TUNING FLINK FOR ROBUSTNESS AND PERFORMANCE

STEFAN RICHTER

@STEFANRRICHTER

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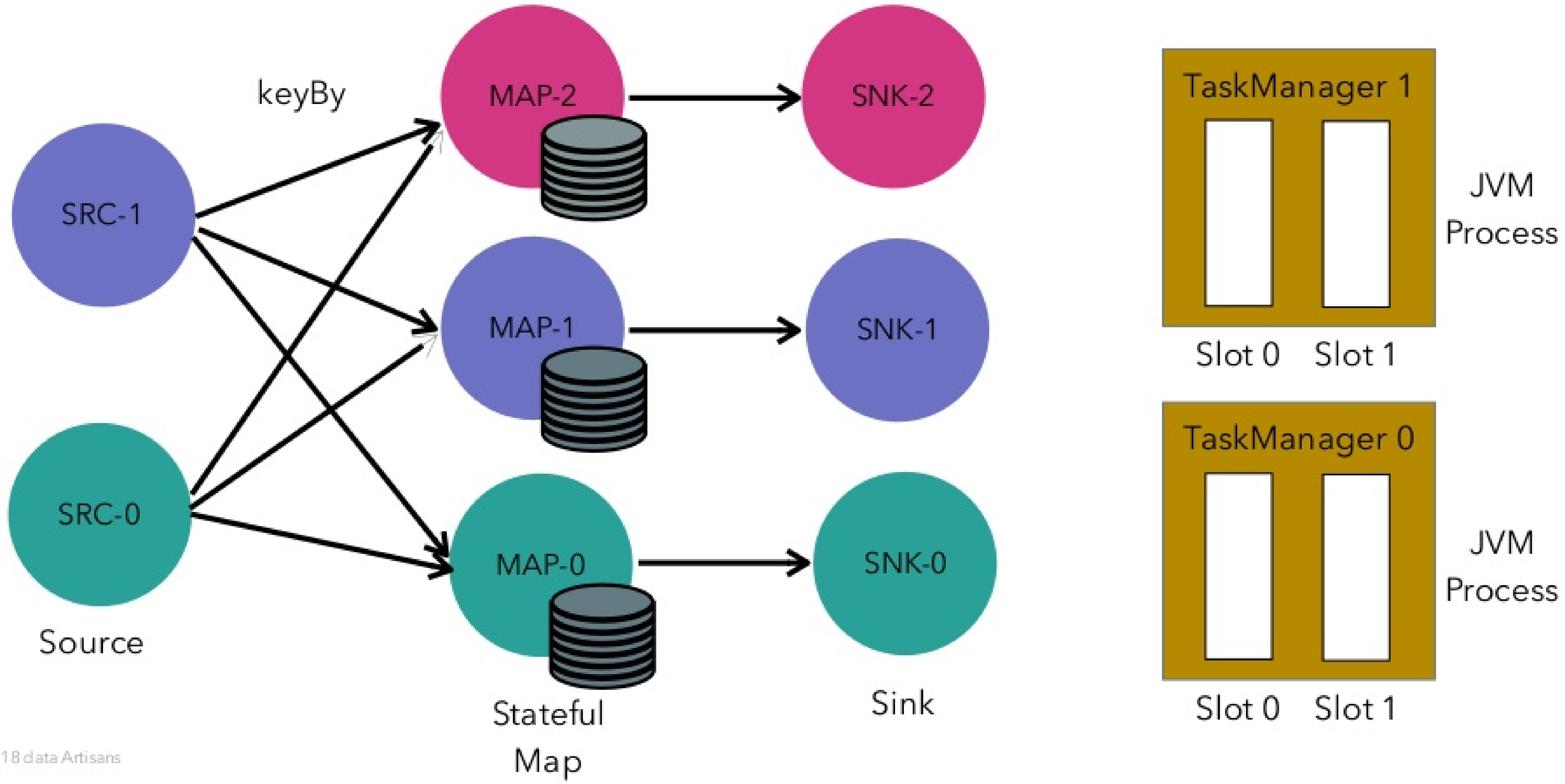
dataArtisans

