi[†] Stefan Richter[‡] Kostas Tzoumas[‡]

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@data-artisans.com

Outline

- Introduction
- Flink ➡ IBM Streams ➡ Spark Structured Streaming
  - Problem statement
  - System overview
  - Snapshotting protocol
  - Discussion (based on results)
- Comparison & Conclusion

Introduction

Introduction - Data Stream Processing

Slide borrowed from Paris Carbone, LADIS 2018, Asynchronous Epoch Commits

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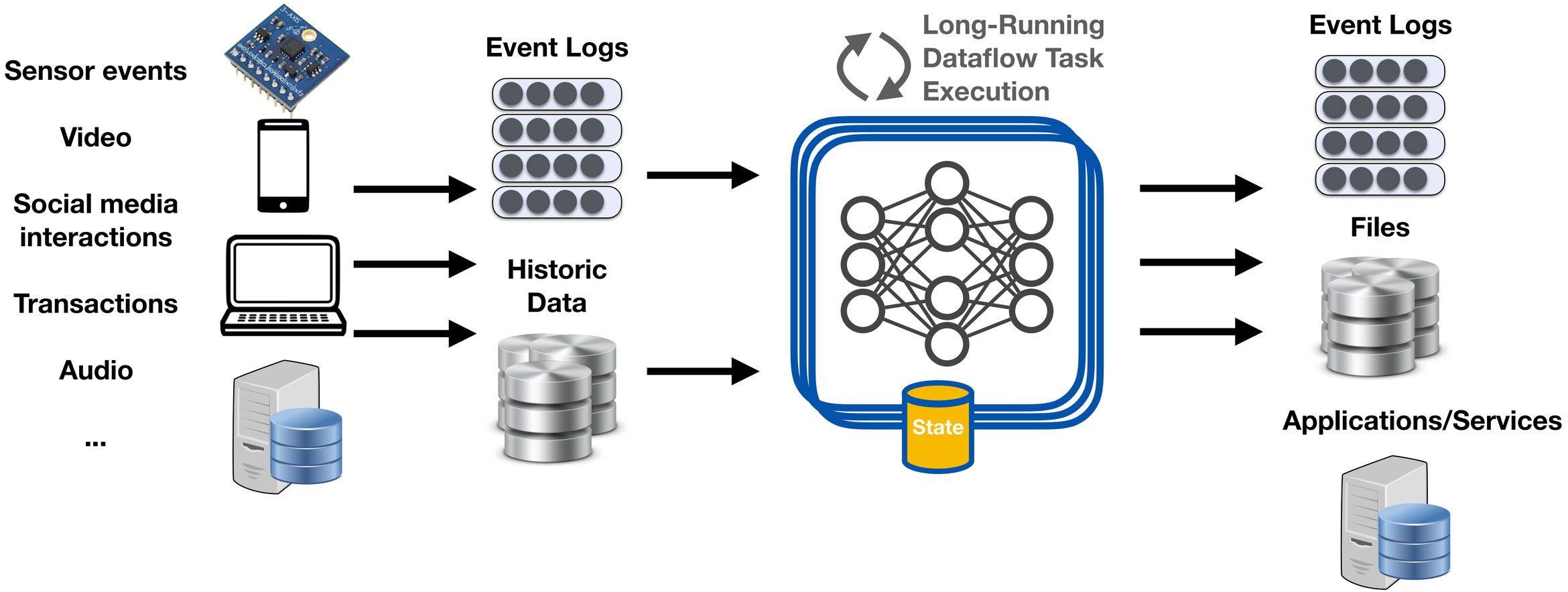

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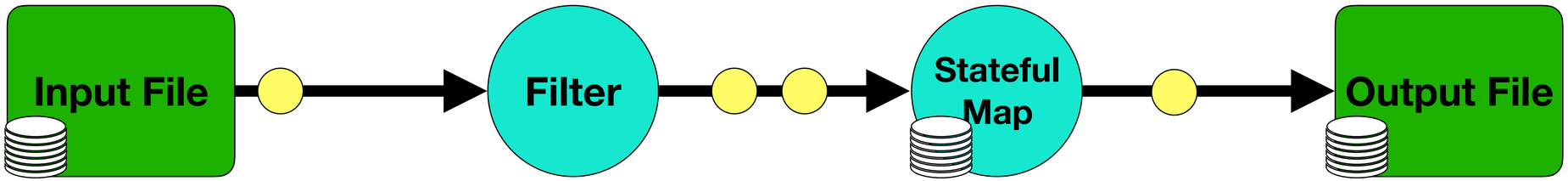
Introduction - Dataflow Graphs



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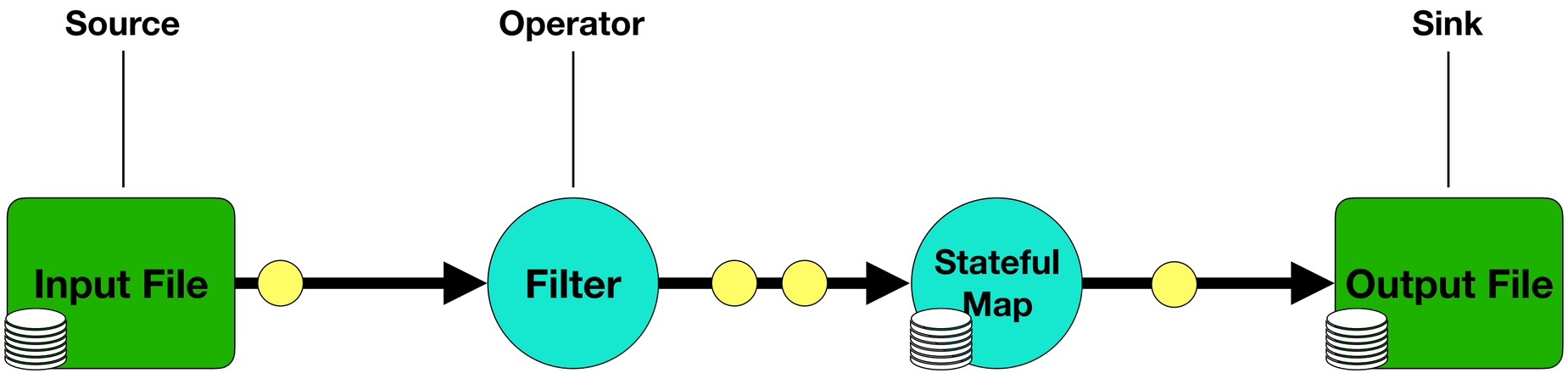

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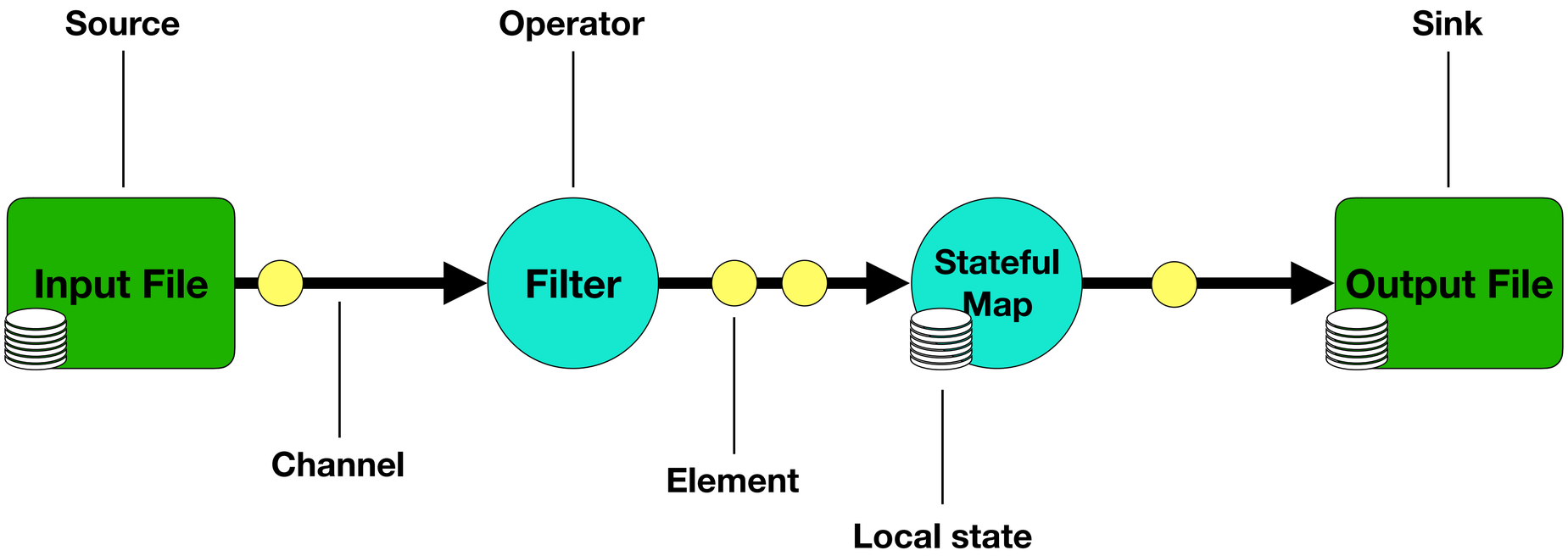

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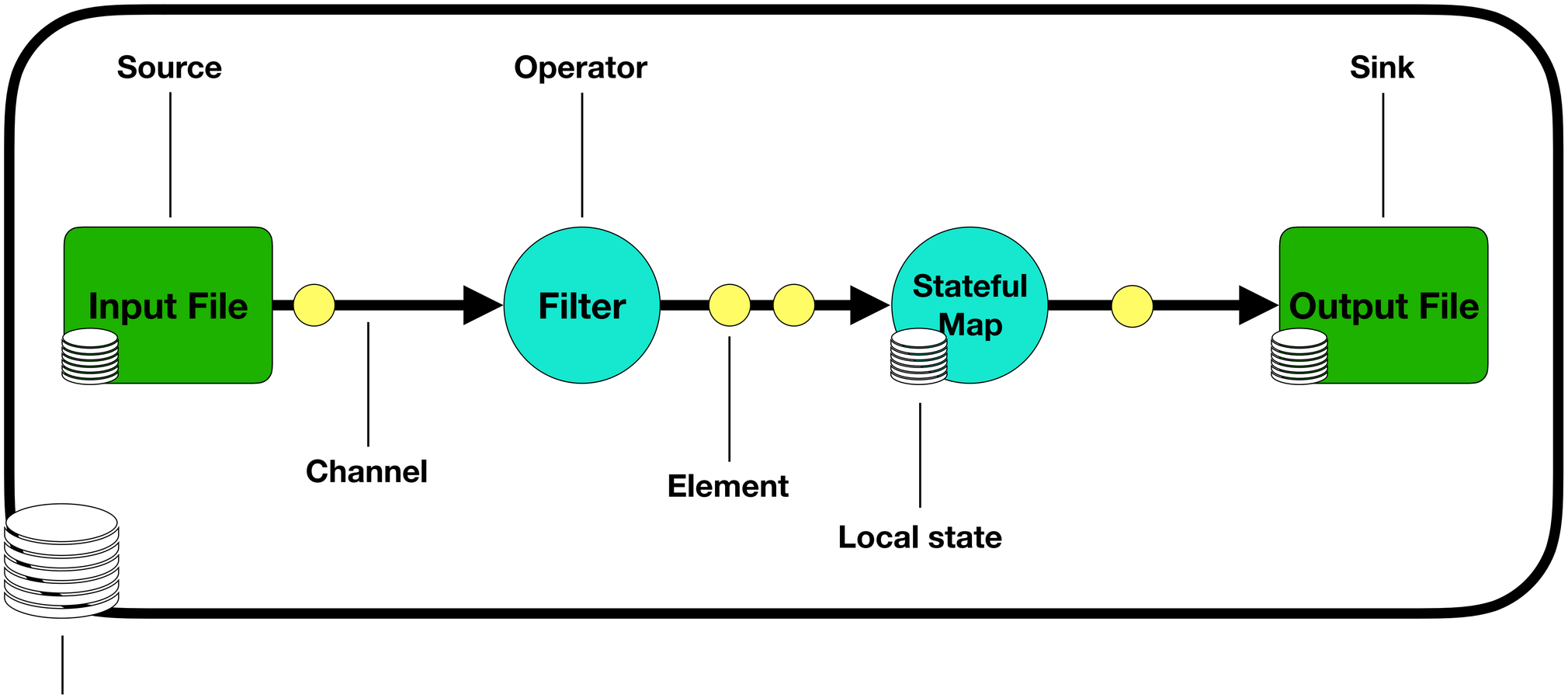

Global state =
in-transit elements
+ local state of operators

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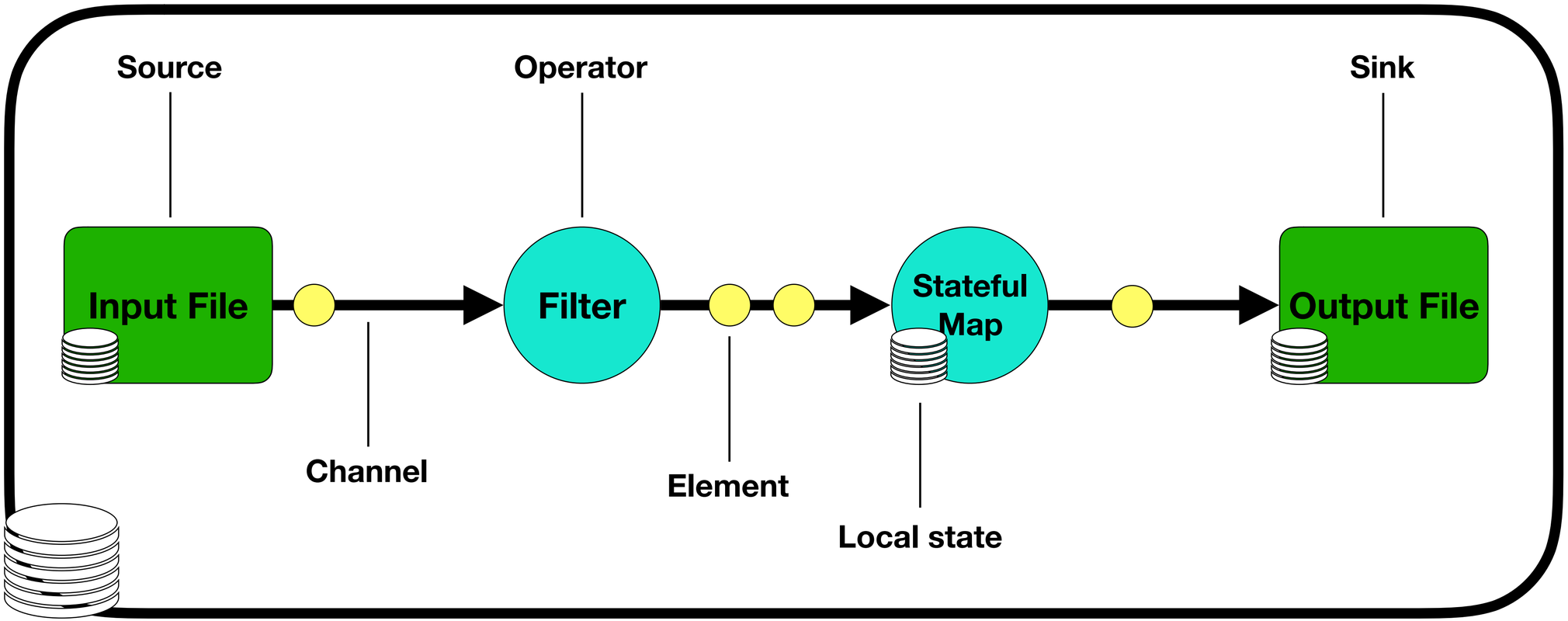

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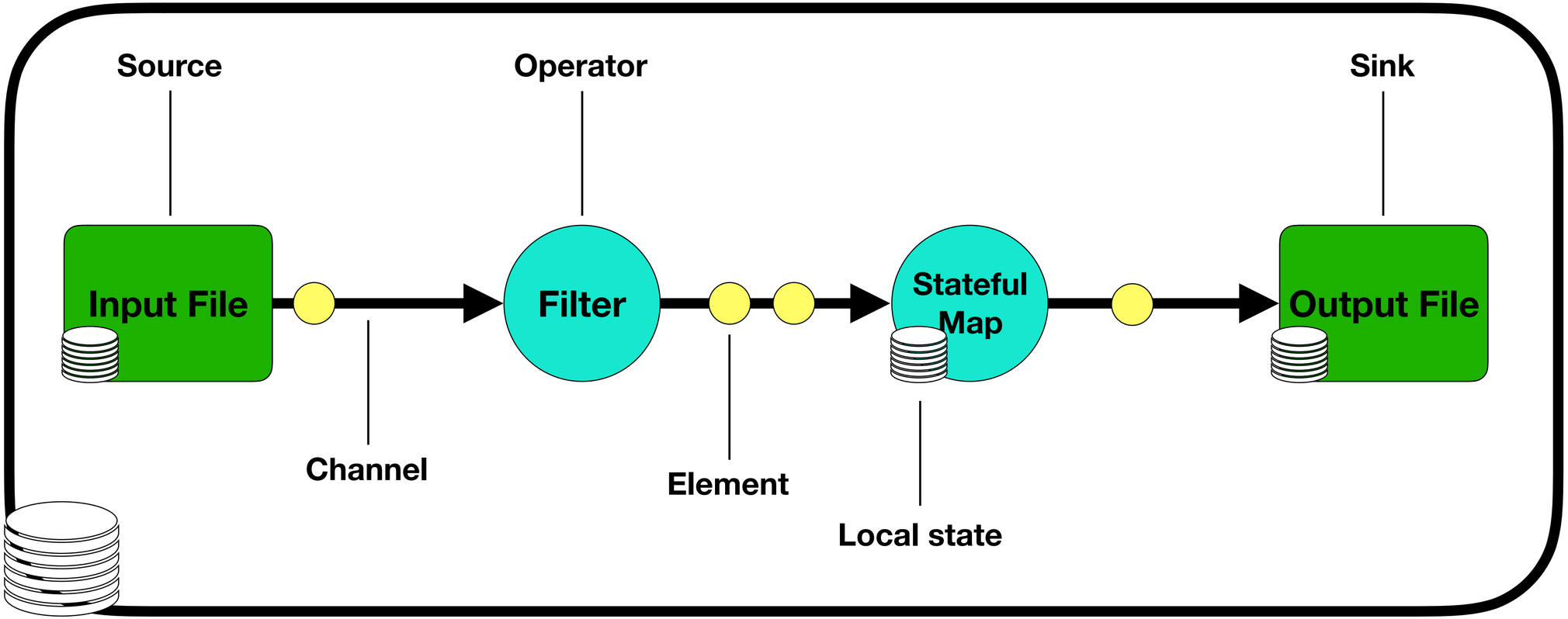

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Exactly-once / At-least-once Processing

Exactly-once / At-least-once Delivery

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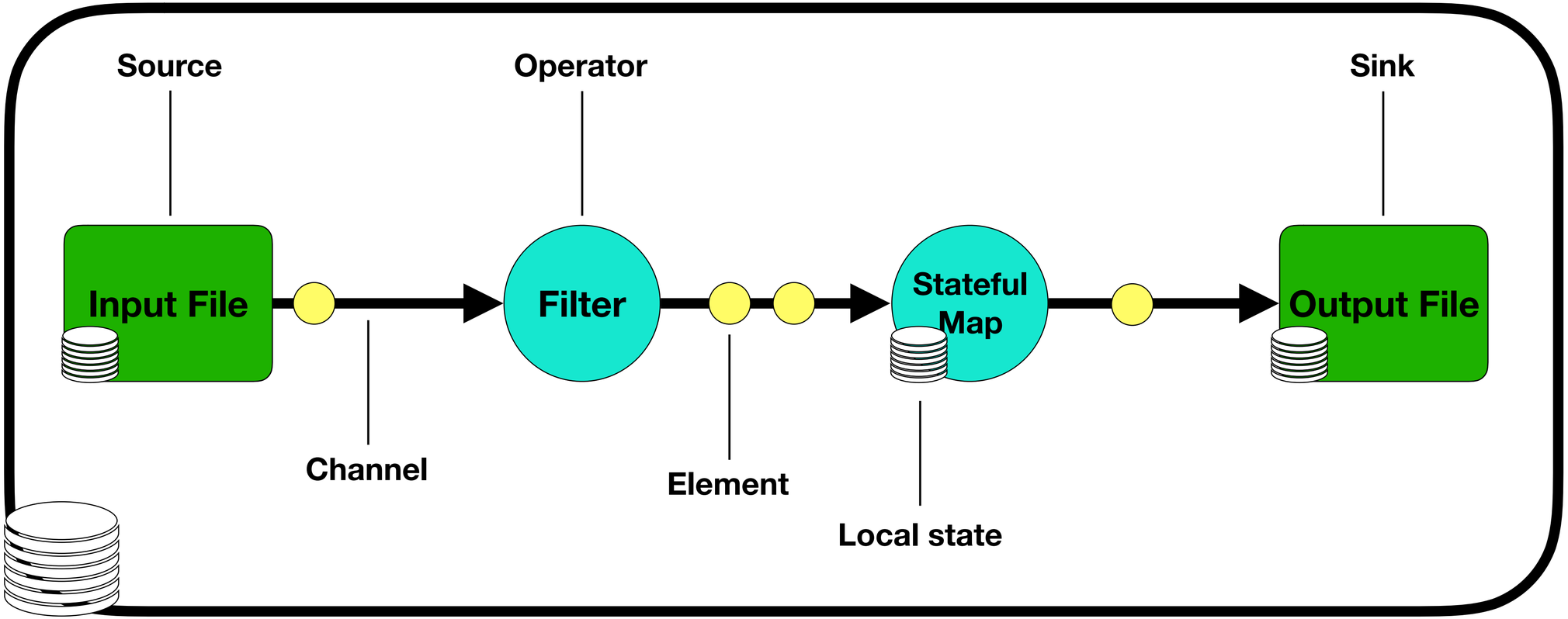

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Snapshotting Protocols: Distributed Algorithms that implement **distributed cuts** in a system execution to yield a global state

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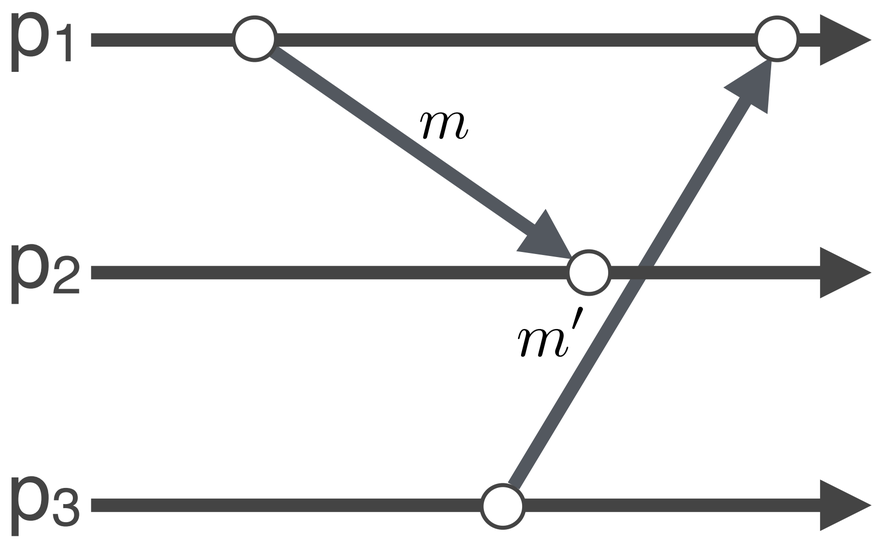

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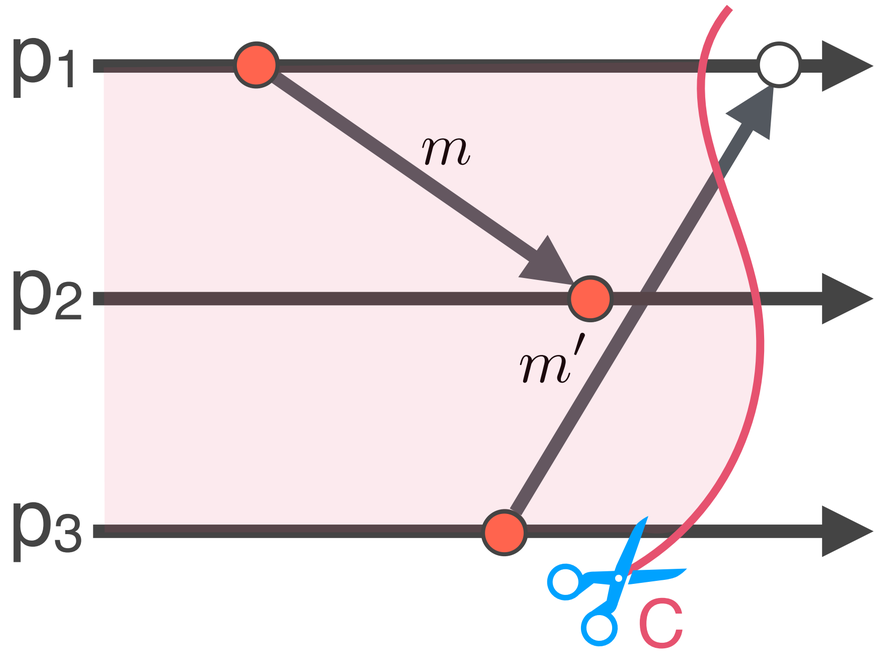

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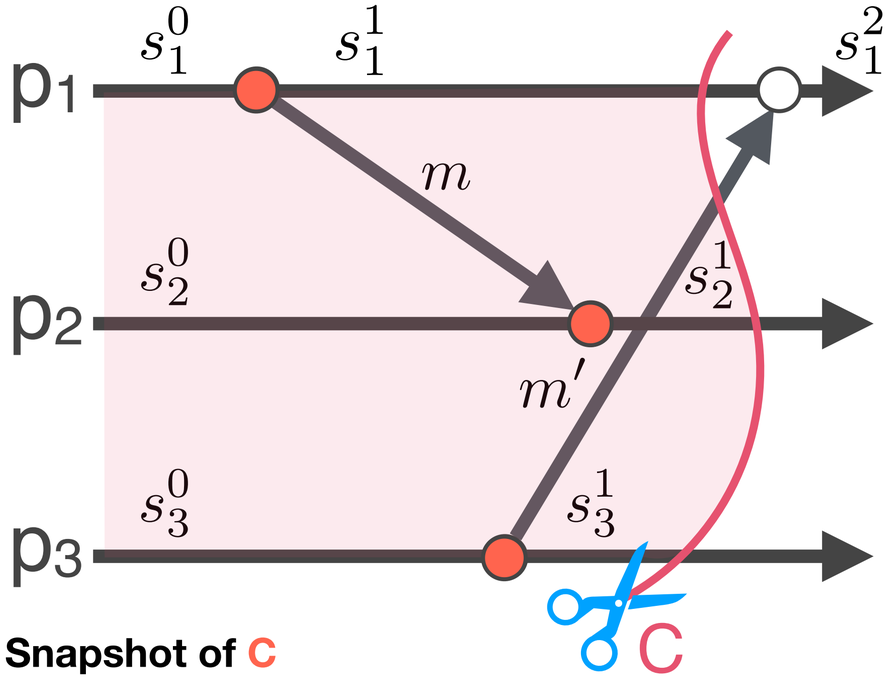

Snapshot of C

$\{s_1^1, s_2^1, s_3^1\}$
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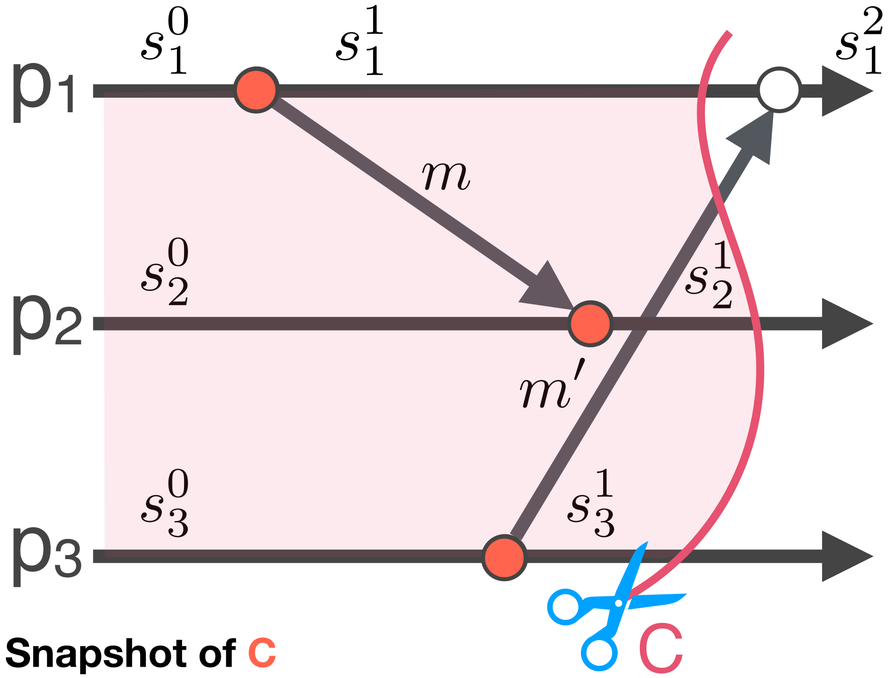

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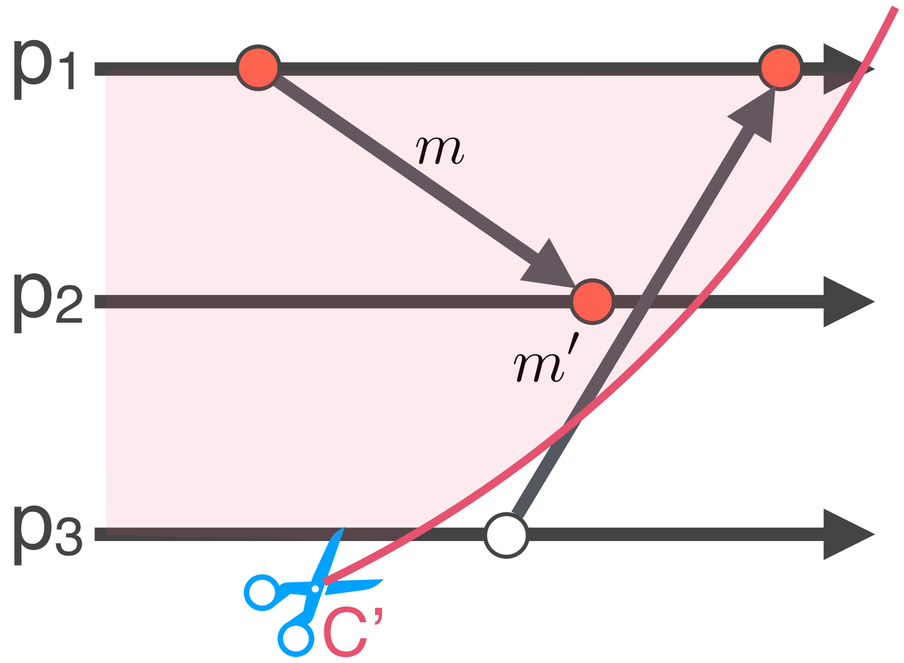

Inconsistent cut (Violates causality)

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Apache Flink

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Solution: Distributed Snapshots

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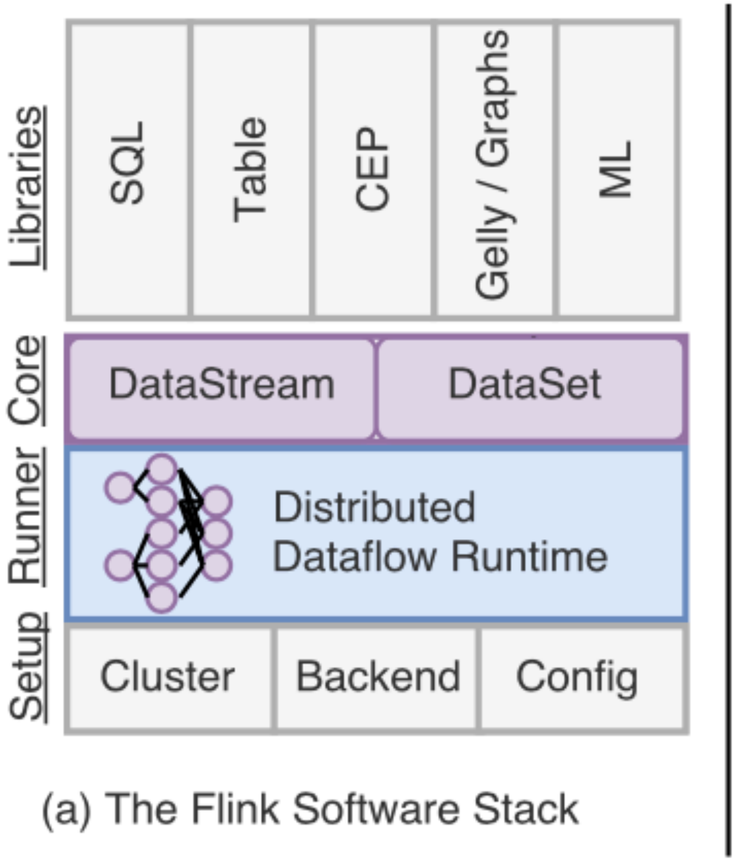

(a) The Flink Software Stack

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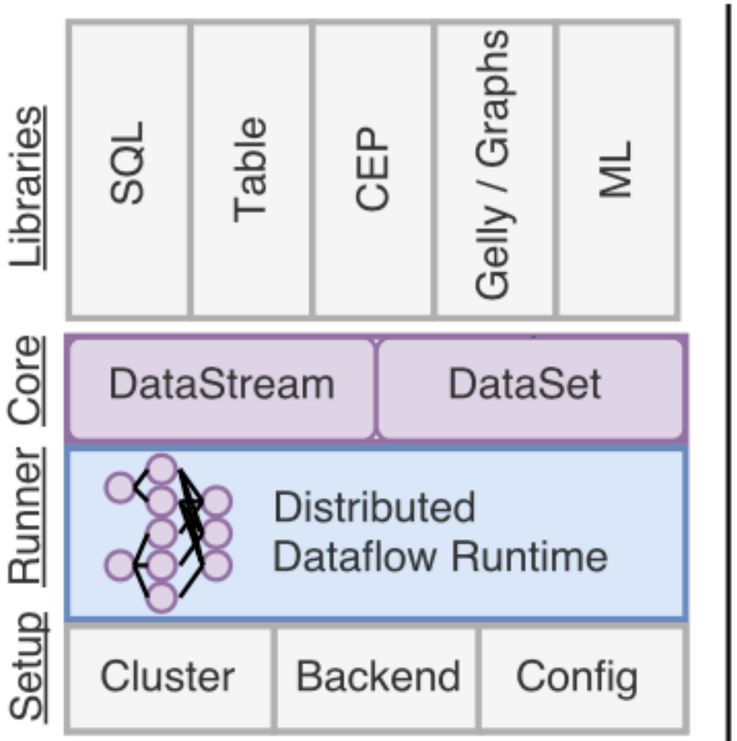

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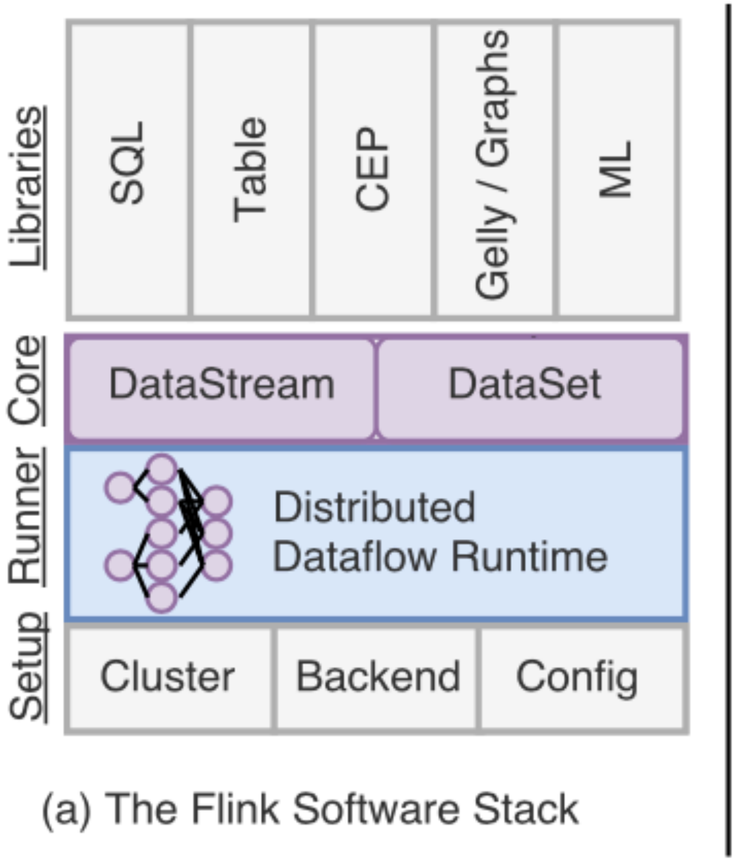

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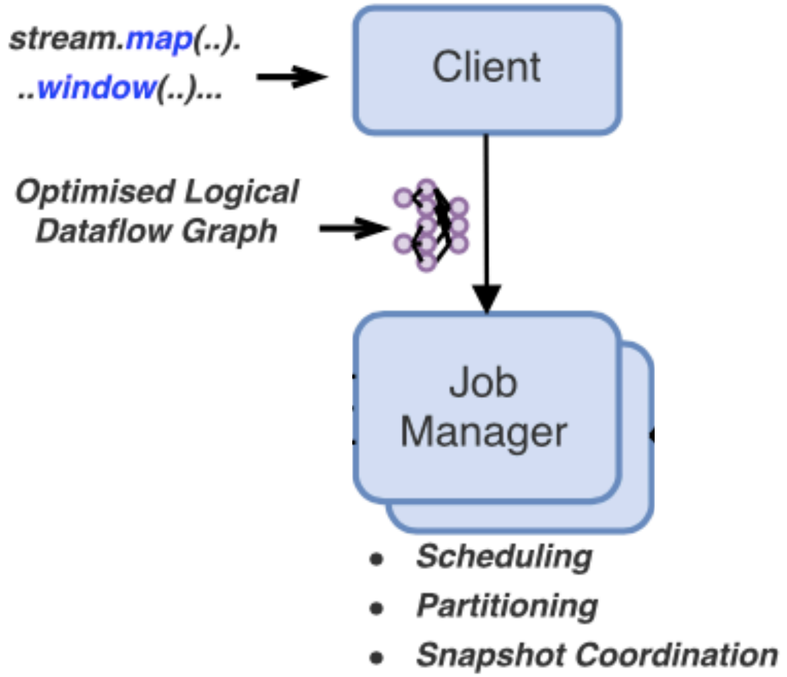

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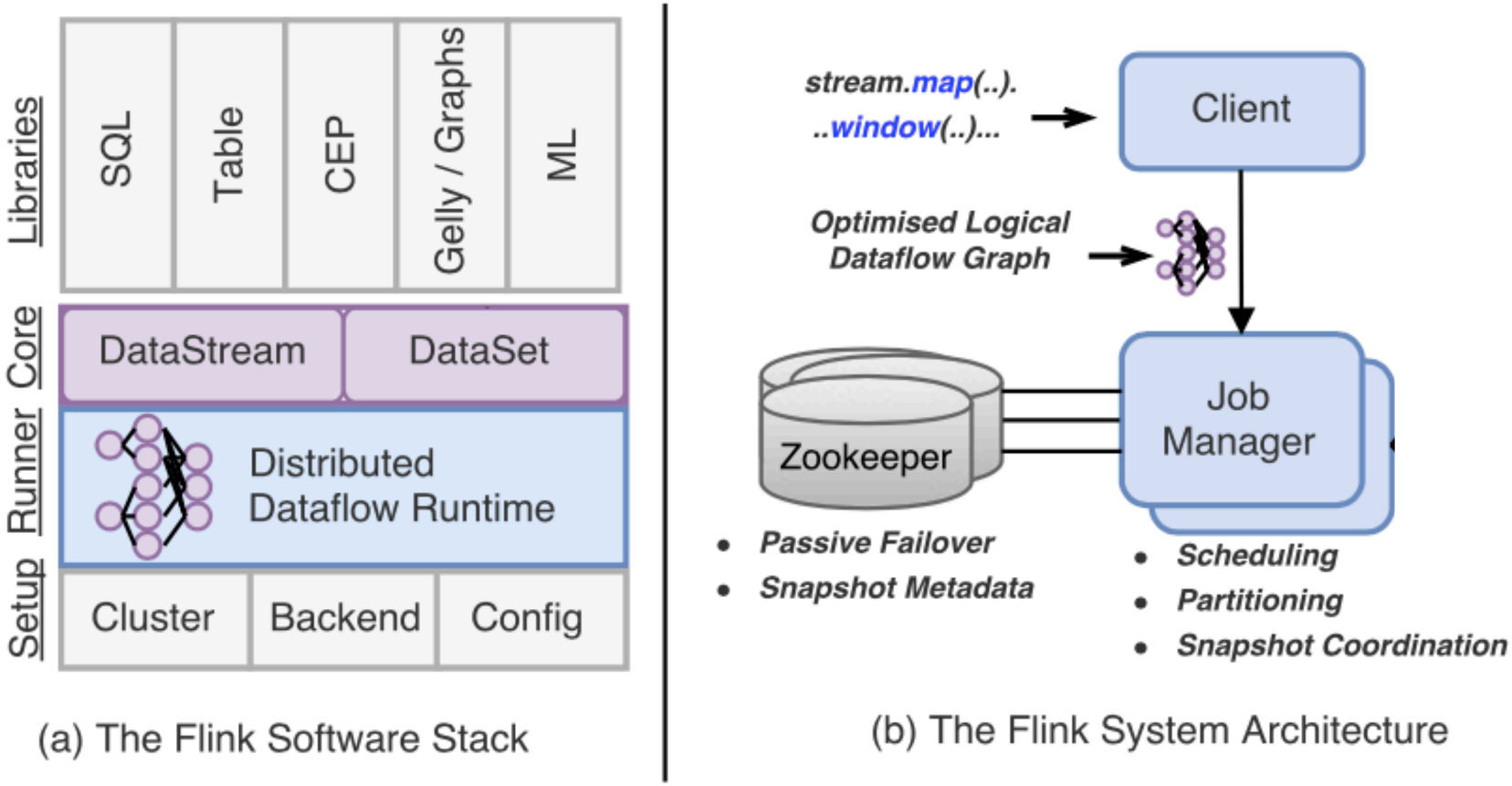

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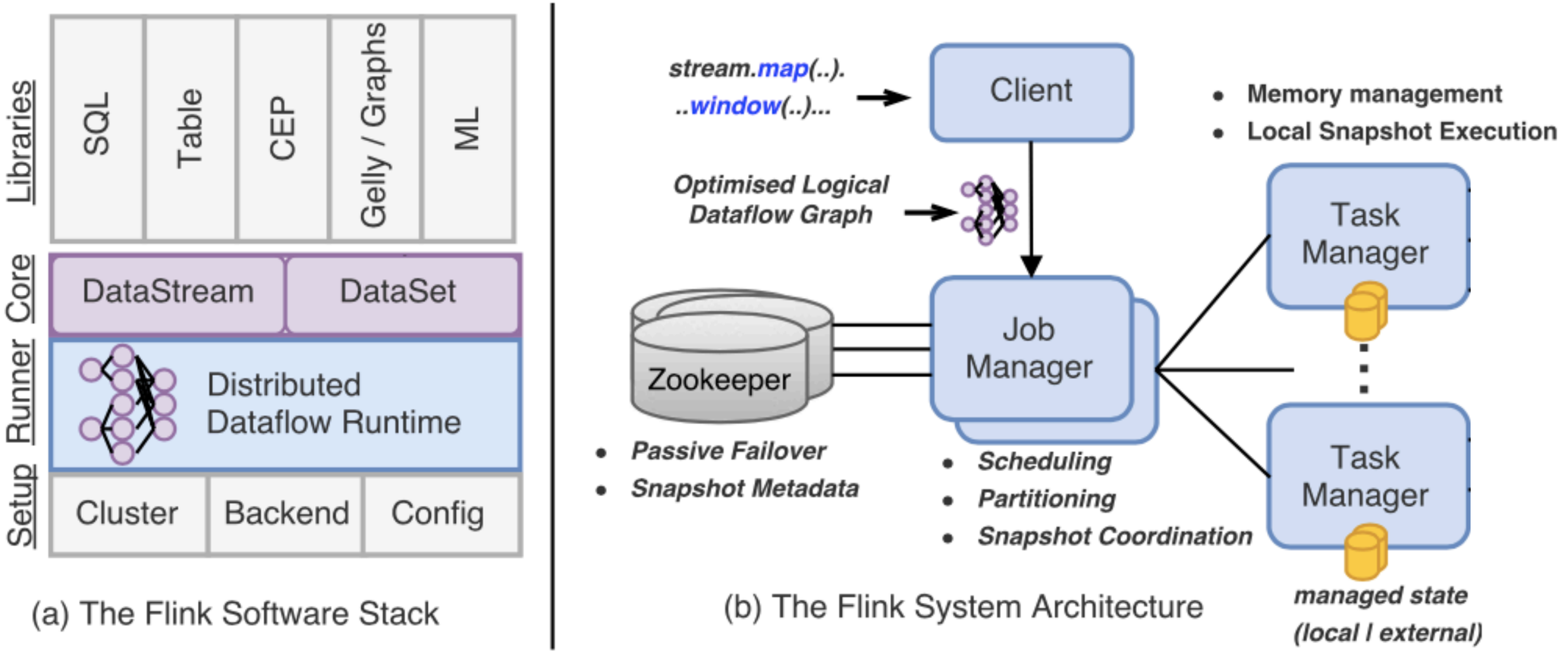

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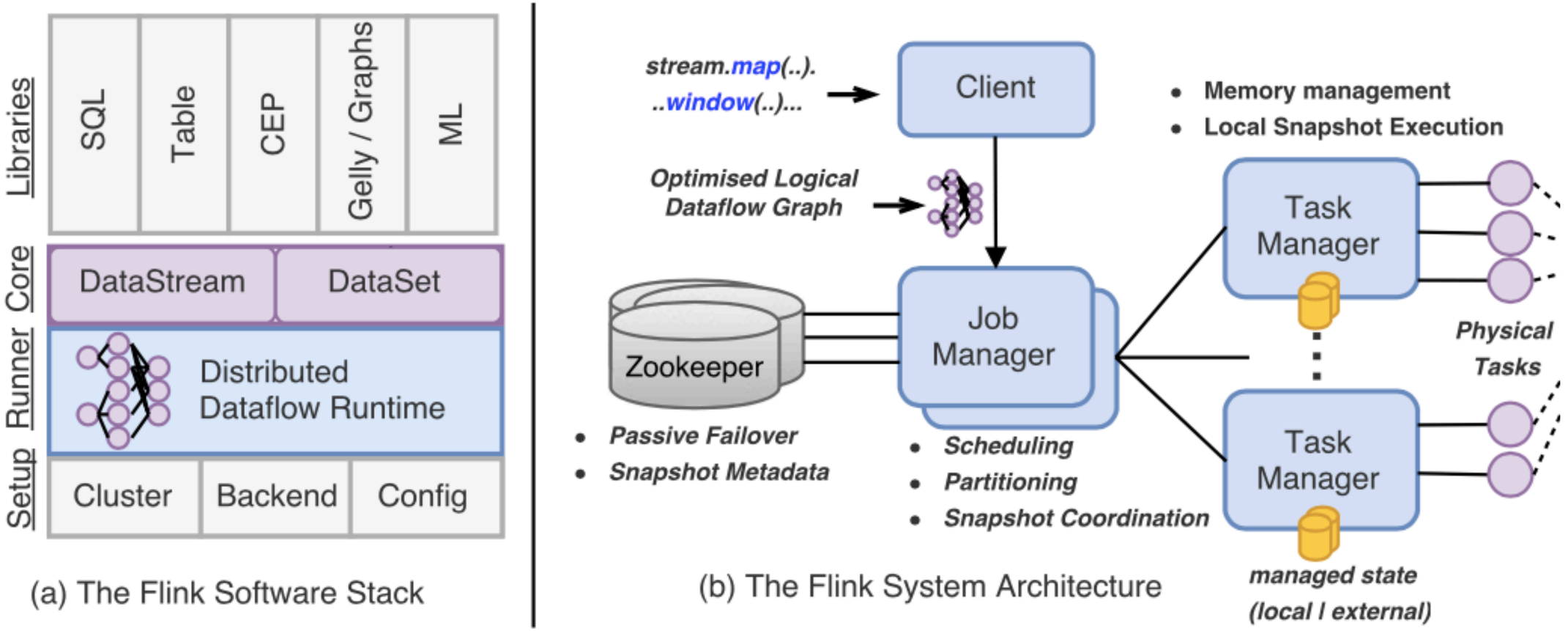

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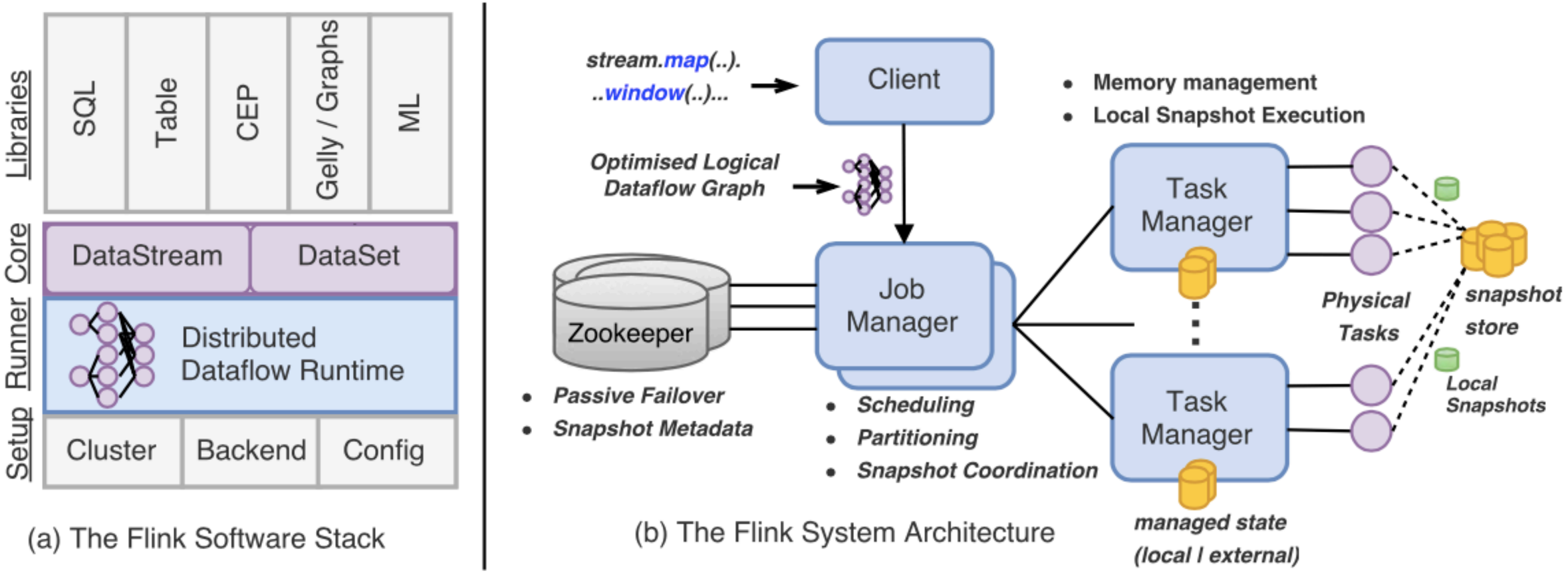

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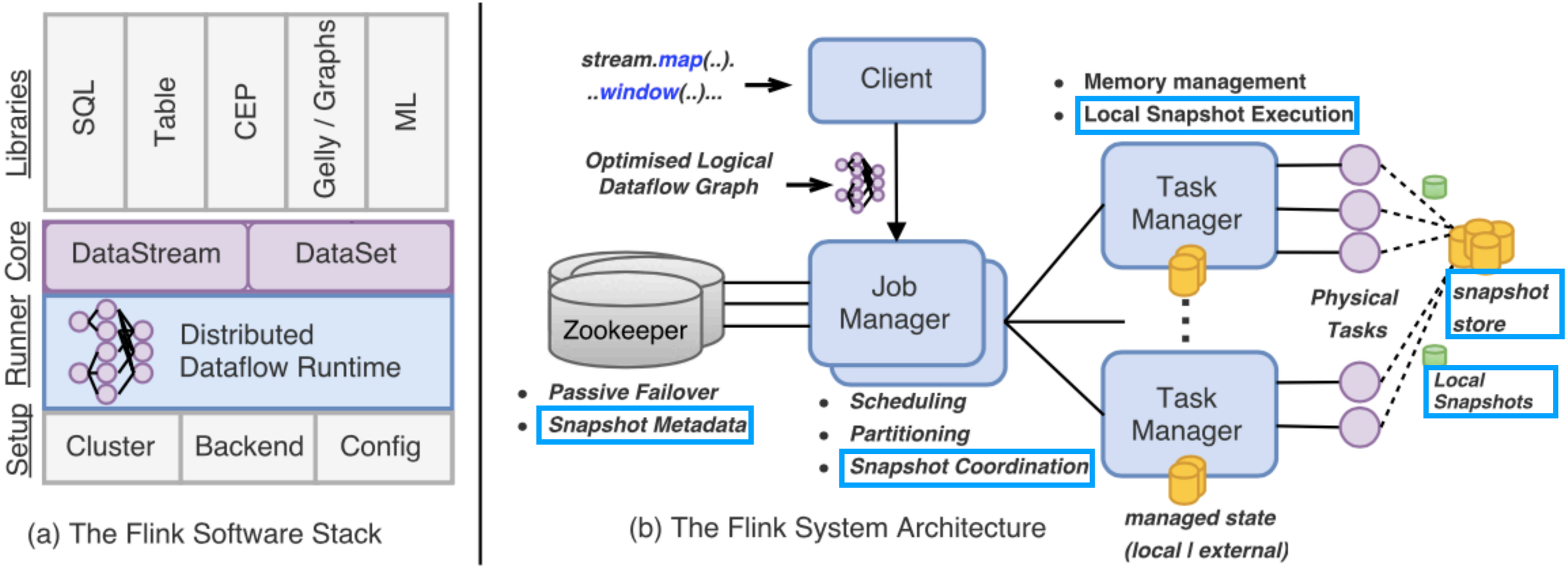

How do snapshots work?