GENERAL MEMORY CONSIDERATIONS

BASIC TASK SCHEDULING



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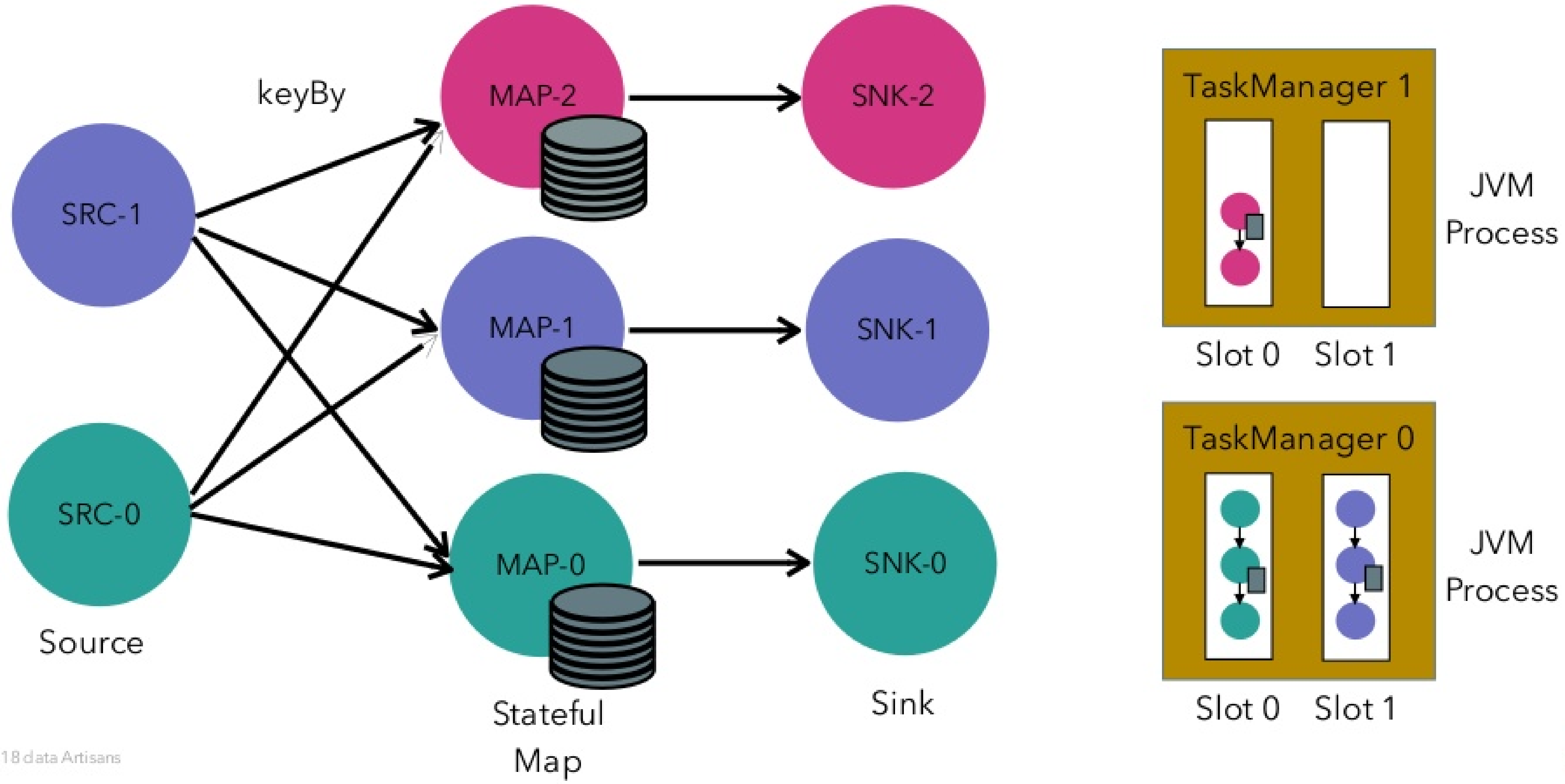
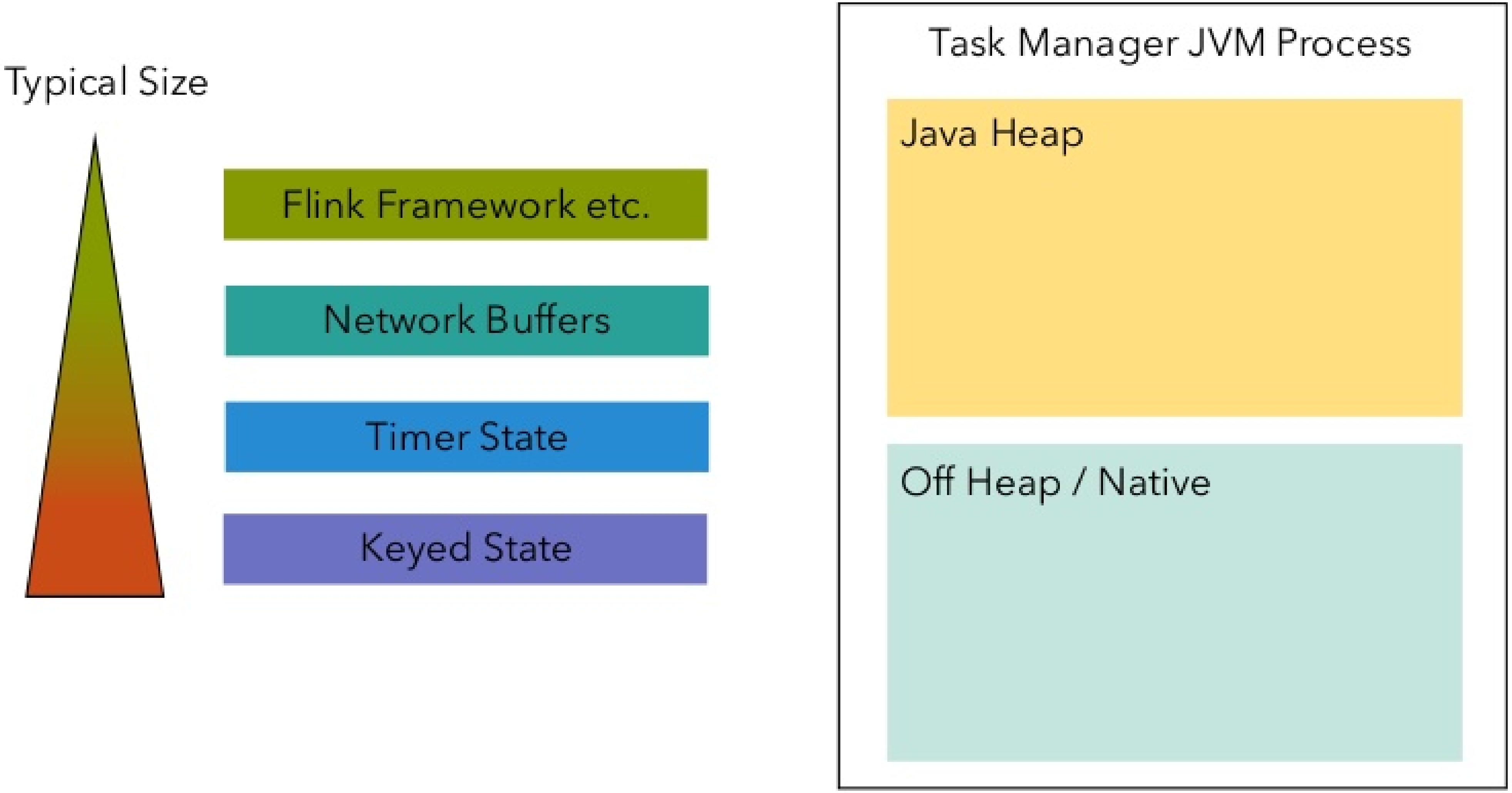


TASK MANAGER PROCESS MEMORY LAYOUT



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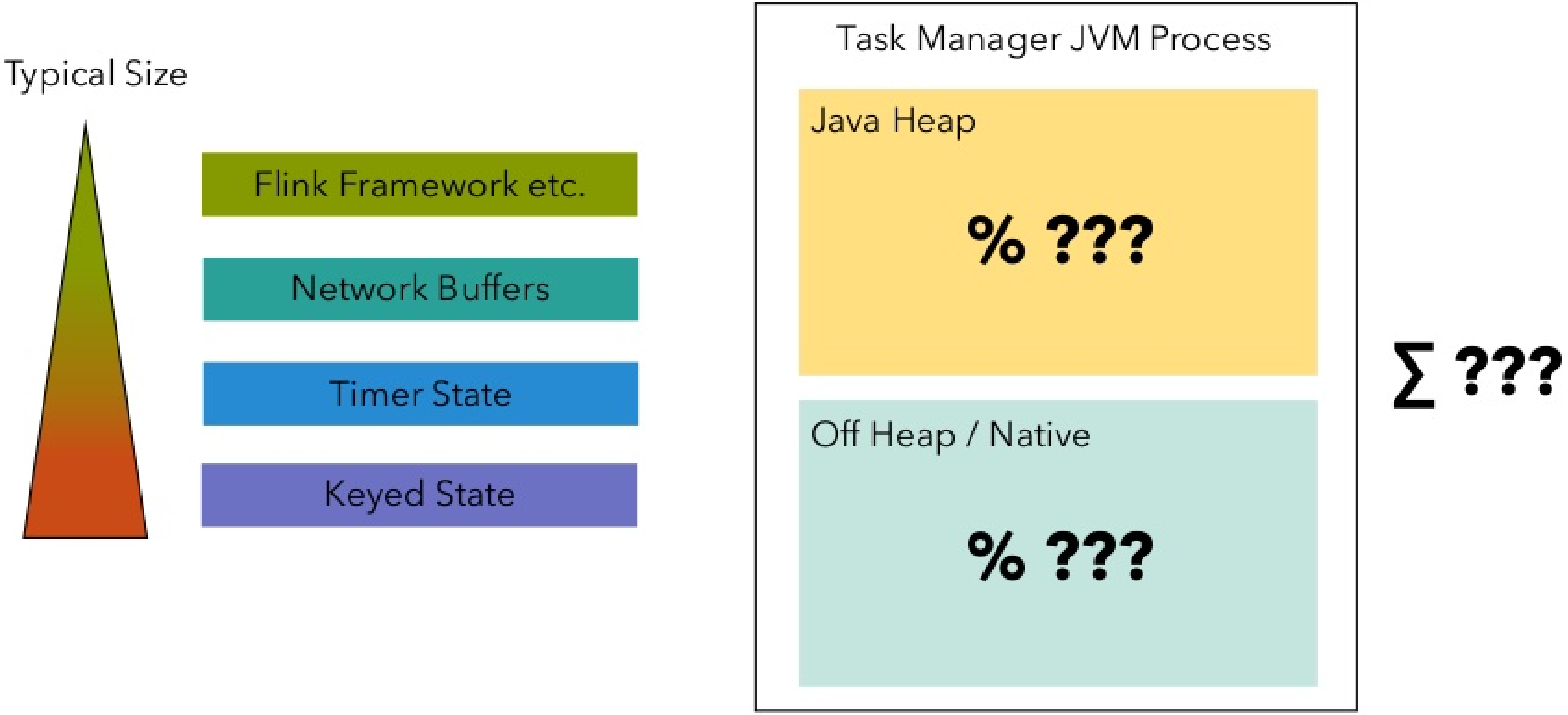

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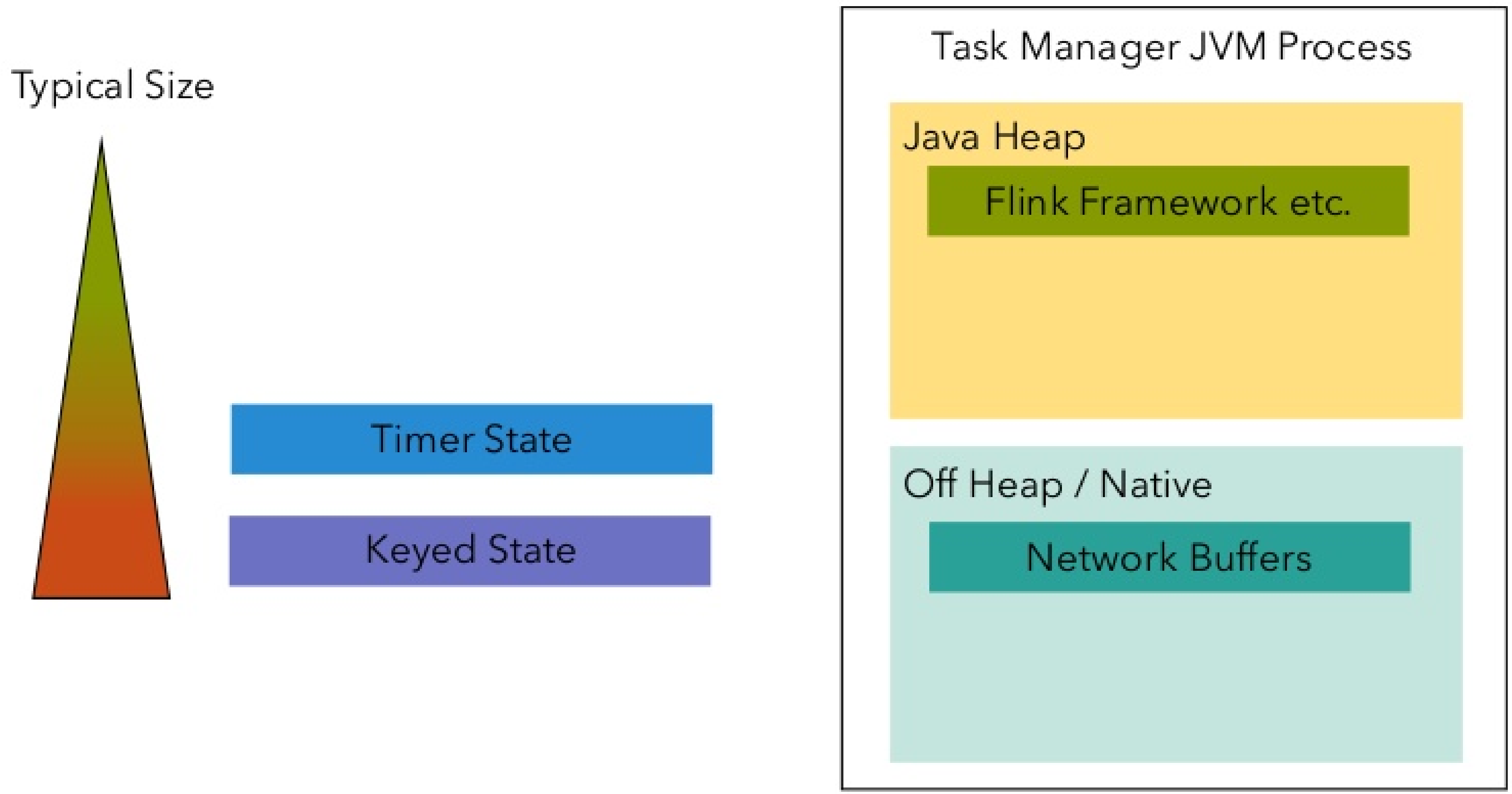