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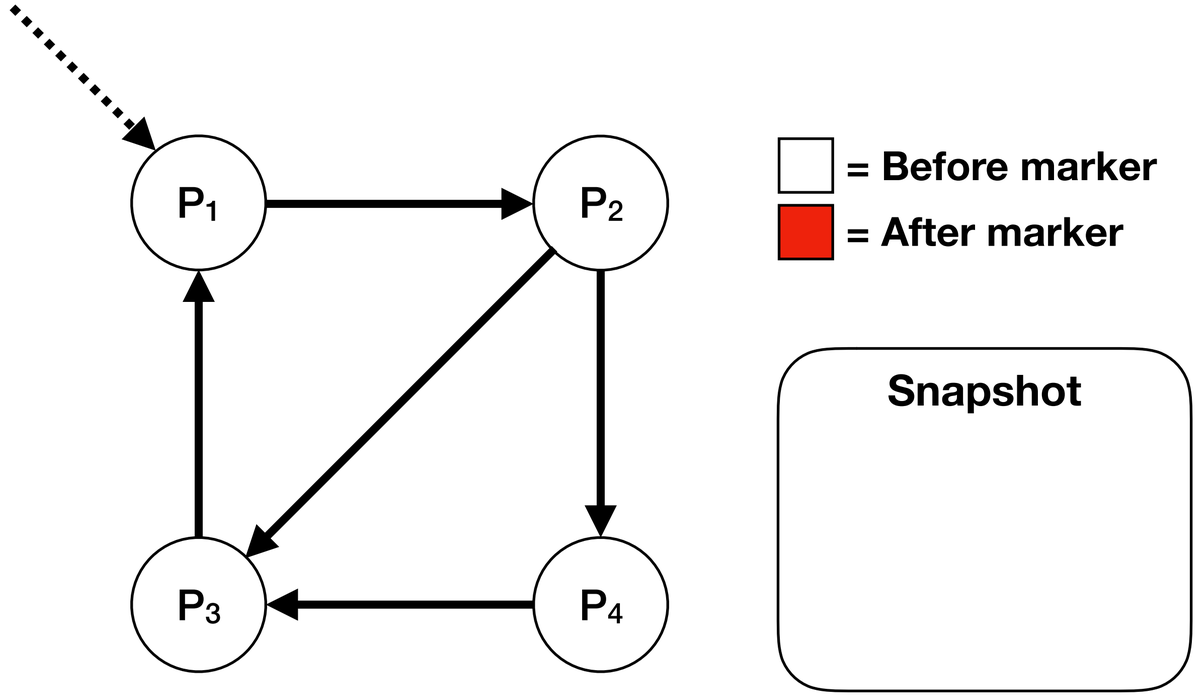

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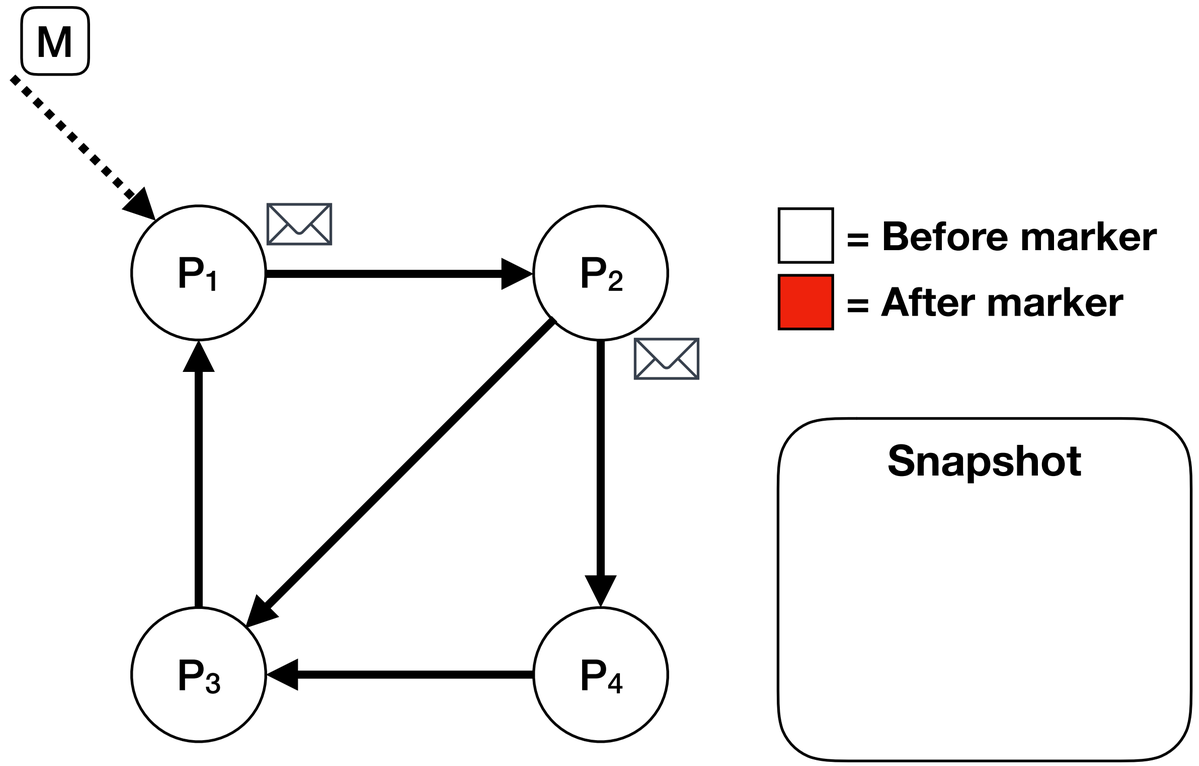

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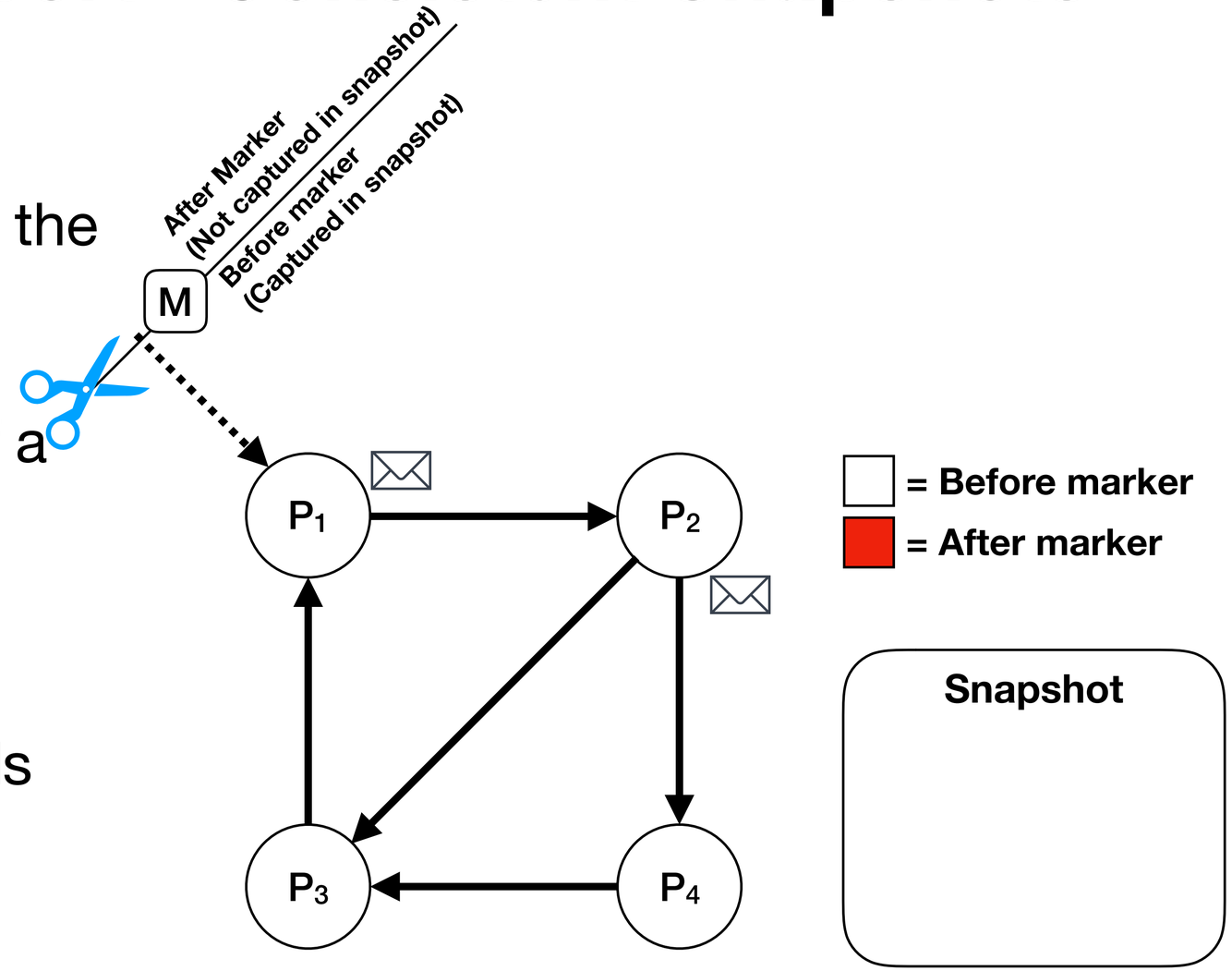

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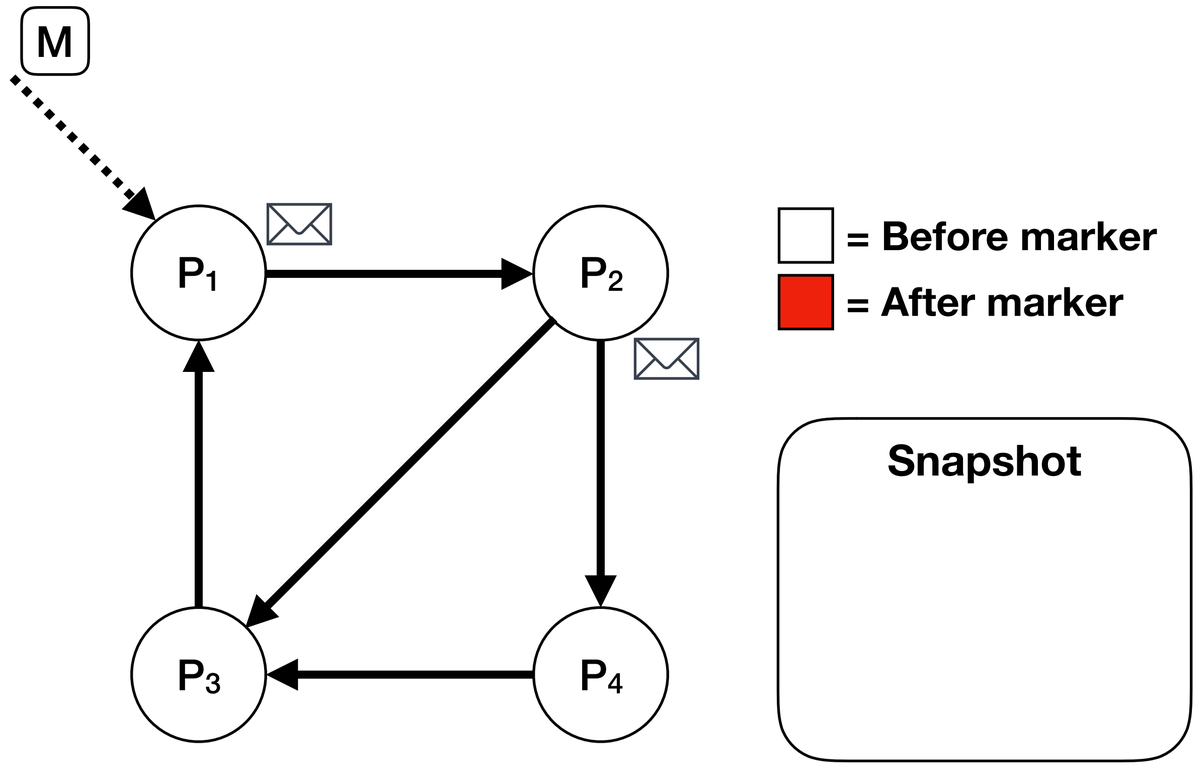

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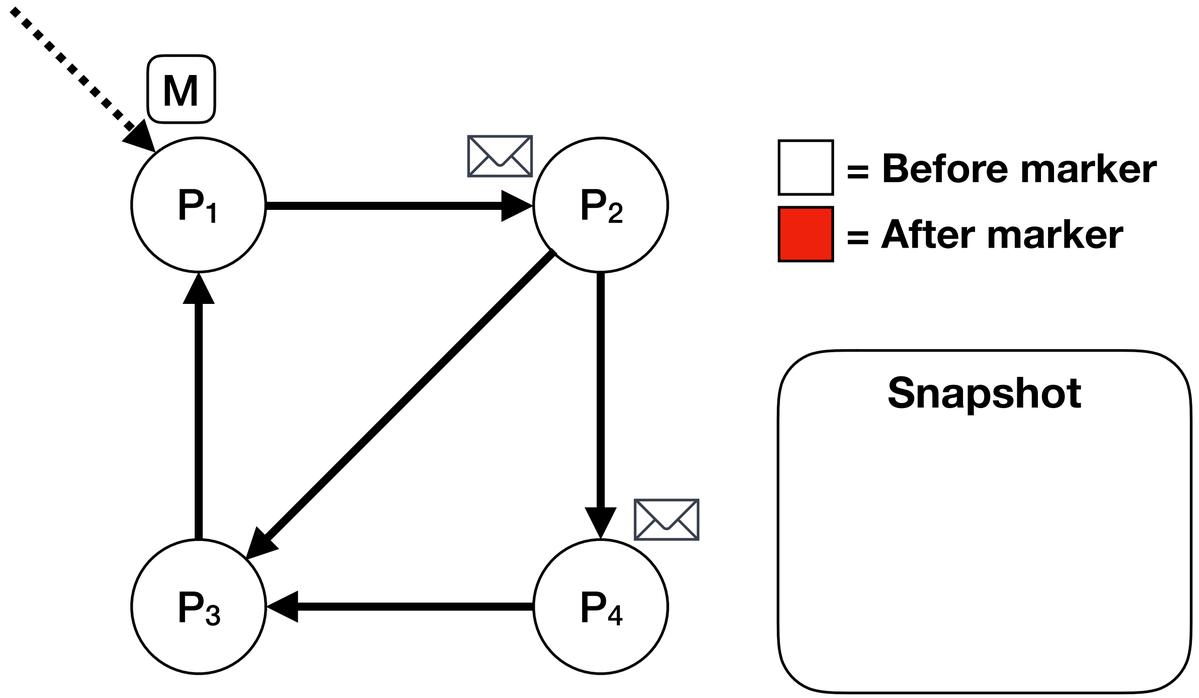

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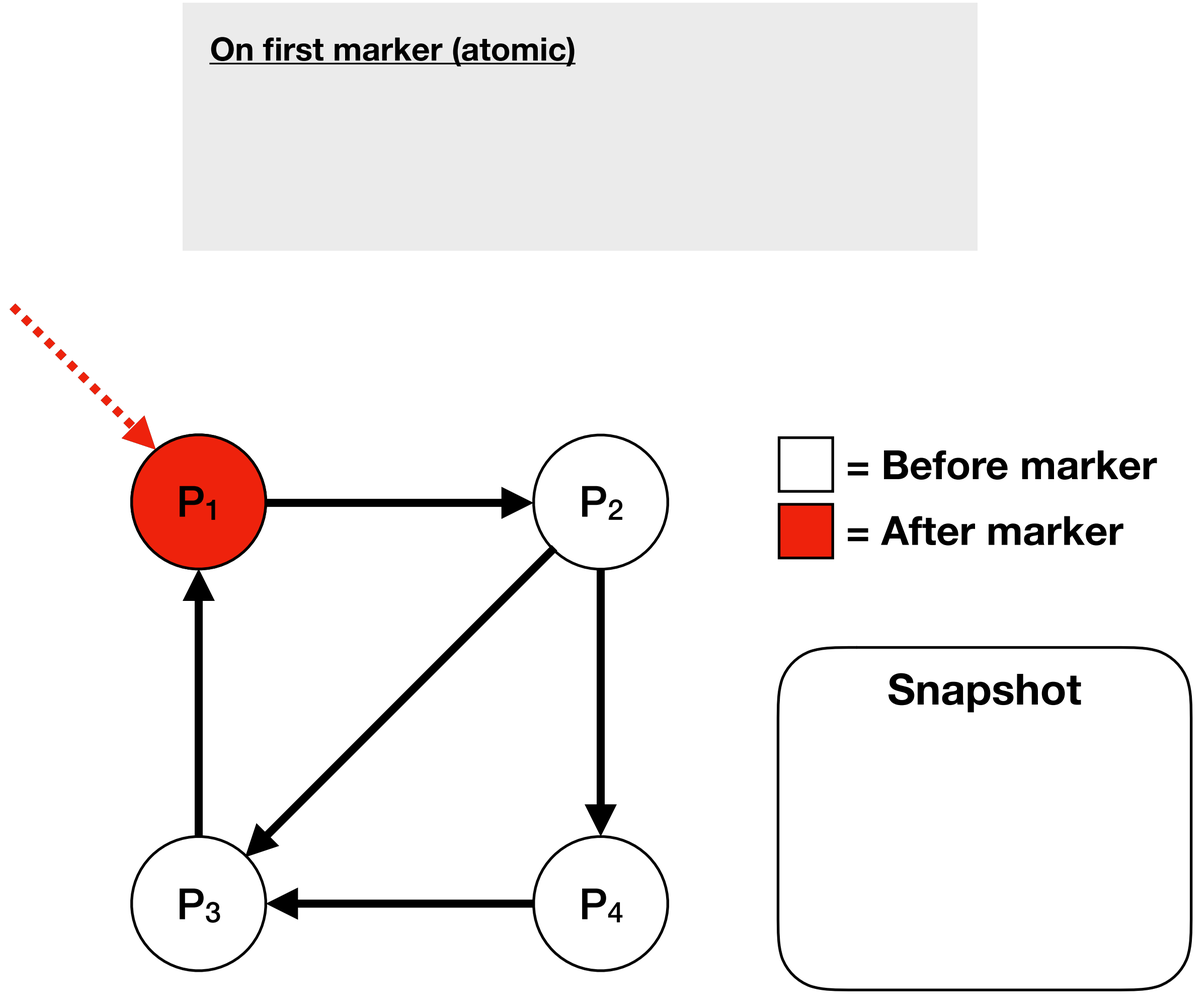

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On first marker (atomic)
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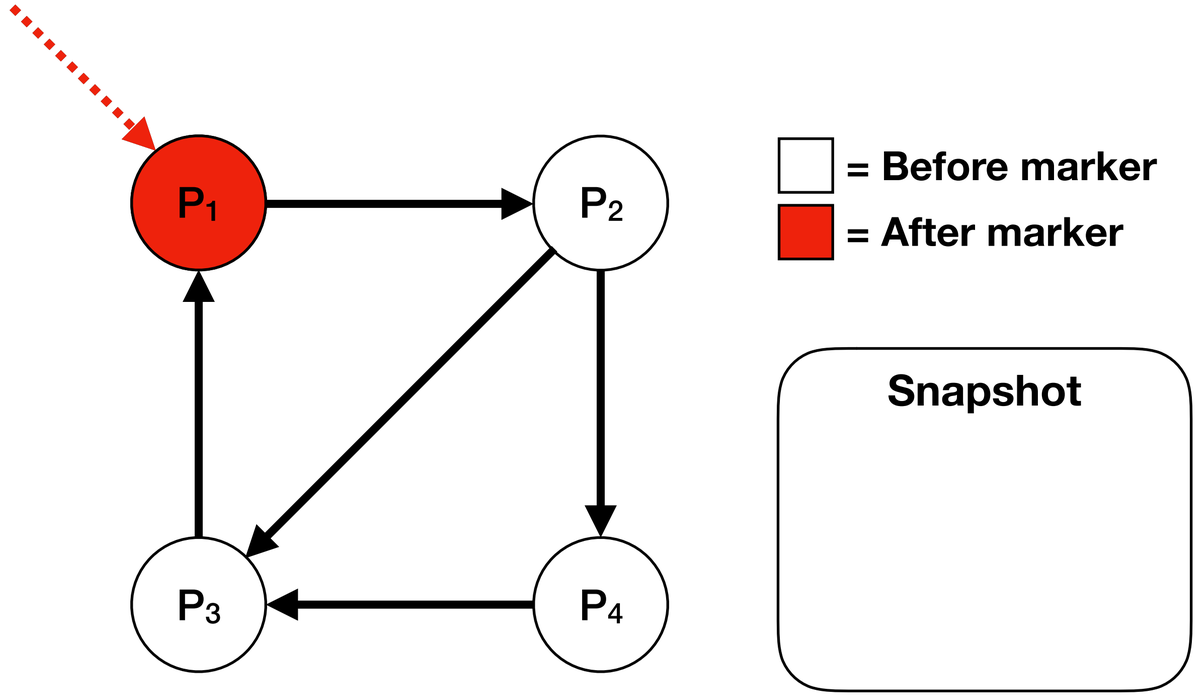

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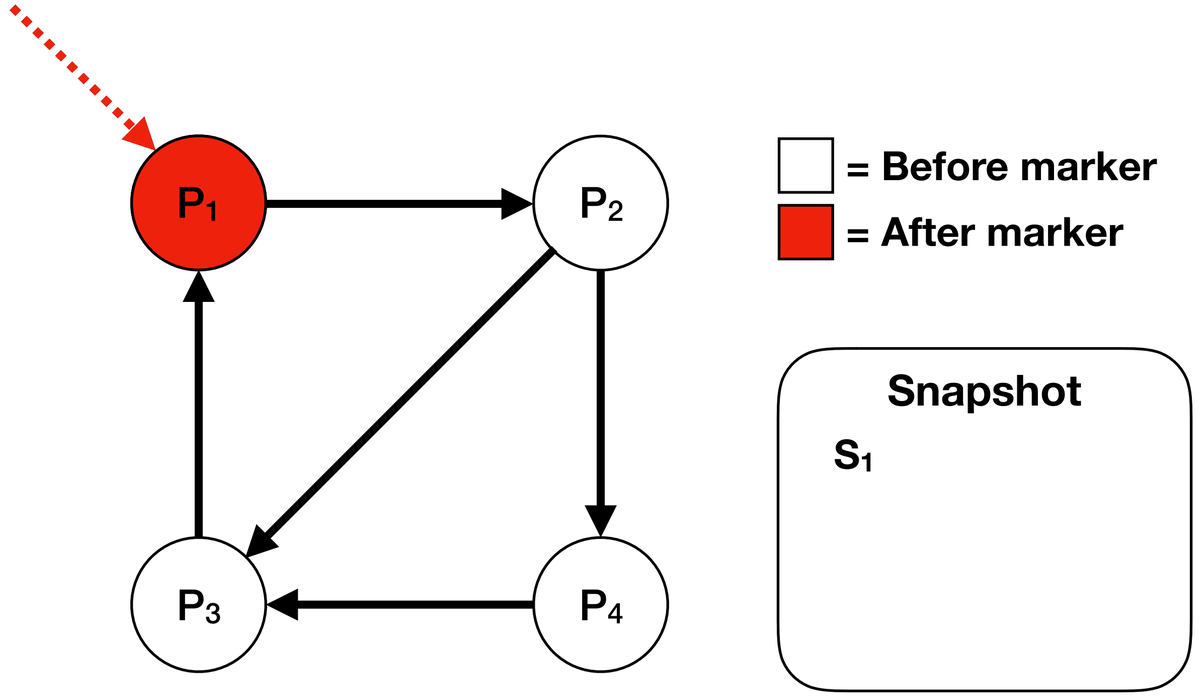

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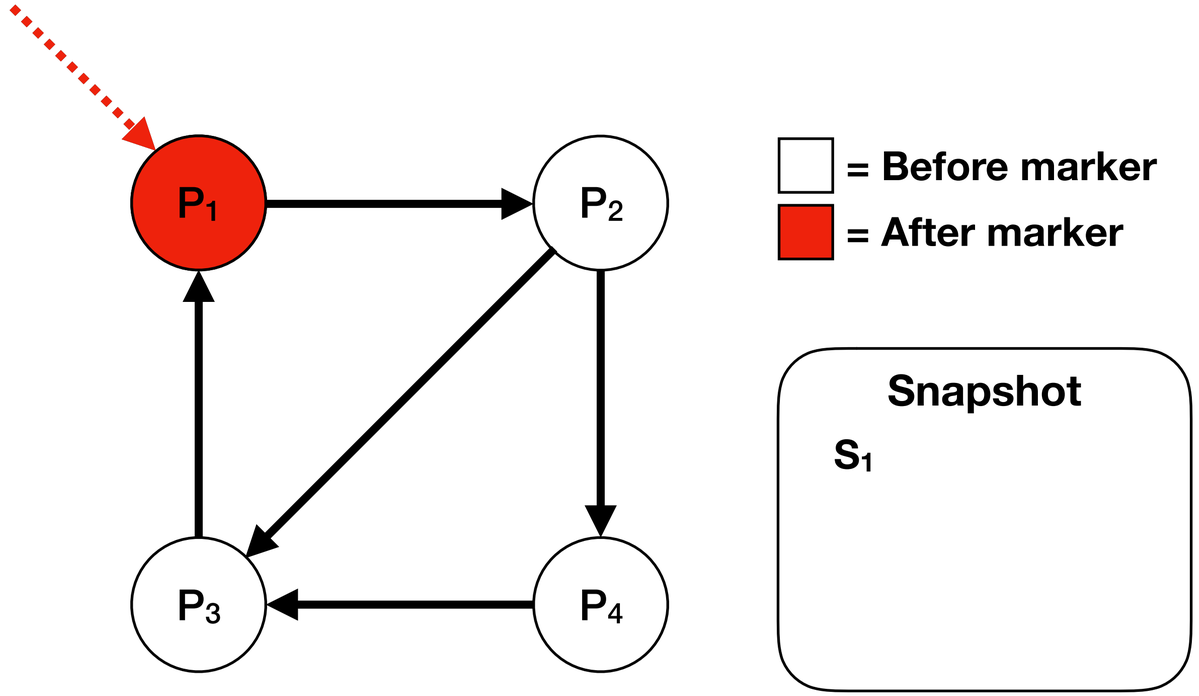

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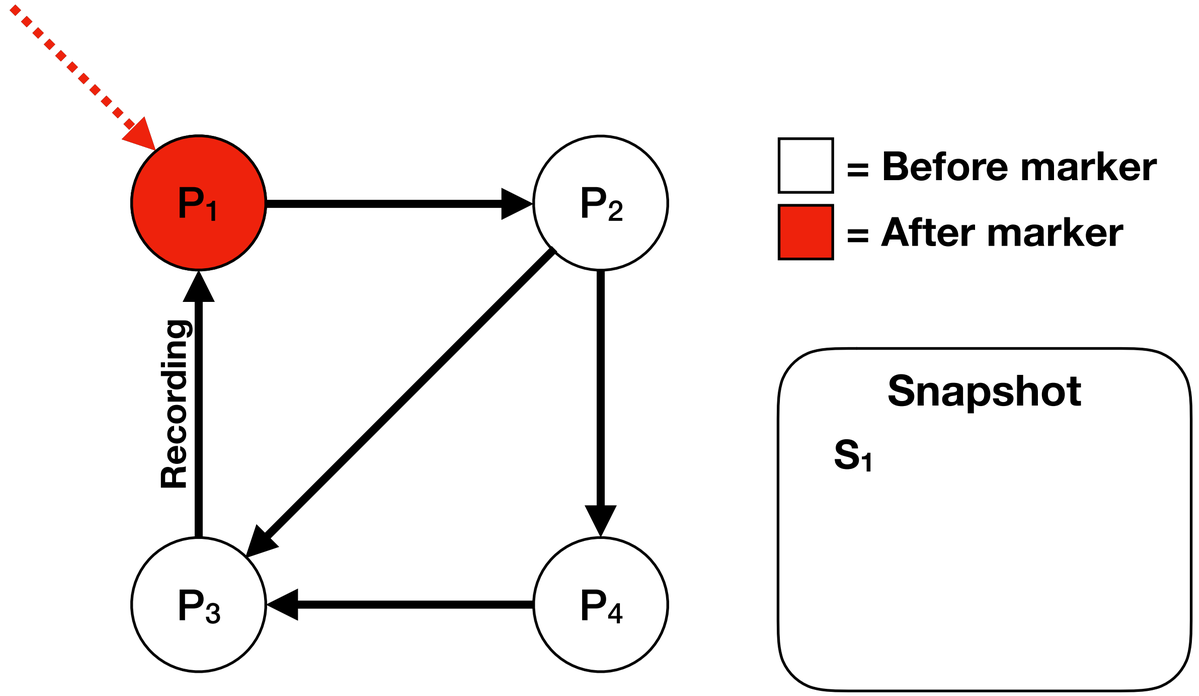

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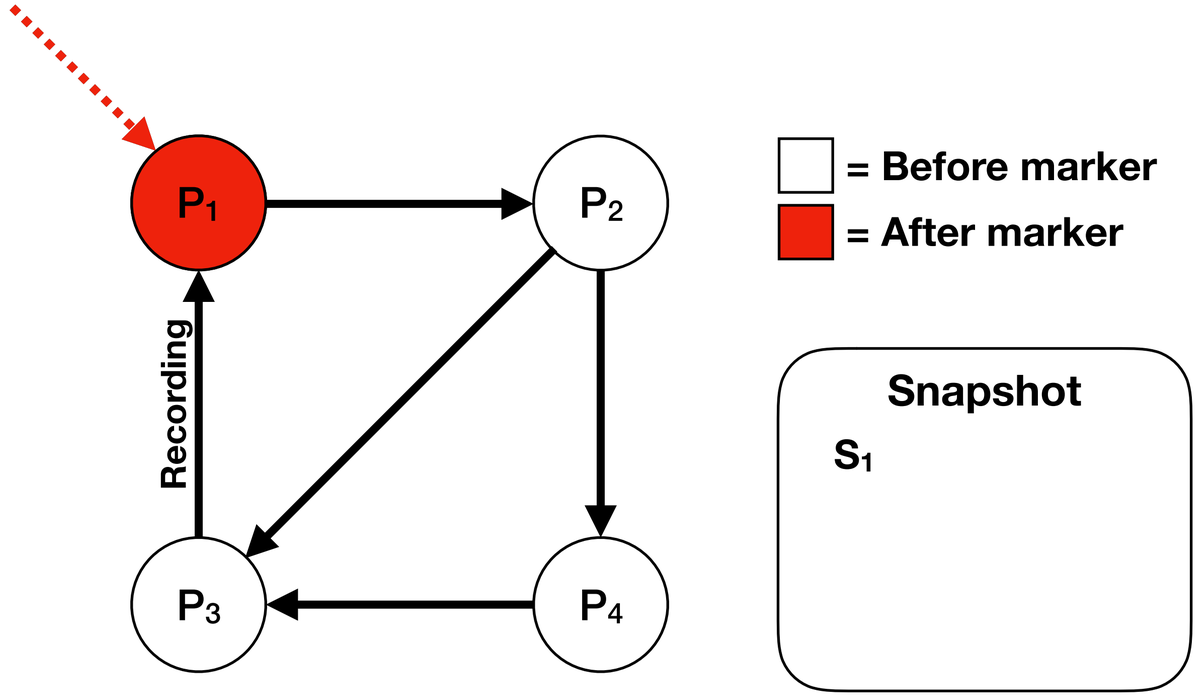
3. **Forward** marker



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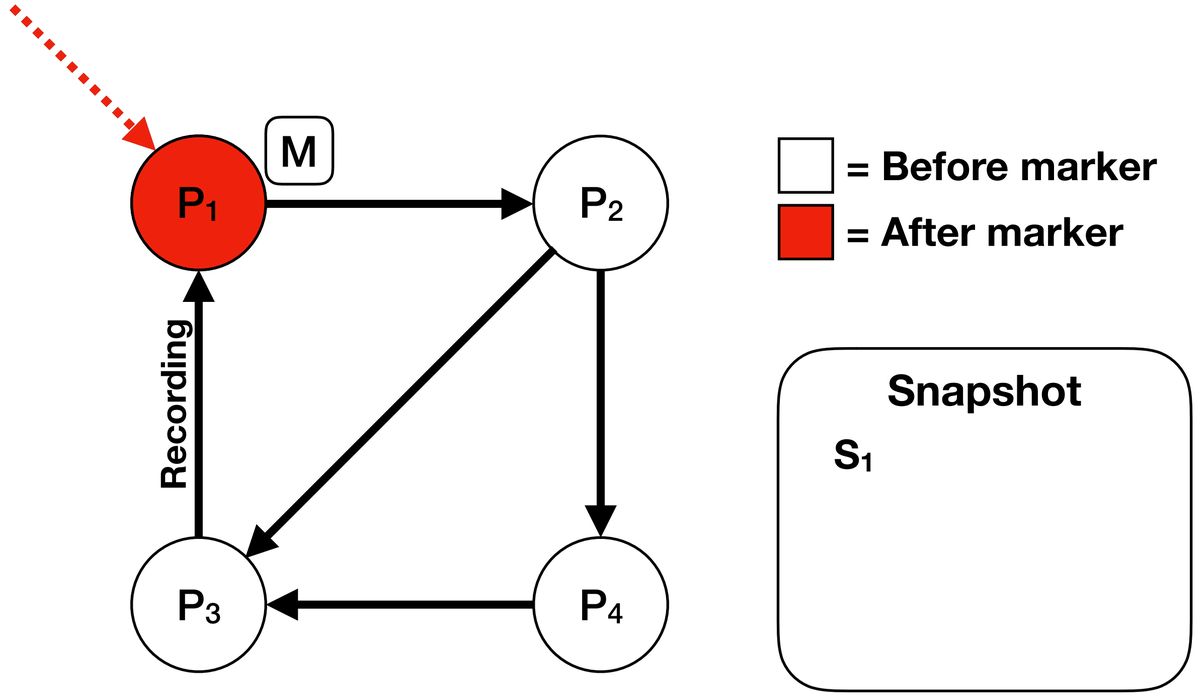

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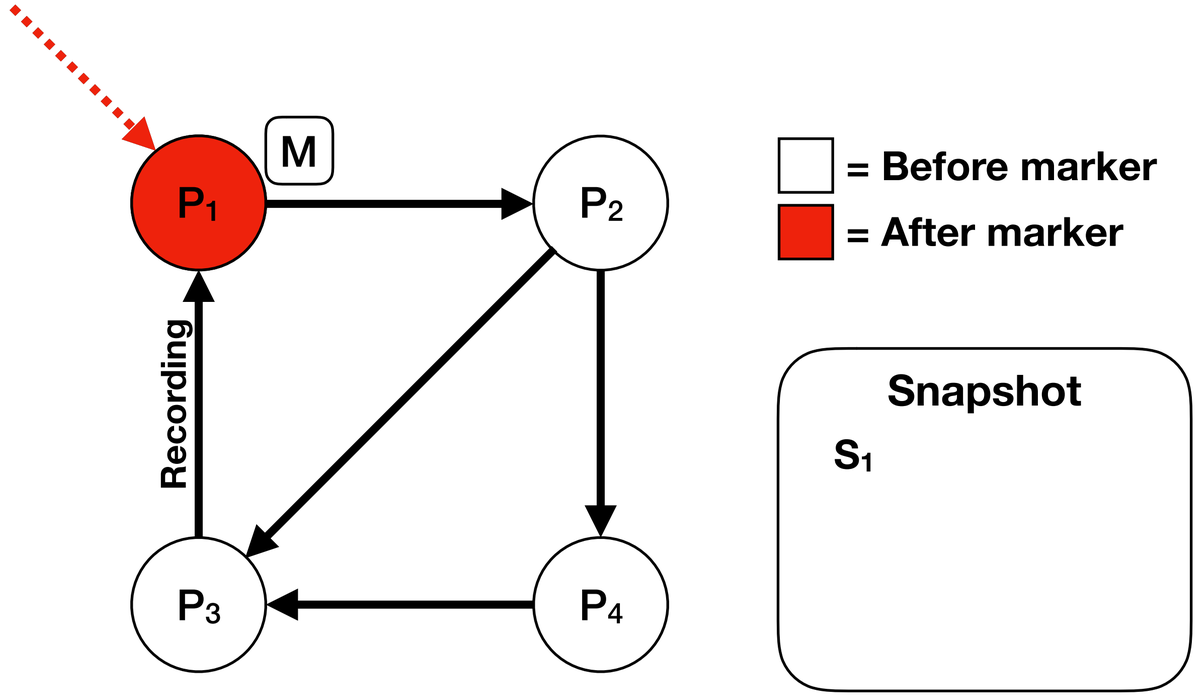

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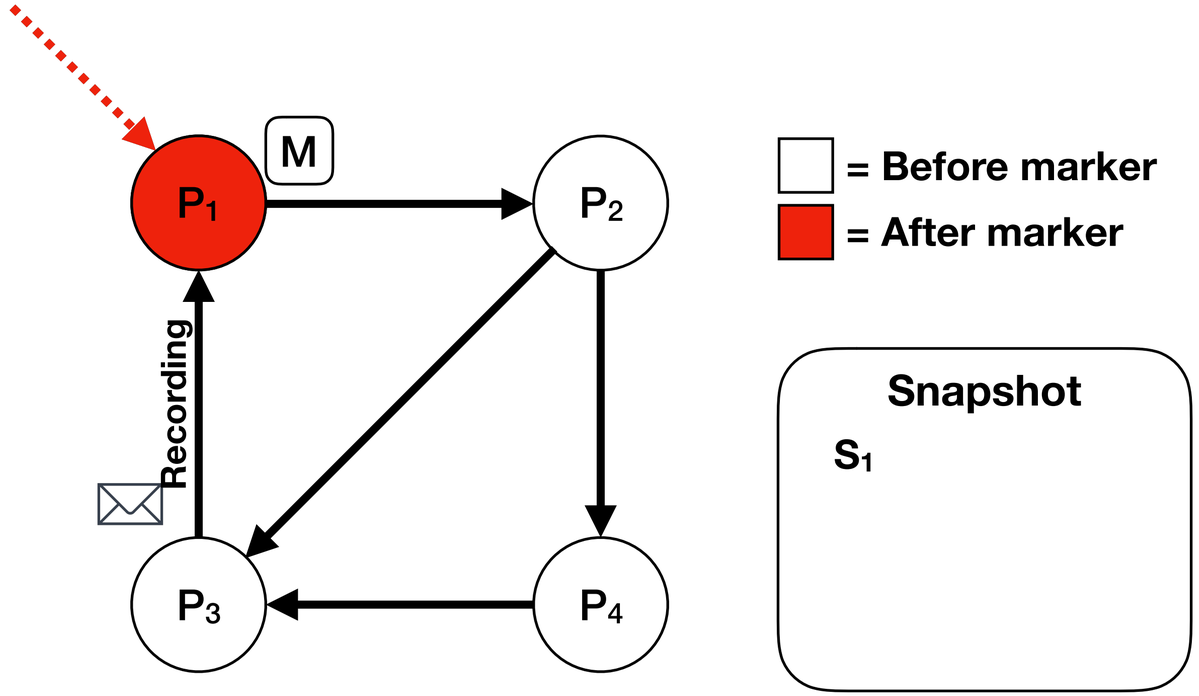

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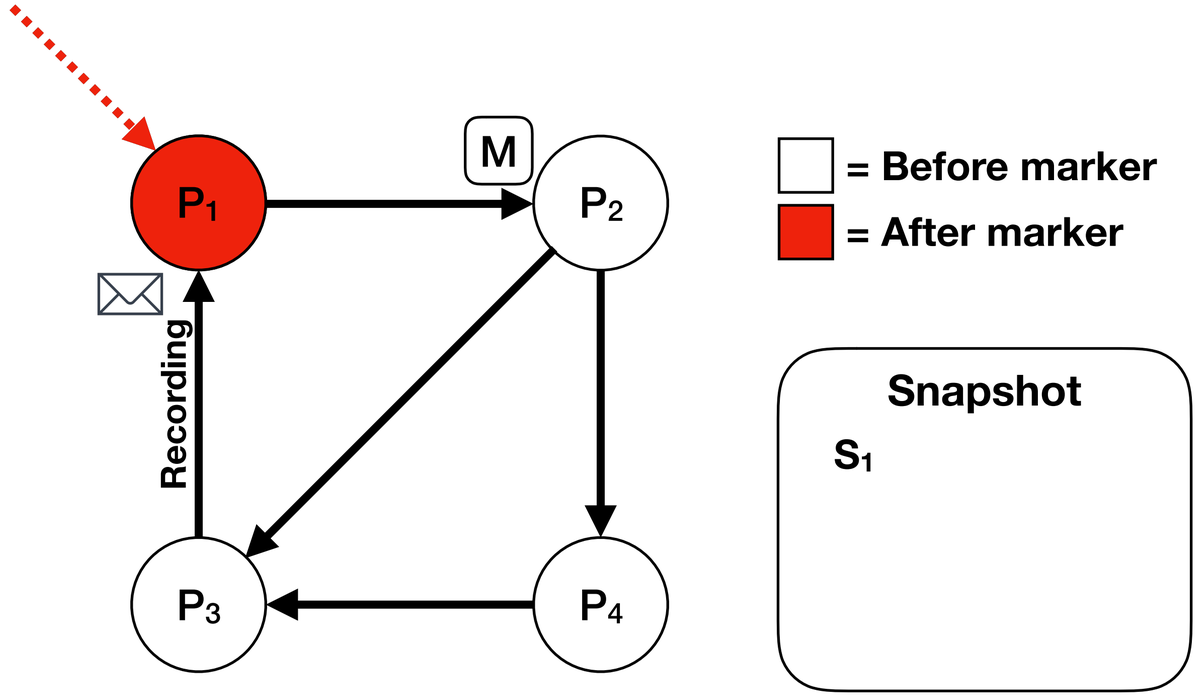