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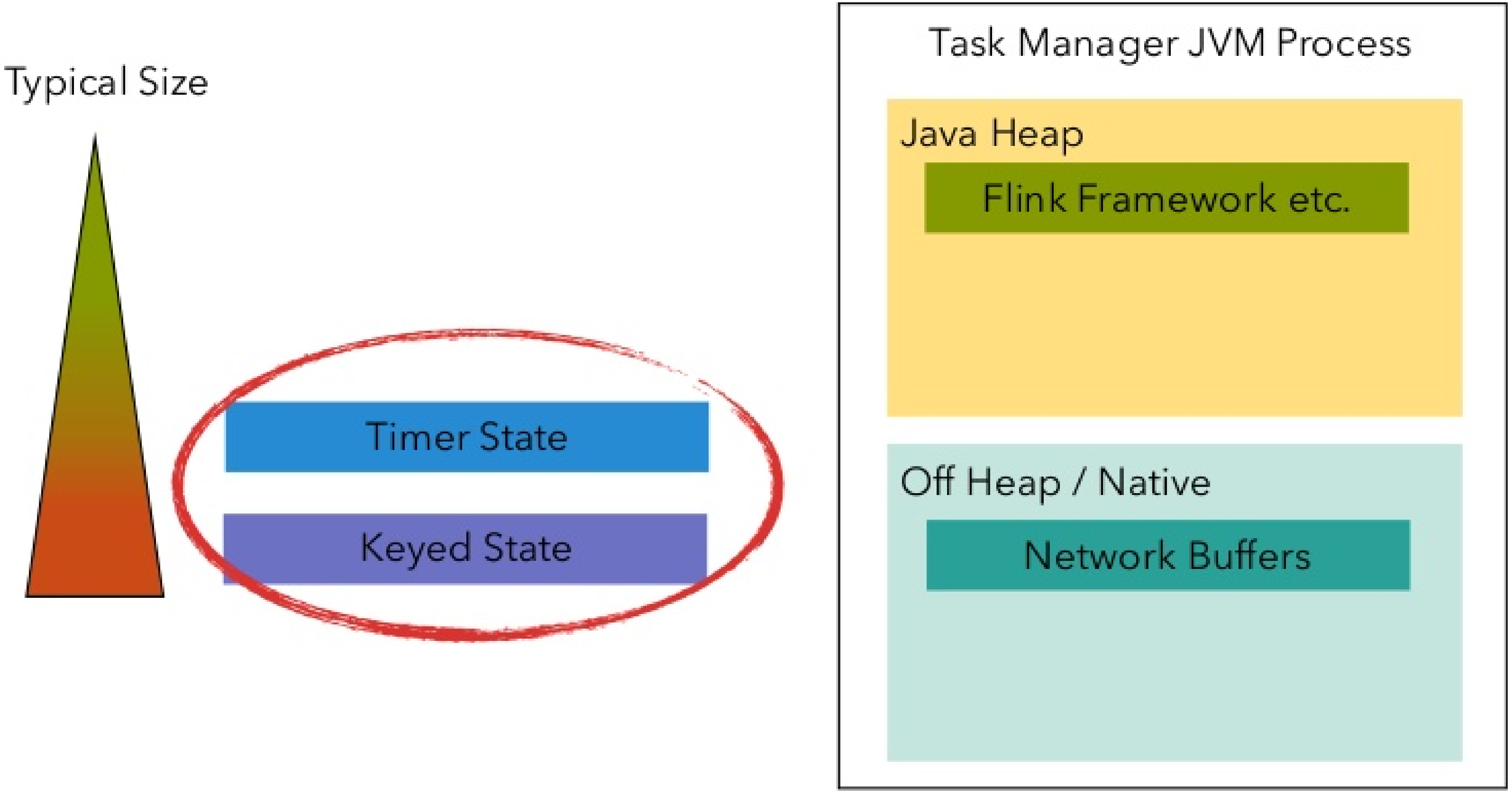
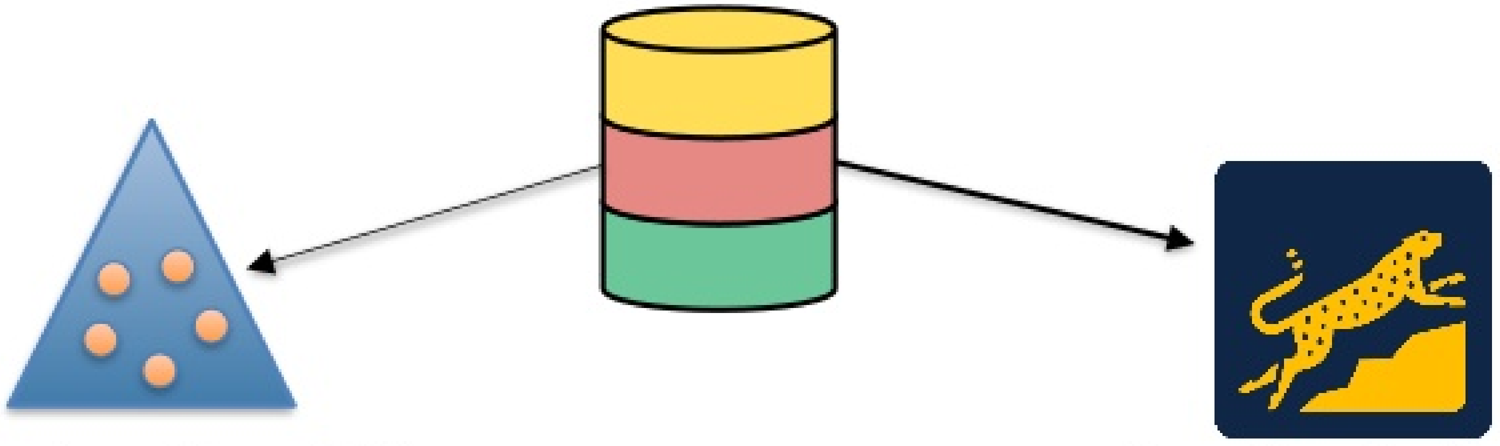


STATE BACKENDS

FLINK KEYED STATE BACKENDS CHOICES



Based on Java Heap Objects

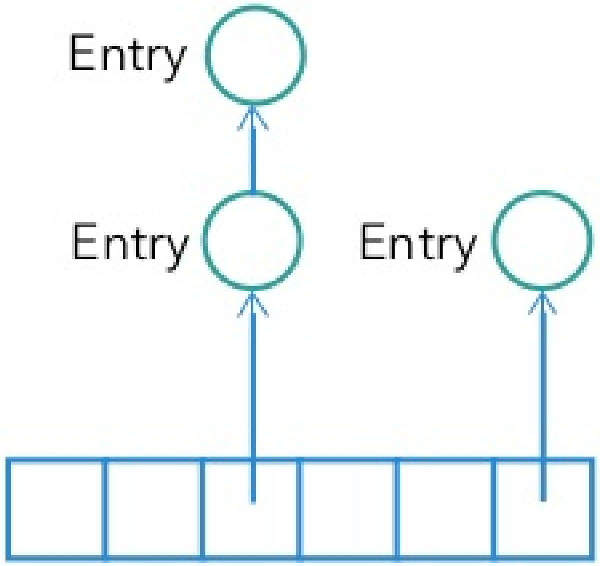
Based on RocksDB

HEAP KEYED STATE BACKEND CHARACTERISTICS

- State lives as Java objects on the heap.
- Organized as chained hash table, key ↦ state.
- One hash table per registered state.
- Supports asynchronous state snapshots through copy-on-write MVCC.
- Data is de/serialized only during state snapshot and restore.

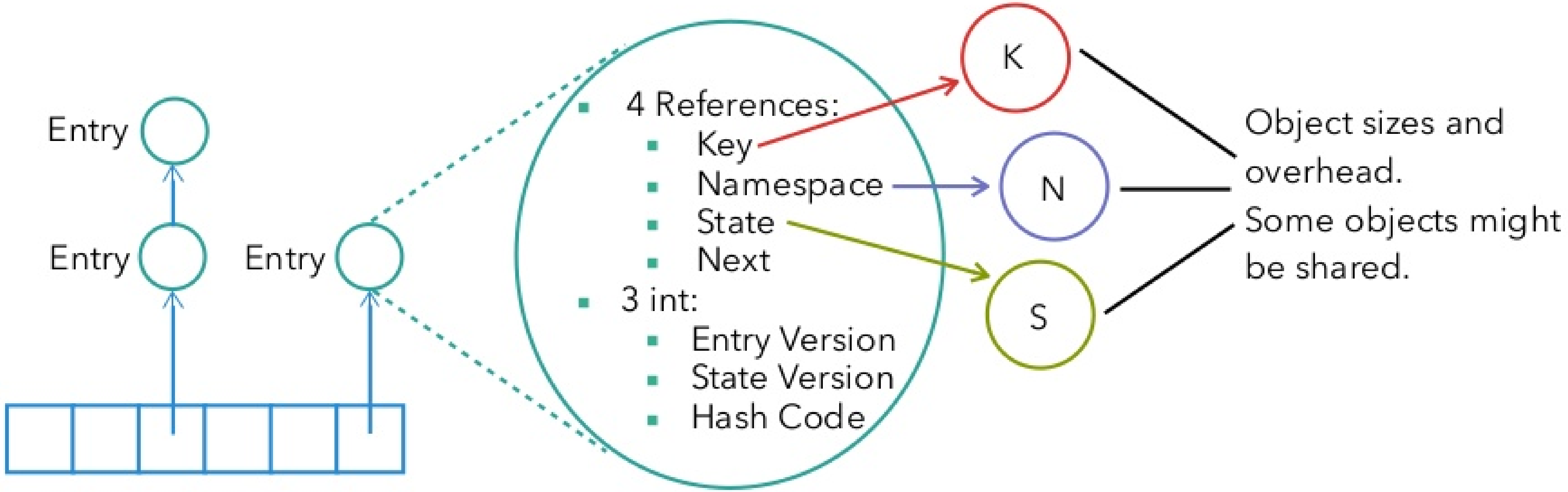
- Highest performance.
- Affected by garbage collection overhead / pauses.
- Currently no incremental checkpoints.
- Memory overhead of representation.
- State size limited by available heap memory.