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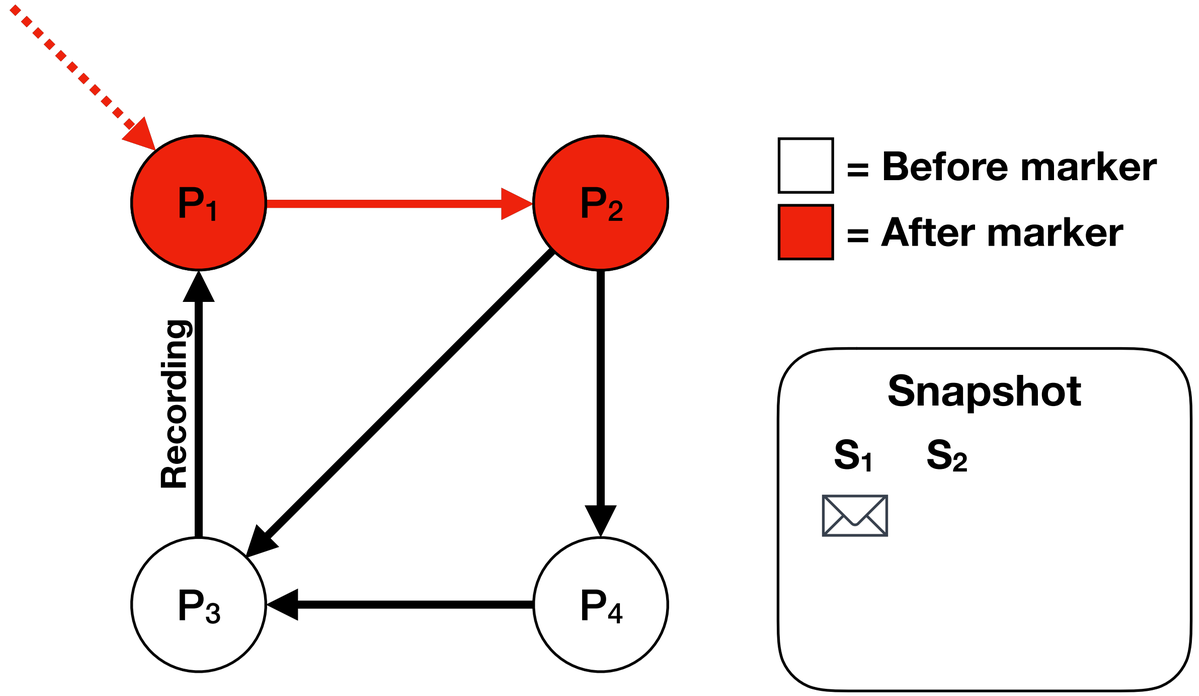

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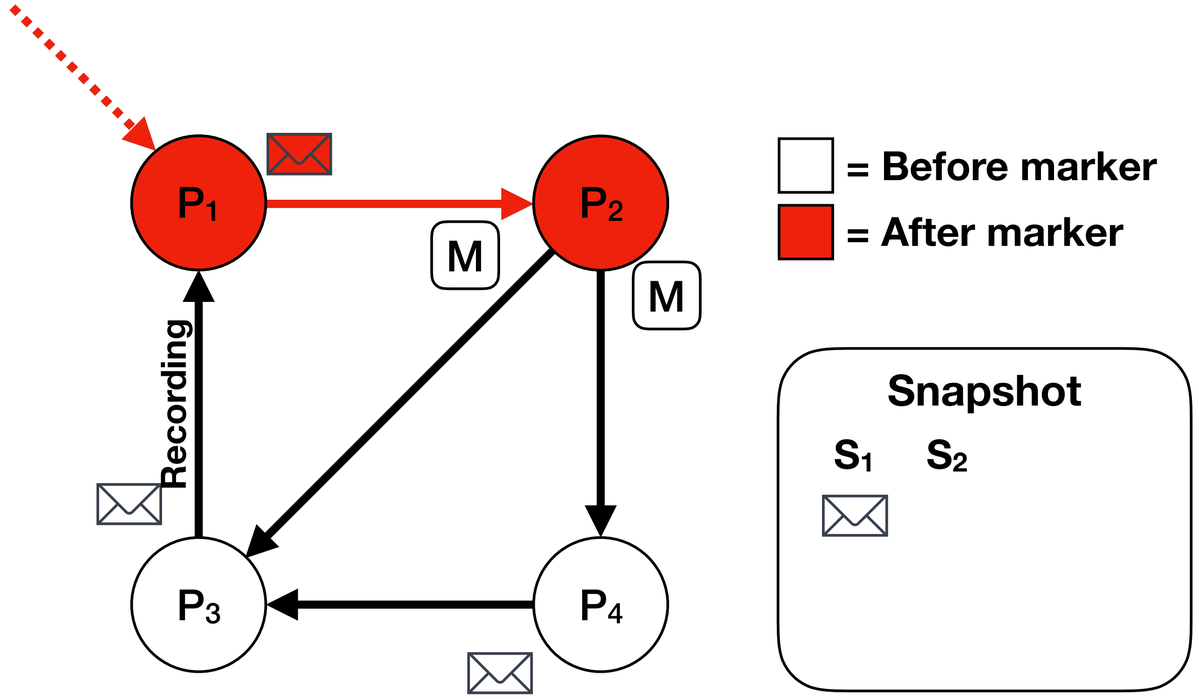

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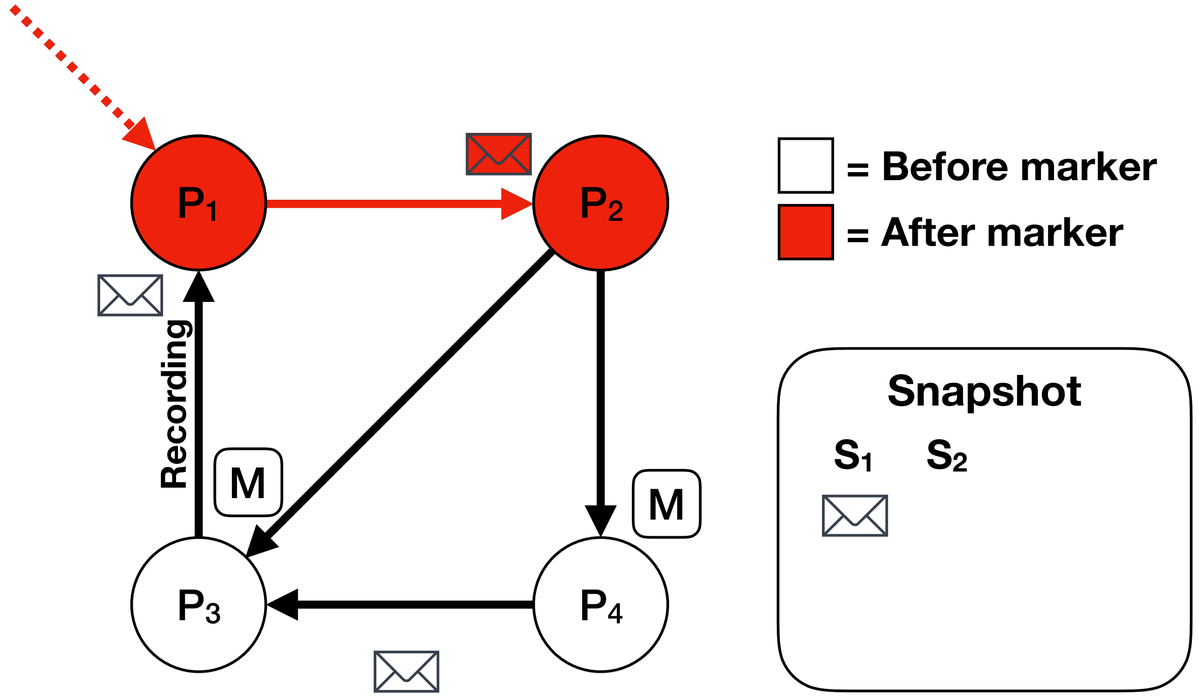

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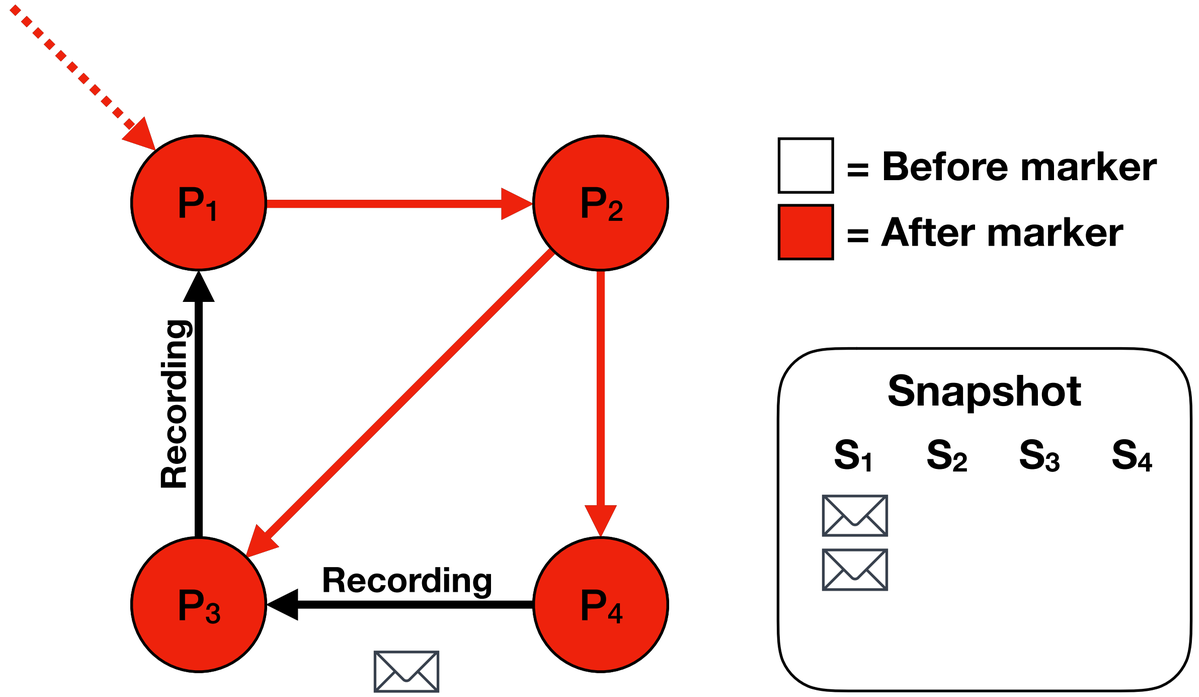

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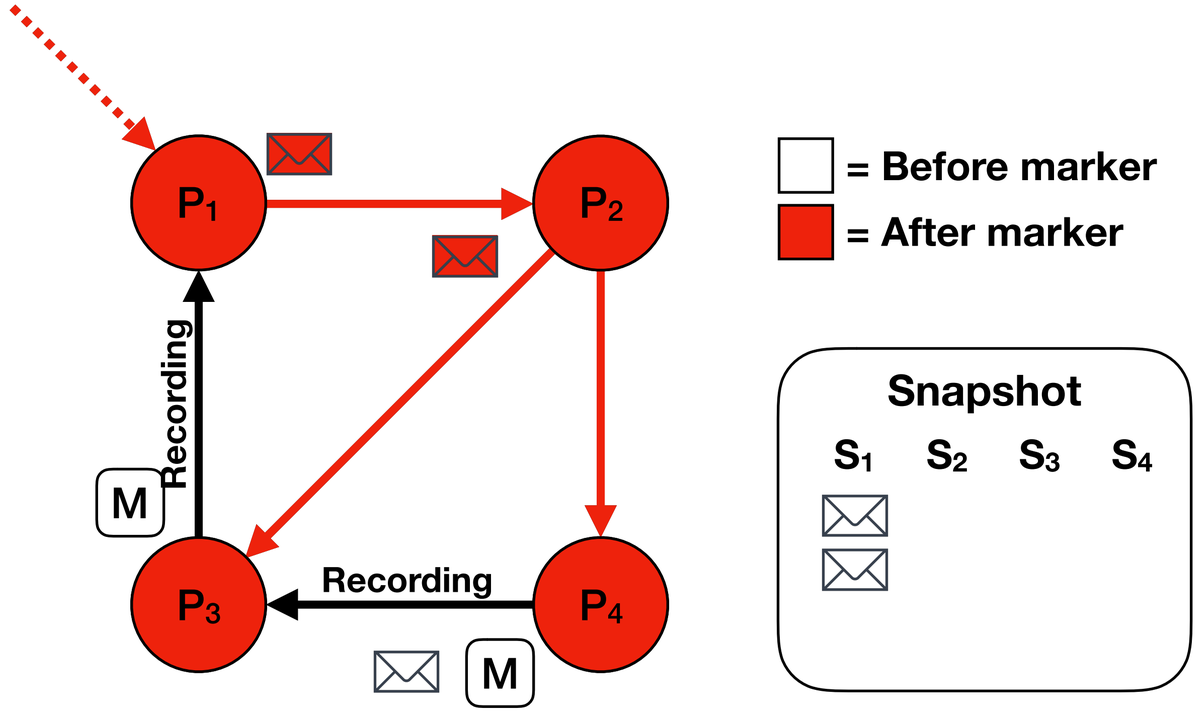

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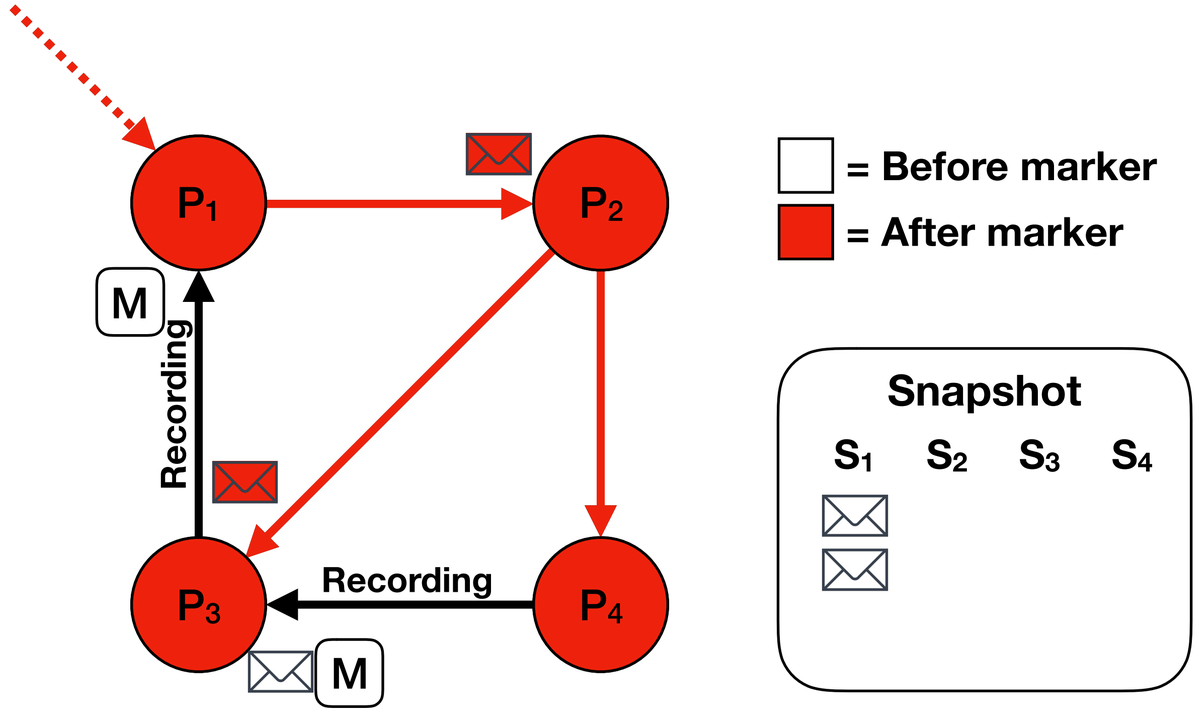

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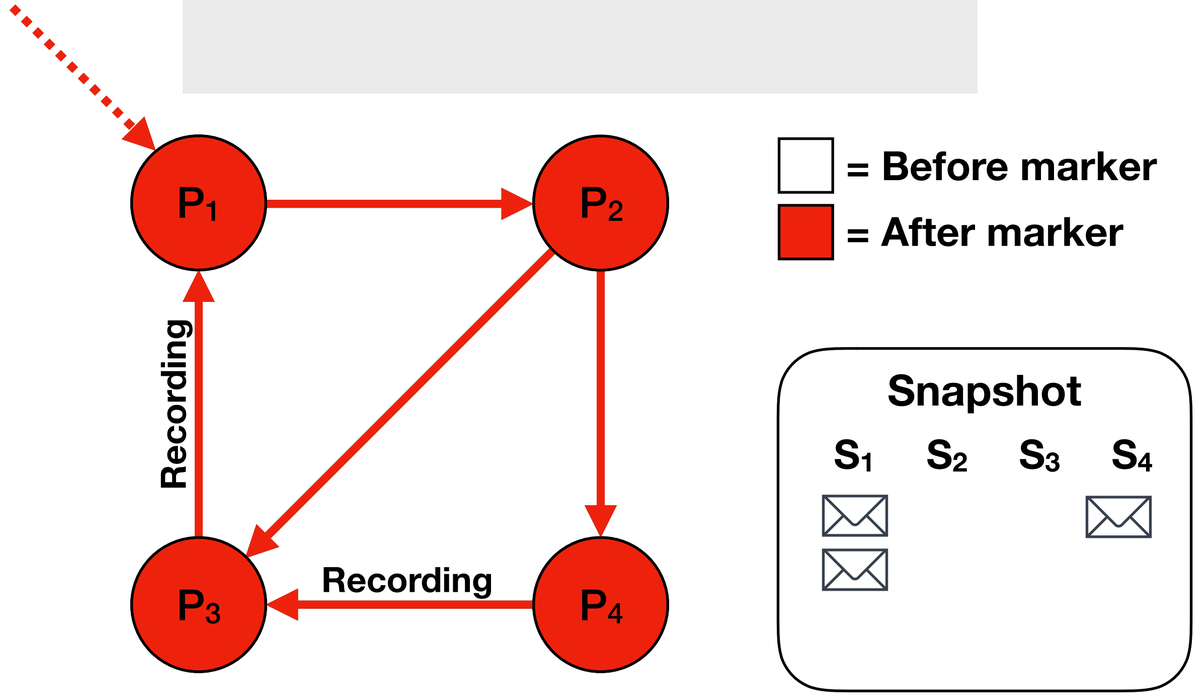

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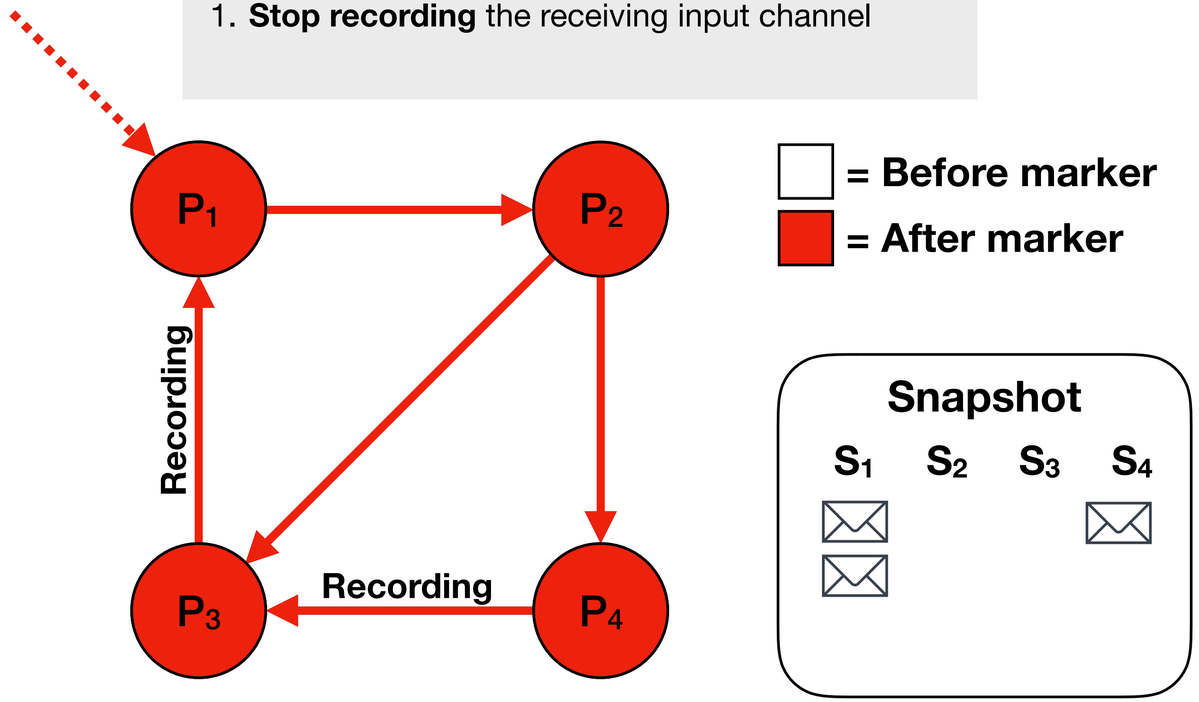

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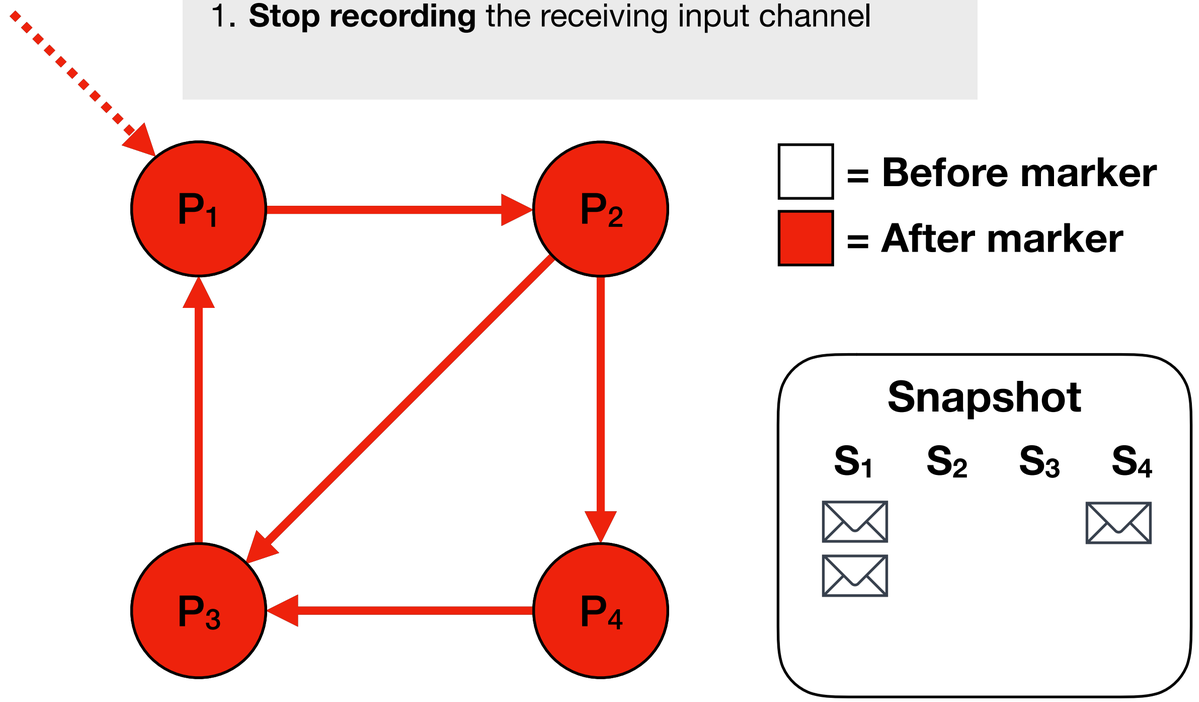

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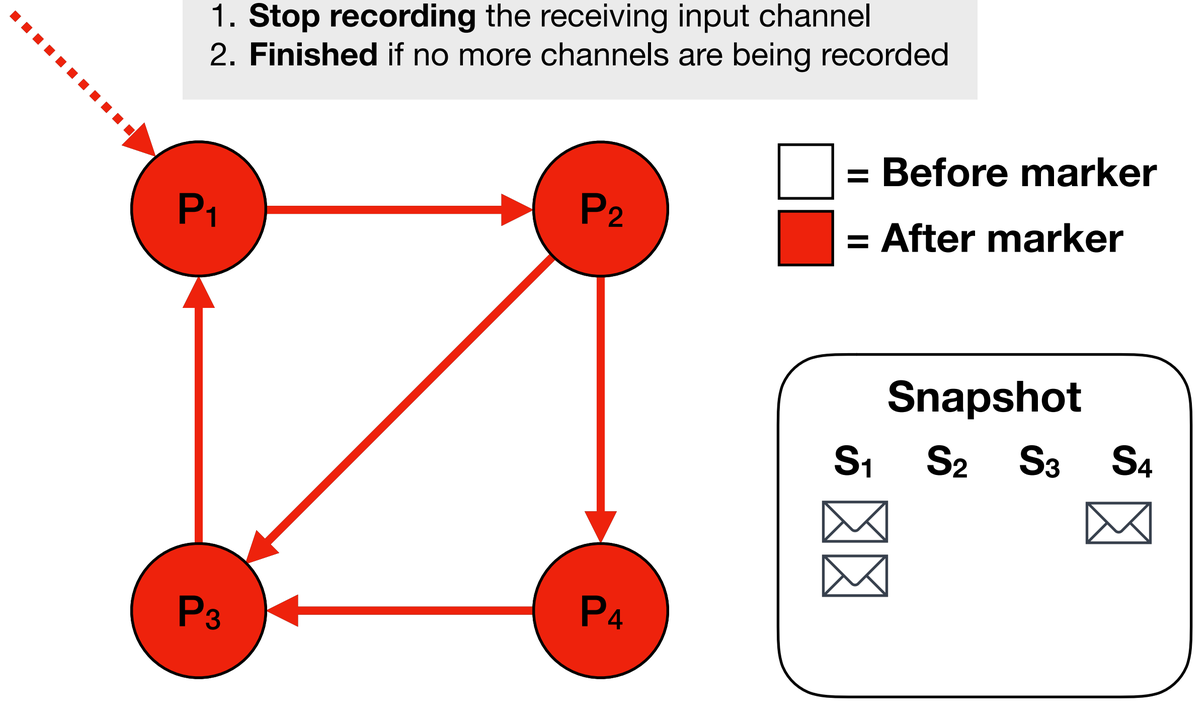

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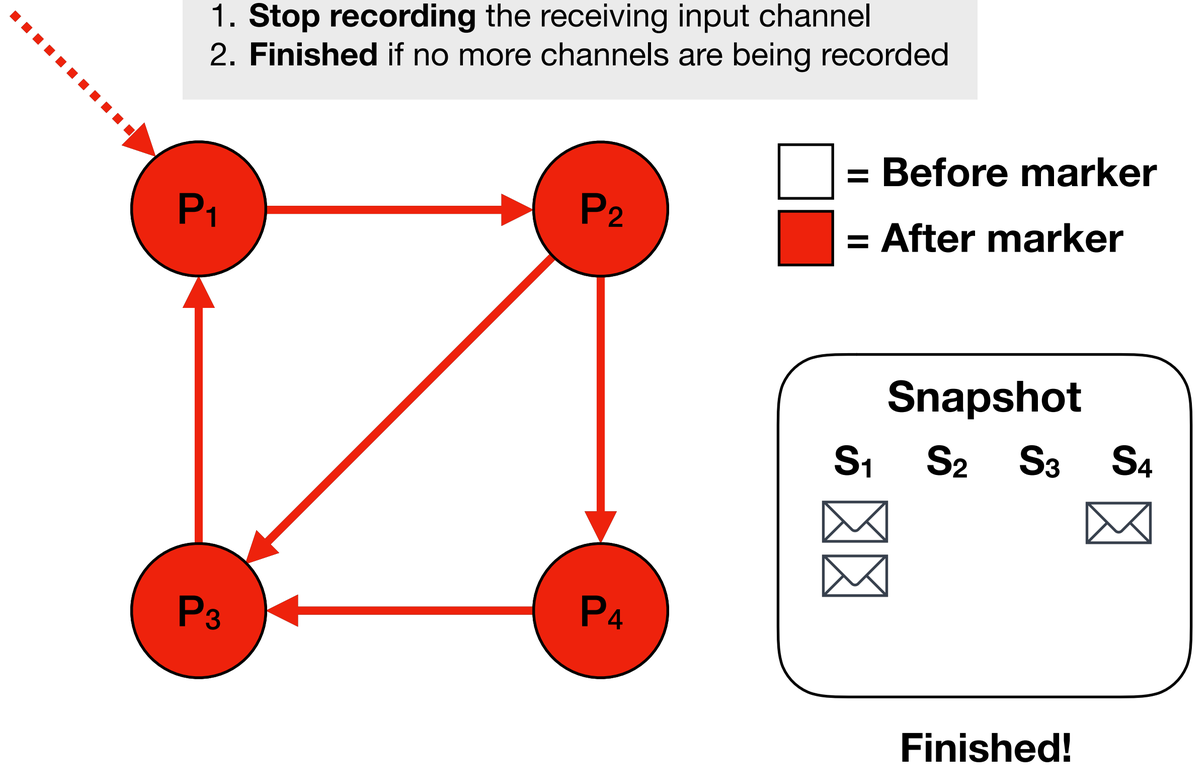

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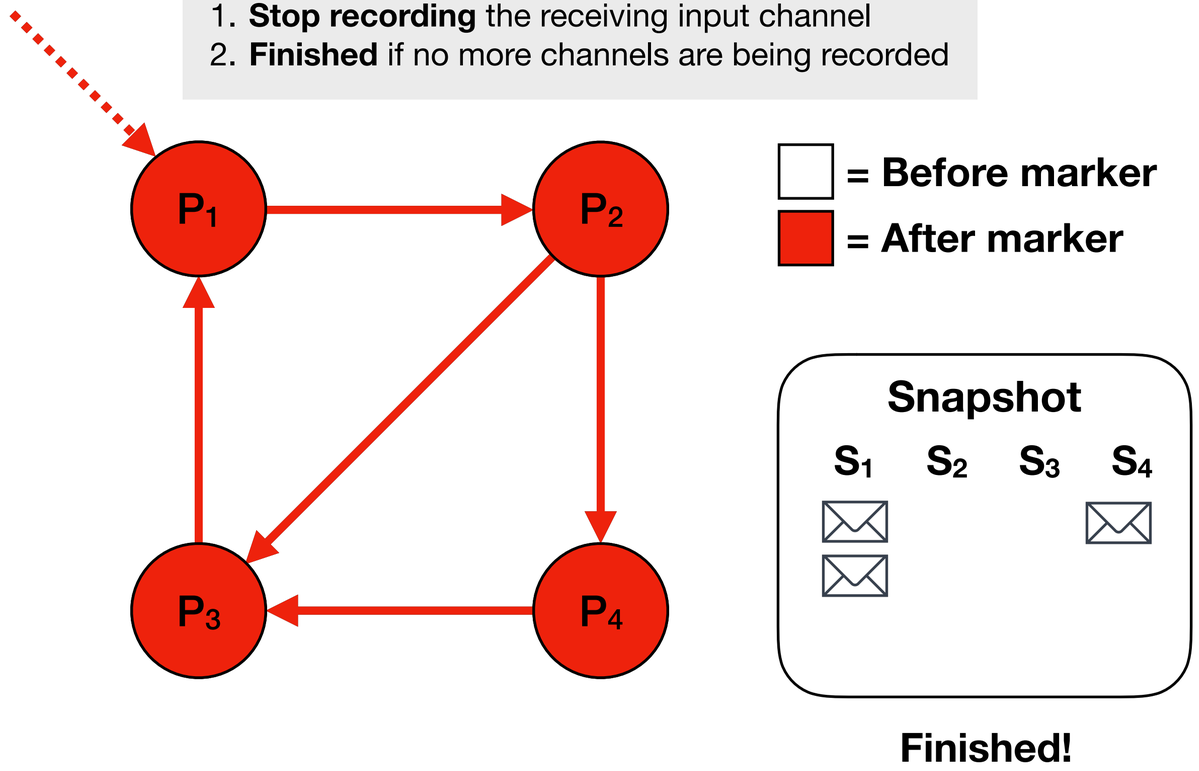

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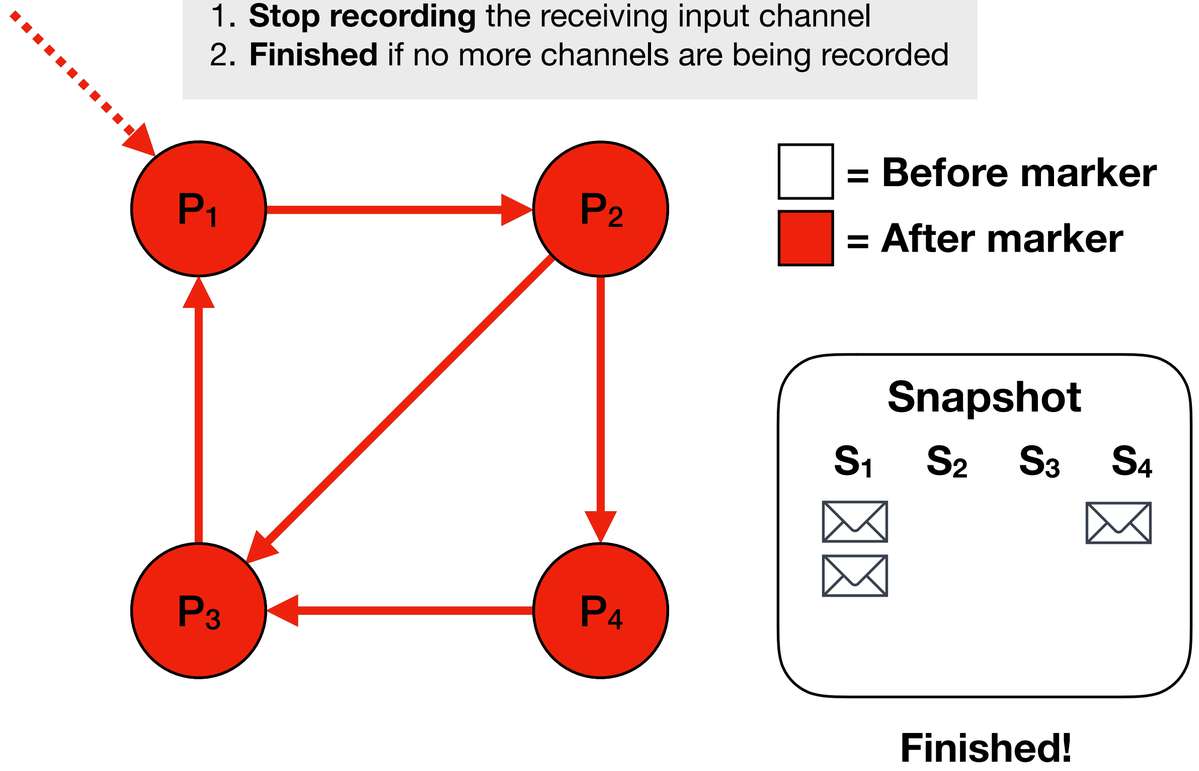

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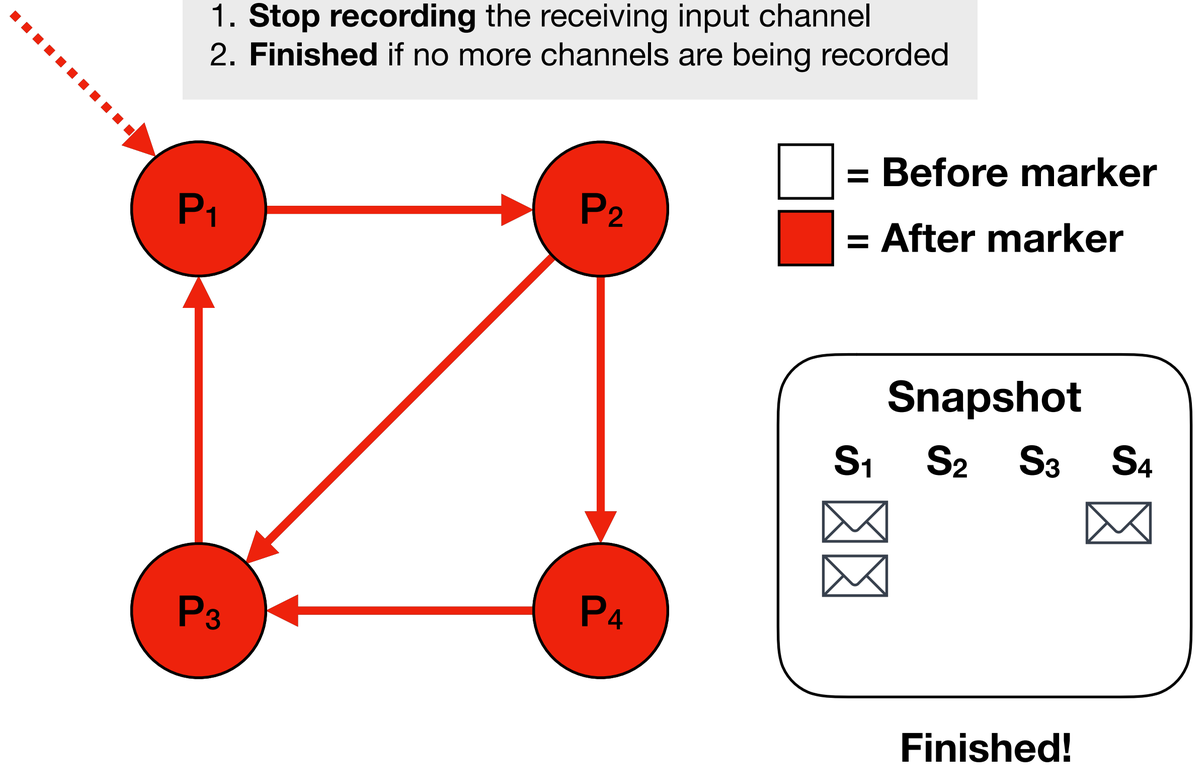

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Can the assumptions be modified to fit the stream-processing use-case?

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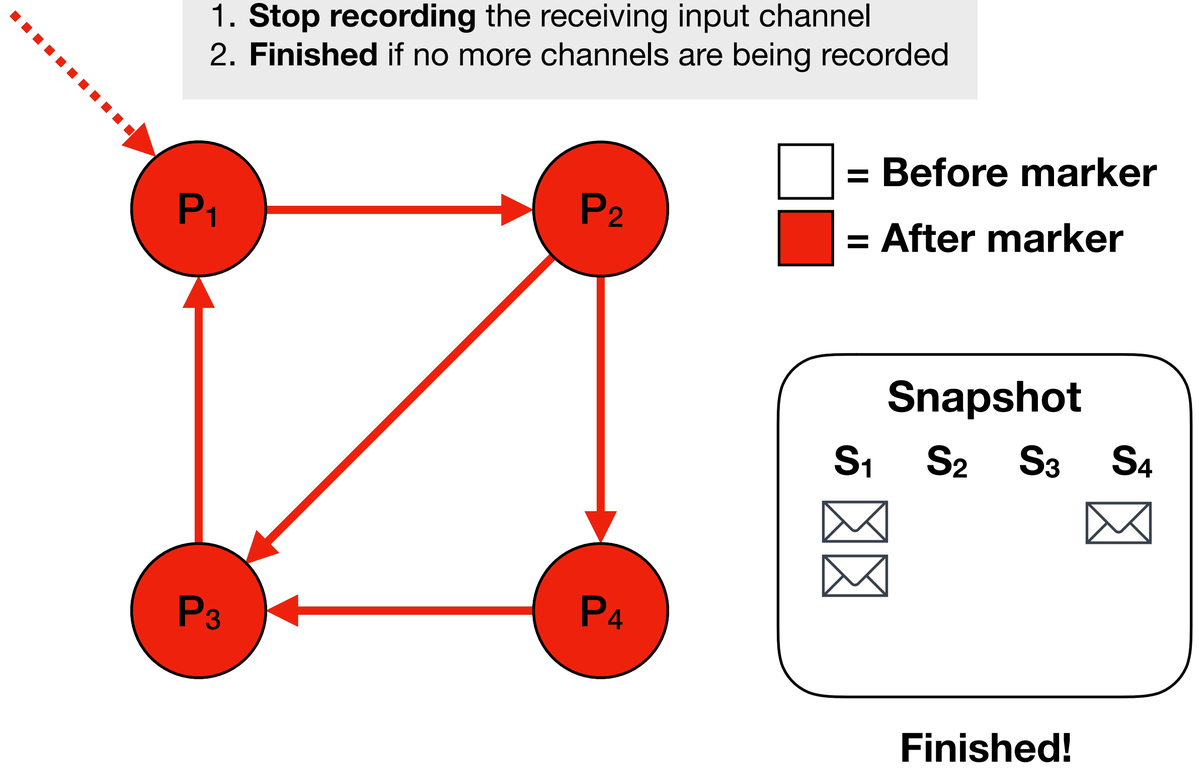

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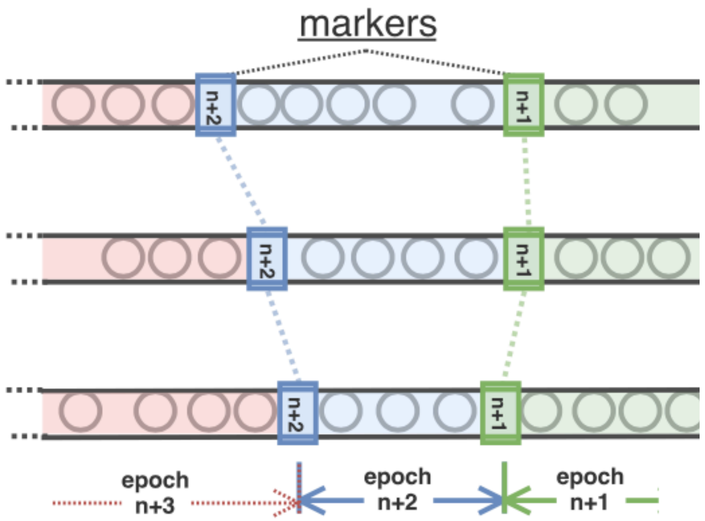
Begin snapshots by injecting **markers** at the **sources,** that cut the stream into **epochs**.