HEAP STATE TABLE ARCHITECTURE



- Hash buckets (Object[]), 4B-8B per slot
- Load factor <= 75%
- Incremental rehash

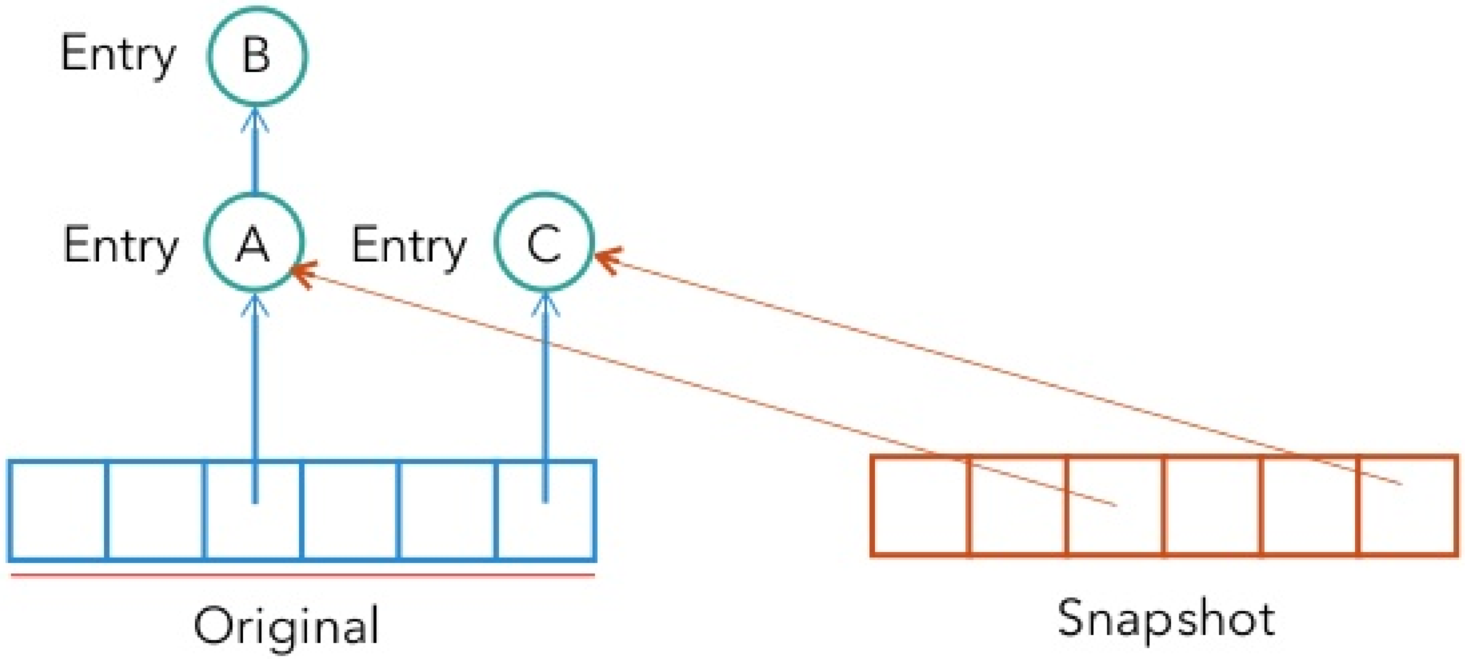
HEAP STATE TABLE ARCHITECTURE



- Hash buckets (Object[]), 4B-8B per slot
- Load factor <= 75%
- Incremental rehash

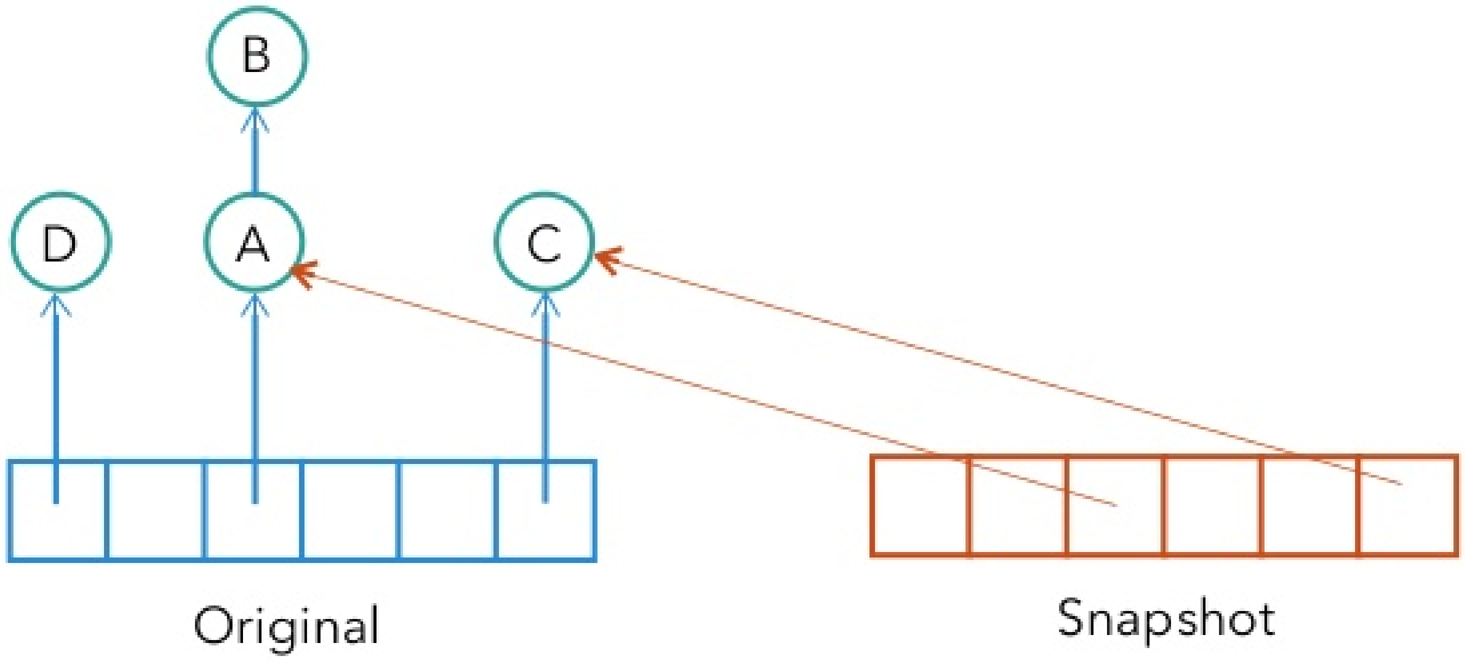
4 x (4B-8B)
+ 3 x 4B
+ ~8B-16B (Object overhead)

HEAP STATE TABLE SNAPSHOT MVCC



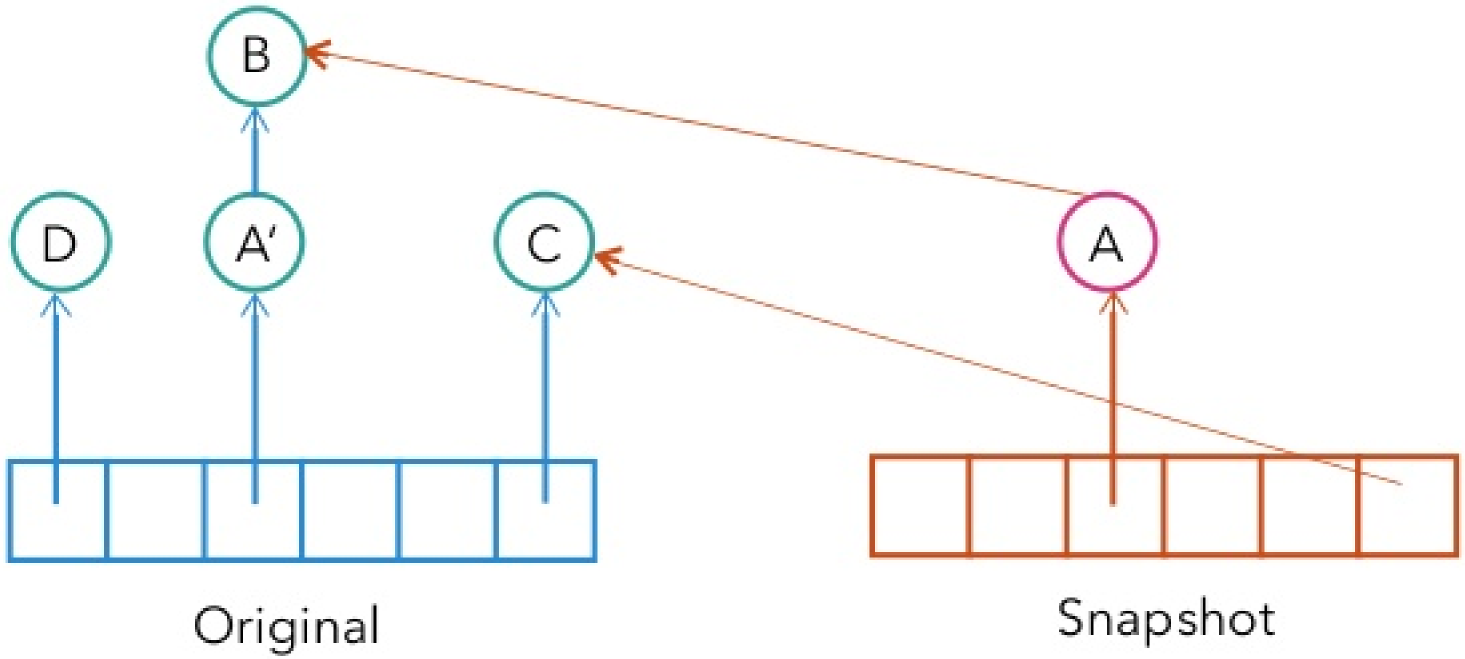
Copy of hash bucket array is snapshot overhead

HEAP STATE TABLE SNAPSHOT MVCC



No conflicting modification = no overhead

HEAP STATE TABLE SNAPSHOT MVCC



Modifications trigger deep copy of entry - only as much as required. This depends on what was modified and what is immutable (as determined by type serializer).
Worst case overhead = size of original state table at time of snapshot.