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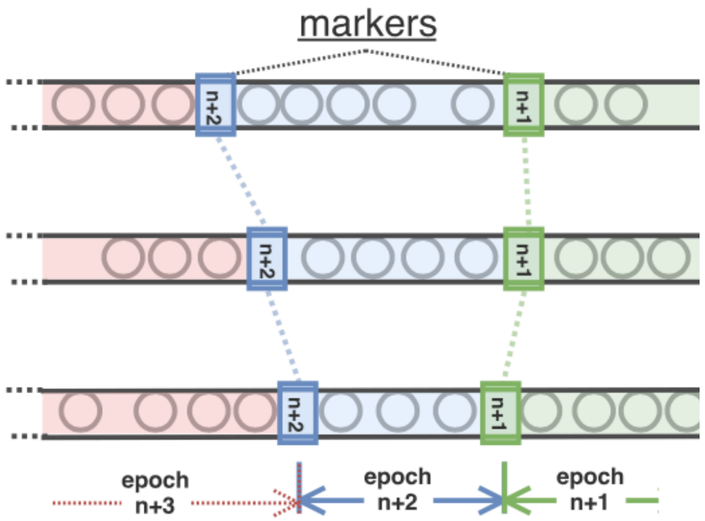

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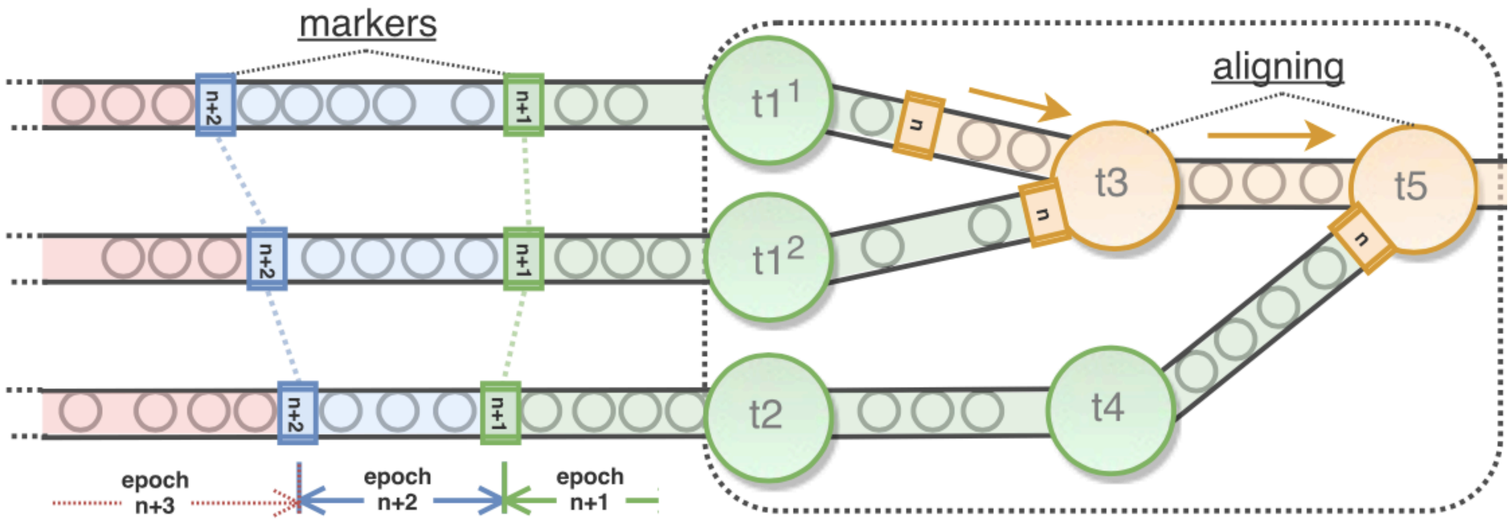

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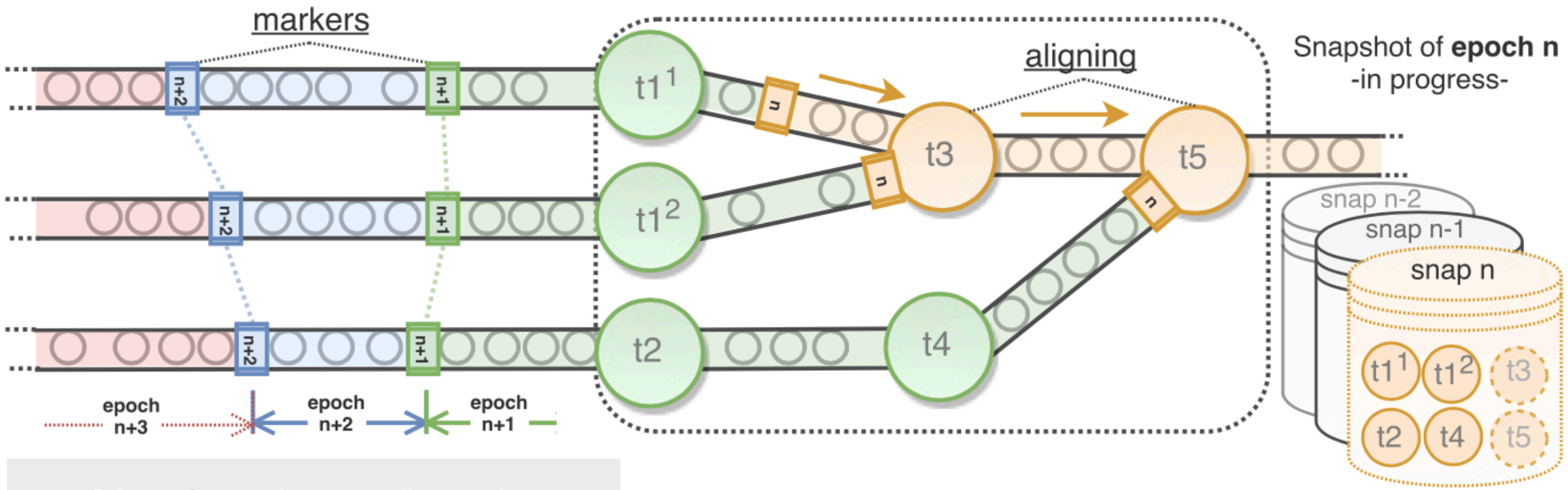

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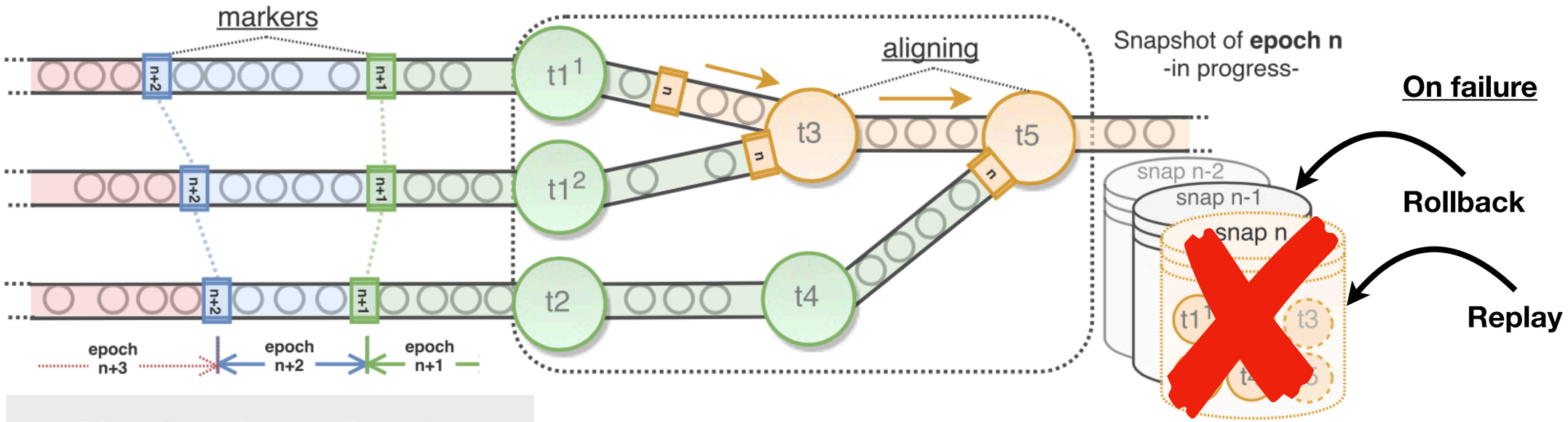

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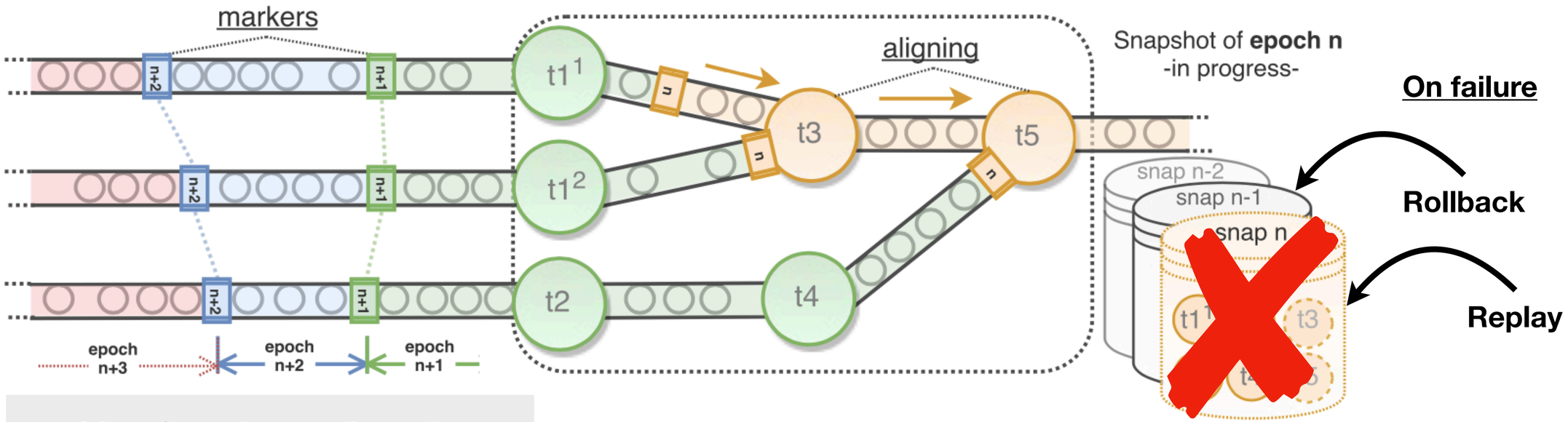

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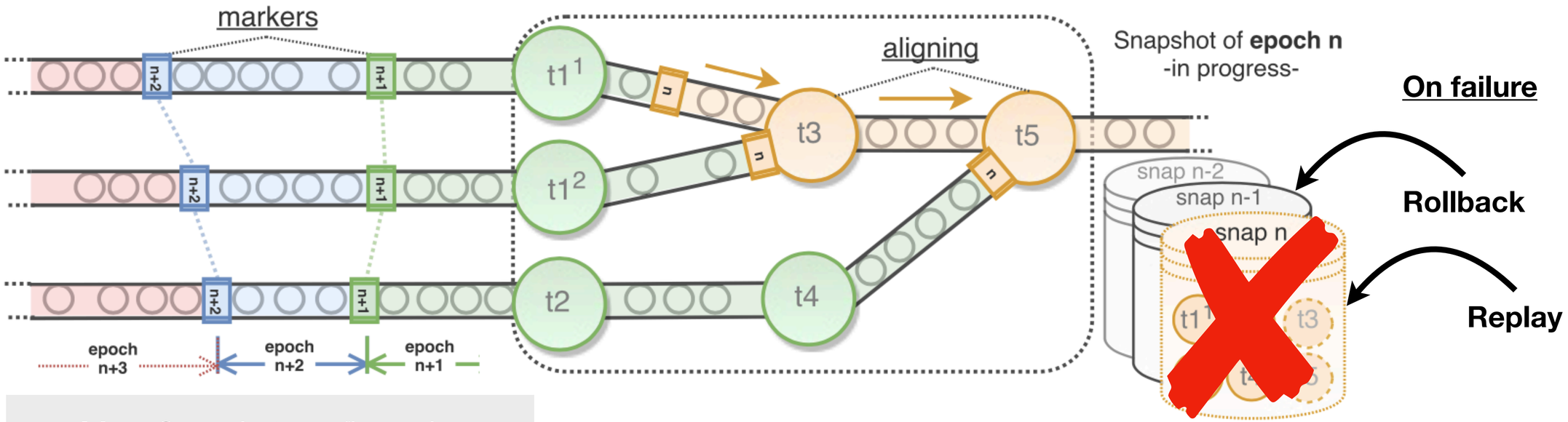

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Exactly-once delivery:
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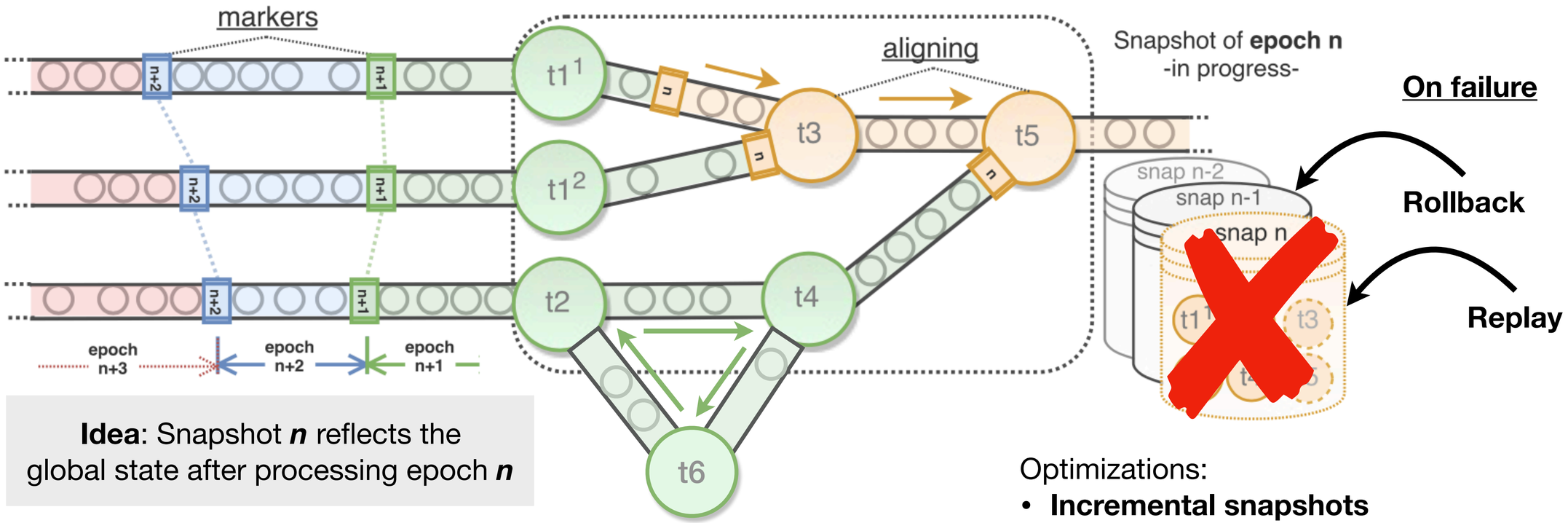

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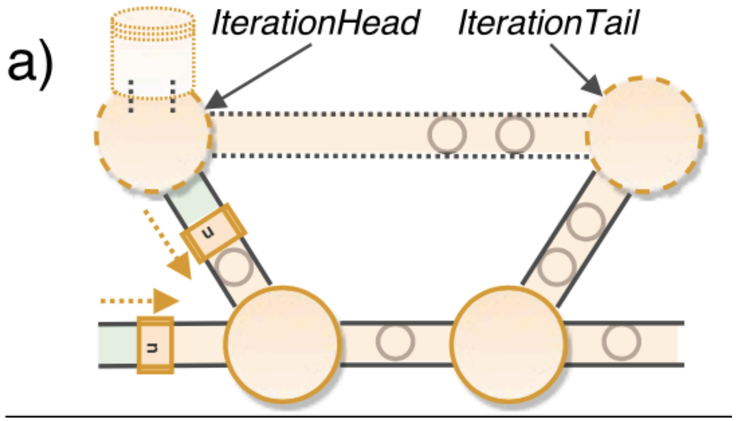
What about cyclic graphs?

Optimizations:
- **Incremental snapshots**
- **Asynchronous compactions**

Exactly-once delivery:
- **Idempotent sinks**
- **Transactional sinks**

Flink - Distributed Snapshots

1. When cycles are present,
Flink falls back to **Chandy Lamport**



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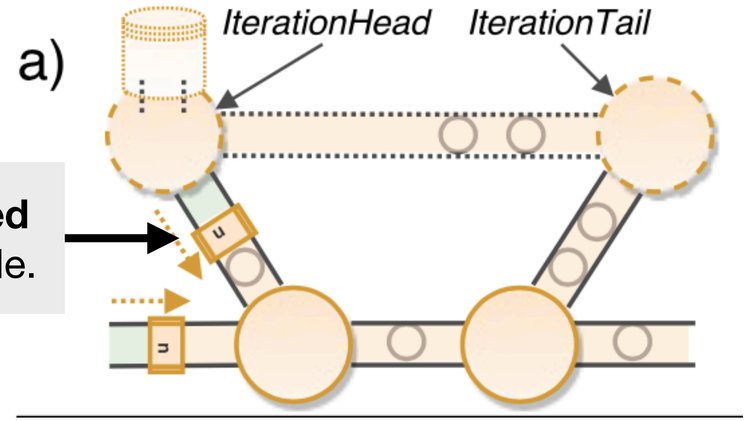

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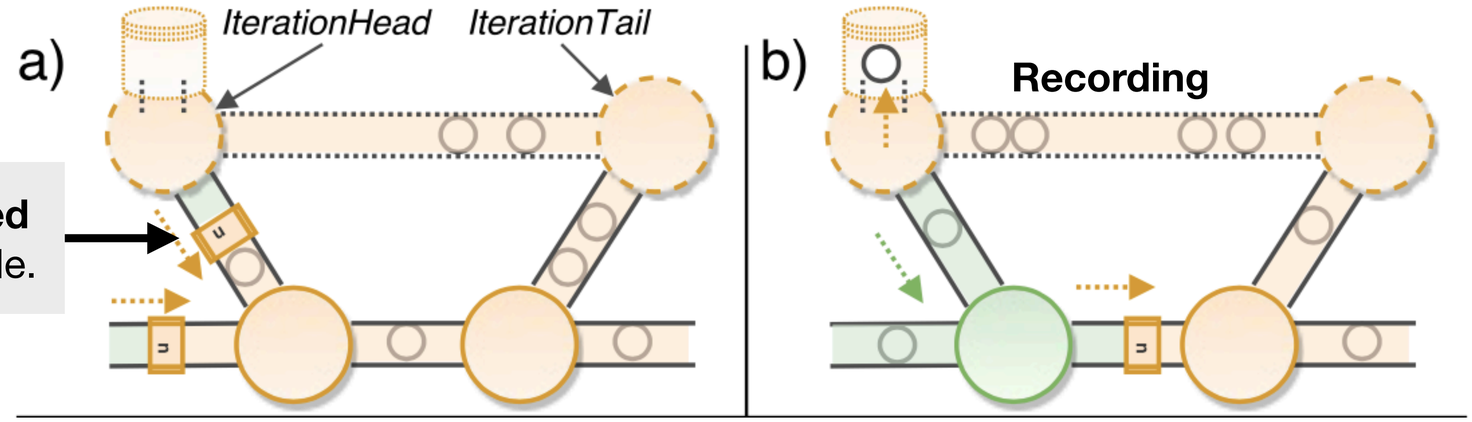

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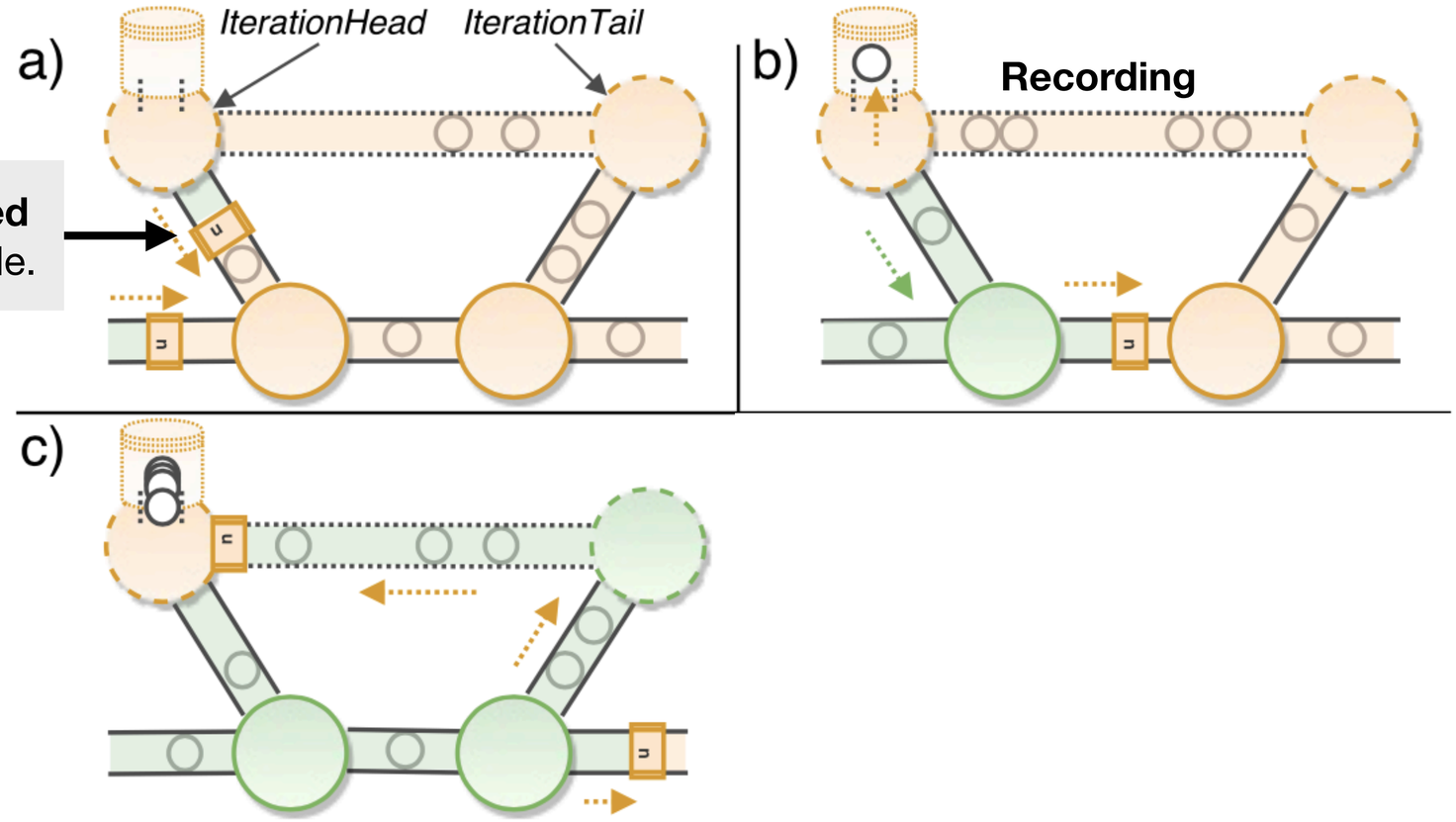

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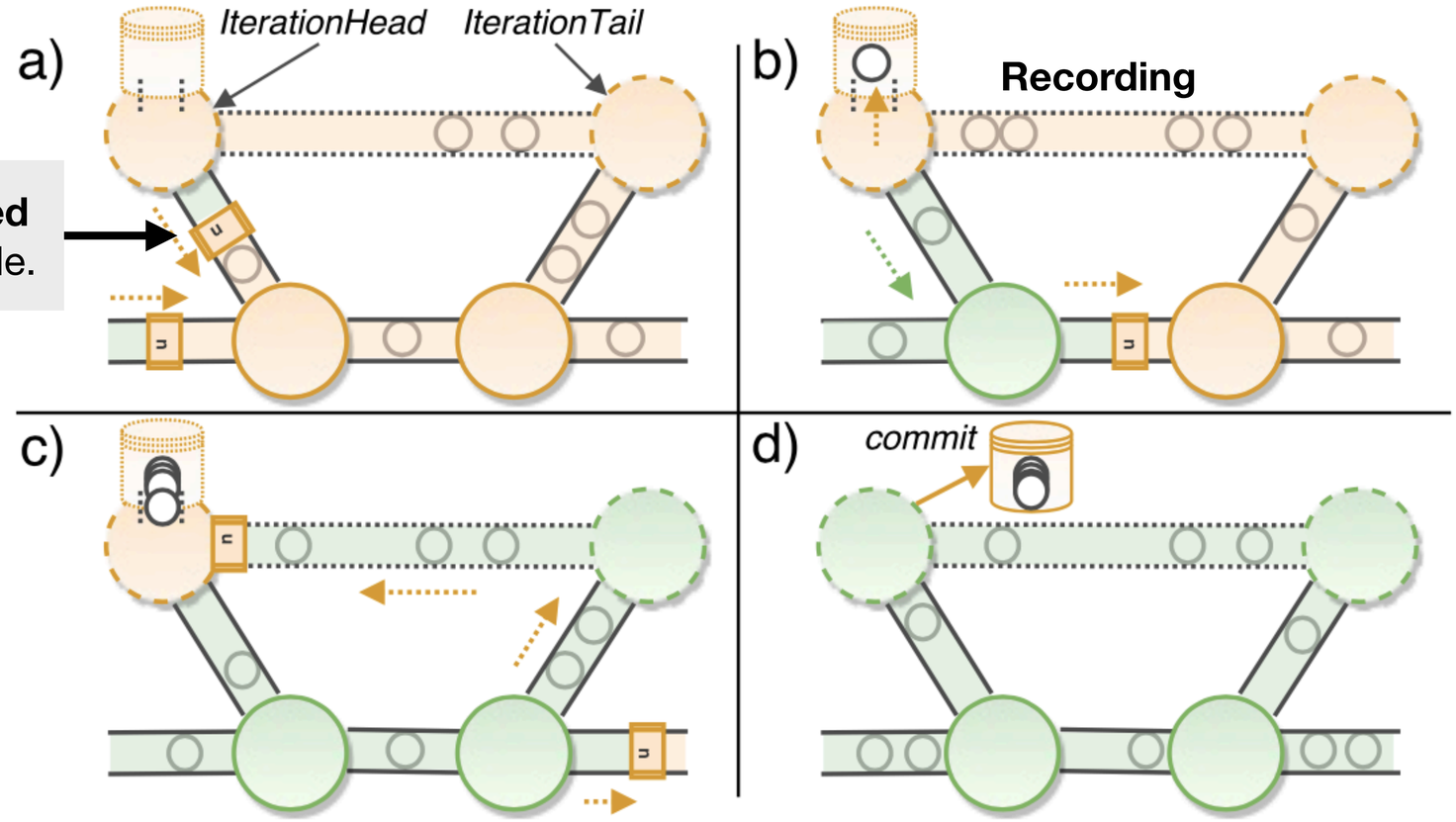

Flink - Discussion

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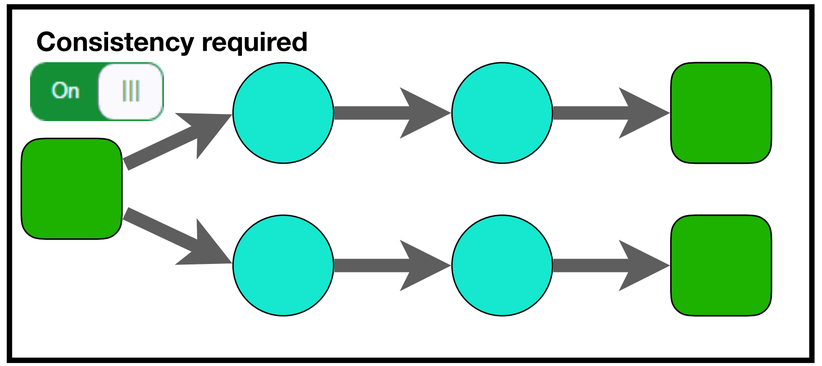
Q: What affects the **alignment time**?

A: The **number of input channels** (determined by shuffles & data parallelism).

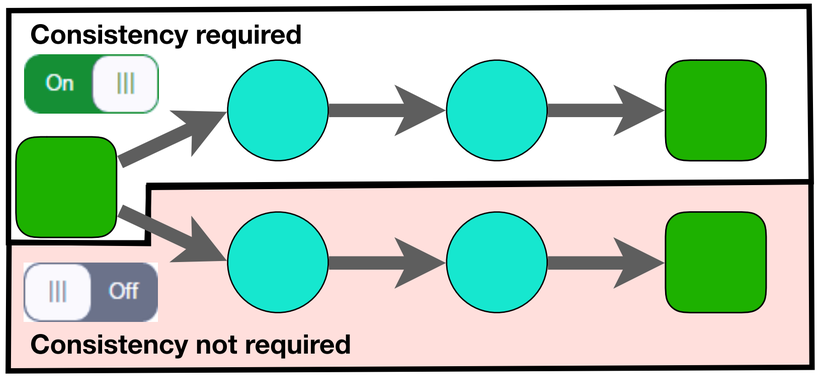
IBM-Streams

IBM-Streams - Problem statement

Apache Flink



IBM Streams



IBM-Streams - Problem statement

- Snapshots impose overhead

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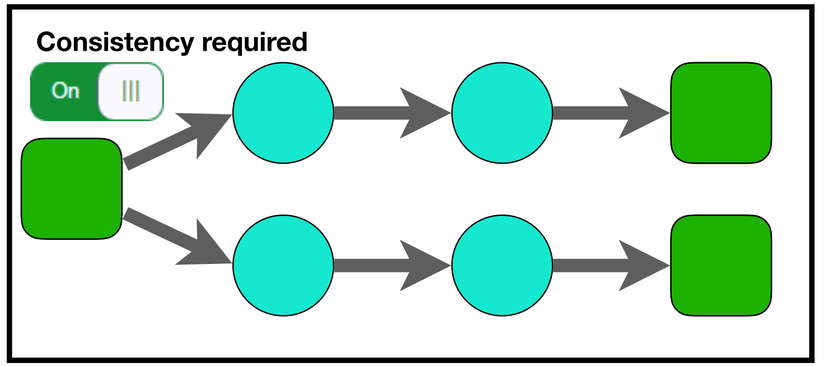

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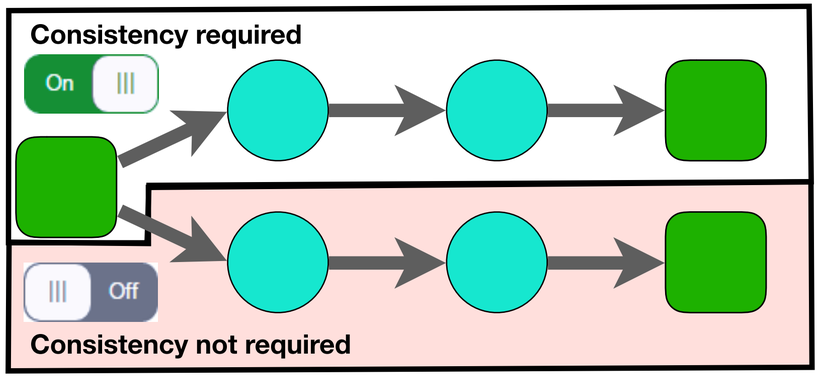

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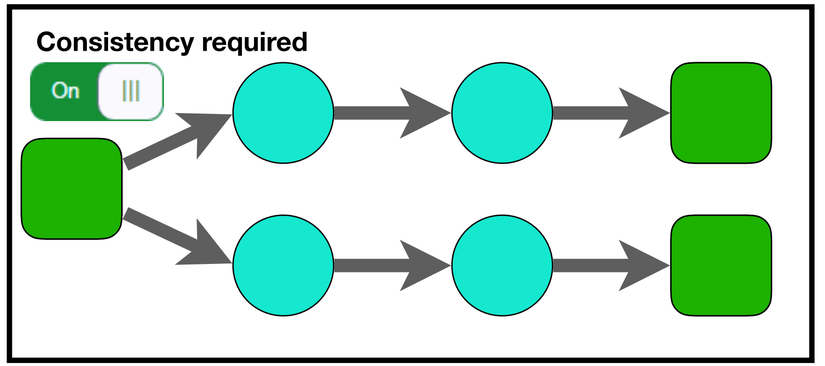

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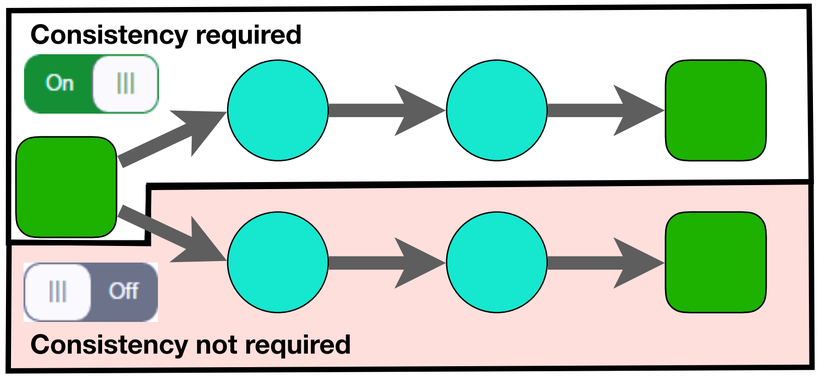
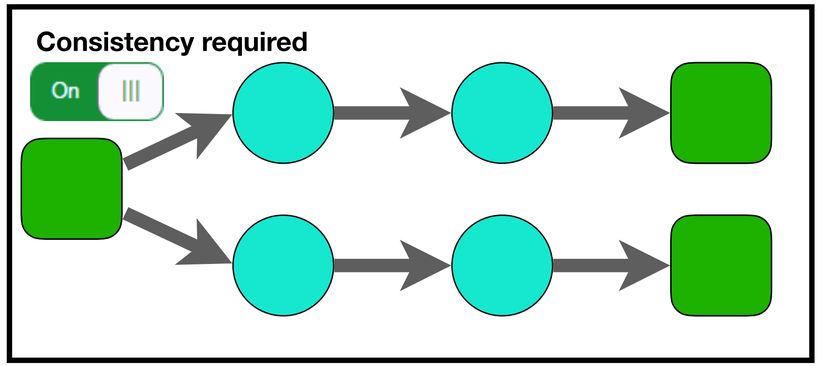


IBM-Streams - Problem statement

- Snapshots impose overhead
- What if processing guarantees are only necessary for some operators?
- **Solution?** Create a stream processing language for more fine-grained control

Apache Flink



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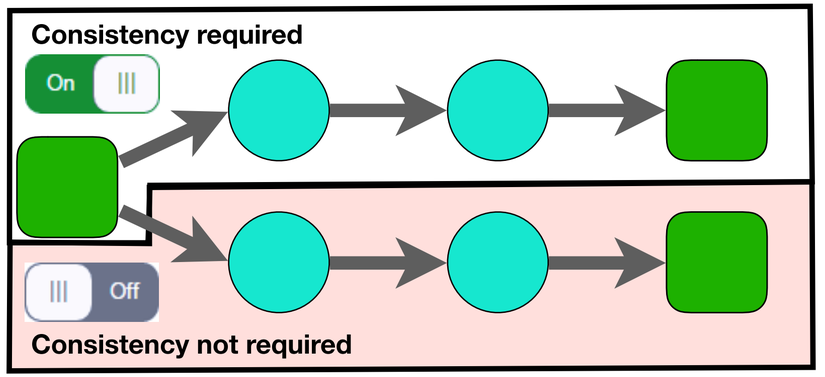
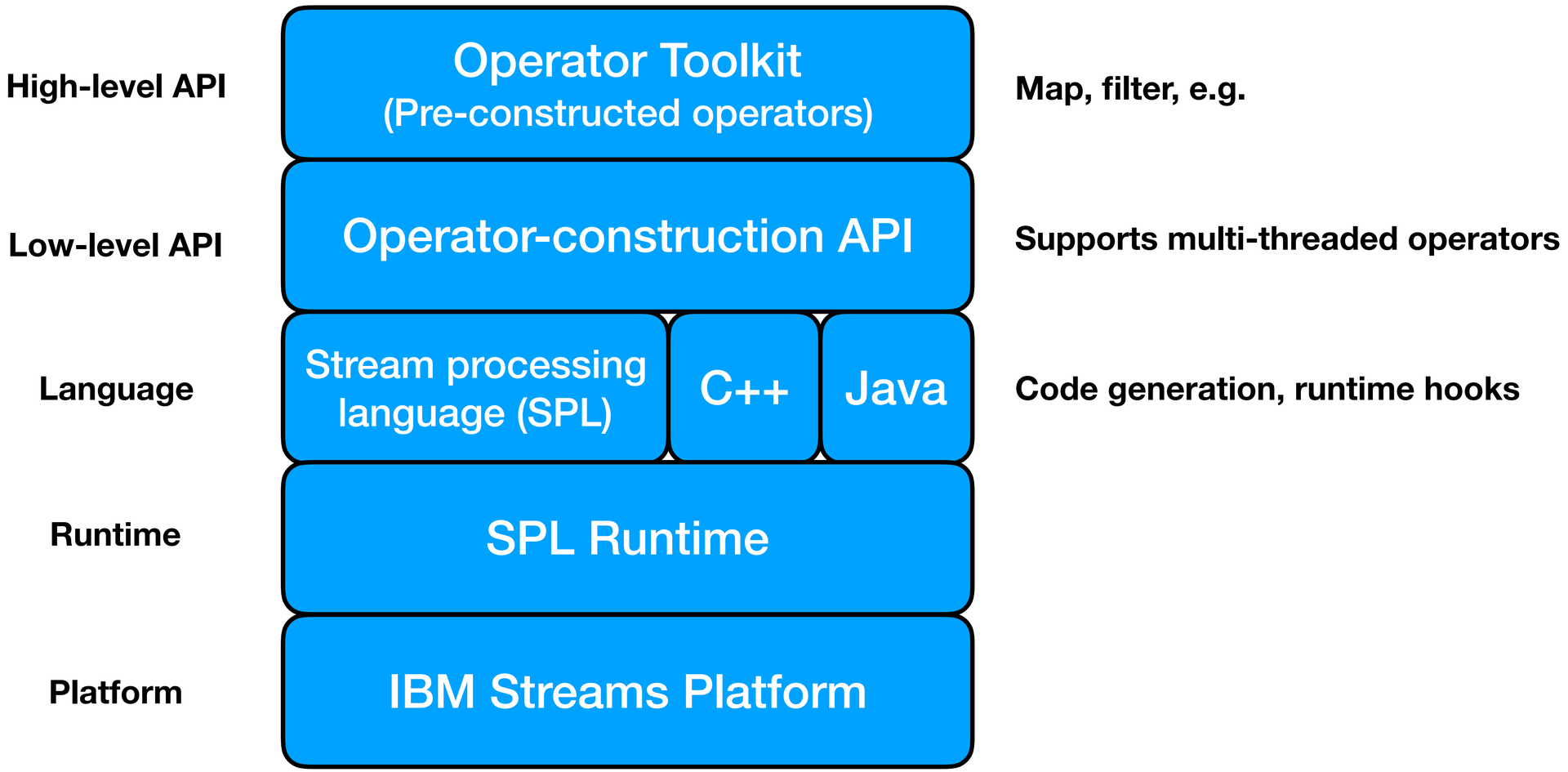


IBM Streams - System Overview



IBM Streams - Consistent Regions

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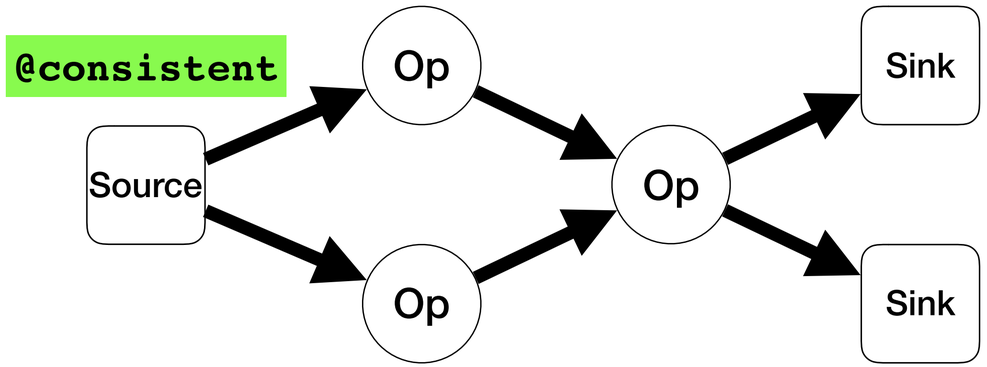

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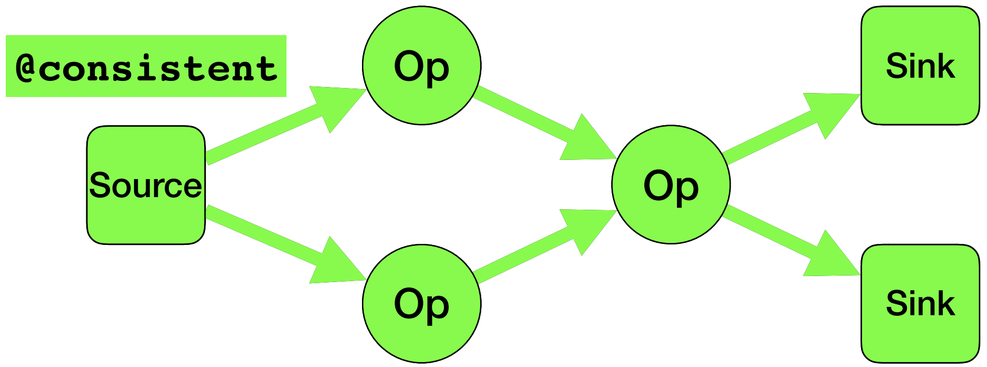

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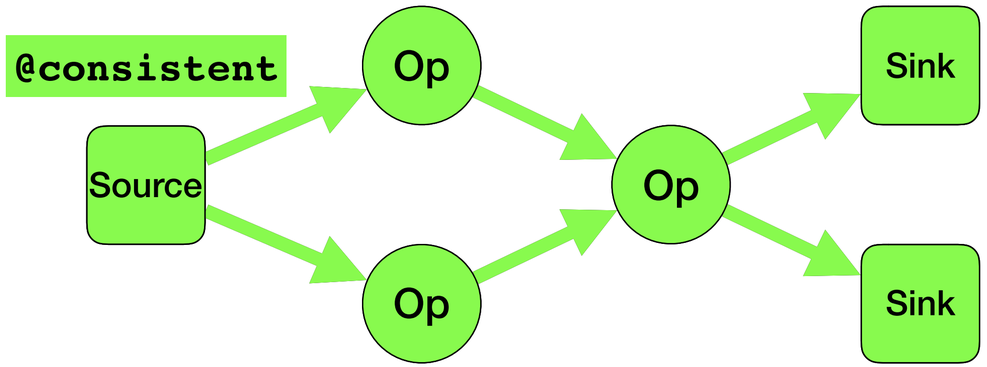

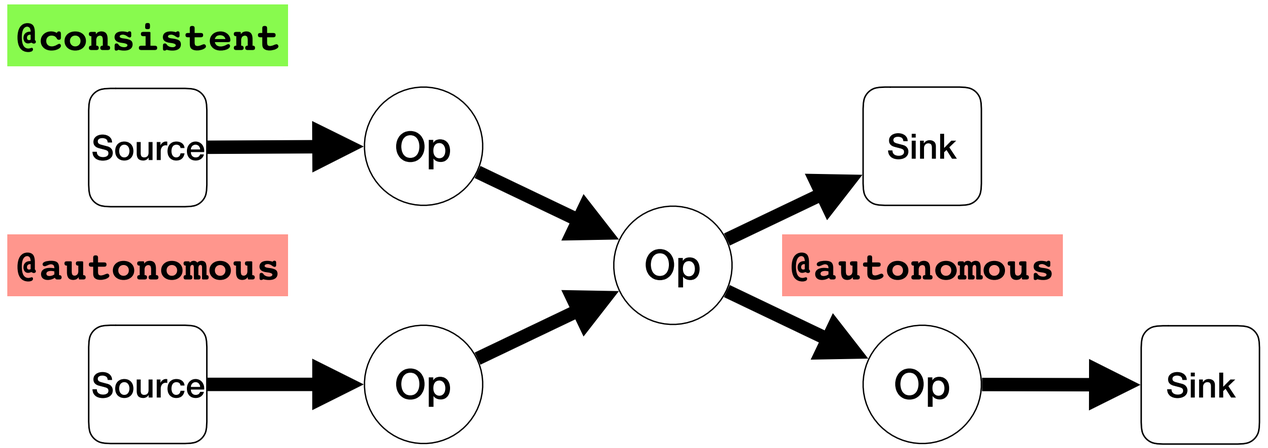

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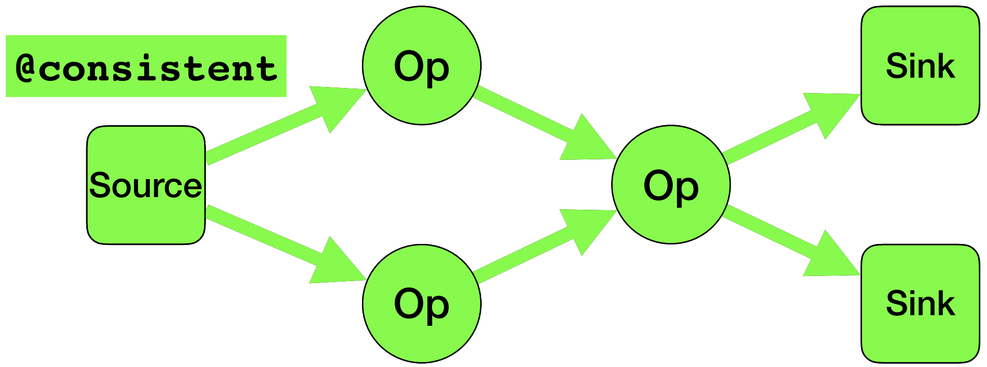

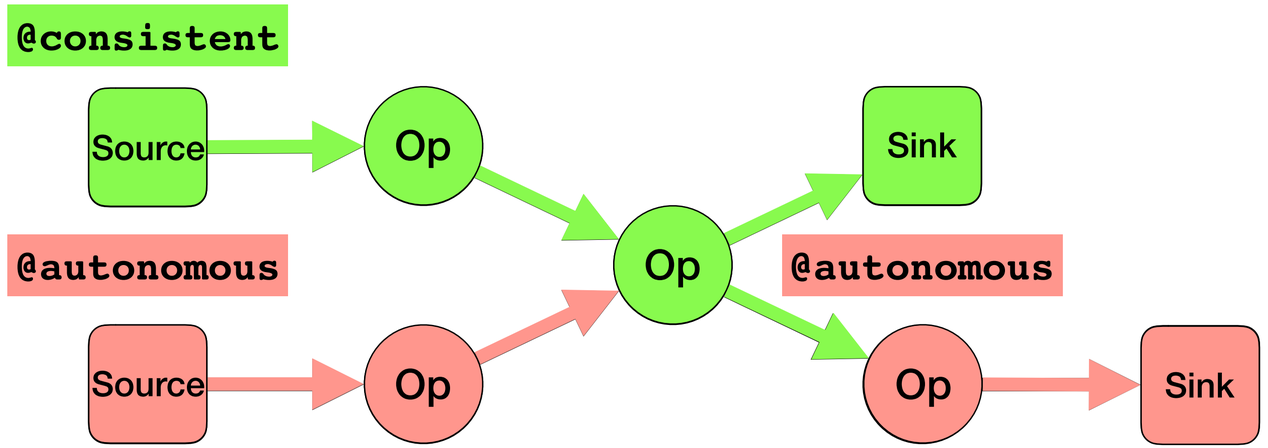

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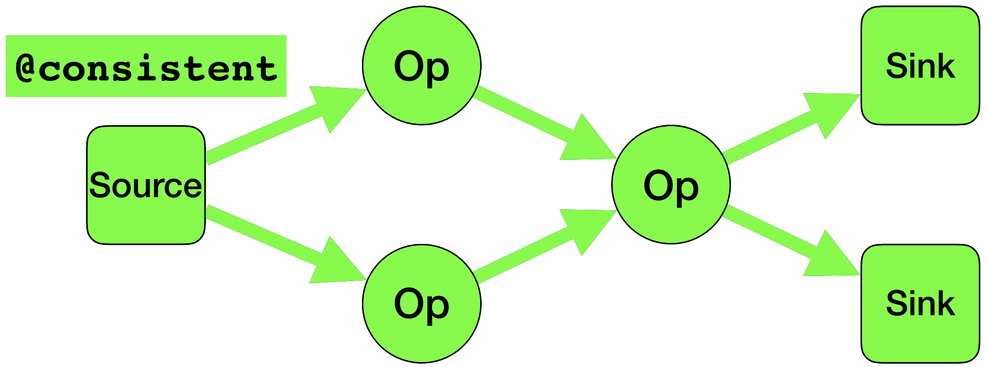
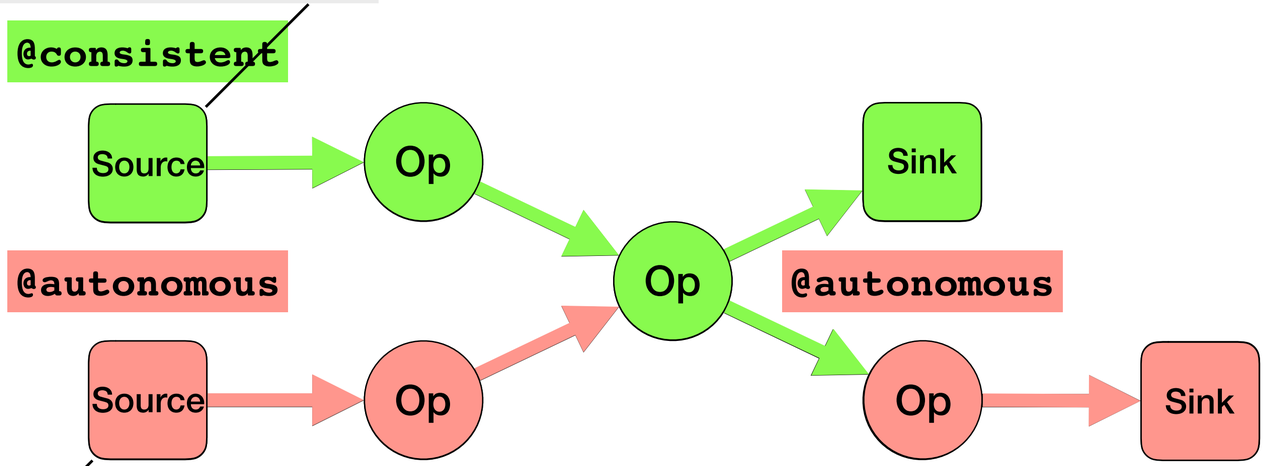


Consistent sources replay tuples



Autonomous sources do not replay tuples

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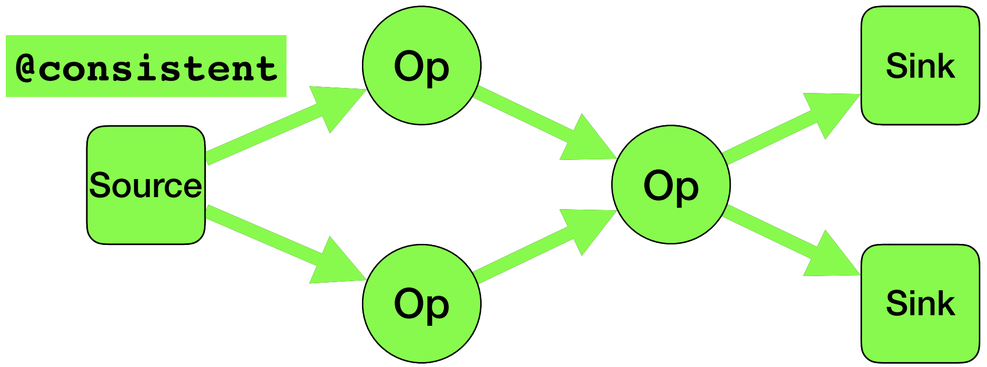
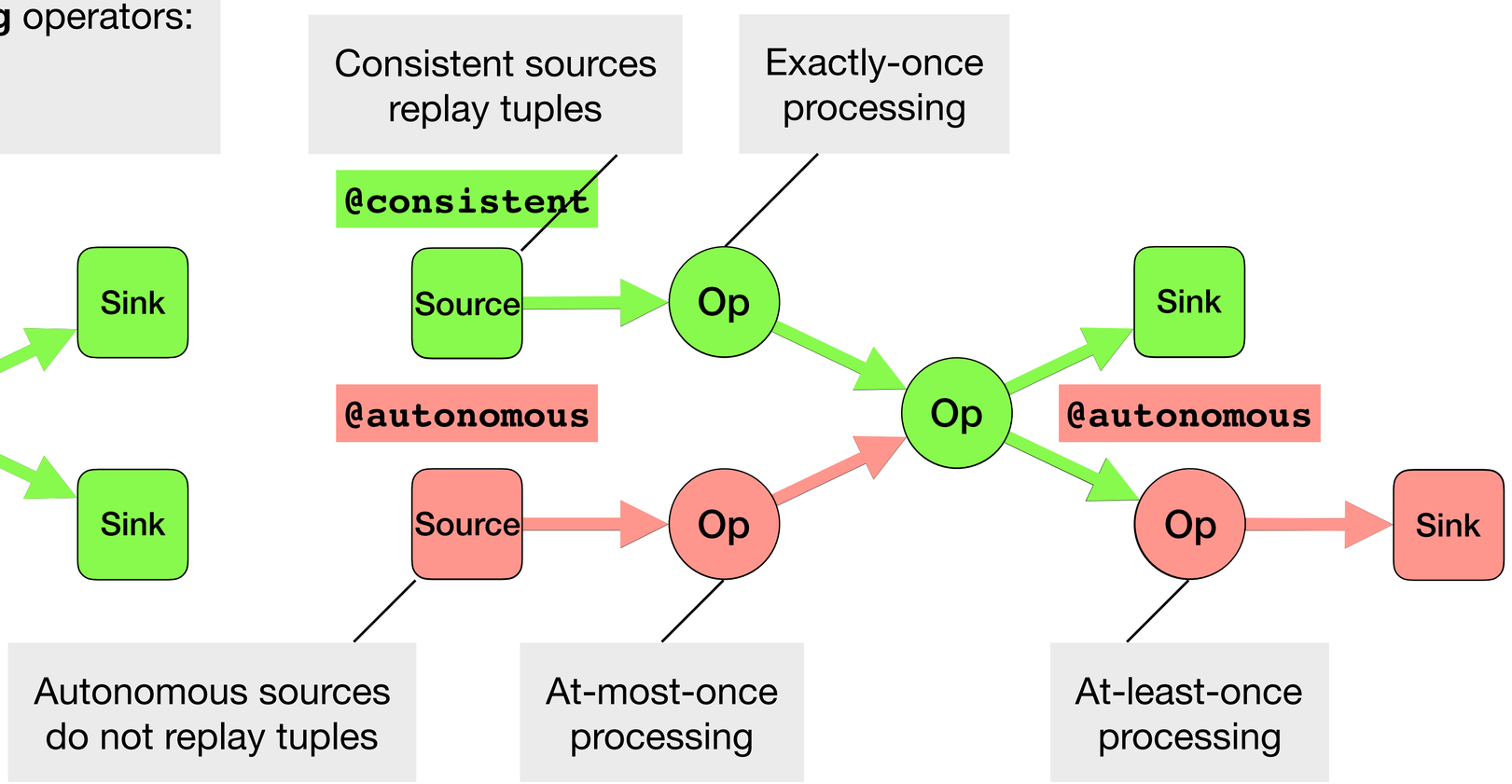
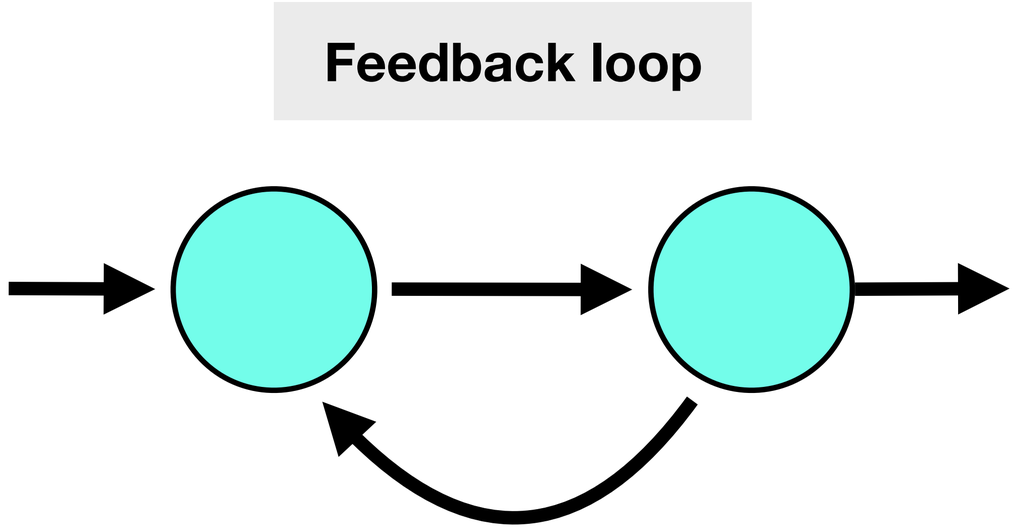




IBM Streams - Input ports

Problem: As in Flink, **feedback loops** must be considered when snapshotting



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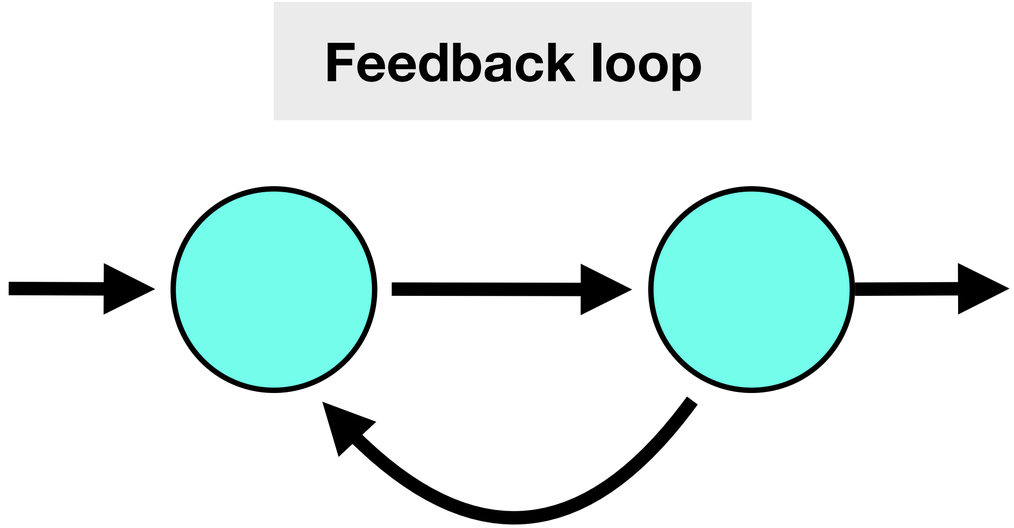

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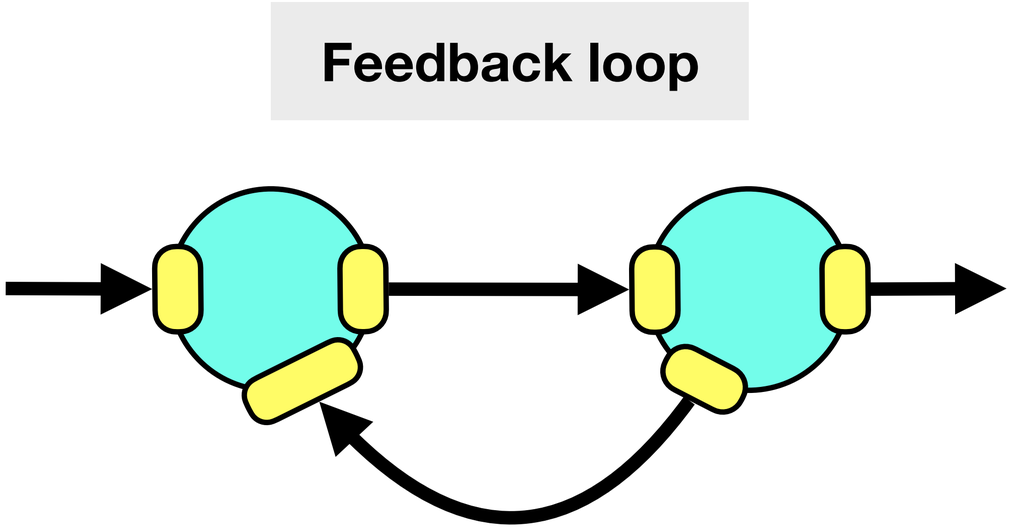

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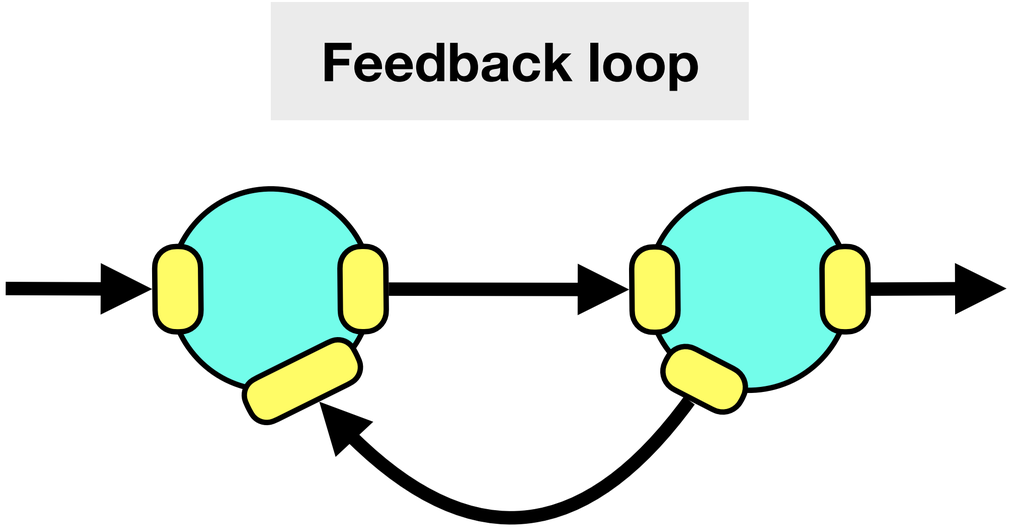

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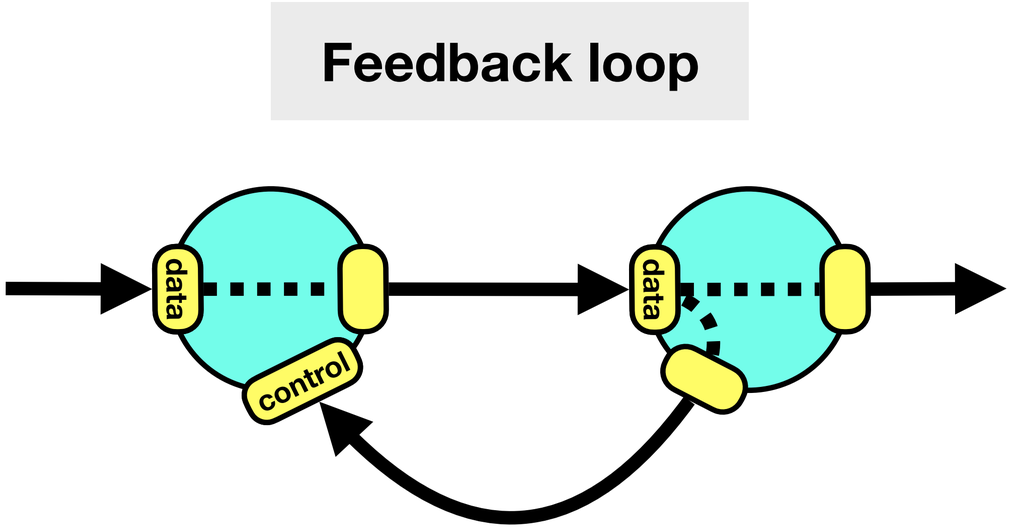

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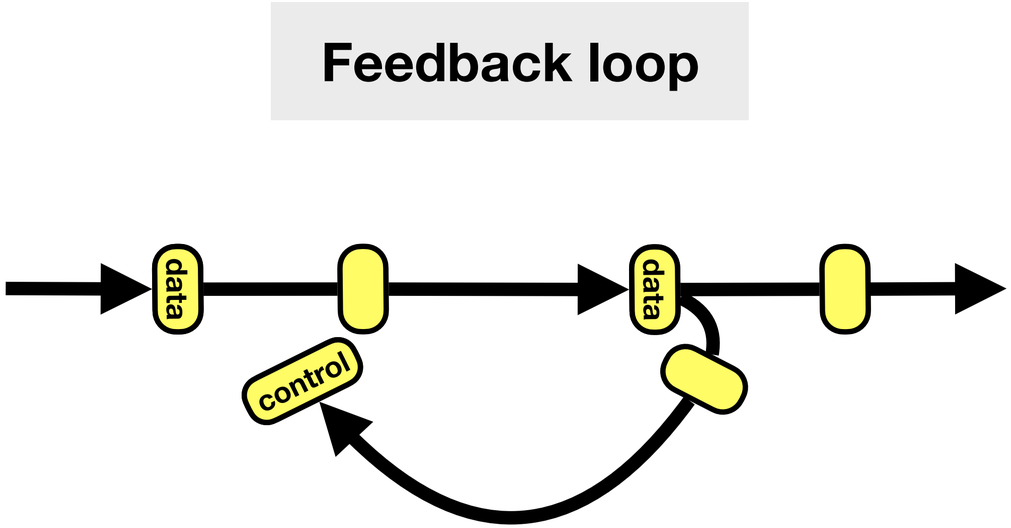
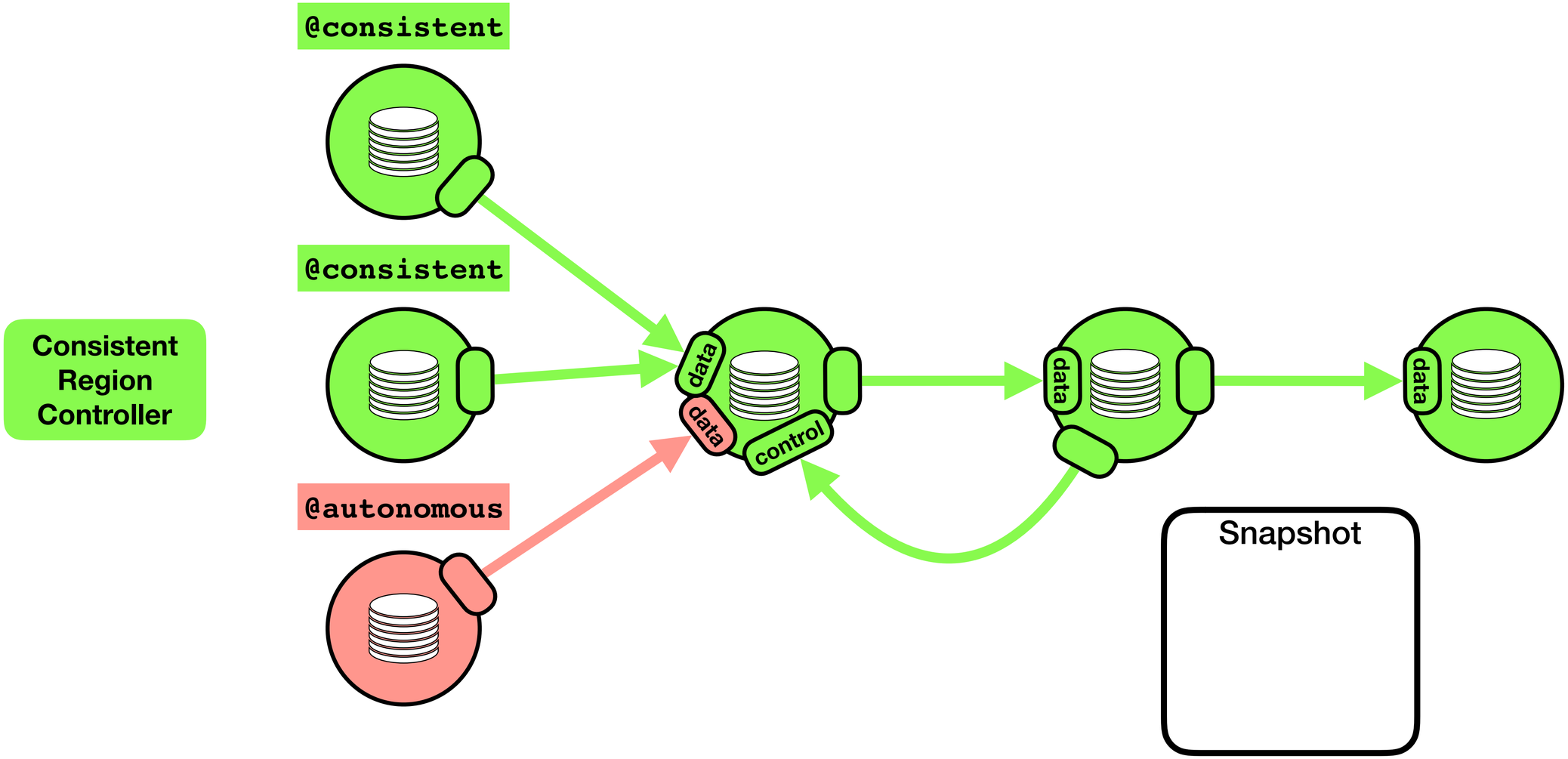


IBM Streams - Snapshotting Protocol



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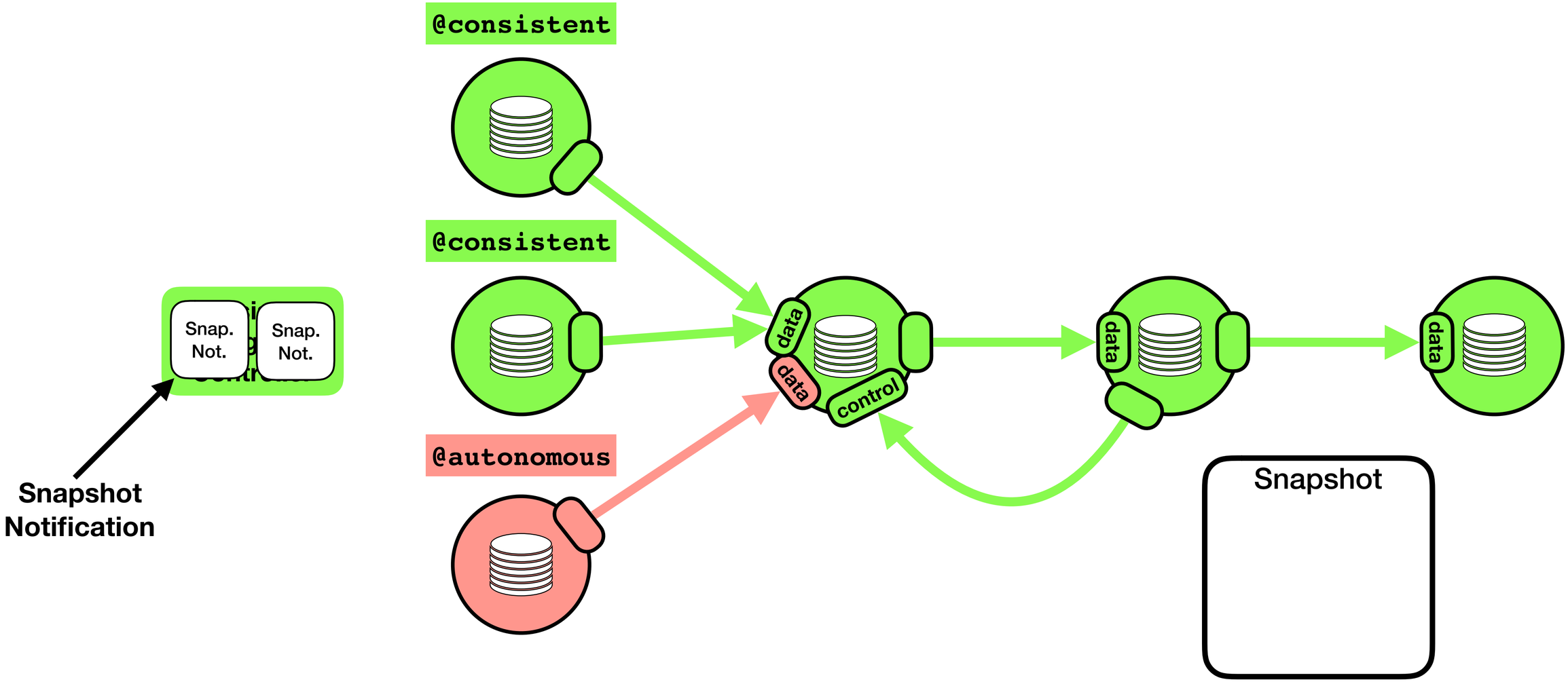

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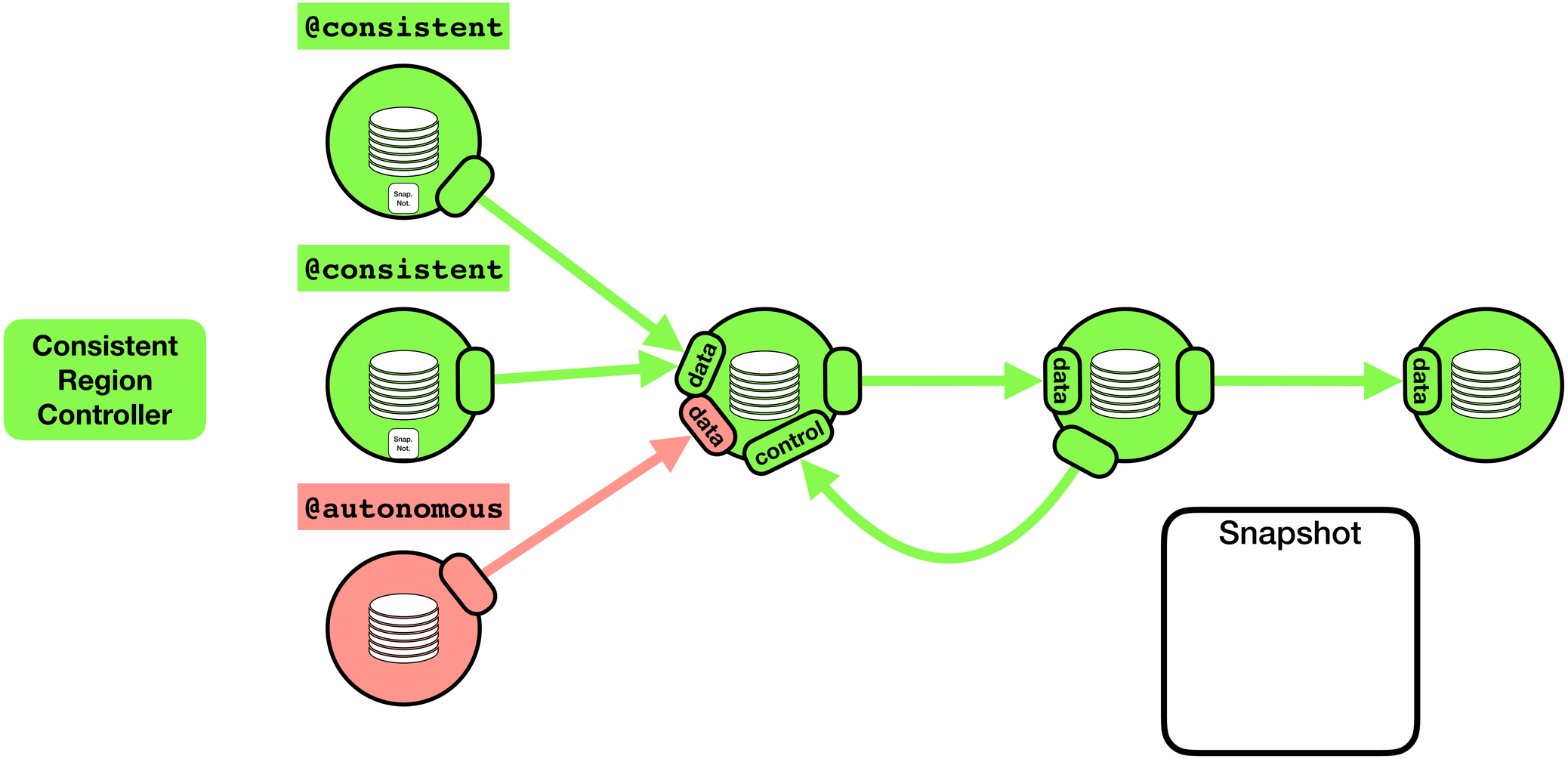

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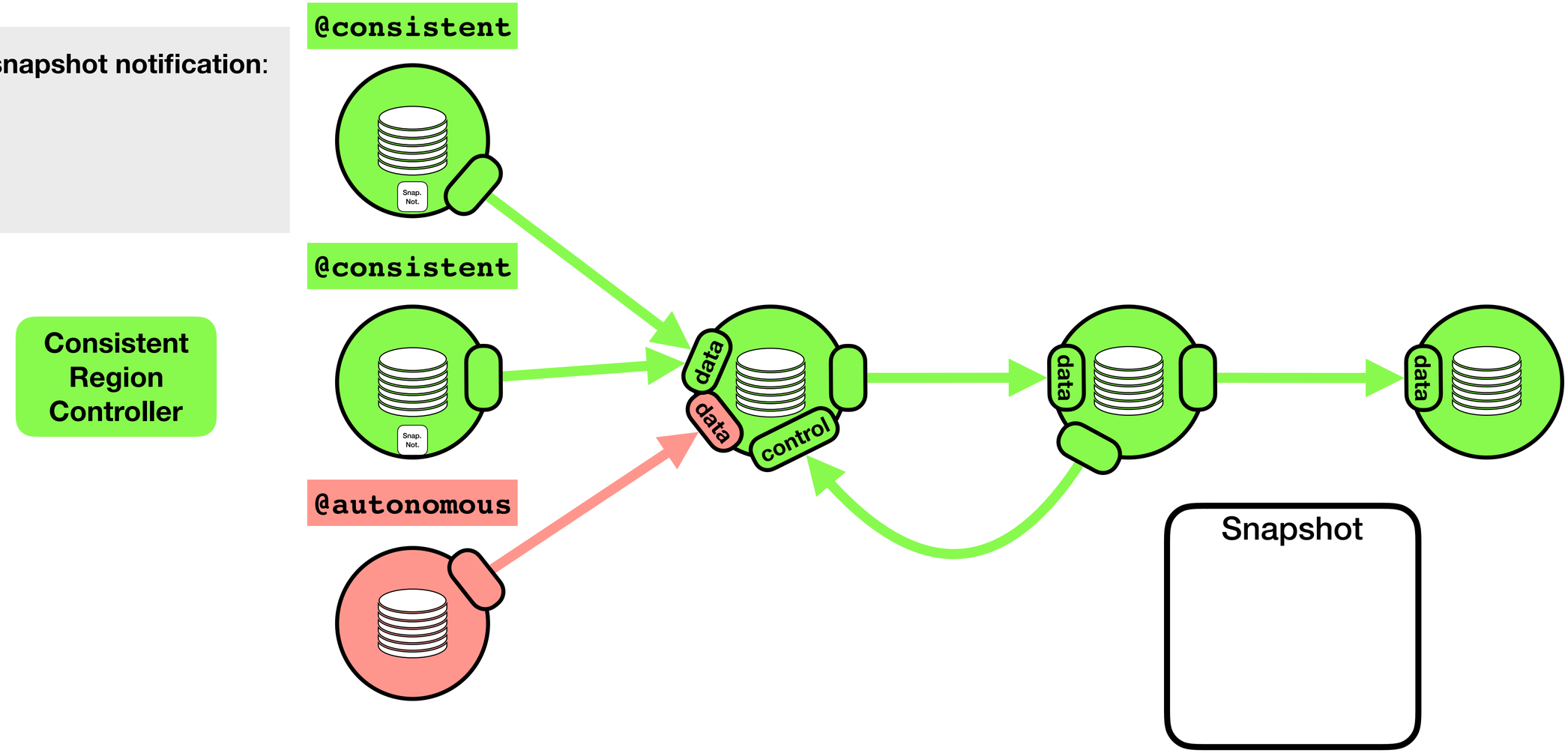

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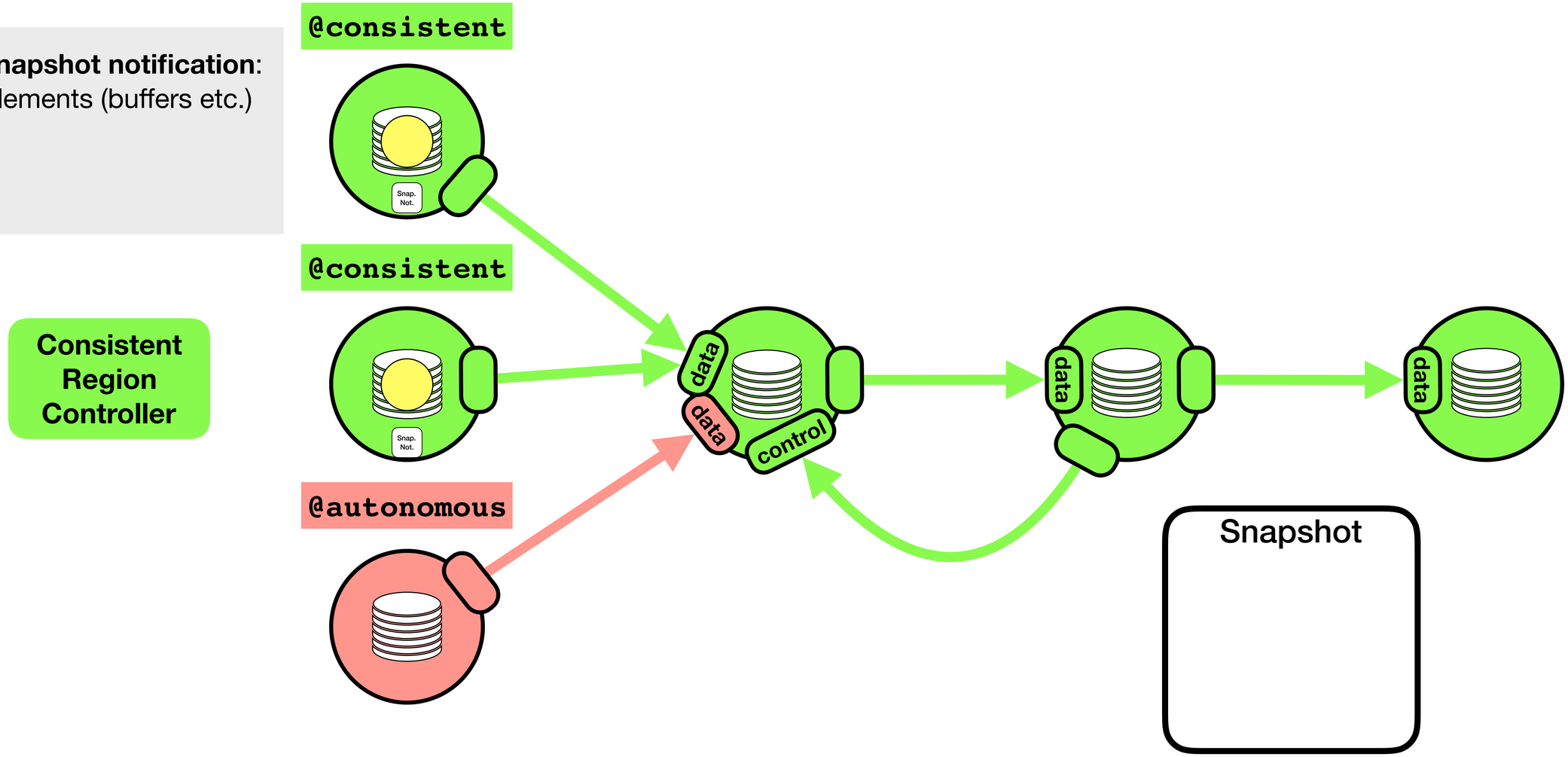

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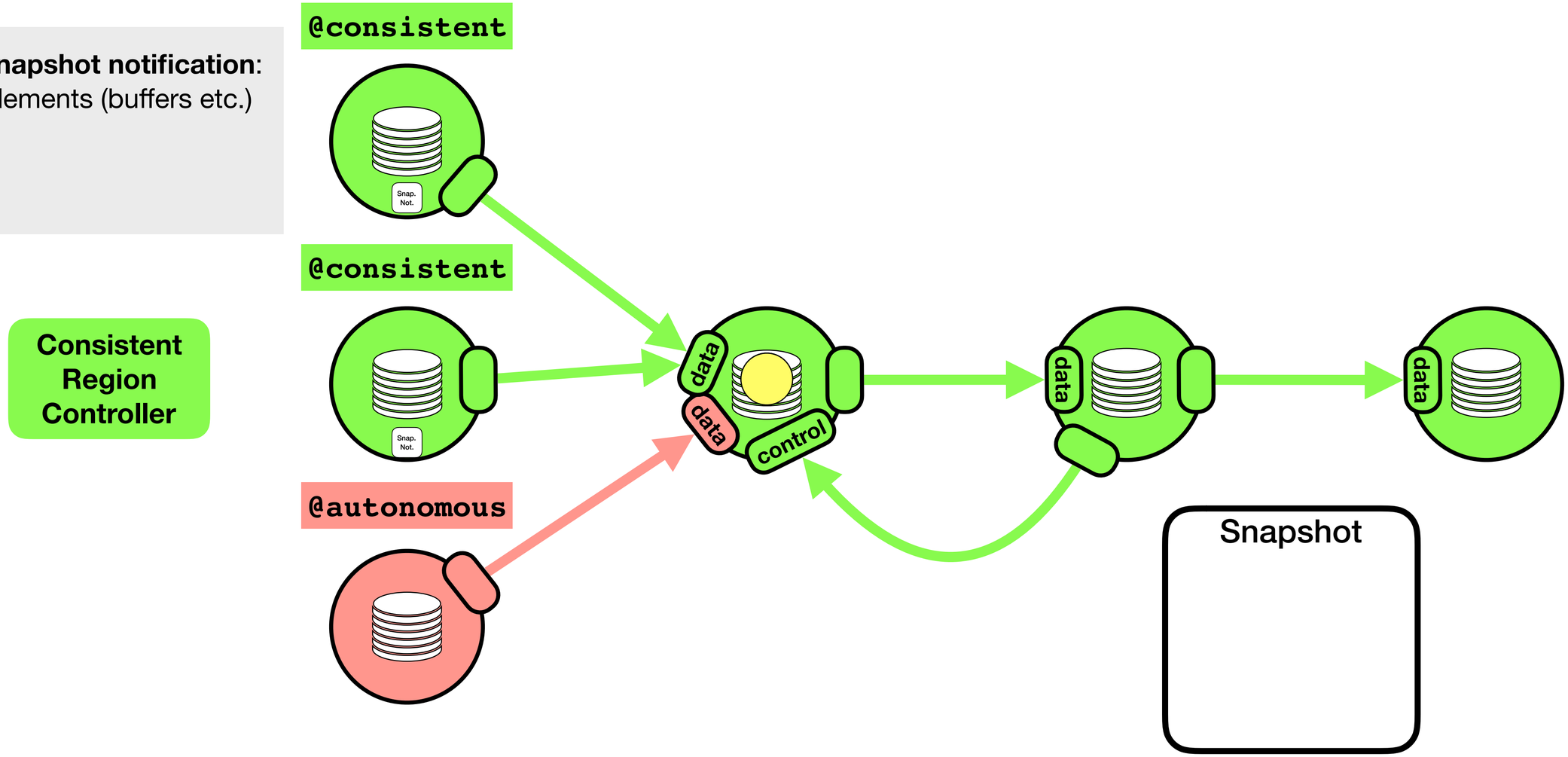

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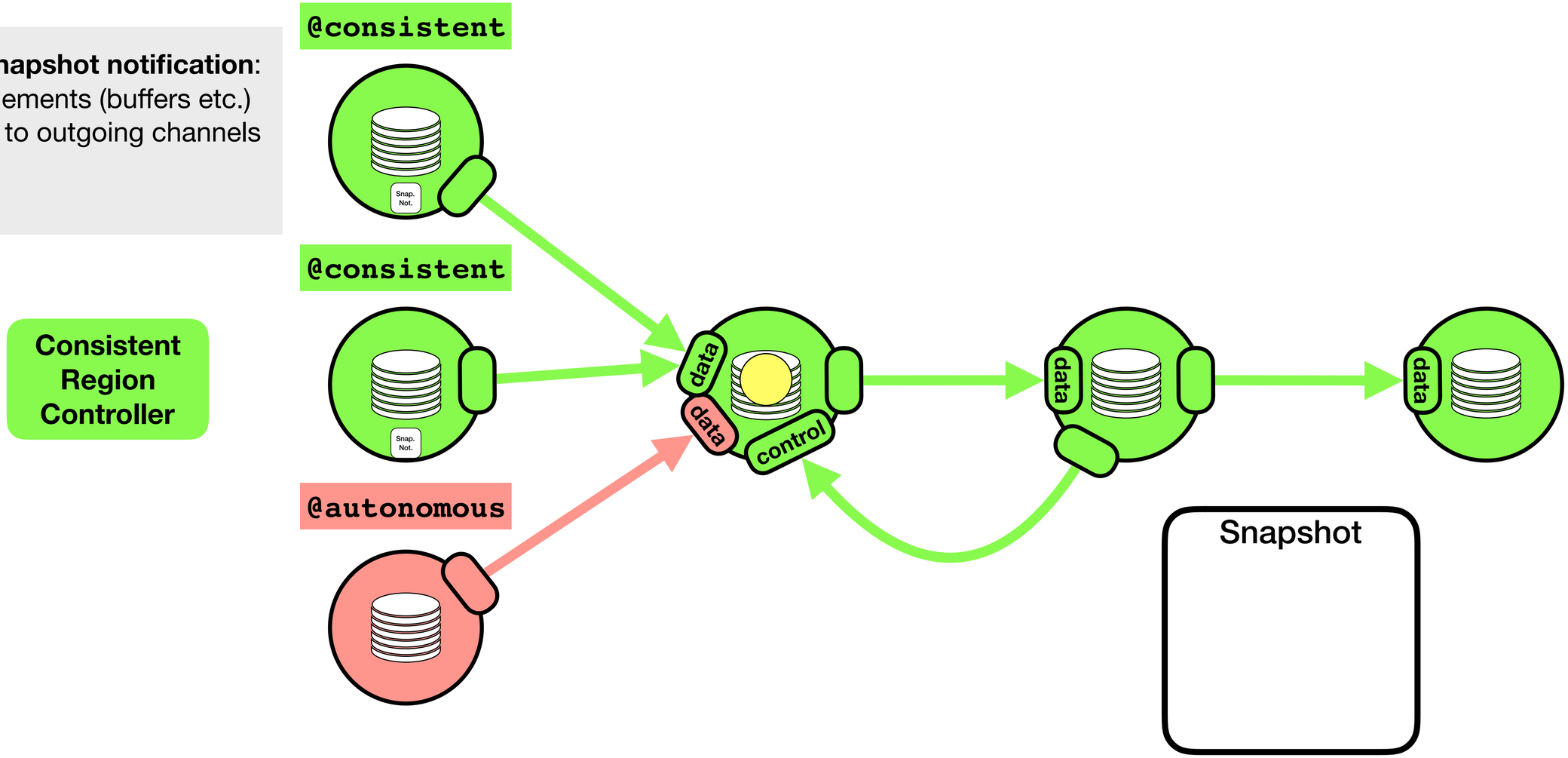

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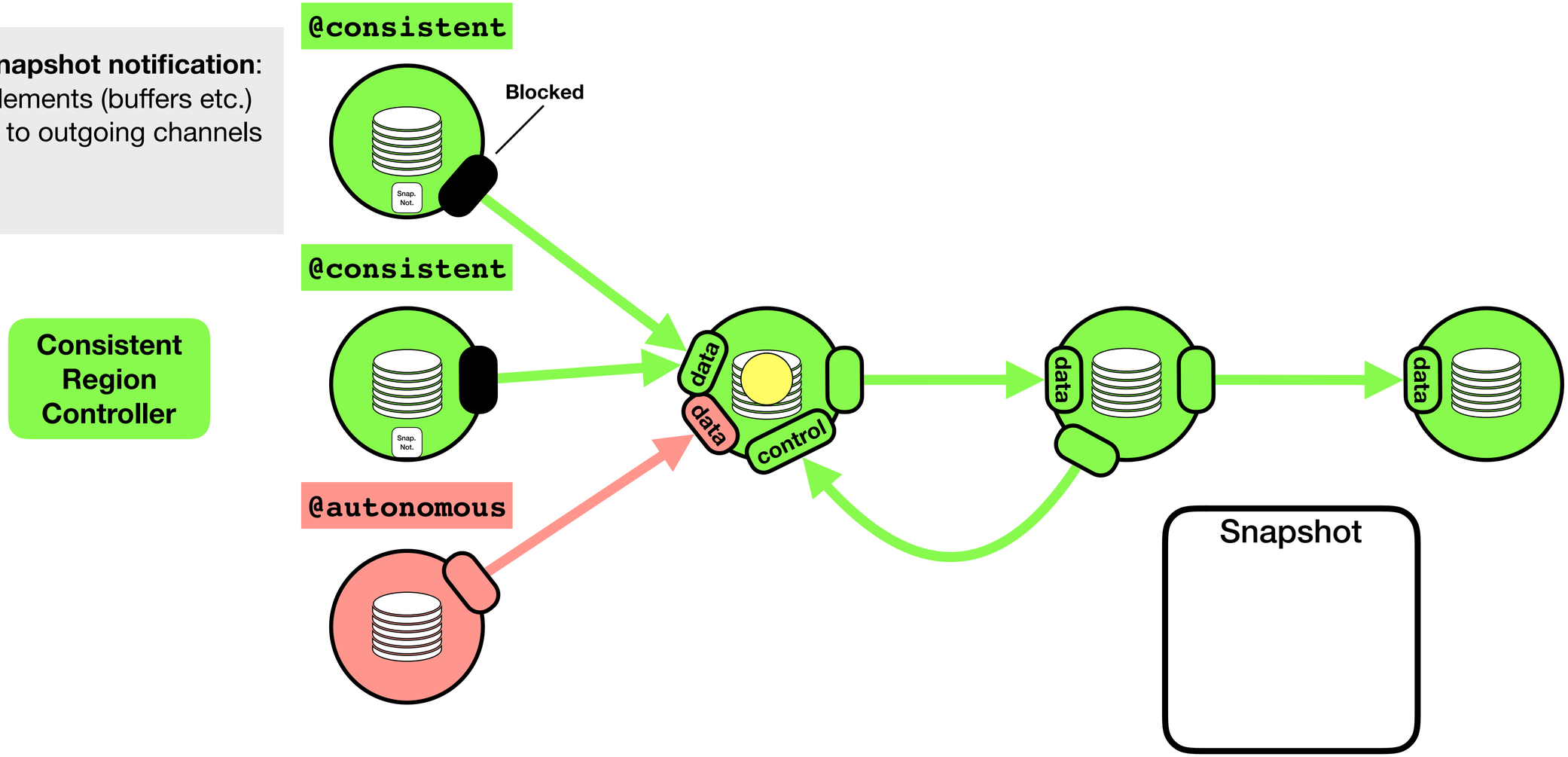

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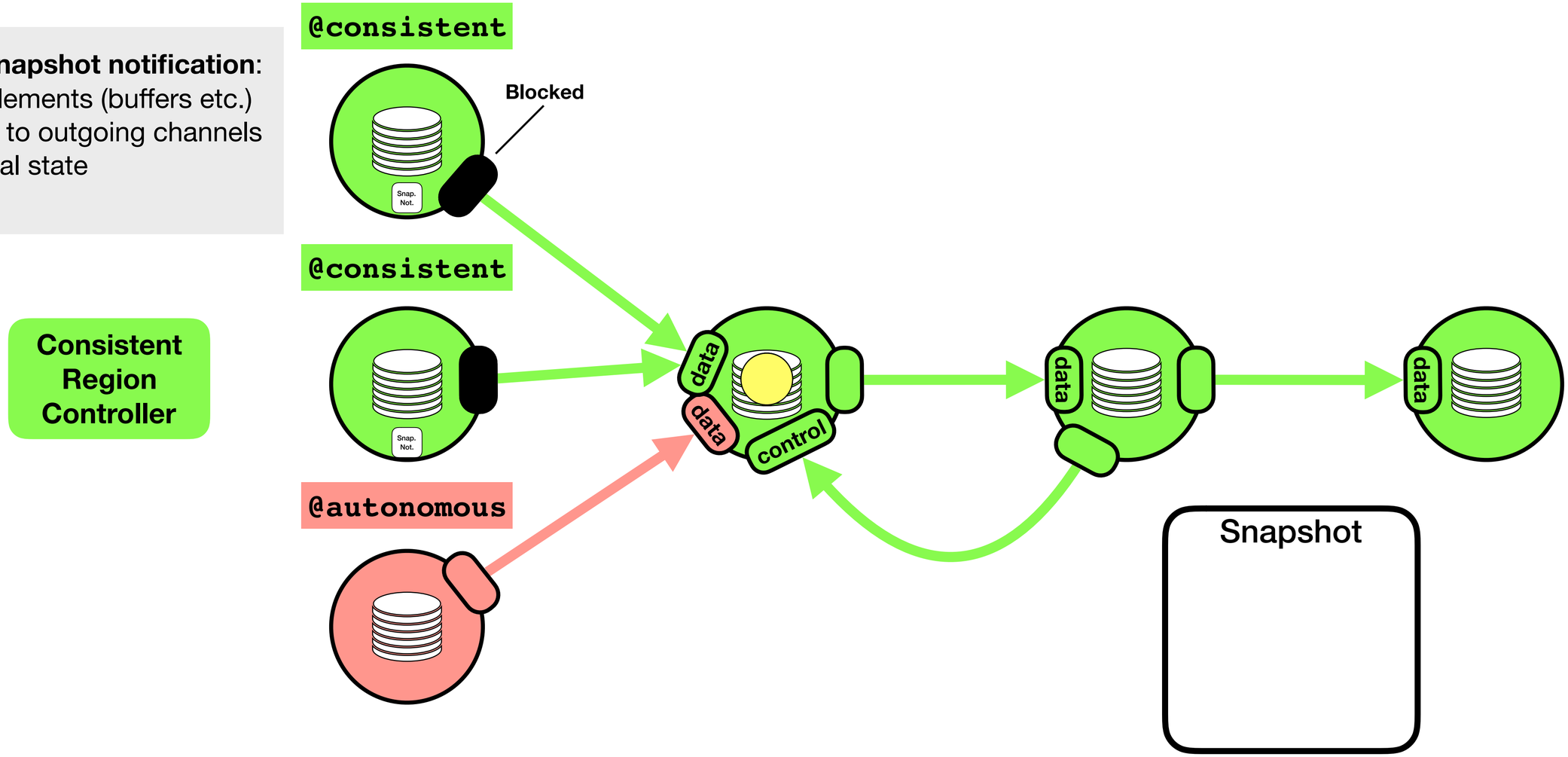

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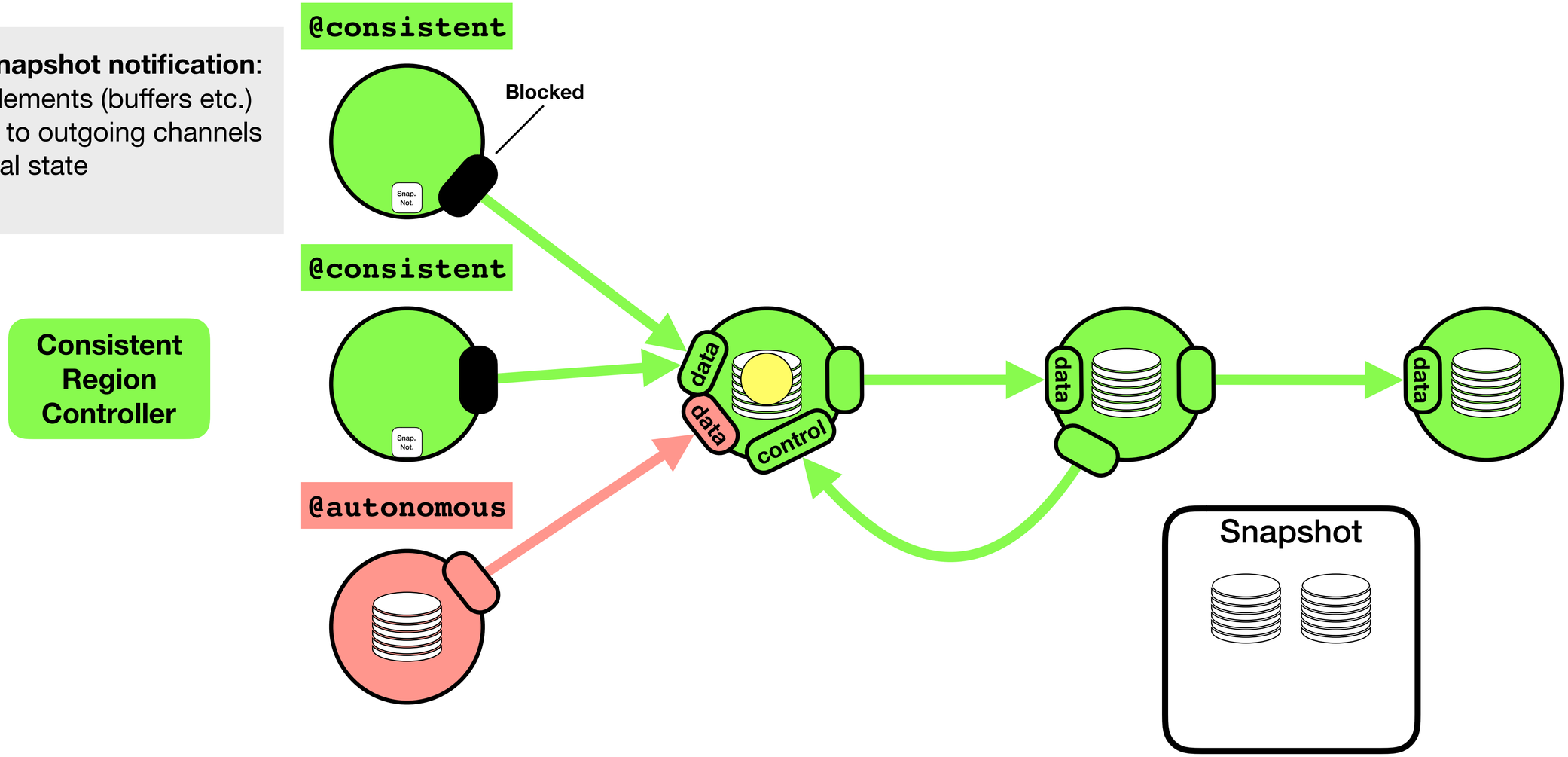

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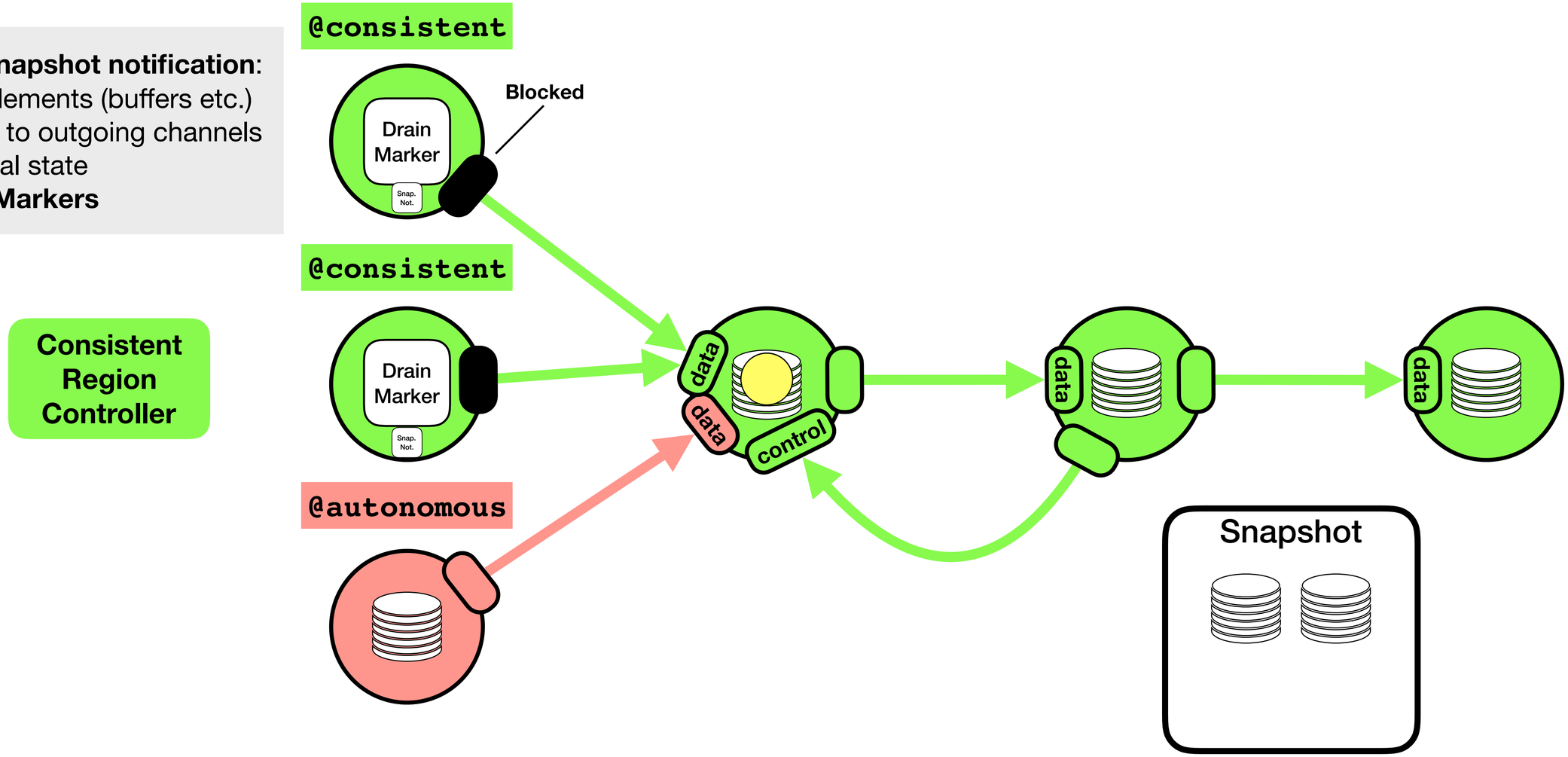

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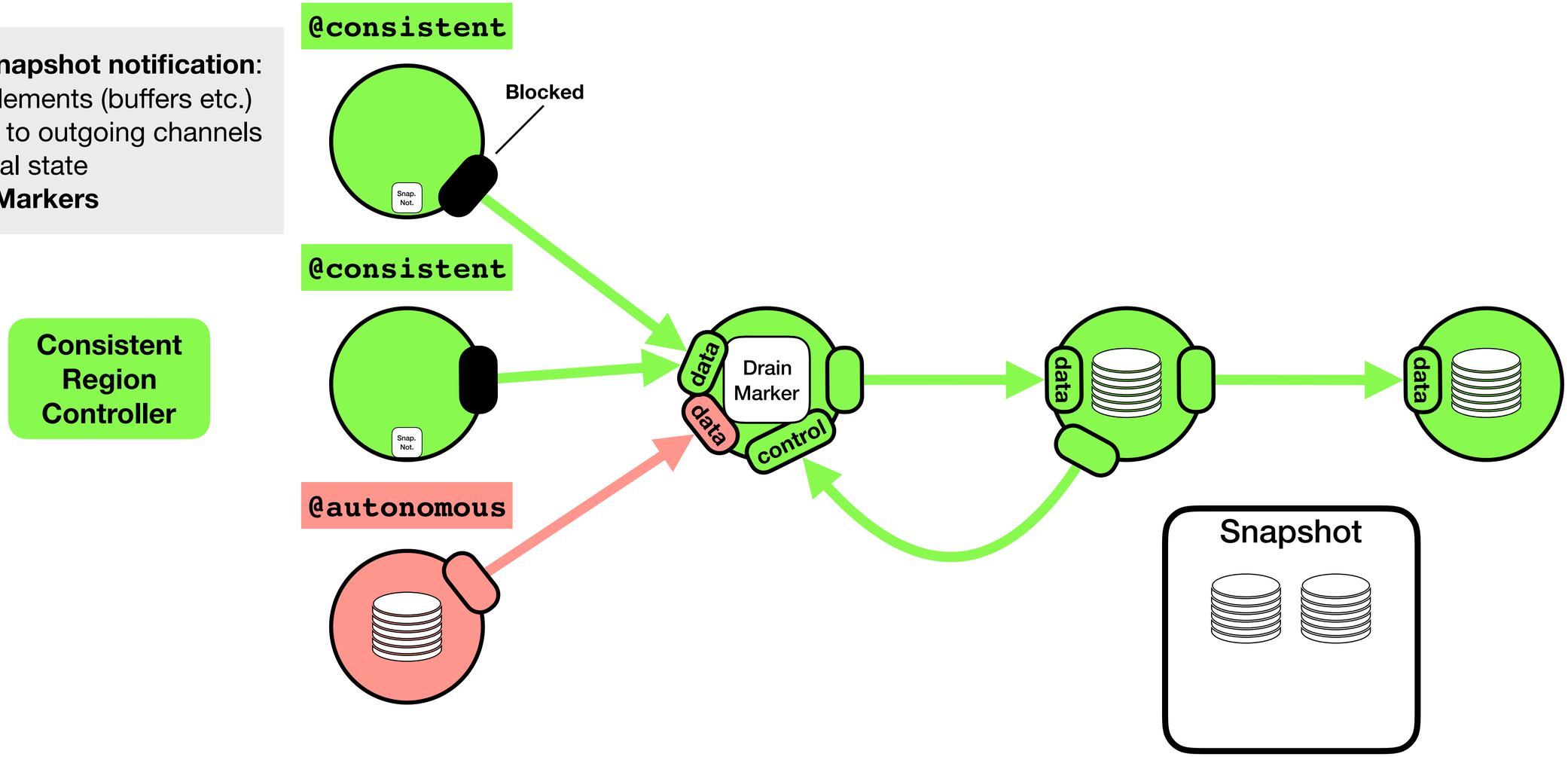

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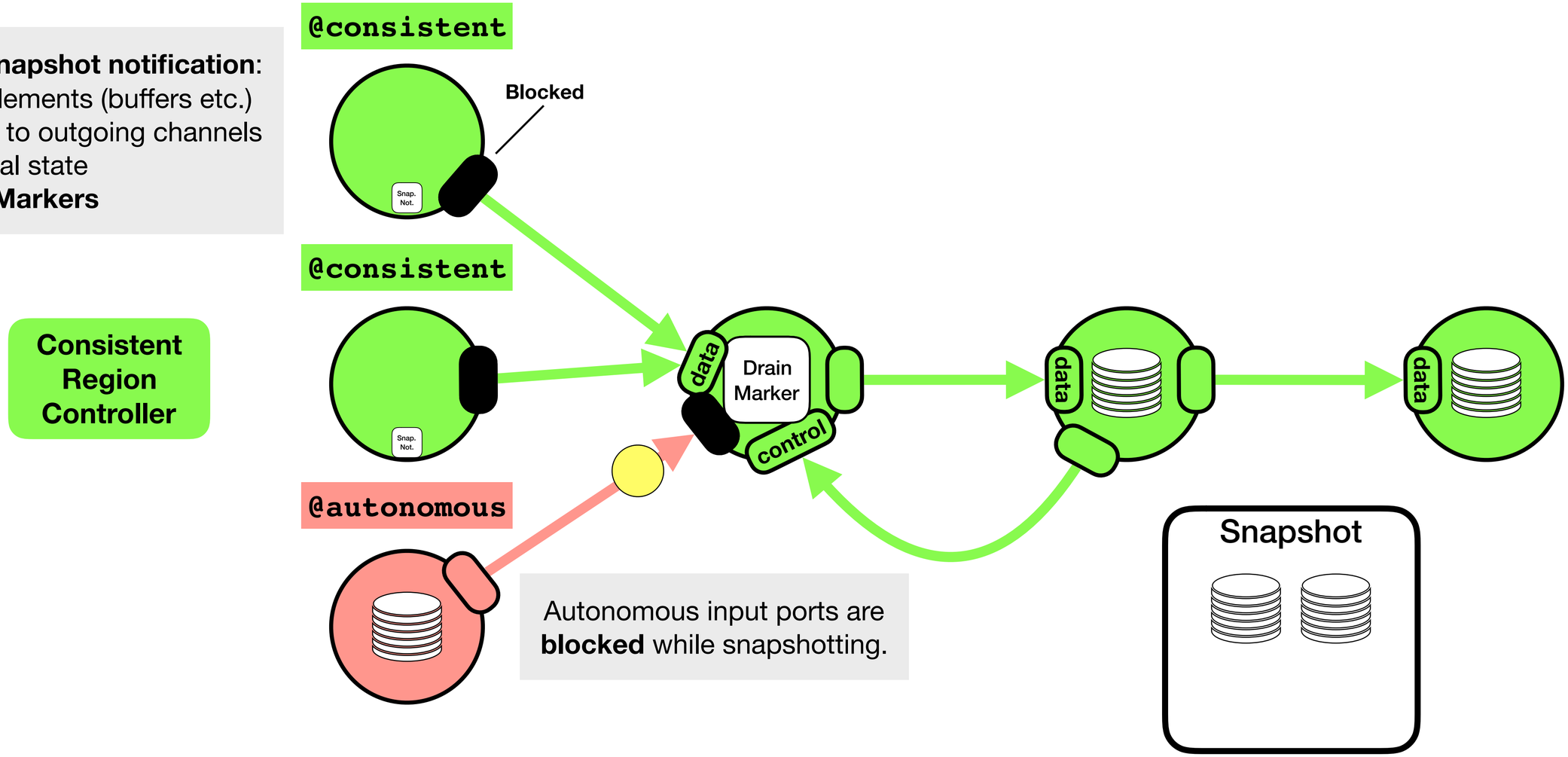

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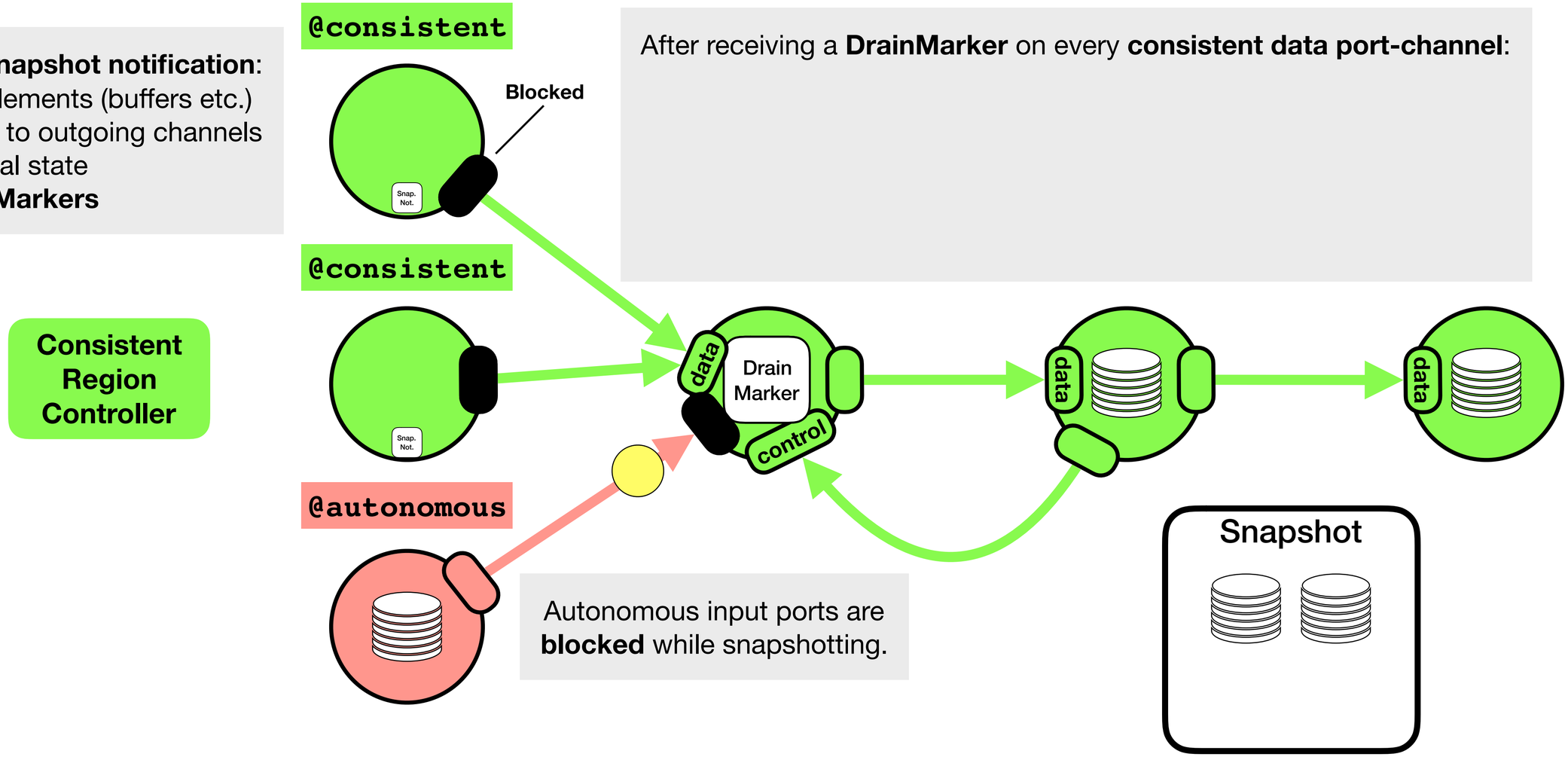

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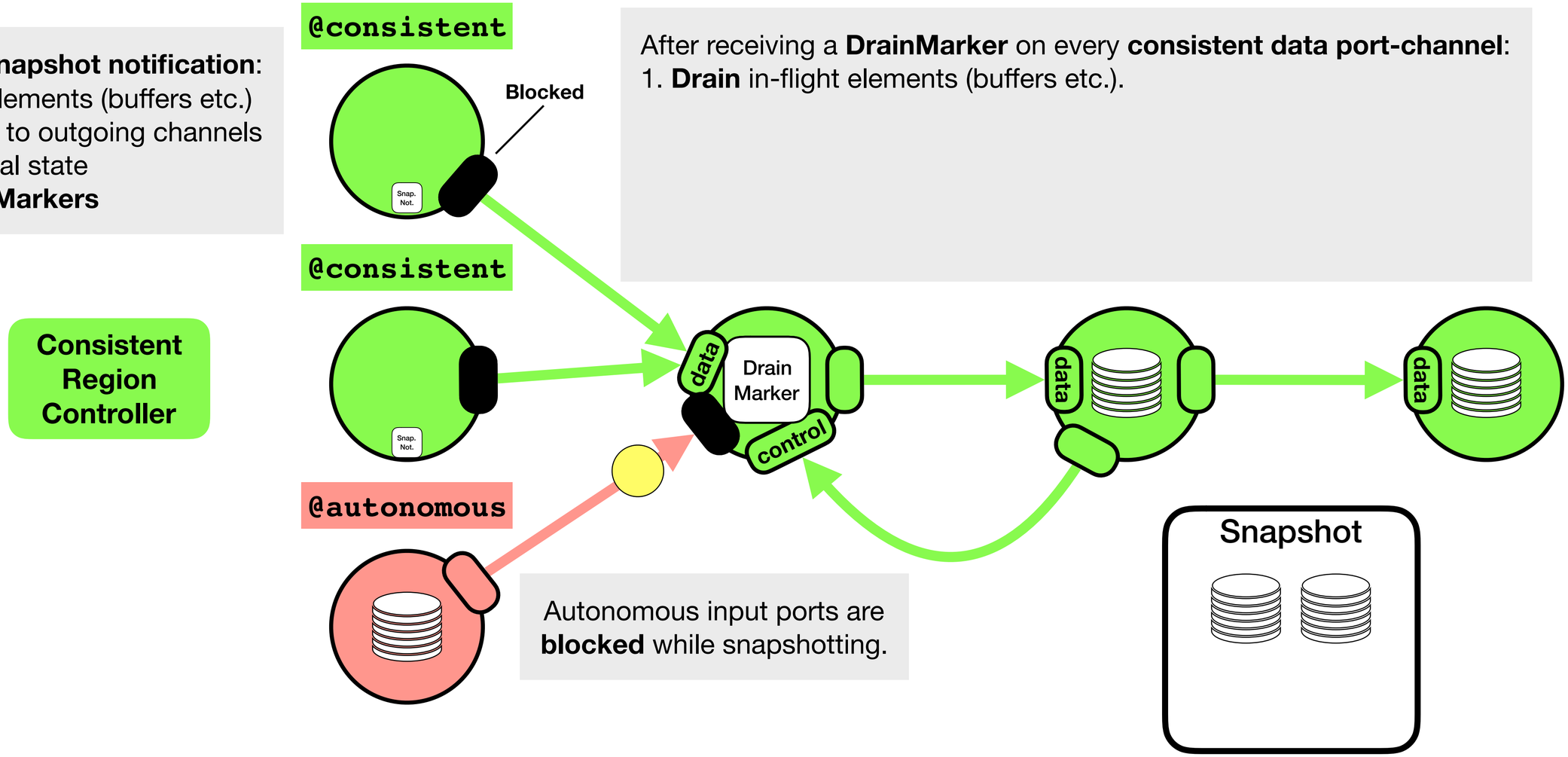

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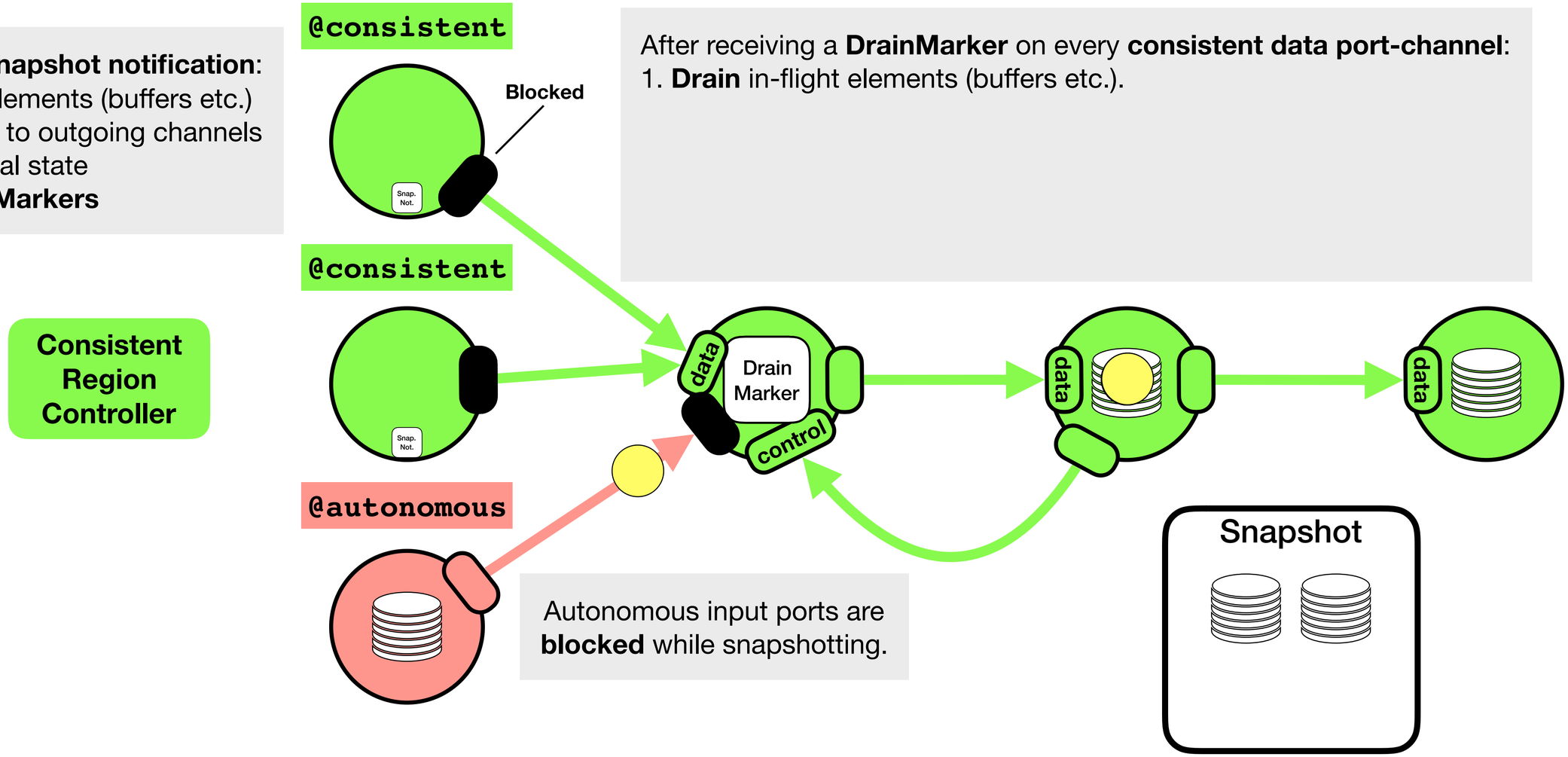

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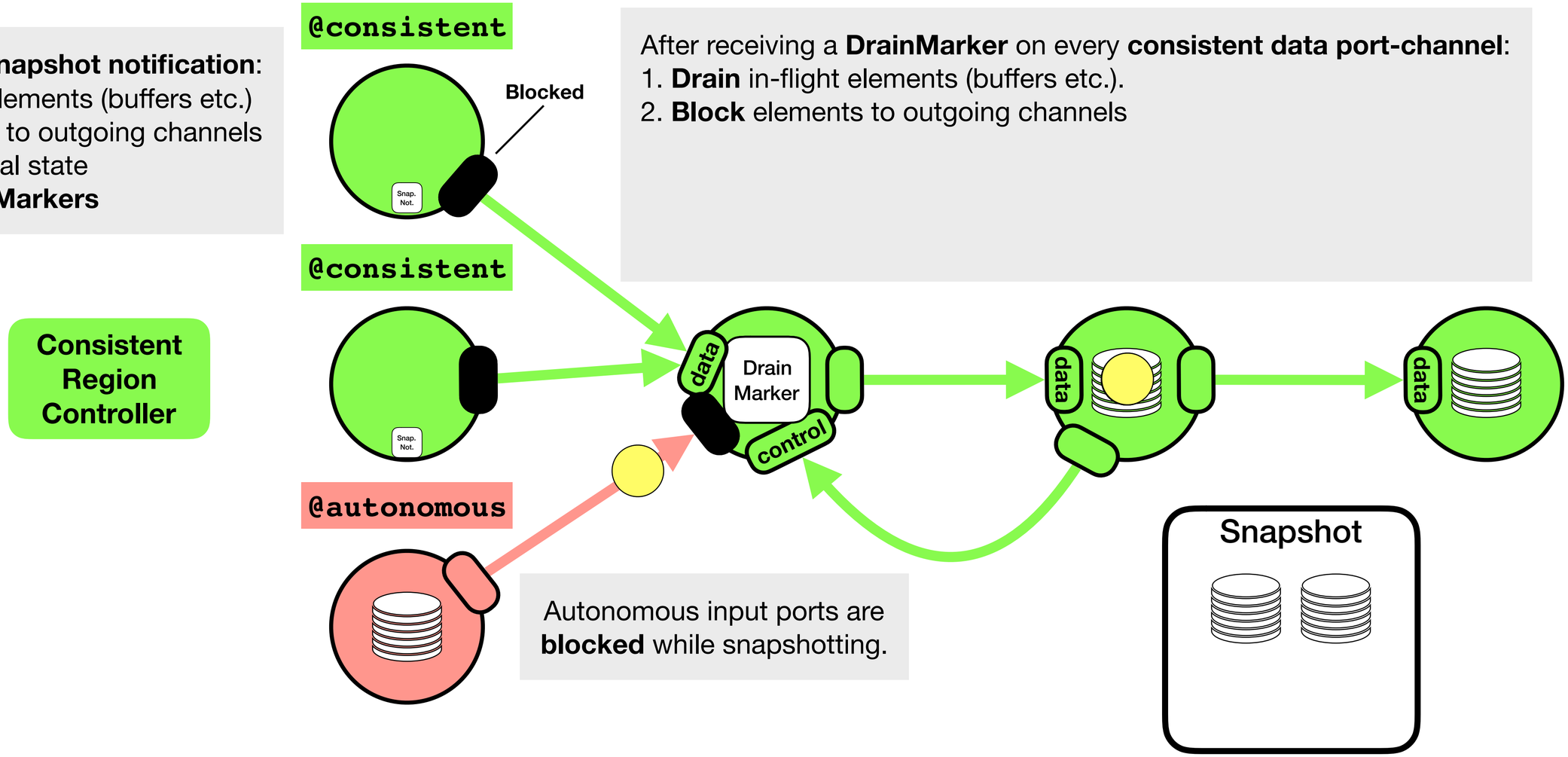

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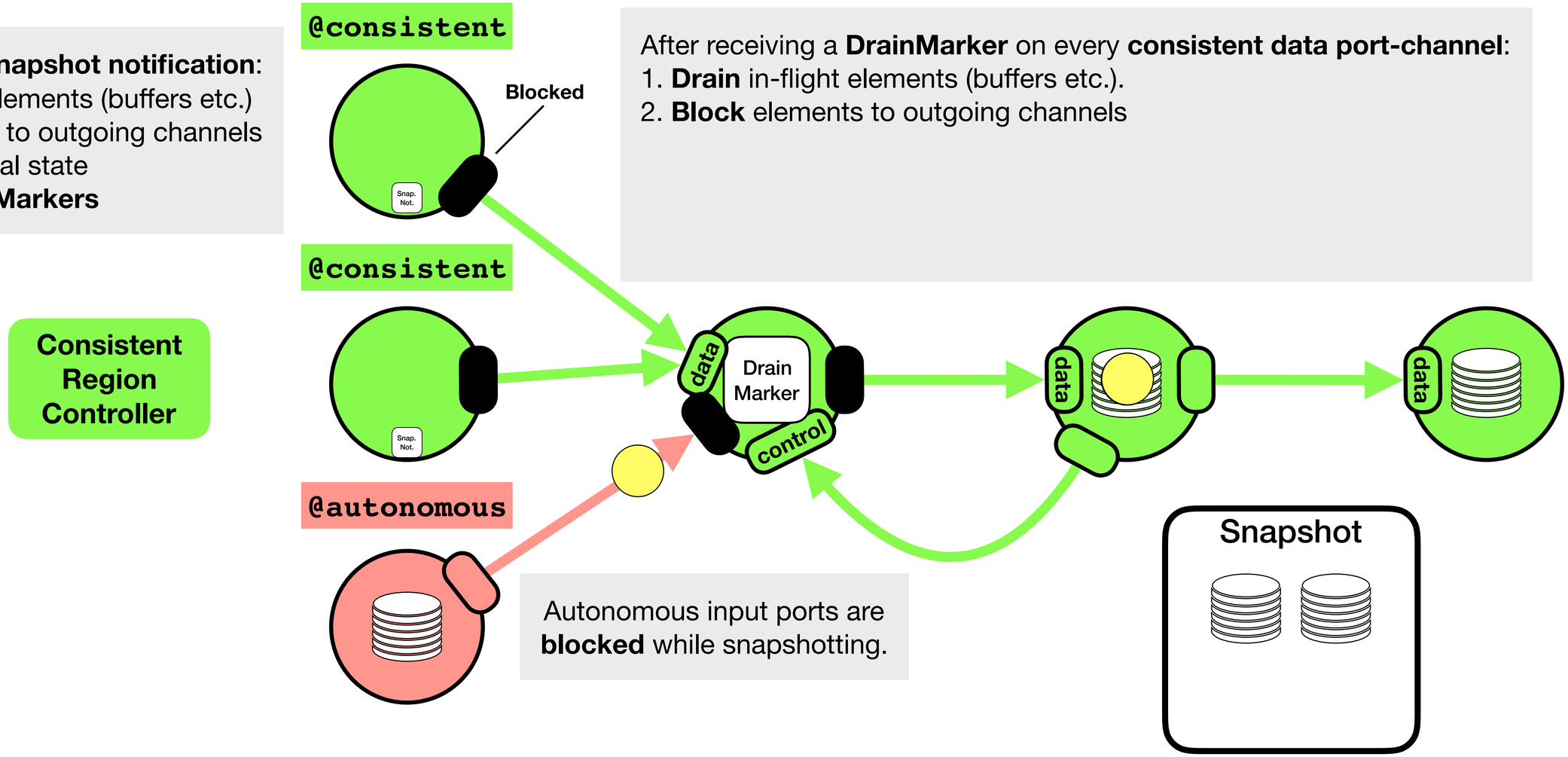

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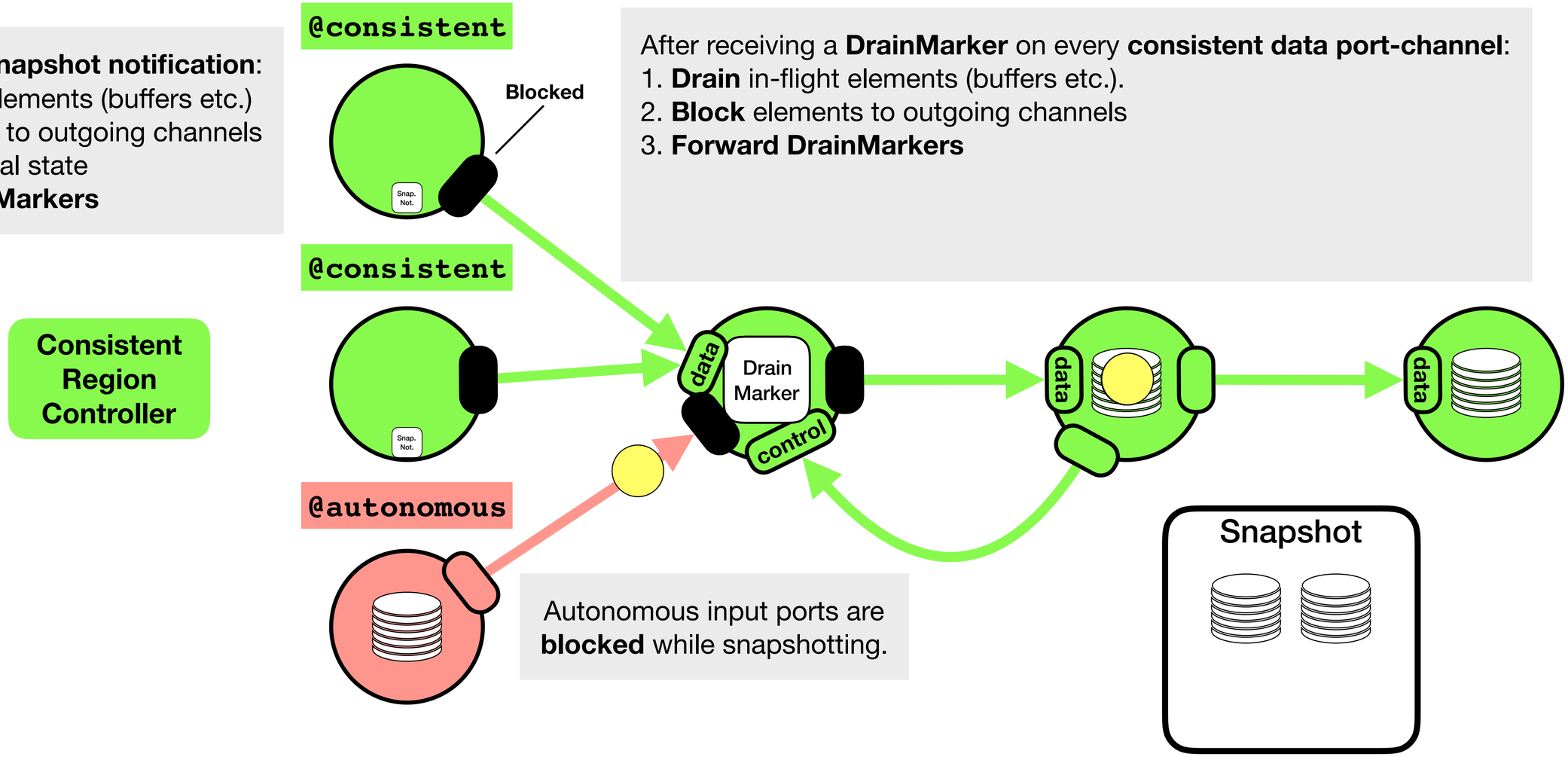

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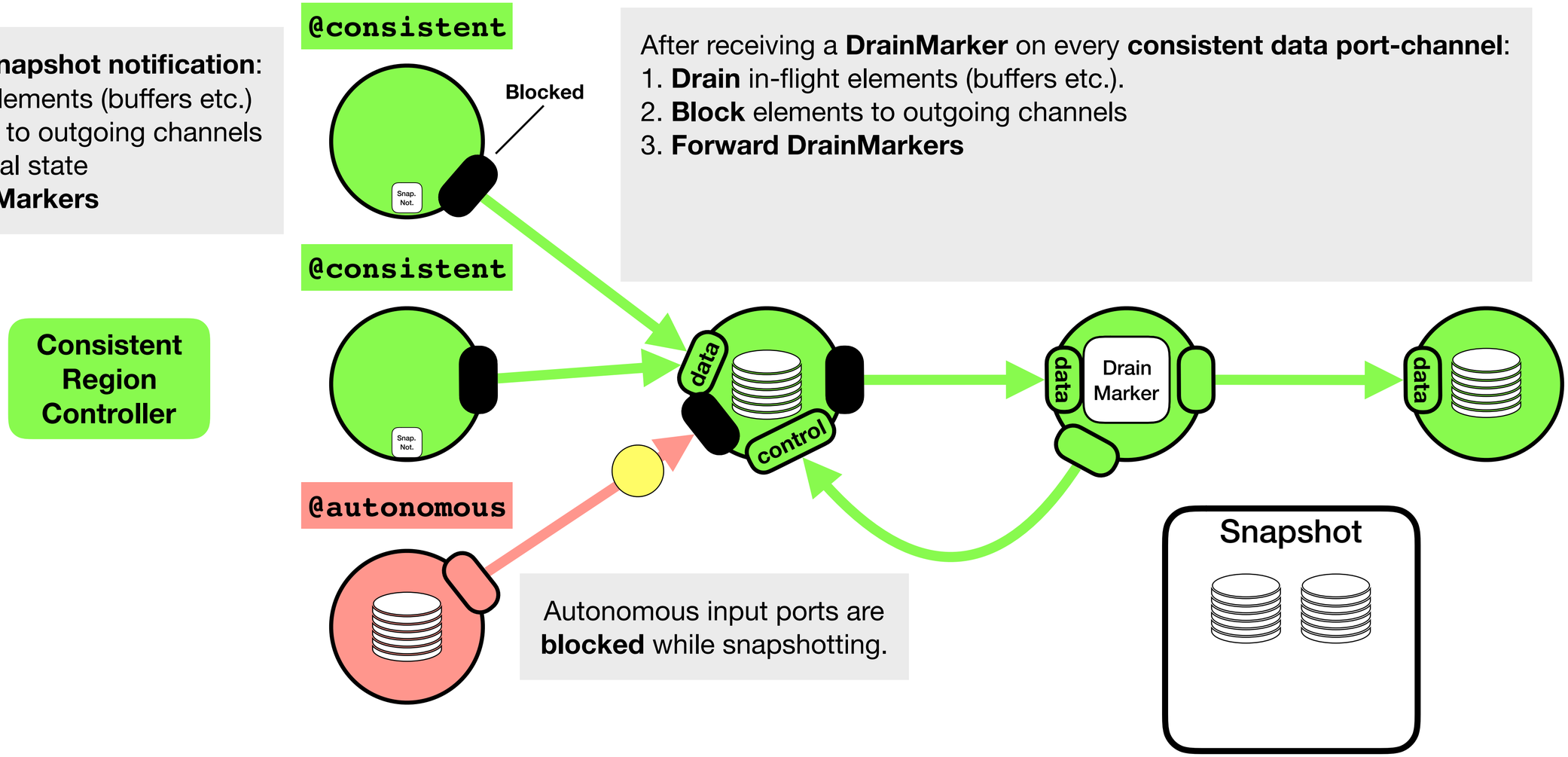

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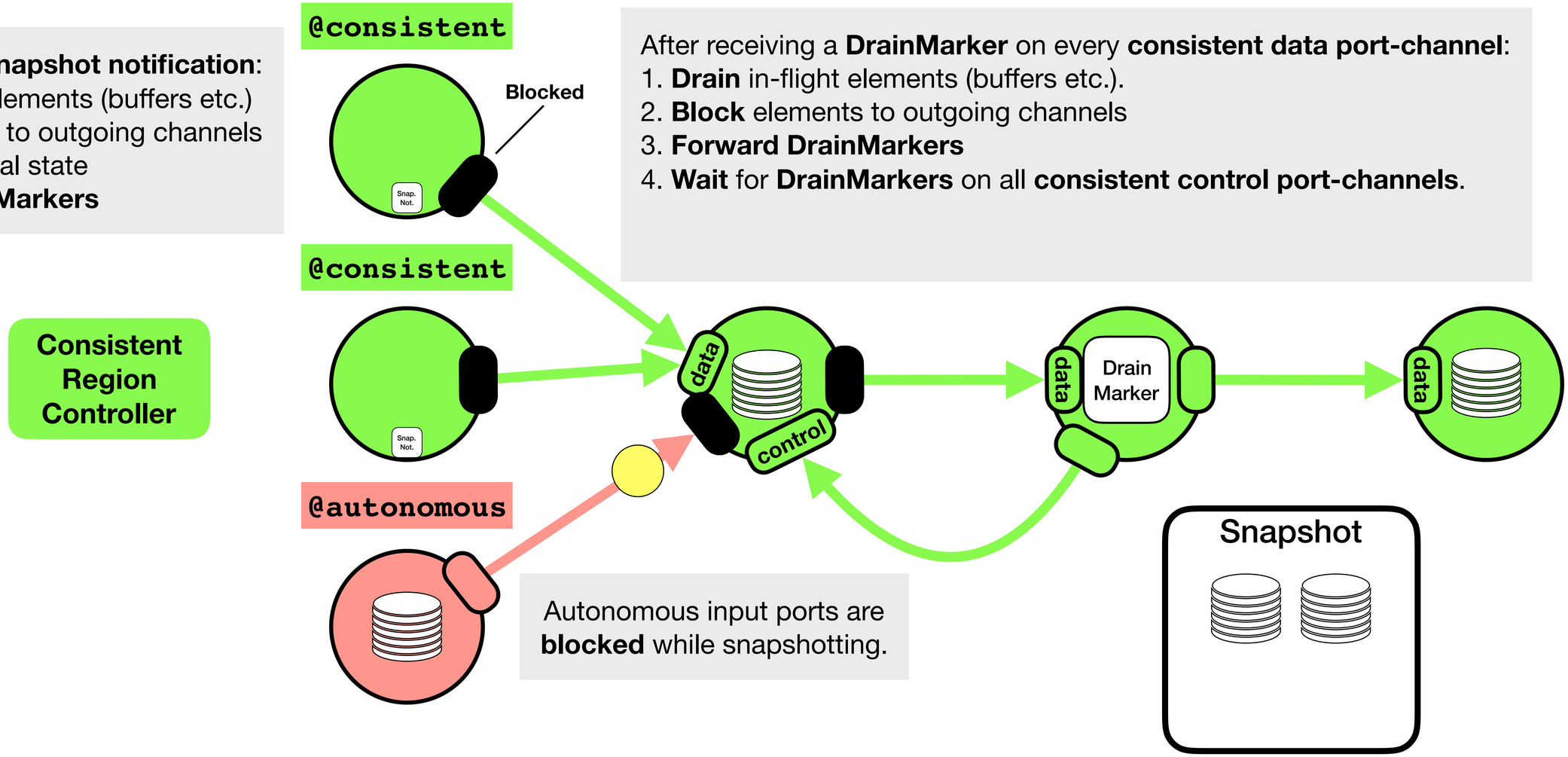

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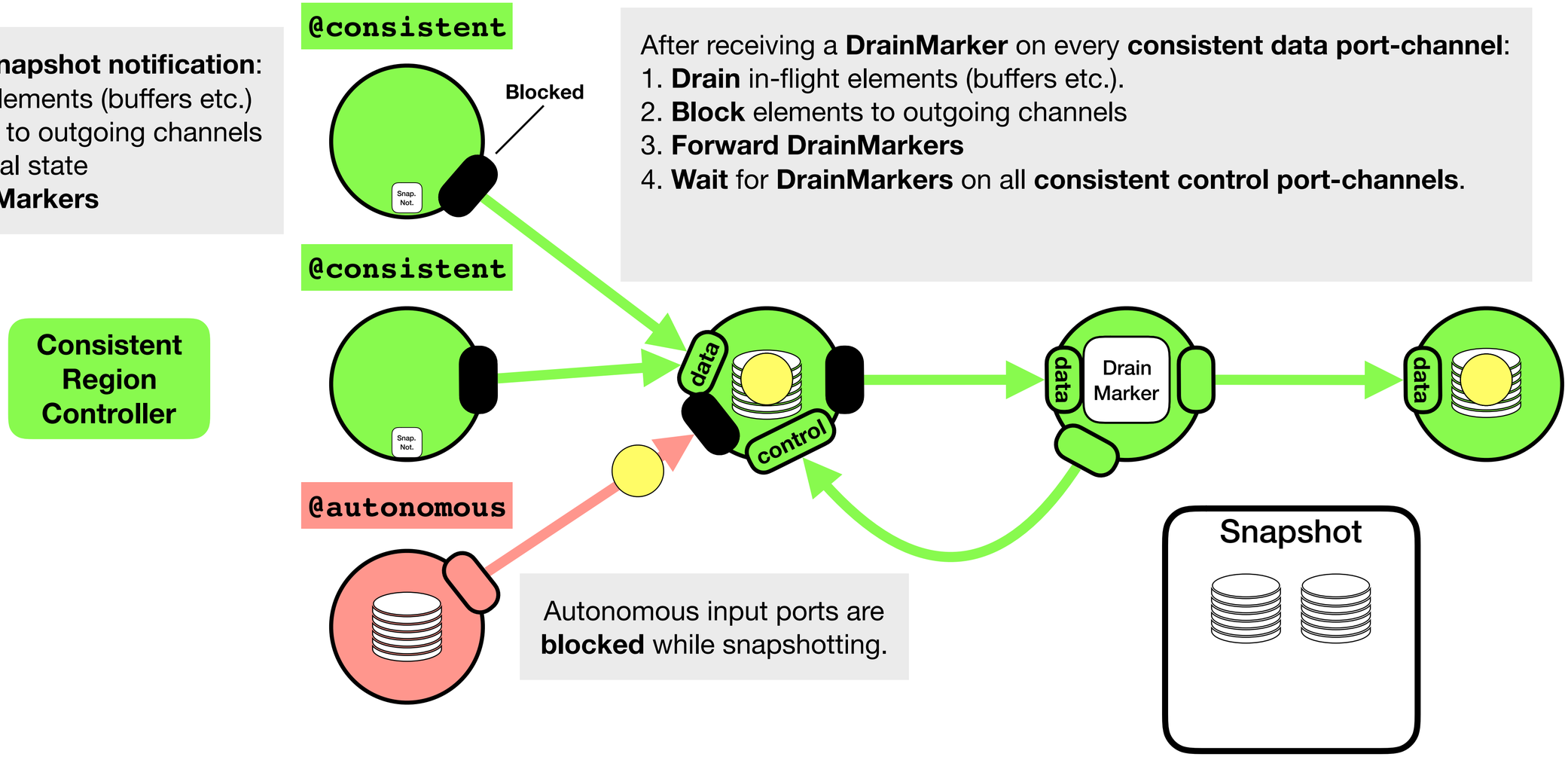

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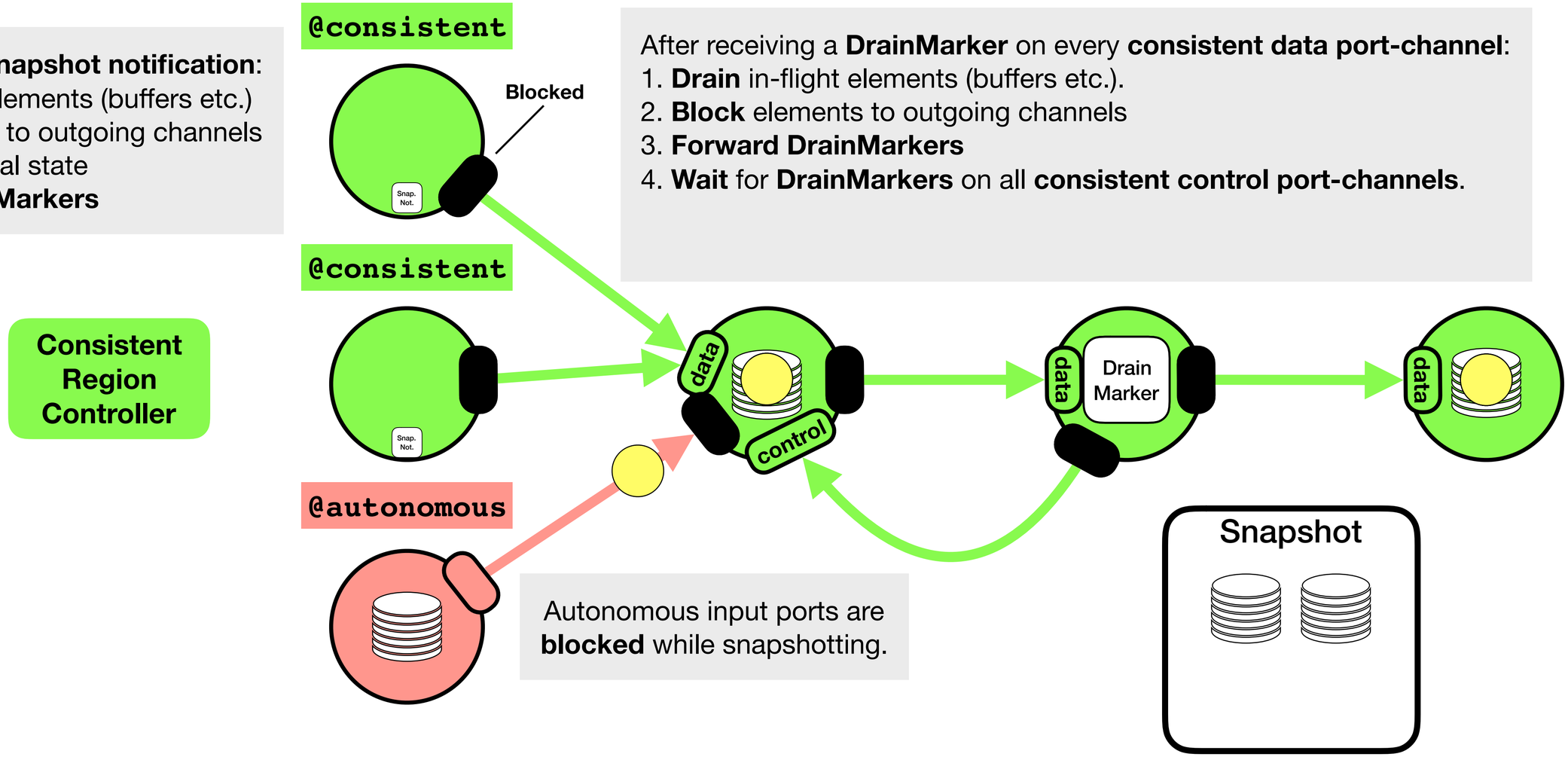

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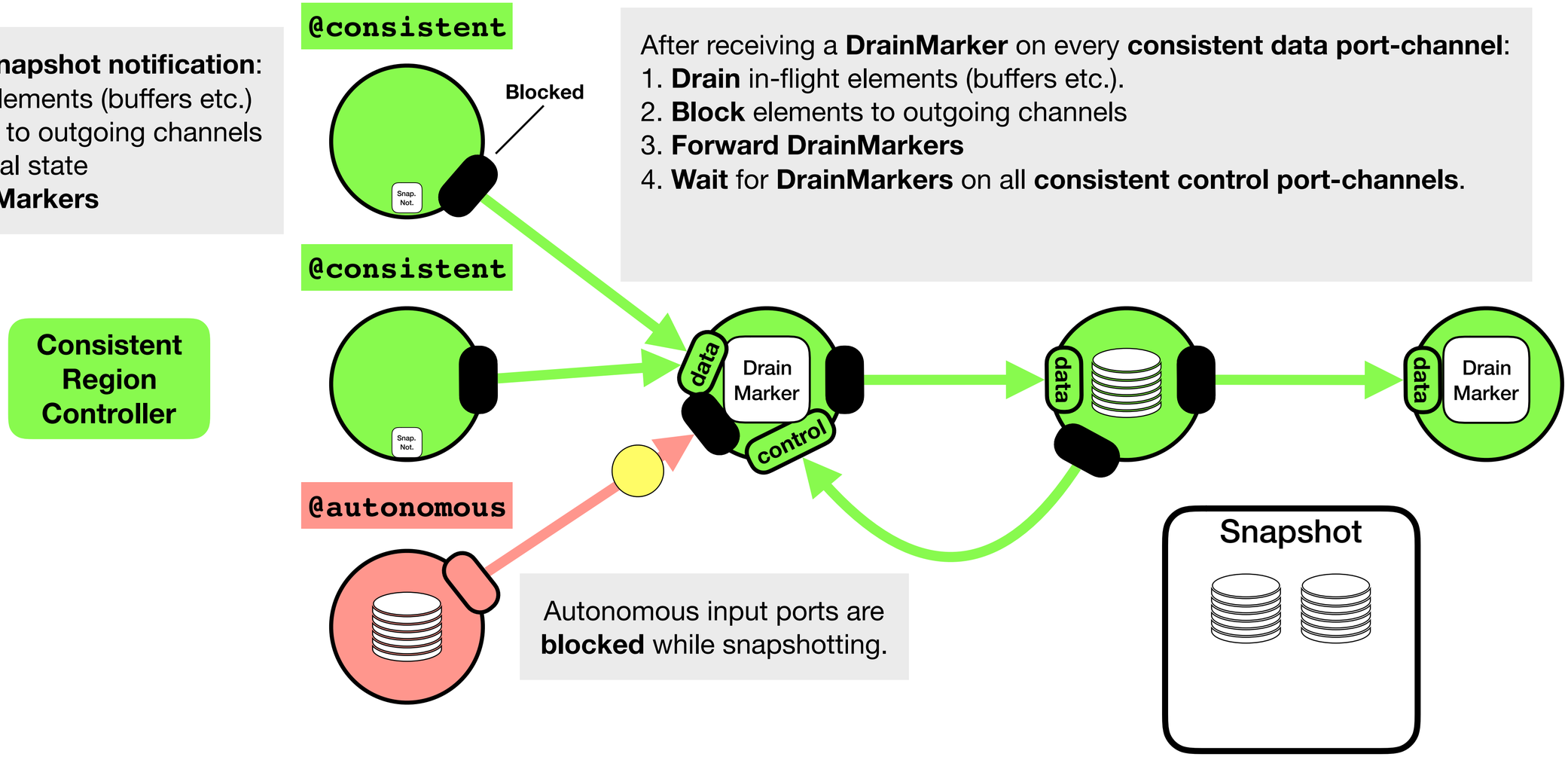

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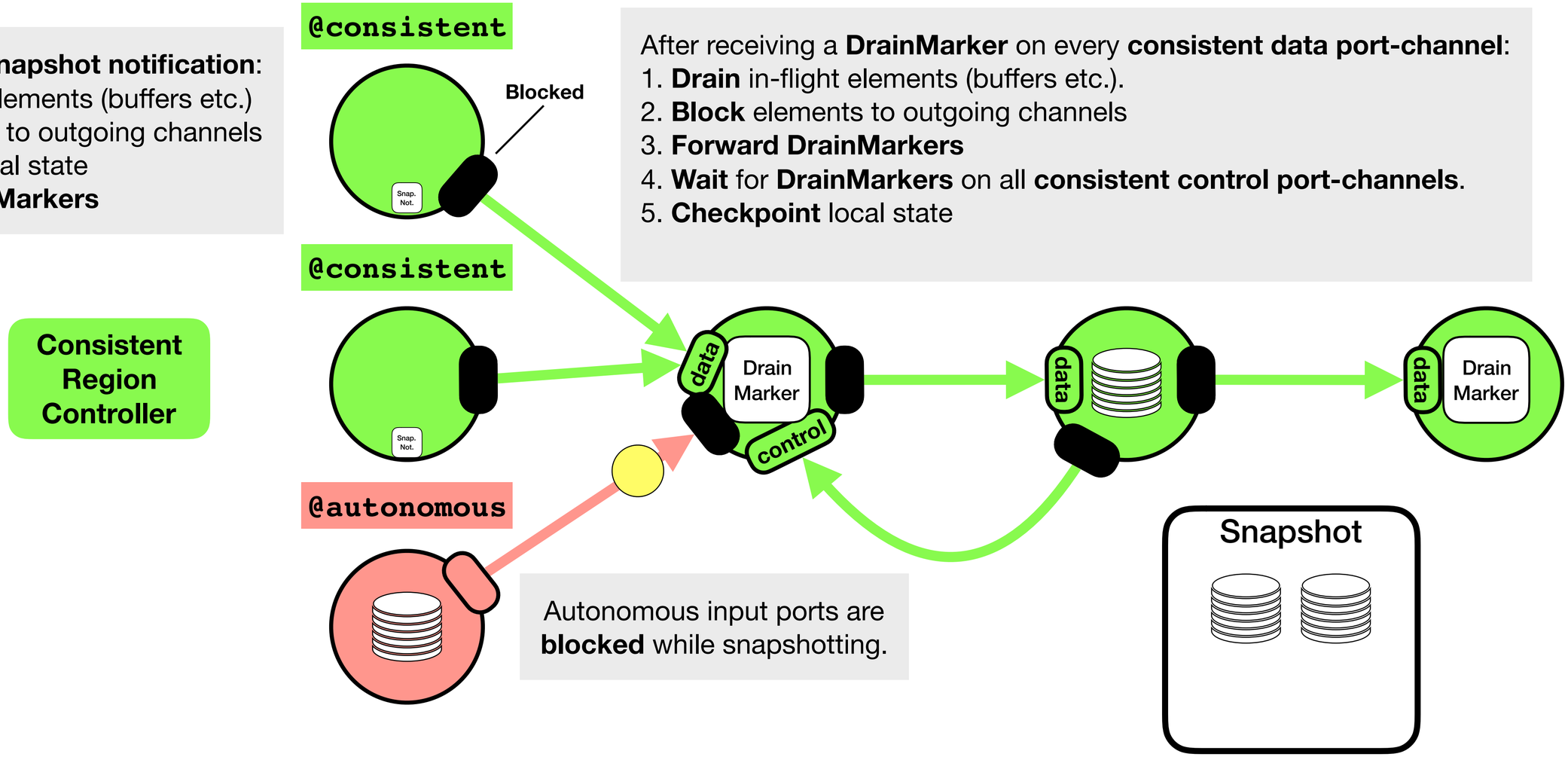

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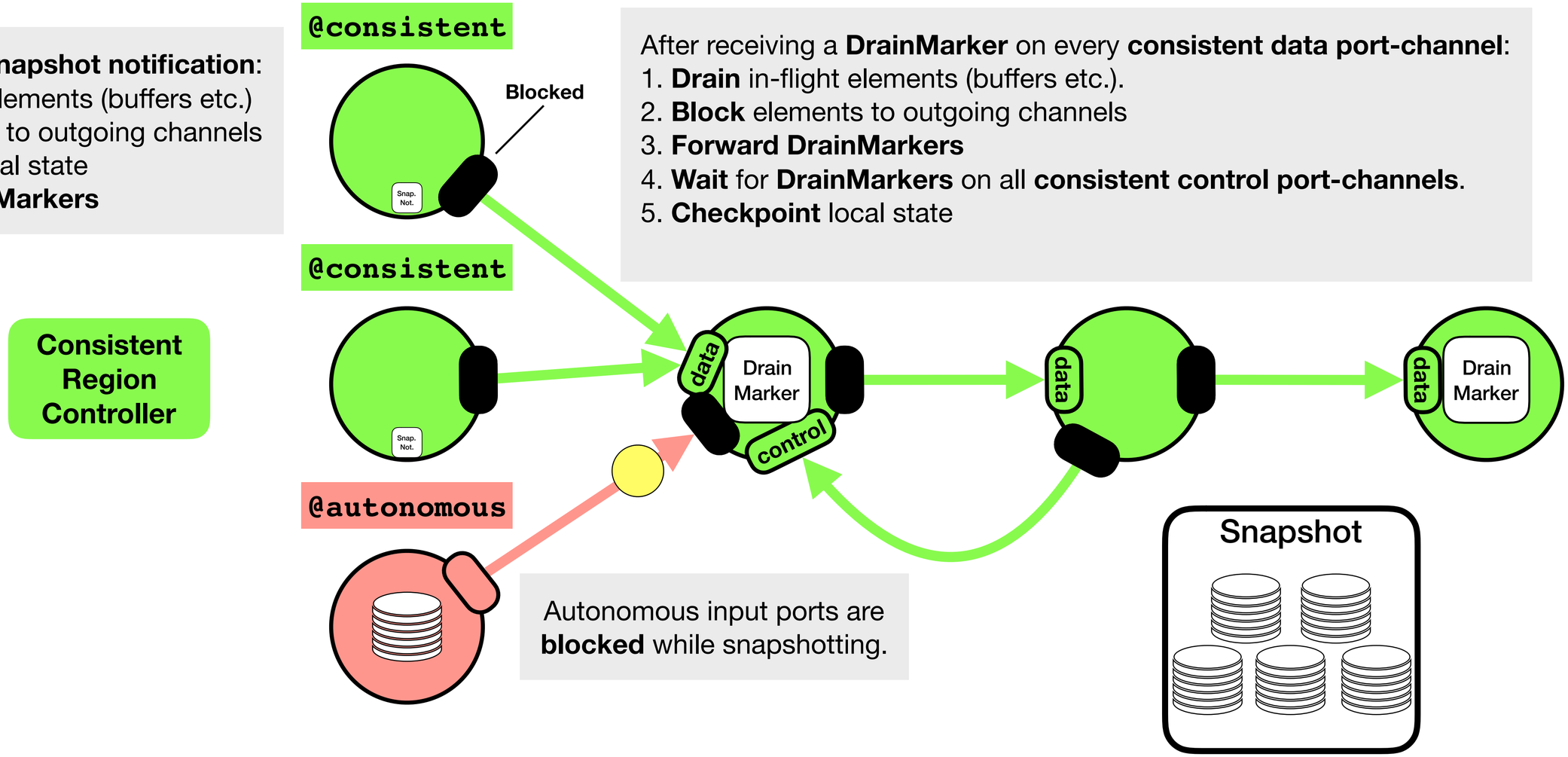

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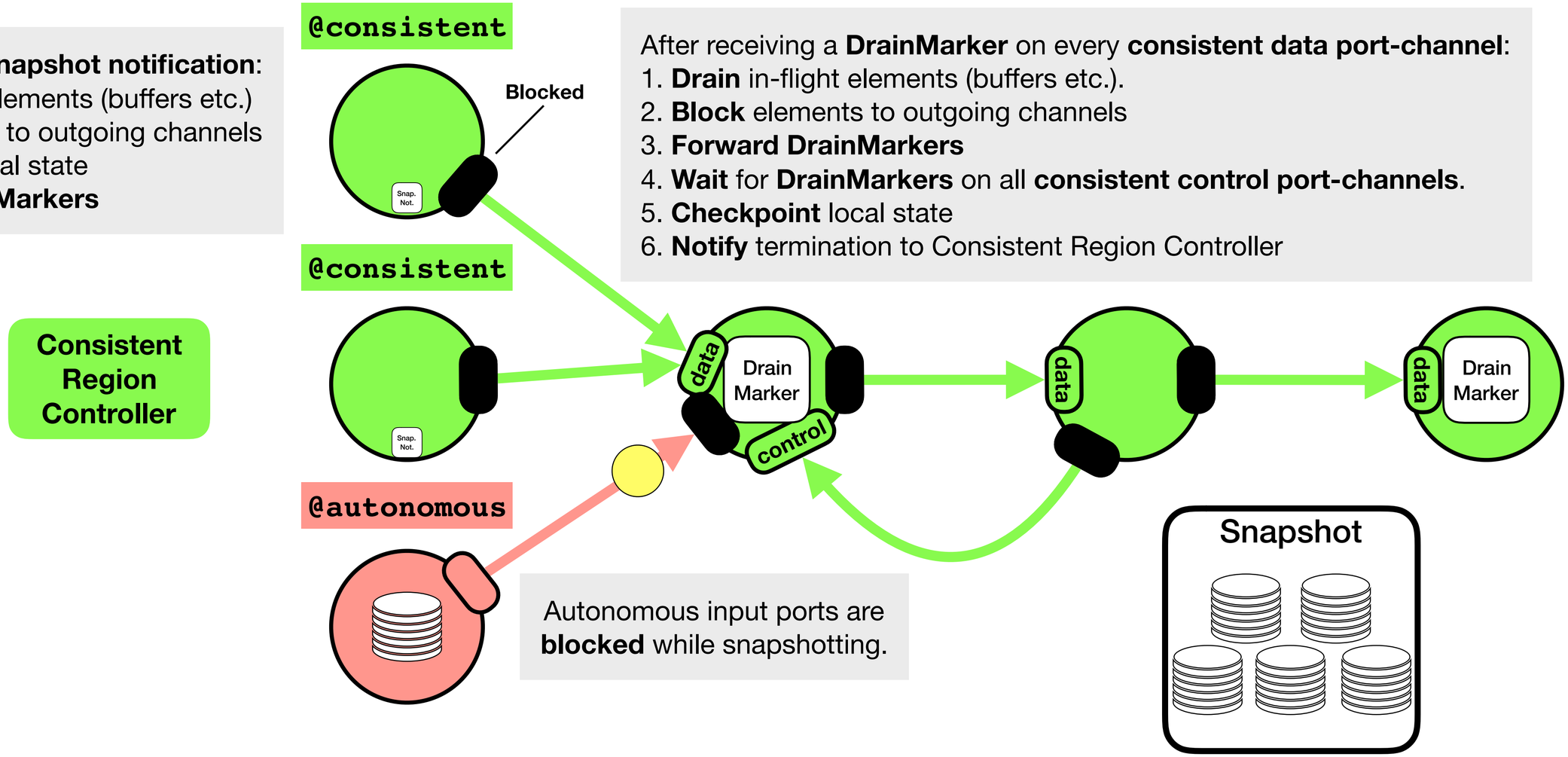

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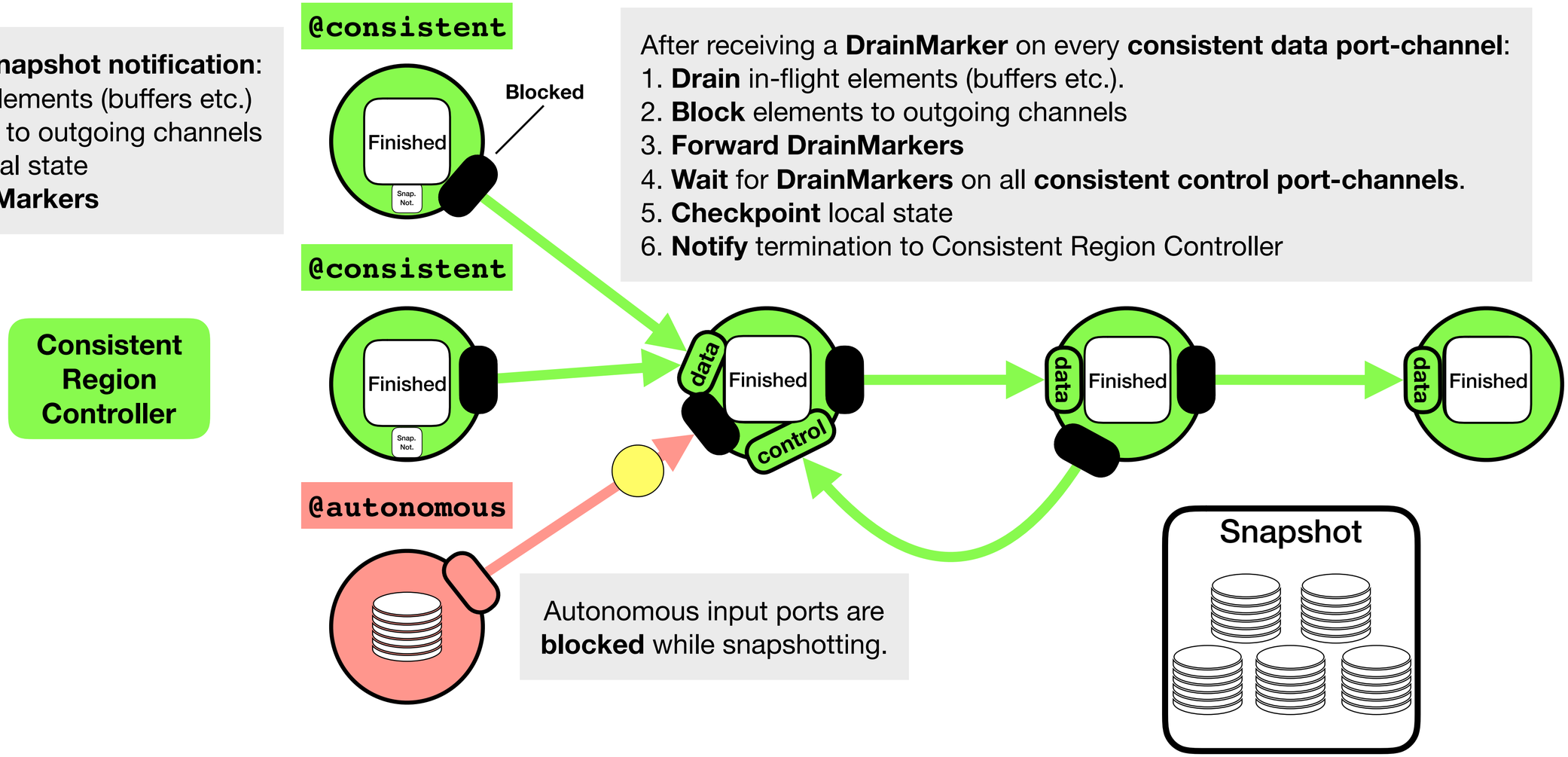

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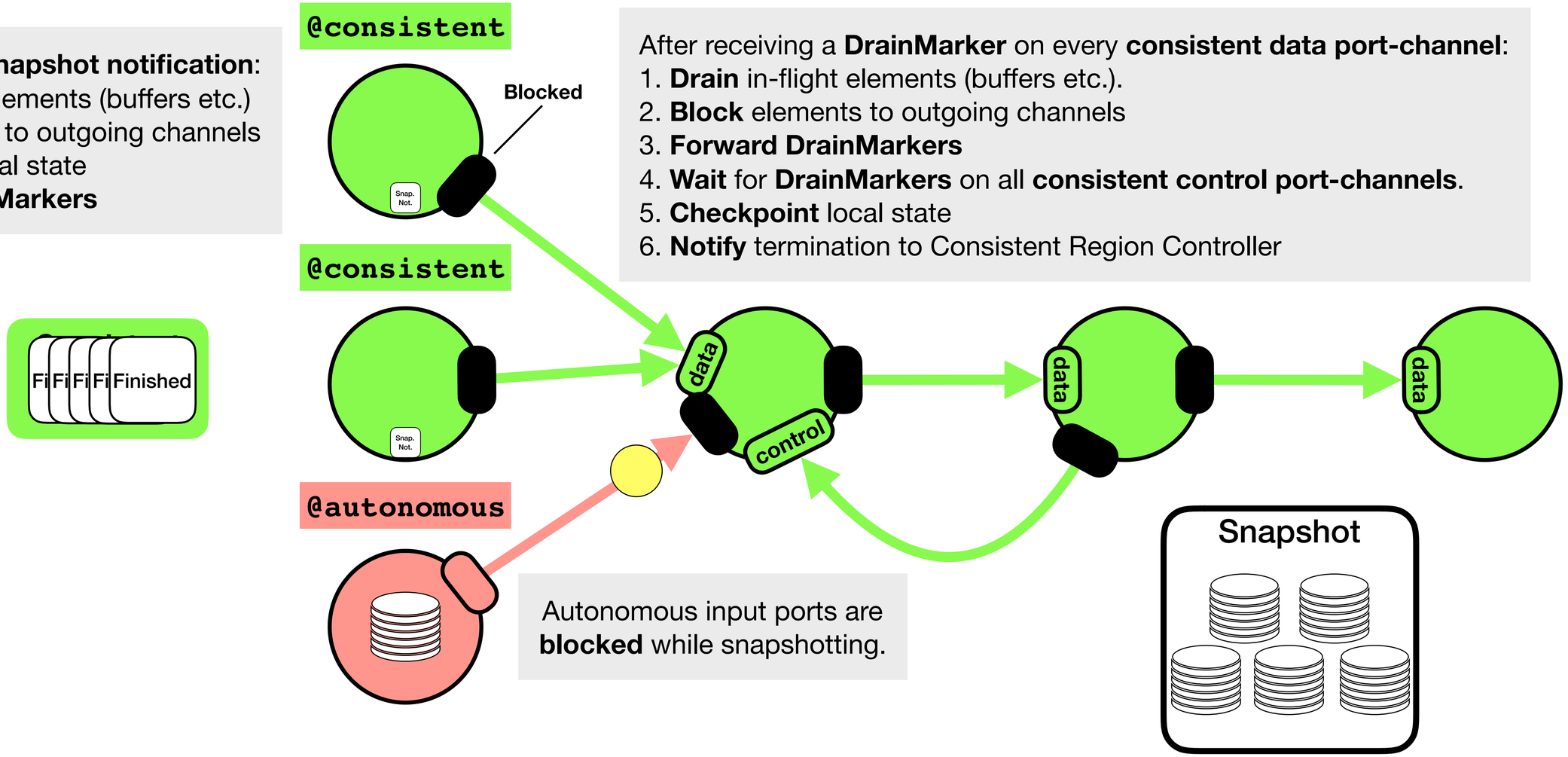

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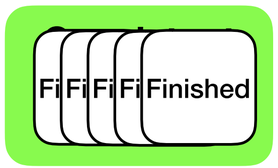

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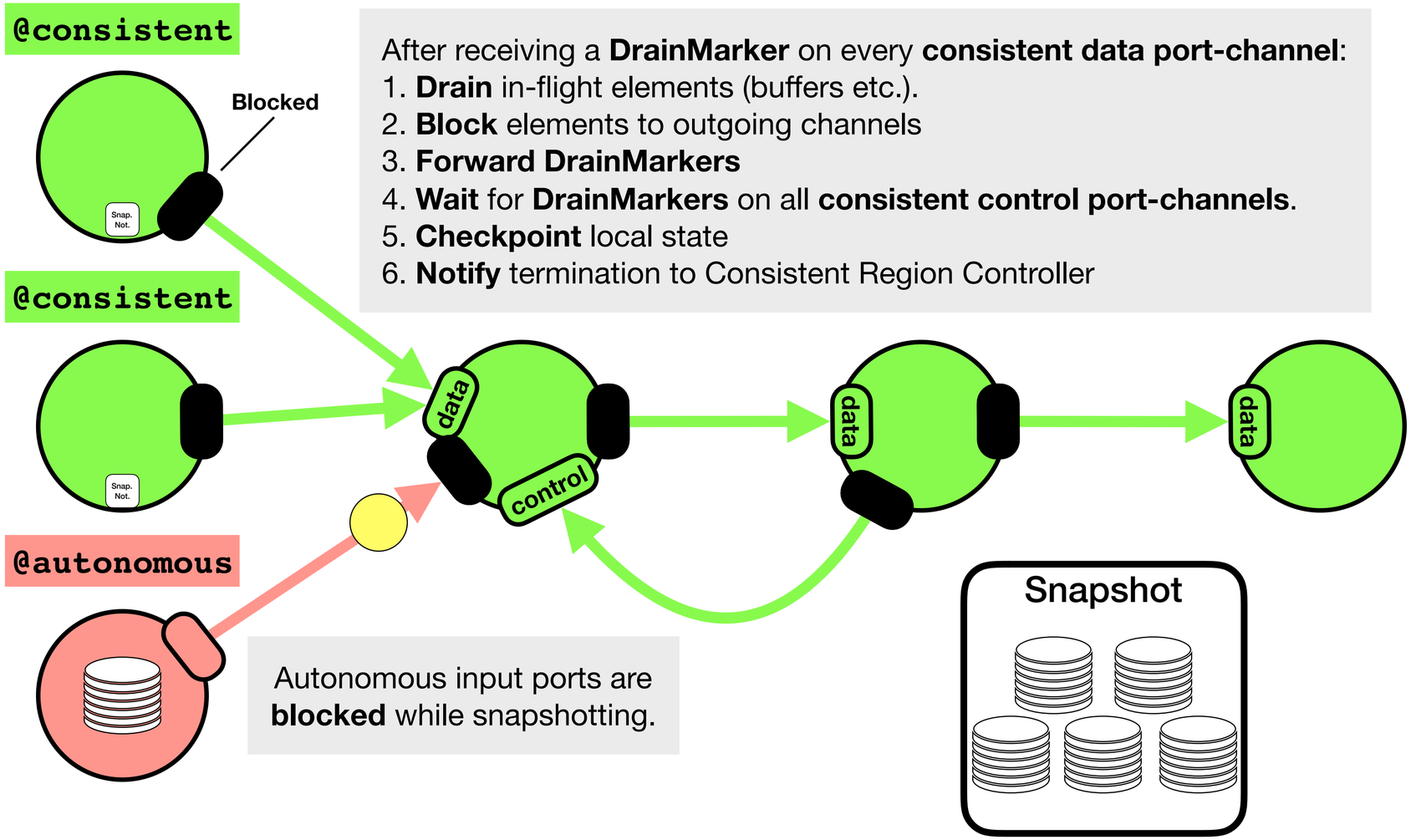

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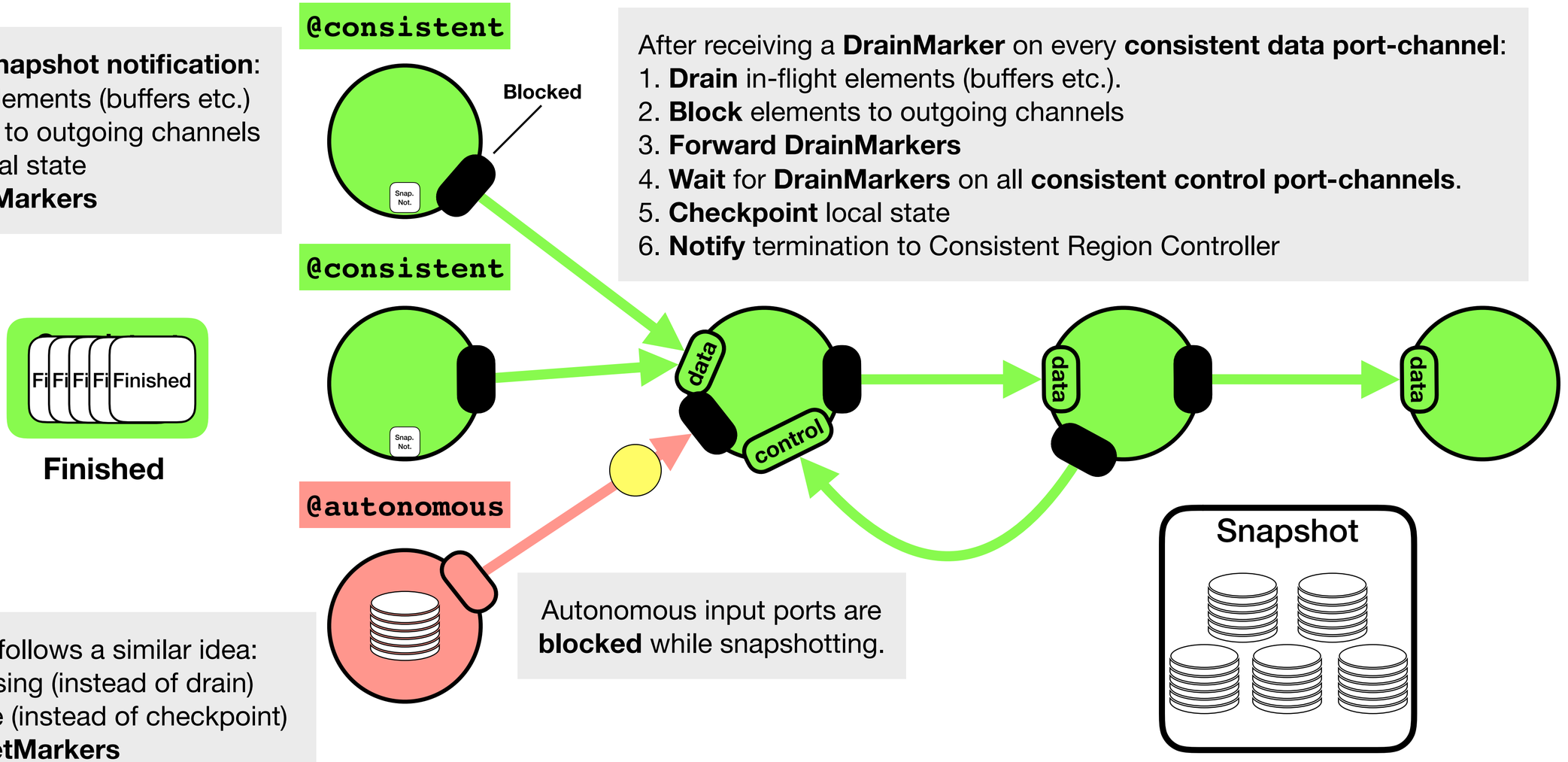

Autonomous input ports are **blocked** while snapshotting.

Failure recovery follows a similar idea:
1. **Pause** processing (instead of drain)
2. **Rollback** state (instead of checkpoint)
3. **Forward ResetMarkers**

Finally, start **replaying** elements

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A: Dataflow is **blocked** until sinks receive drain markers on all channels.

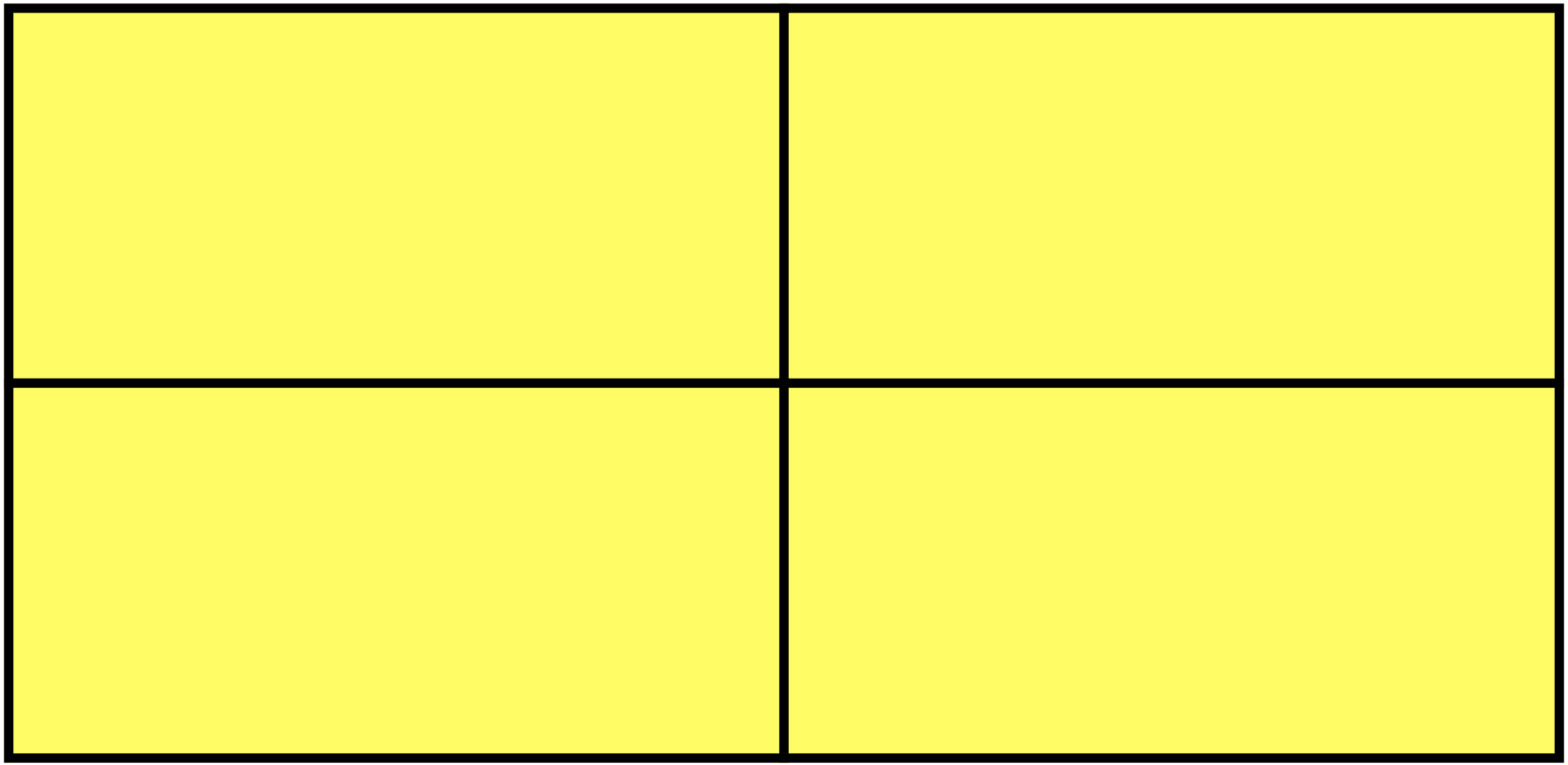
A: State checkpoints are currently **synchronous**.

Apache Spark

Structured Streaming

(Version 2.3.0)

Spark Structured Streaming - Problem Statement



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Solution: Unified API & Runtime for Stream & Batch

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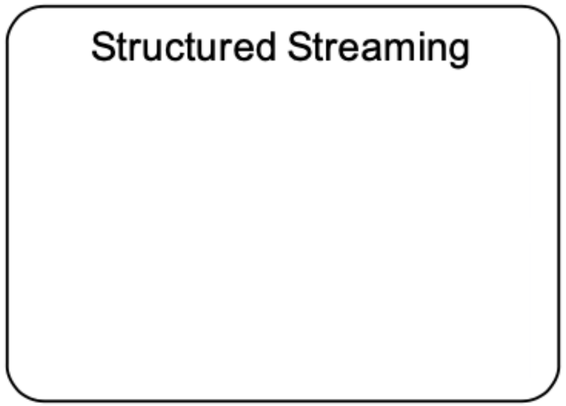

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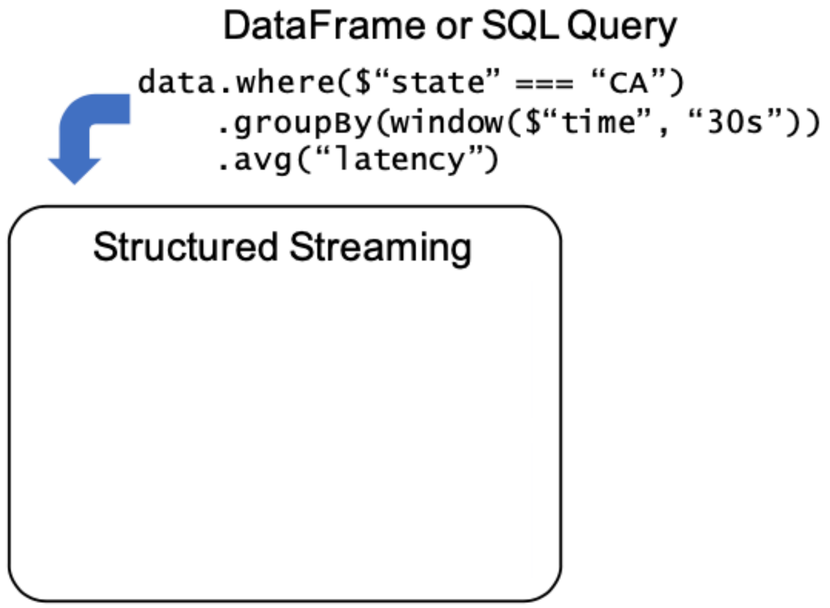

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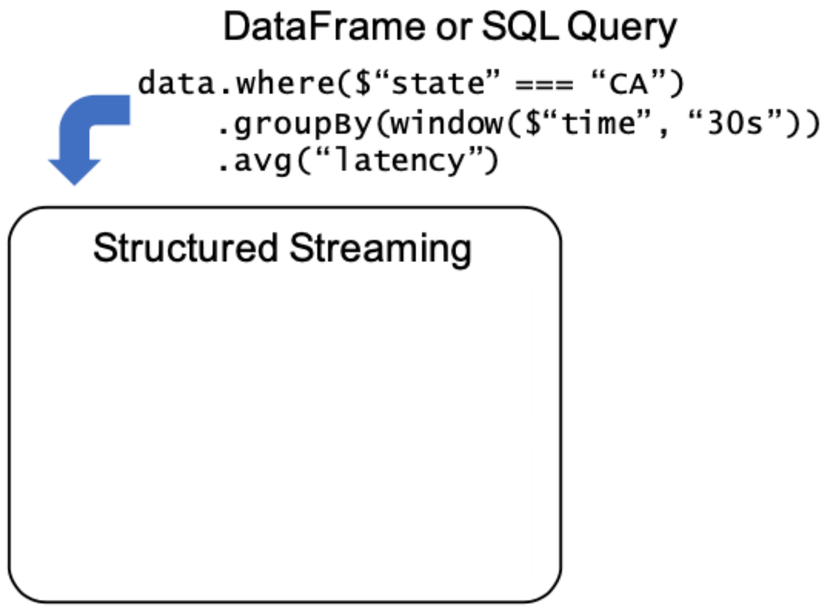

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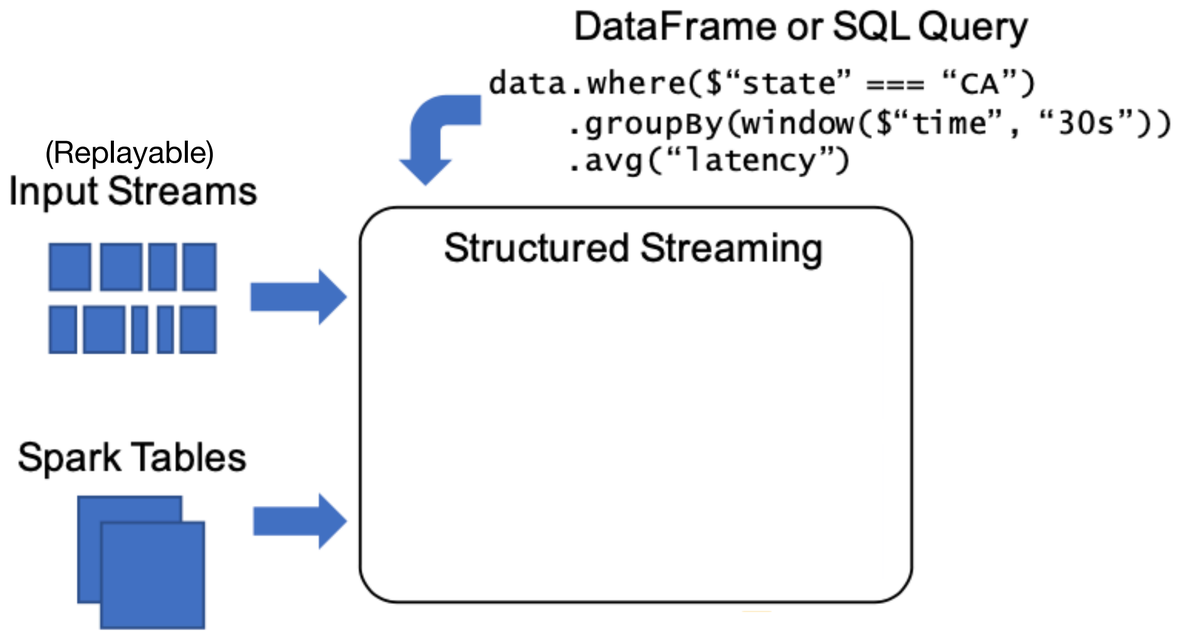

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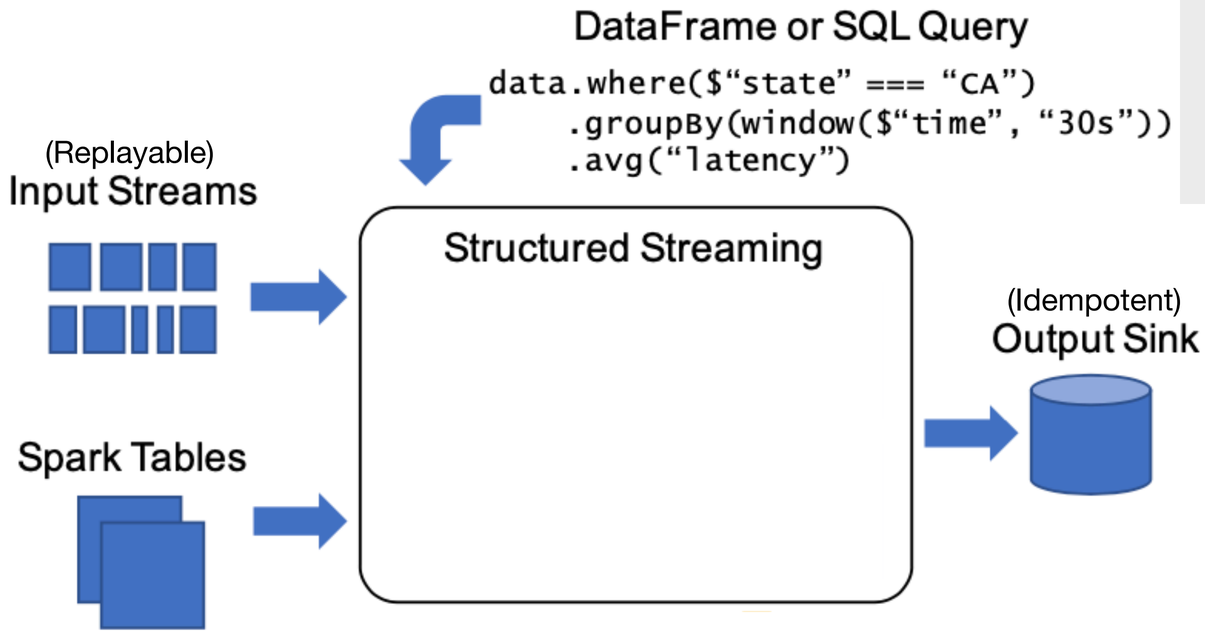

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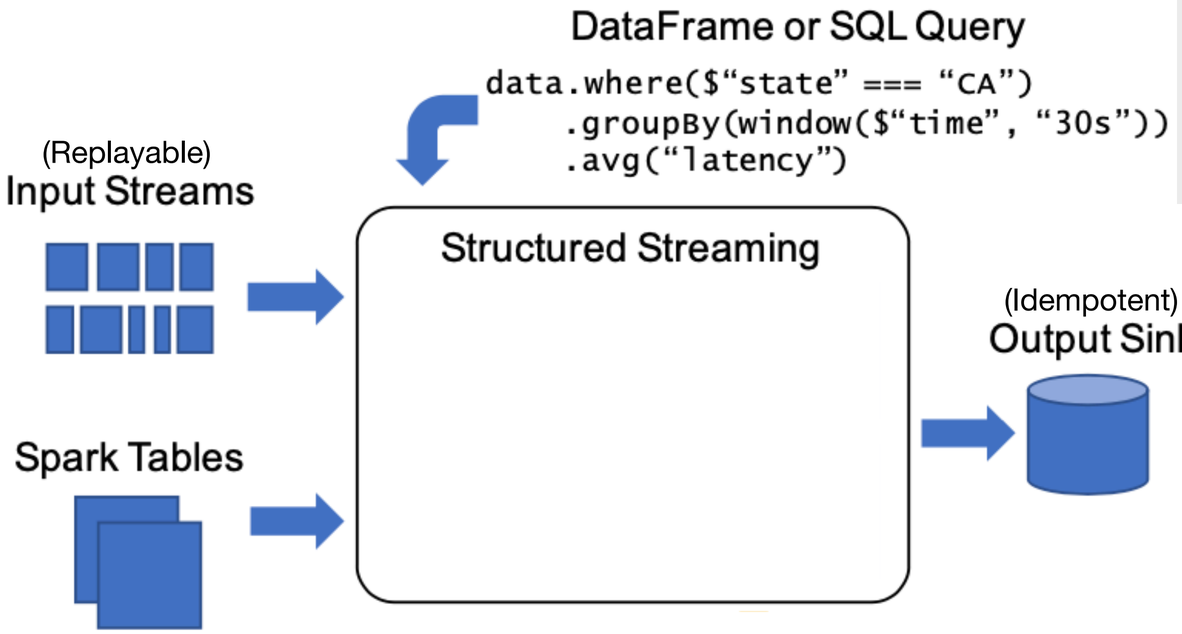
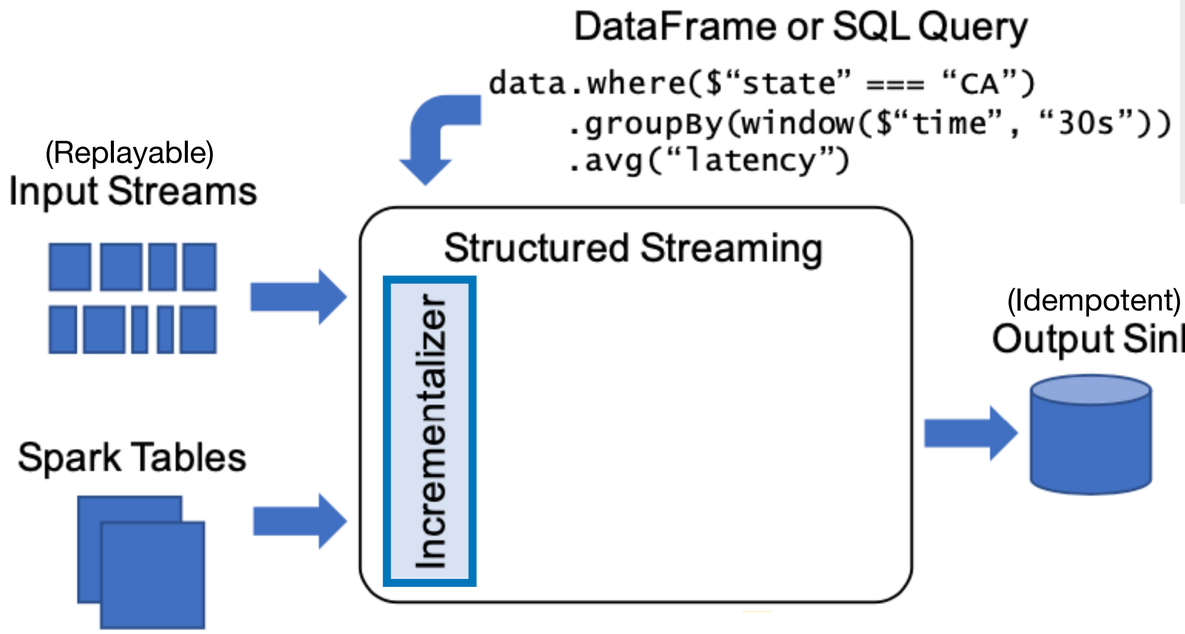


API additions
- Event-time
- Stateful operators
- Triggers (When to output)

Output modes
(What to output)
- Complete
- Append
- Update

Spark Structured Streaming - System Overview



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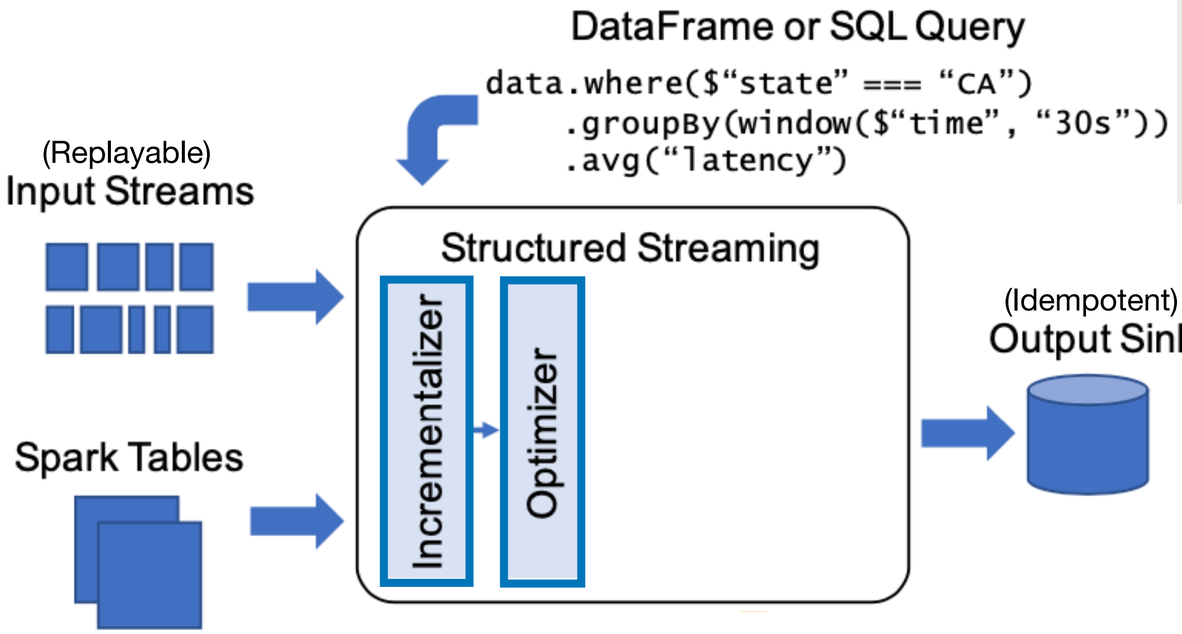

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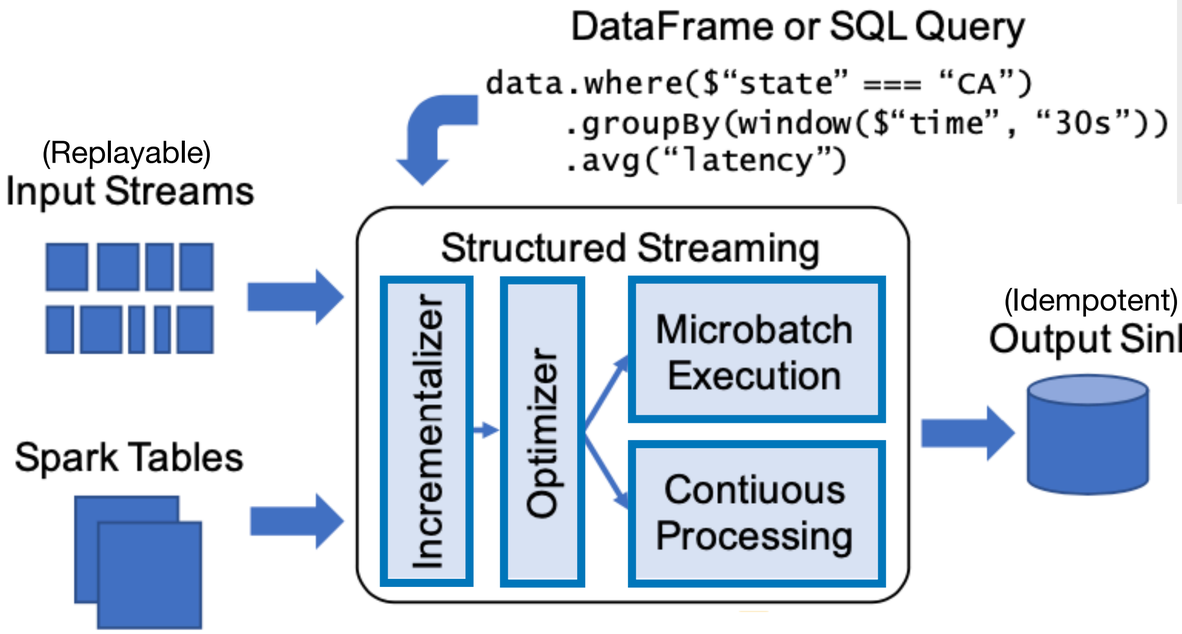

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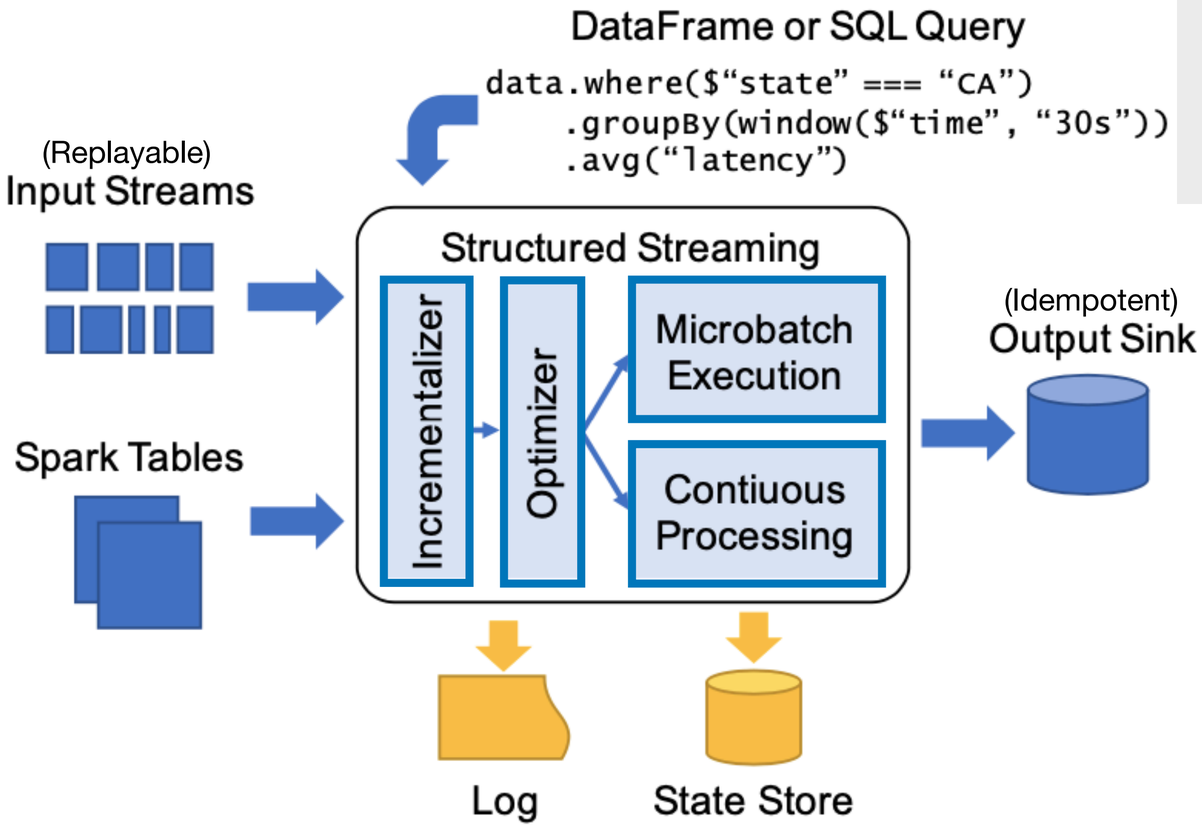

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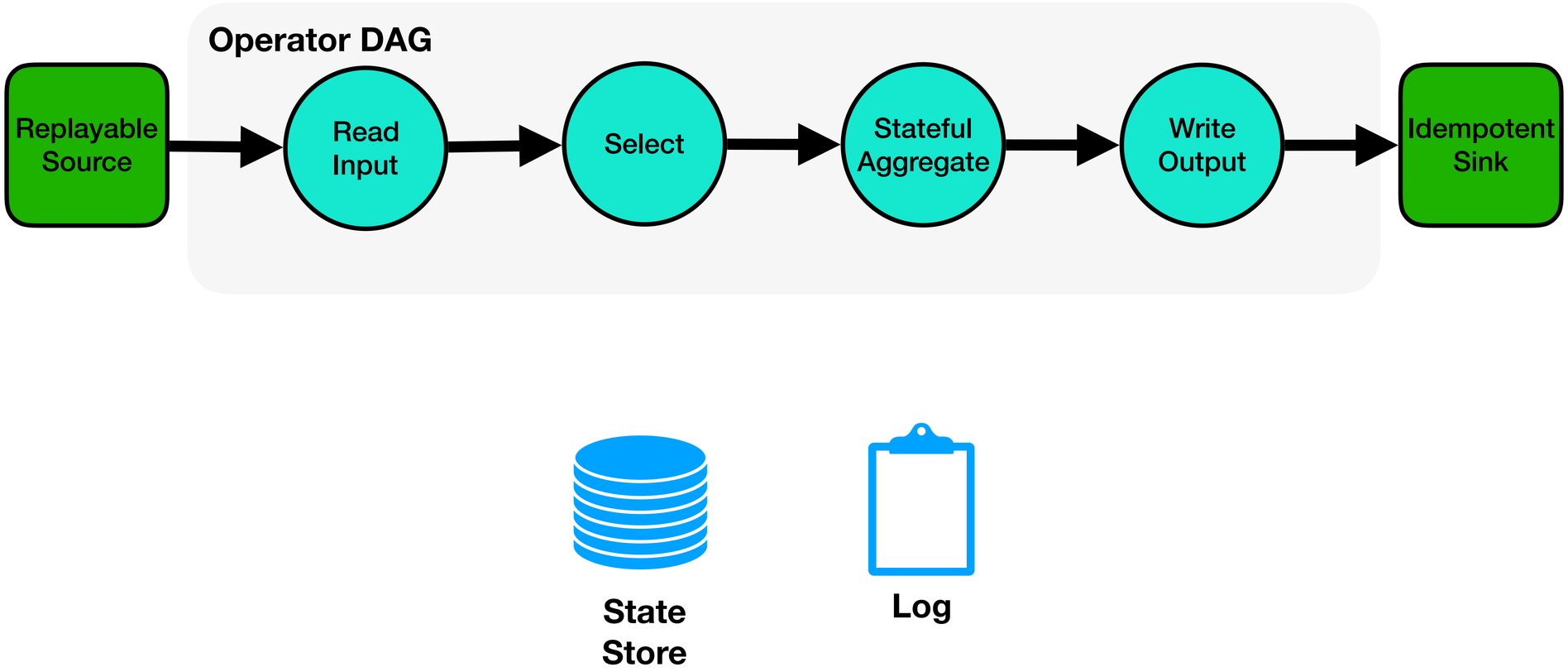
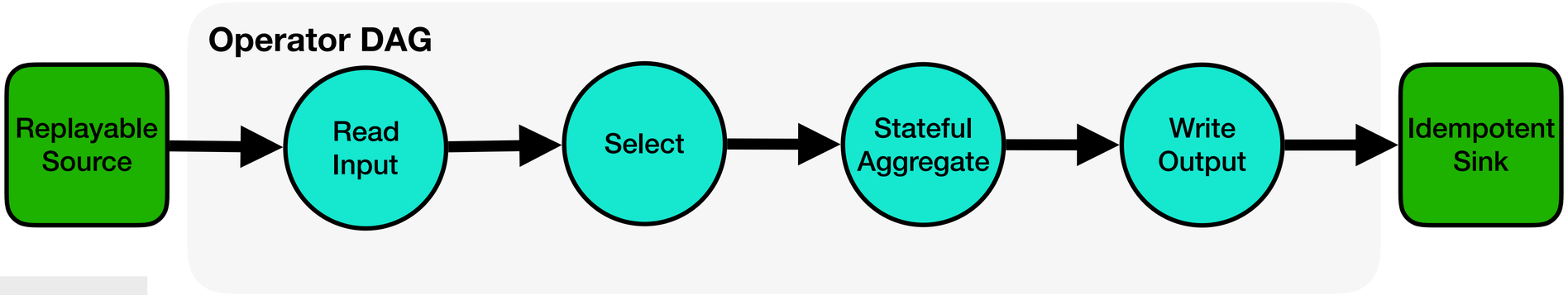
Spark Structured Streaming - Checkpointing

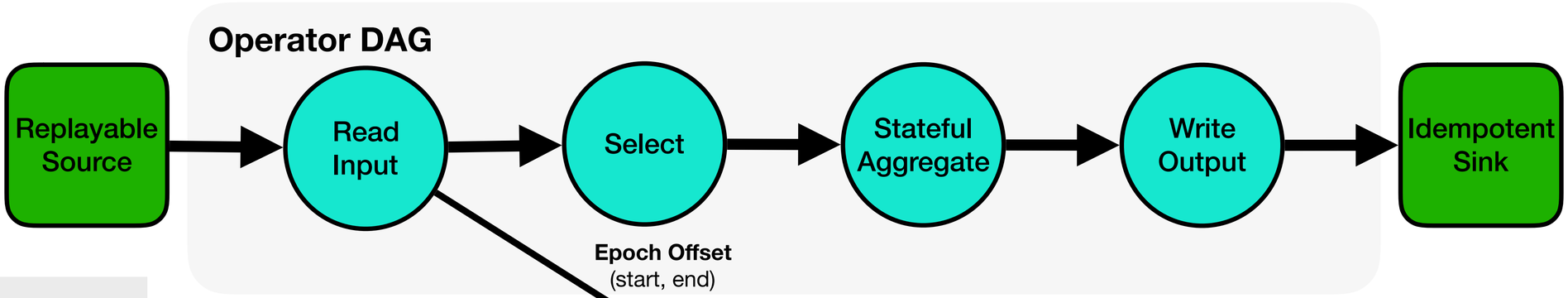


Spark Structured Streaming - Checkpointing



Spark's master node divides the input into **epochs**

Spark Structured Streaming - Checkpointing



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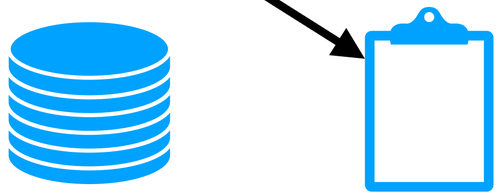
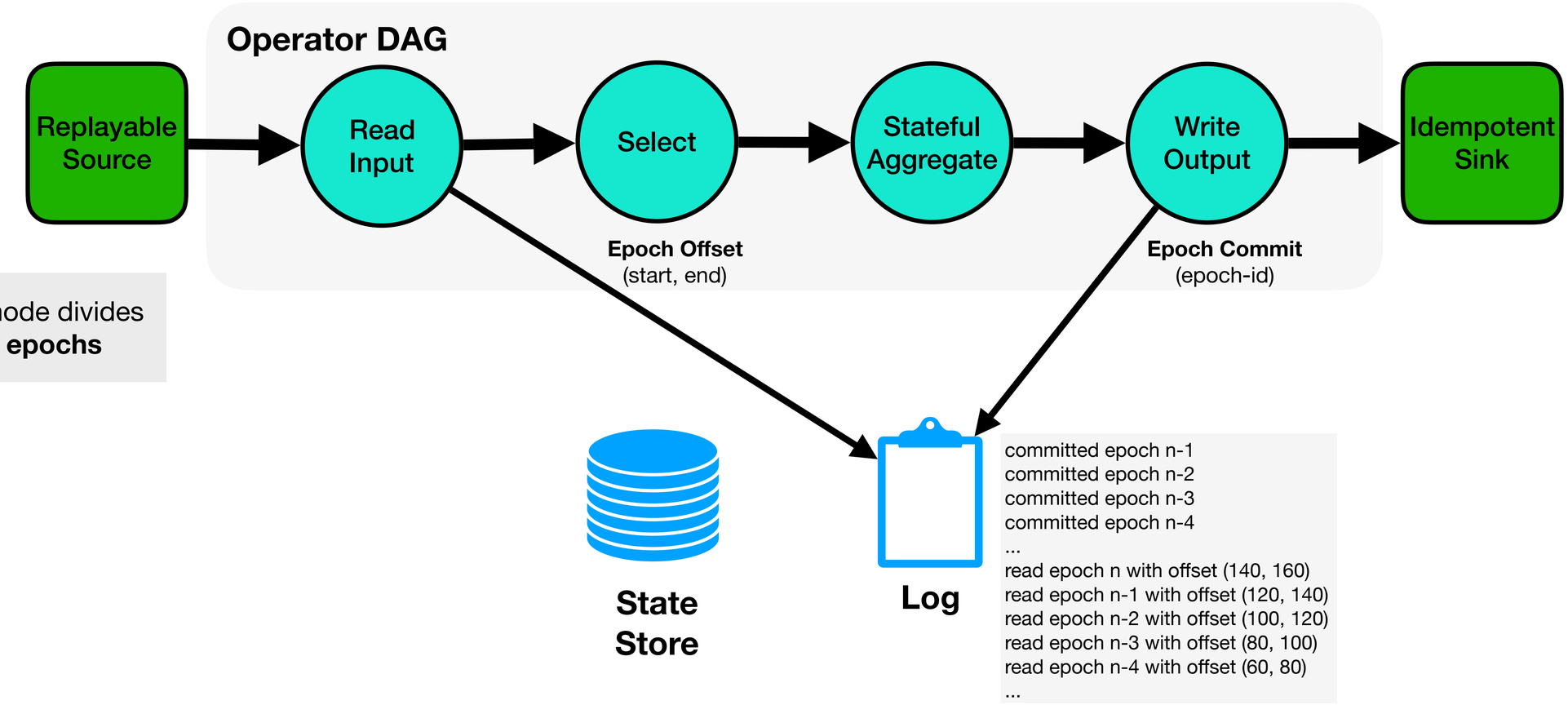


State Store

Log

read epoch n with offset (140, 160)
read epoch n-1 with offset (120, 140)
read epoch n-2 with offset (100, 120)
read epoch n-3 with offset (80, 100)
read epoch n-4 with offset (60, 80)
...

Spark Structured Streaming - Checkpointing



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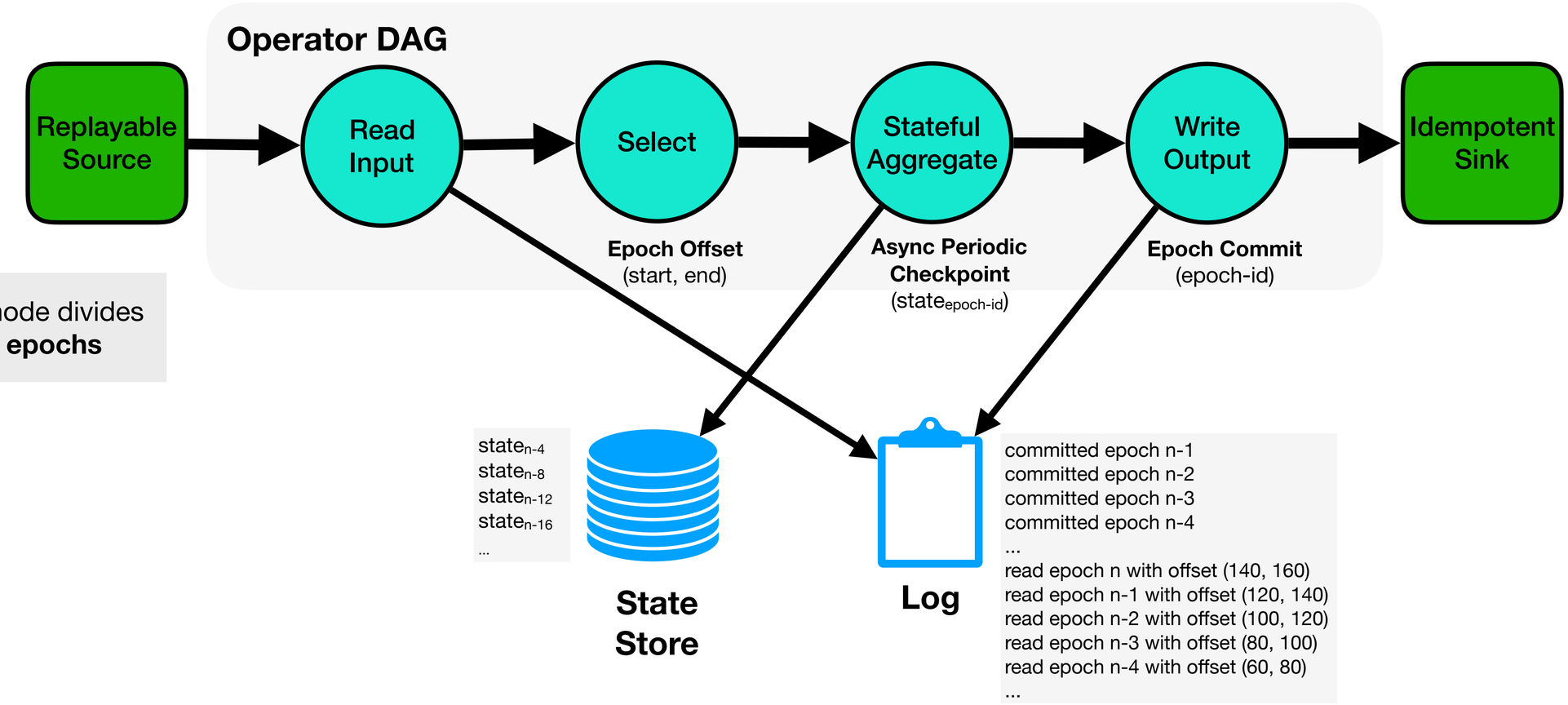

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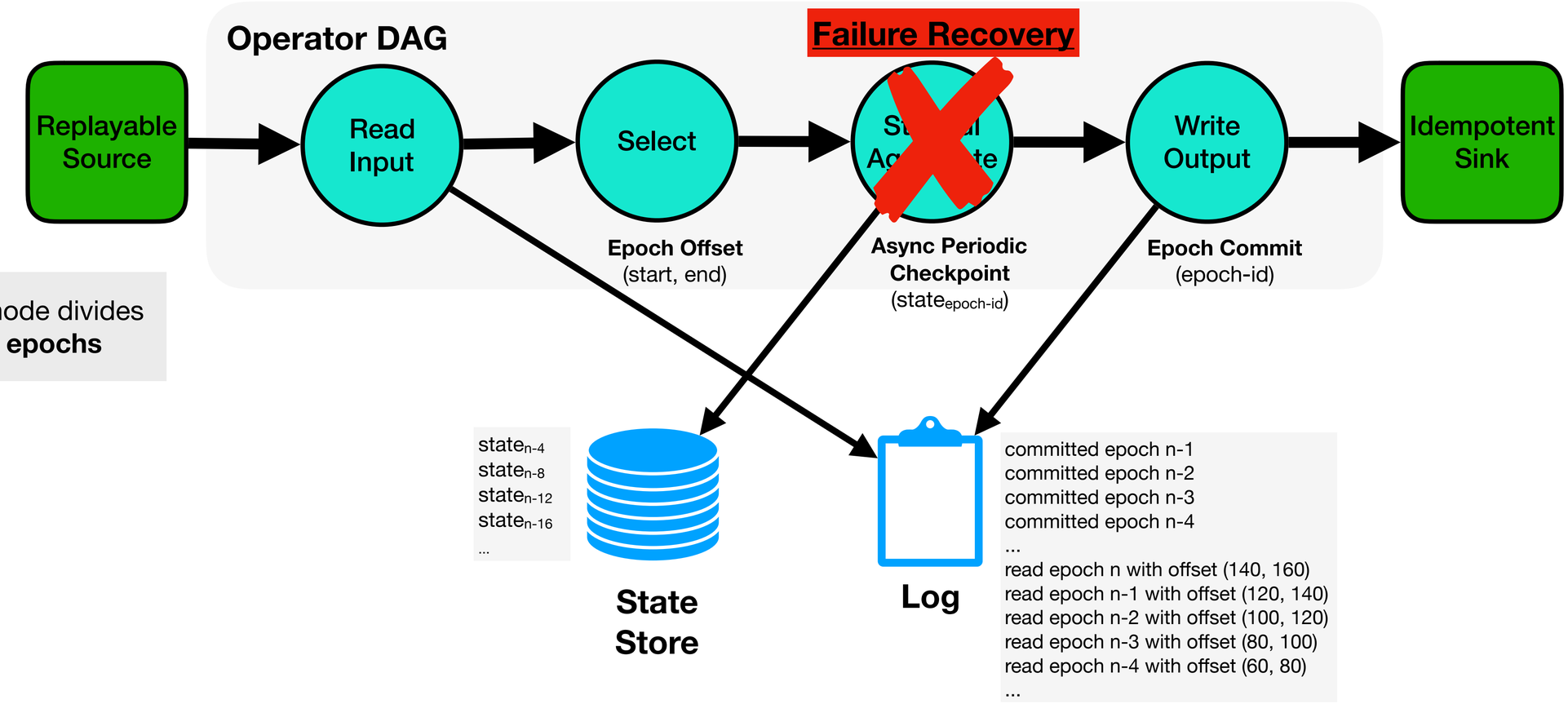

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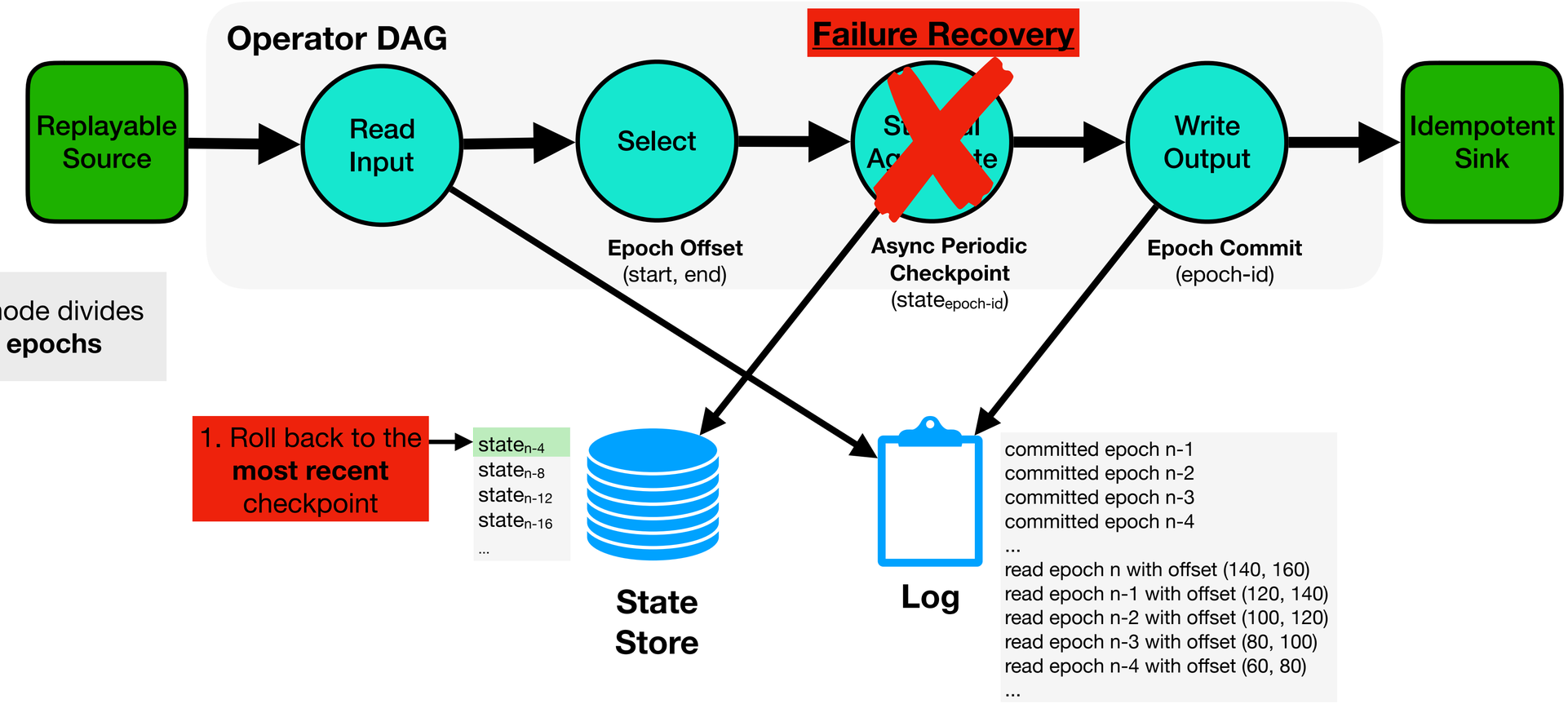

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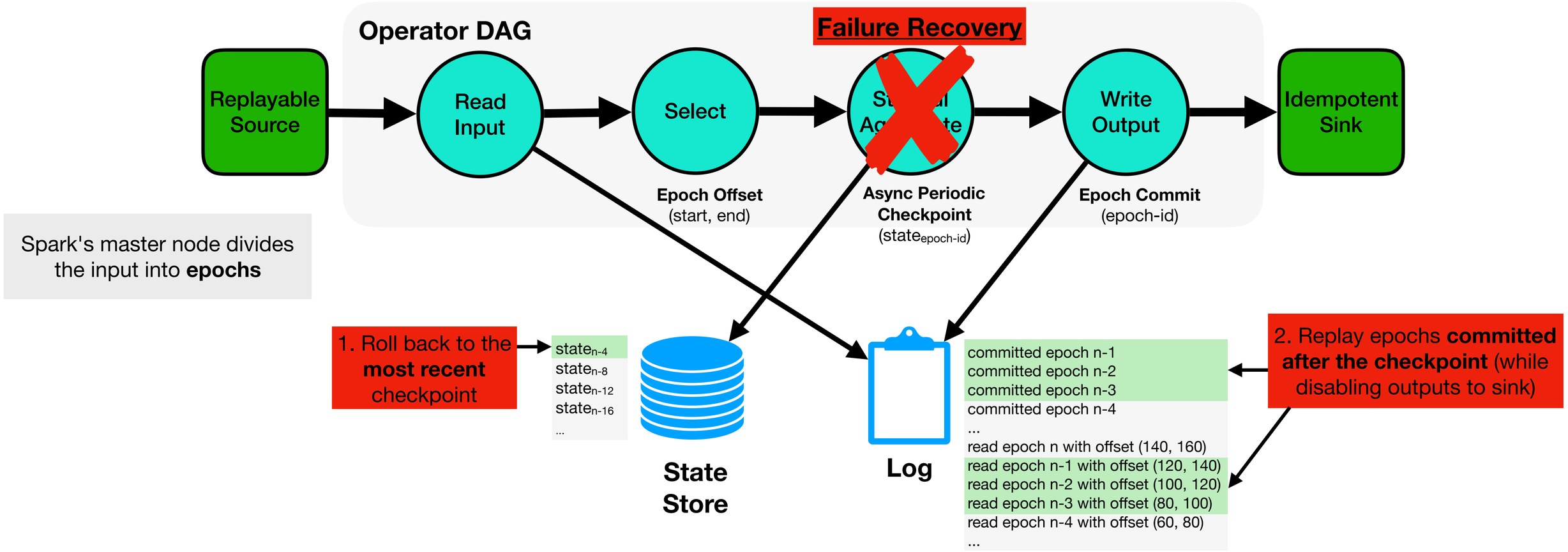

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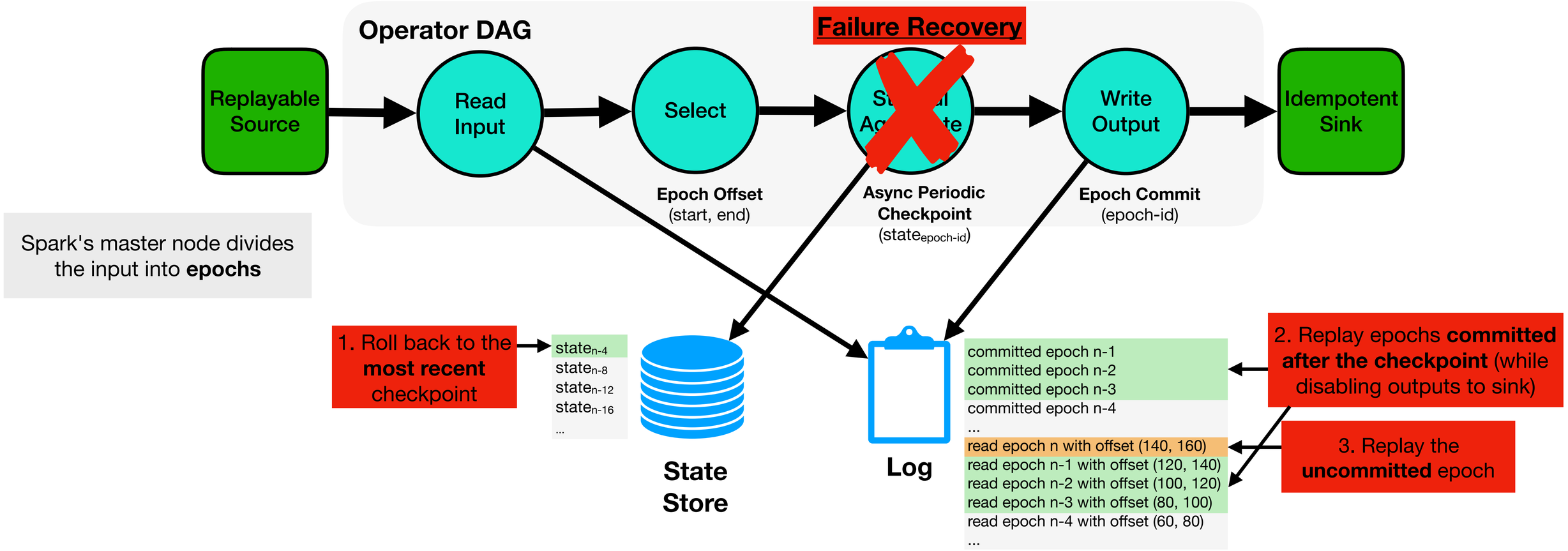

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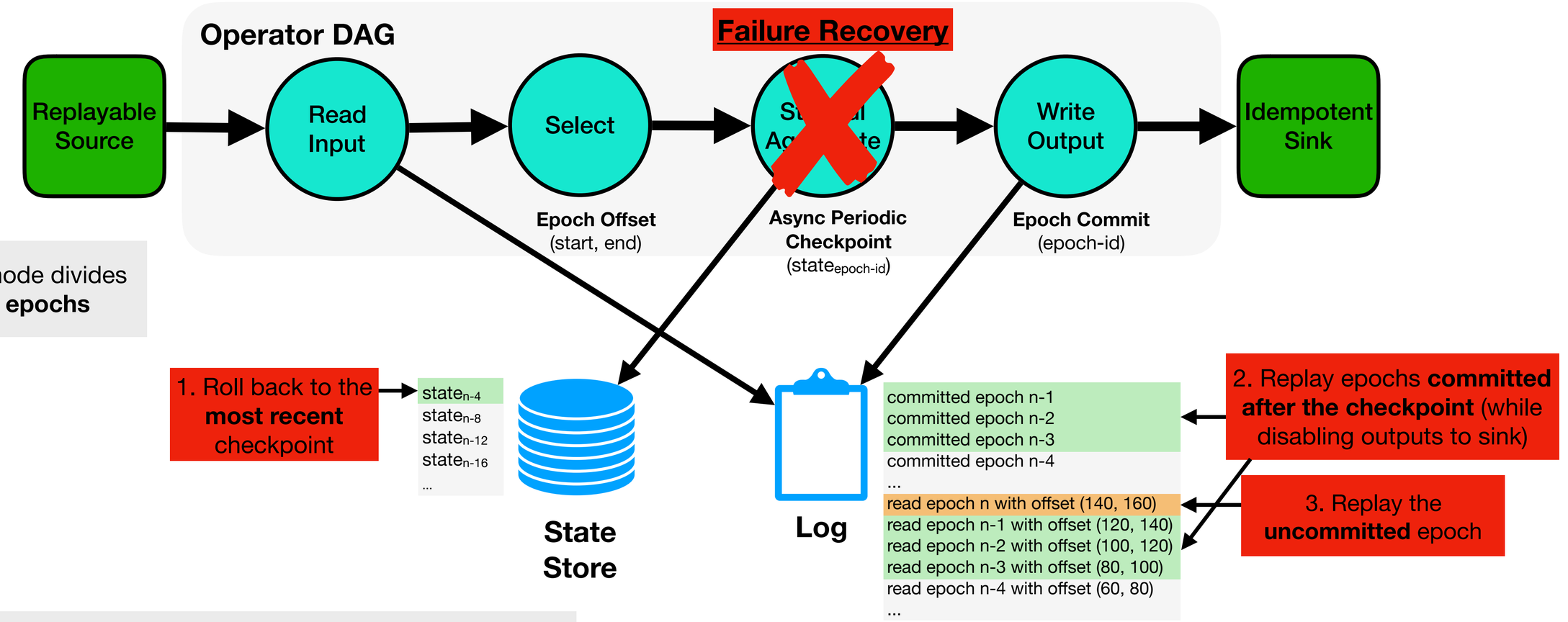
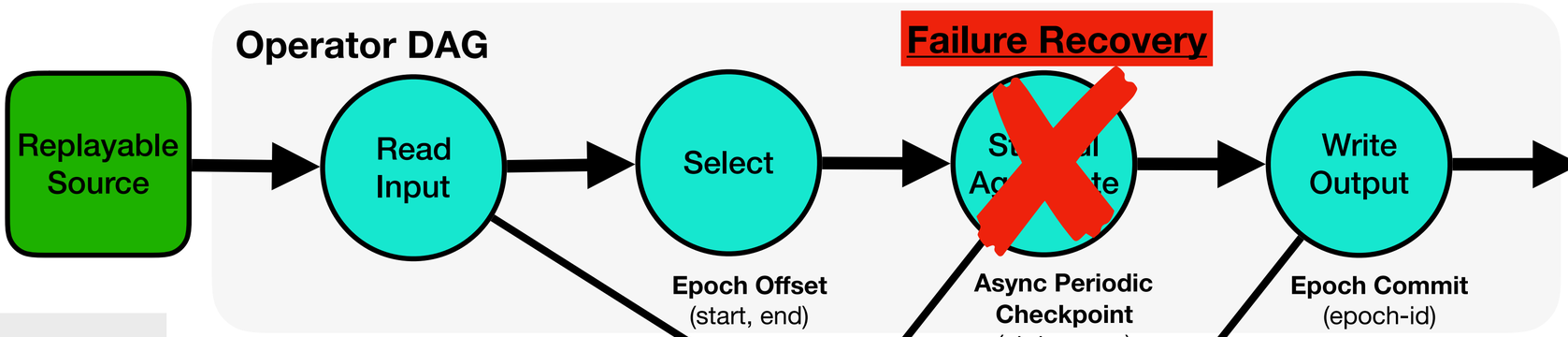


Spark's master node divides the input into **epochs**

Minibatch Execution:
Each **epoch** is executed by **multiple** (short-running) **tasks**

Spark Structured Streaming - Checkpointing



Spark's master node divides the input into **epochs**

1. Roll back to the **most recent** checkpoint

state$_{n-4}$
state$_{n-8}$
state$_{n-12}$
state$_{n-16}$
...

State Store

Log

committed epoch n-1
committed epoch n-2
committed epoch n-3
committed epoch n-4
...
read epoch n with offset (140, 160)
read epoch n-1 with offset (120, 140)
read epoch n-2 with offset (100, 120)
read epoch n-3 with offset (80, 100)
read epoch n-4 with offset (60, 80)
...

2. Replay epochs **committed after the checkpoint** (while disabling outputs to sink)

3. Replay the **uncommitted** epoch

Minibatch Execution:
Each **epoch** is executed by **multiple** (short-running) **tasks**

Continuous Processing:
Each (long-running) **task** reads from **one partition** and executes **multiple epochs** (but no shuffles are allowed)

Spark Structured Streaming - Discussion

Q: What are the **benefits** of each execution mode?

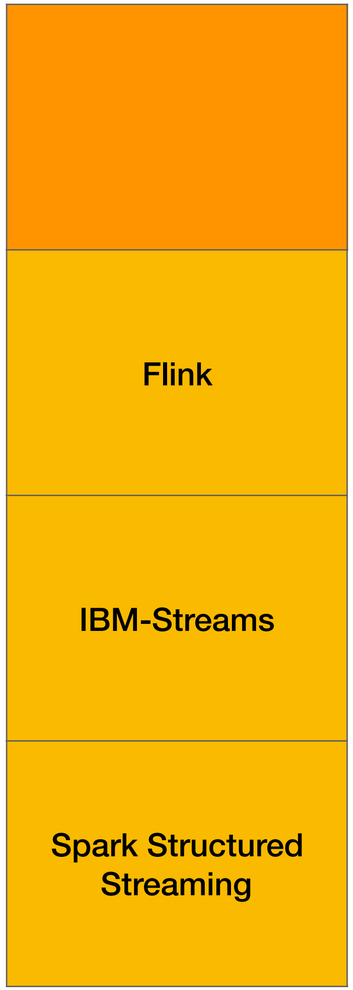
A: Microbatch Execution for **throughput** (load balancing).

A: Continuous Processing for **latency** (less scheduling).

Comparison & Conclusion

Comparison

Comparison



Comparison

	Execution Model?
Flink	Continuous
IBM-Streams	Continuous
Spark Structured Streaming	Continuous & Minibatch

Comparison

	Execution Model?	Queryable State?
Flink	Continuous	Yes
IBM-Streams	Continuous	N/A
Spark Structured Streaming	Continuous & Minibatch	Yes

Comparison

	Execution Model?	Queryable State?	Snapshot Granularity?
Flink	Continuous	Yes	Global
IBM-Streams	Continuous	N/A	Region
Spark Structured Streaming	Continuous & Minibatch	Yes	Global

Comparison

	Execution Model?	Queryable State?	Snapshot Granularity?	Cyclic Snapshots Method?
Flink	Continuous	Yes	Global	Chandy Lamport
IBM-Streams	Continuous	N/A	Region	Data & Control Ports (Only feedback loops)
Spark Structured Streaming	Continuous & Minibatch	Yes	Global	N/A

Comparison

	Execution Model?	Queryable State?	Snapshot Granularity?	Cyclic Snapshots Method?	Exactly-once Delivery Requirements?
Flink	Continuous	Yes	Global	Chandy Lamport	Idempotent or Transactional sinks
IBM-Streams	Continuous	N/A	Region	Data & Control Ports (Only feedback loops)	Retractable sinks
Spark Structured Streaming	Continuous & Minibatch	Yes	Global	N/A	Idempotent sinks

Comparison

	Execution Model?	Queryable State?	Snapshot Granularity?	Cyclic Snapshots Method?	Exactly-once Delivery Requirements?	Additional Properties?
Flink	Continuous	Yes	Global	Chandy Lamport	Idempotent or Transactional sinks	Incremental snapshot Async. compaction Channel blocking Channel recording
IBM-Streams	Continuous	N/A	Region	Data & Control Ports (Only feedback loops)	Retractable sinks	Incremental snapshot Channel blocking Sync. state transfer
Spark Structured Streaming	Continuous & Minibatch	Yes	Global	N/A	Idempotent sinks	Incremental snapshot Async. state transfer ???

Predictions / Future Work

Credits to Adam Hasselberg for predictions

Predictions / Future Work

Past

In-house Data center

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Predictions / Future Work

Past	Present
In-house Data center 	Cloud platforms  

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Predictions / Future Work

Past	Present	Future
In-house Data center 	Cloud platforms  	+ Edge devices   5G

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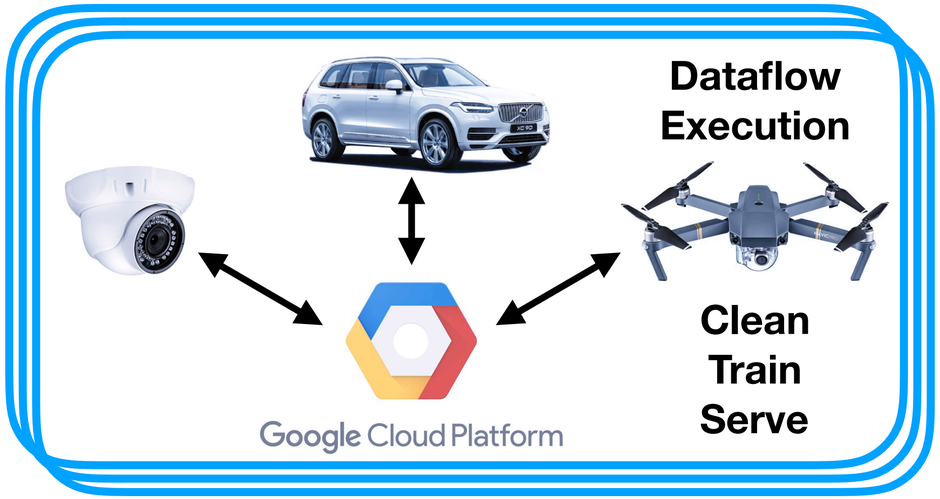
Predictions / Future Work

Past	Present	Future
In-house Data center 	Cloud platforms  Google Cloud Platform 	+ Edge devices  kubernetes  5G



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Predictions / Future Work

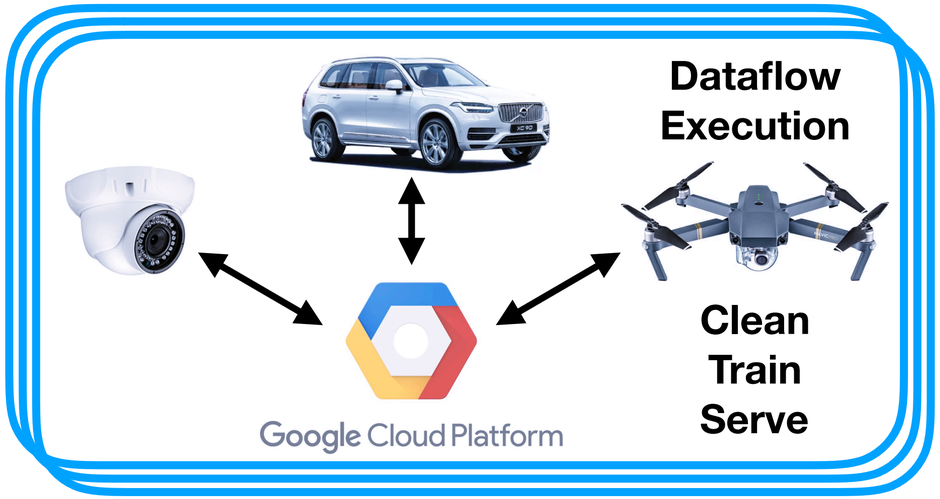
Past	Present	Future
In-house Data center	Cloud platforms	+ Edge devices

Google Cloud Platform

aws

kubernetes

5G



Future work for snapshotting protocols:

- Specialise towards throughput/latency/recovery time/space/...
- Take data into consideration
- Optimise code inside operators for snapshotting
- Hardware acceleration, e.g. Remote Direct Memory Access (RDMA)

Credits to Adam Hasselberg for predictions

END

BIN