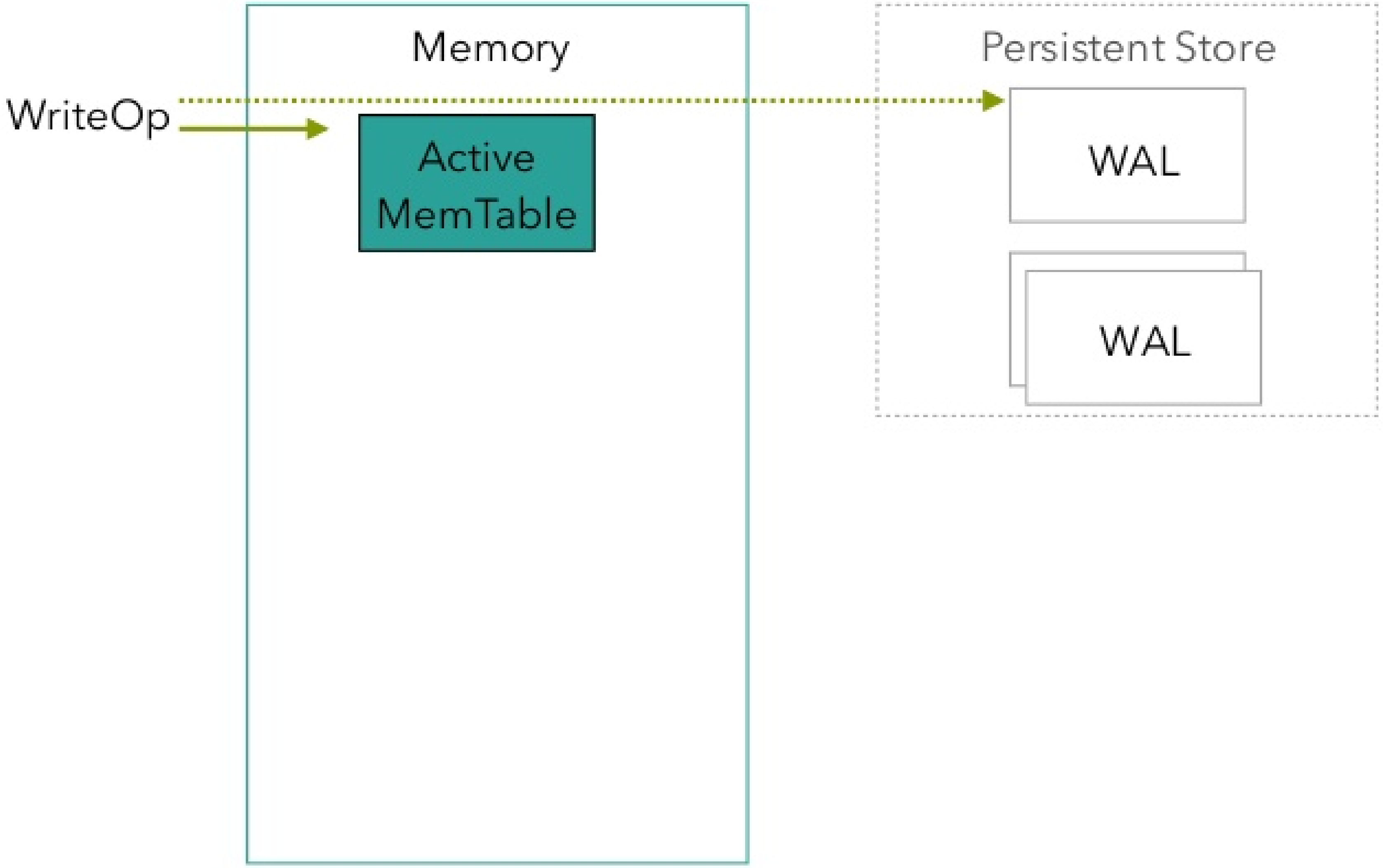
HEAP BACKEND TUNING CONSIDERATIONS

- Chose type serializer with efficient copy-method (for copy-on-write).
- Flag immutability of objects where possible to avoid copy completely.
- Flatten POJOs / avoid deep objects. Reduces object overheads and following references = potential cache misses.
- GC choice/tuning can help. Follow future GC developments.
- Scale-out using multiple task manager per node to support larger state over multiple heap backends rather than having fewer and large heaps.

ROCKSDB KEYED STATE BACKEND CHARACTERISTICS

- State lives as serialized byte-strings in off-heap memory and on local disk.
- Key-Value store, organized as log-structured merge tree (LSM-tree).
  - Key: serialized bytes of <Keygroup, Key, Namespace>.
  - Value: serialized bytes of the state.
- One column family per registered state (~table).
- LSM naturally supports MVCC.
- Data is de/serialized on every read and update.
- Not affected by garbage collection.
- Relative low overhead of representation.
- LSM naturally supports incremental snapshots.
- State size limited by available local disk space.
- Lower performance (~order of magnitude compared to Heap state backend).

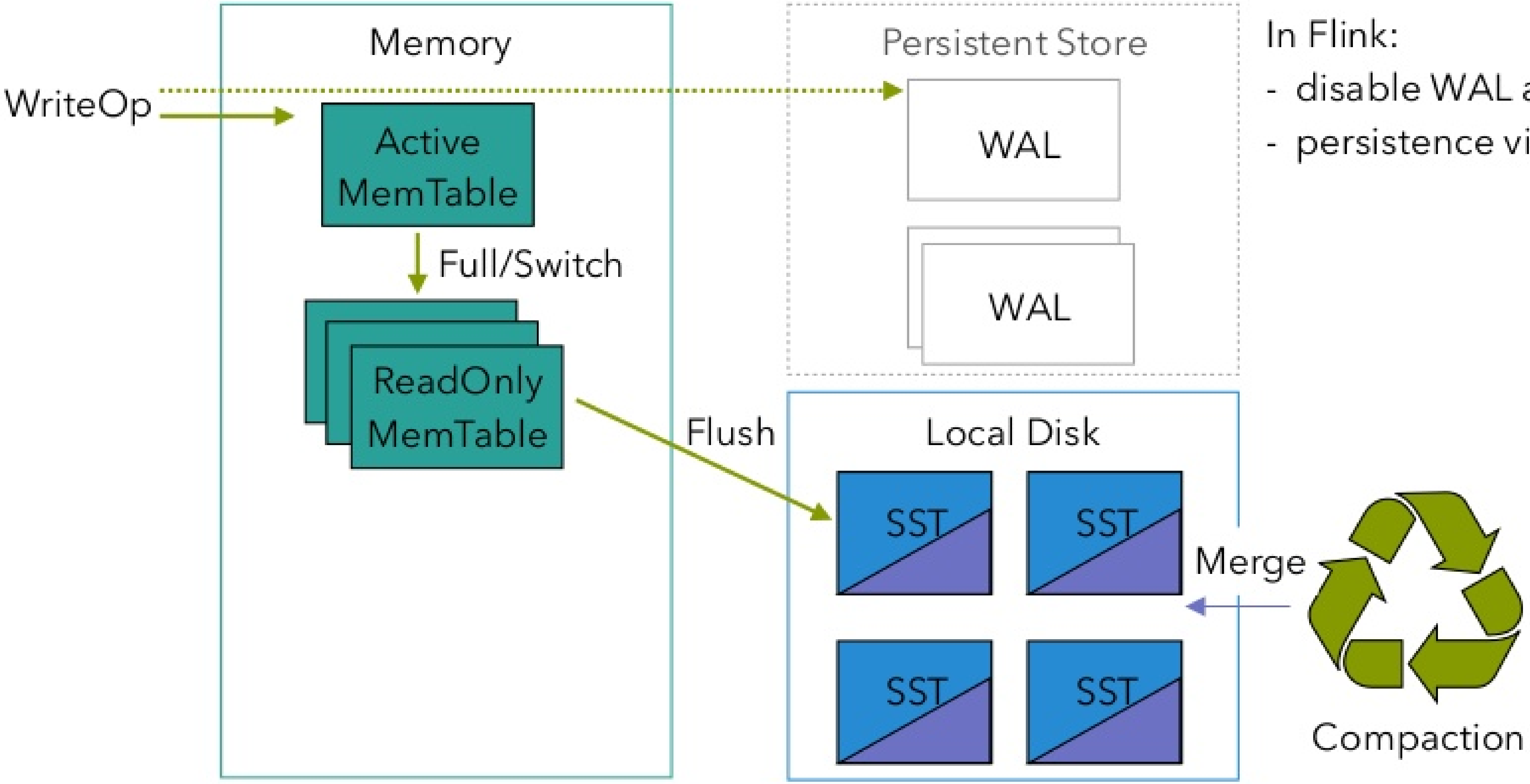
ROCKSDB ARCHITECTURE



In Flink:

- disable WAL and sync
- persistence via checkpoints

ROCKSDB ARCHITECTURE



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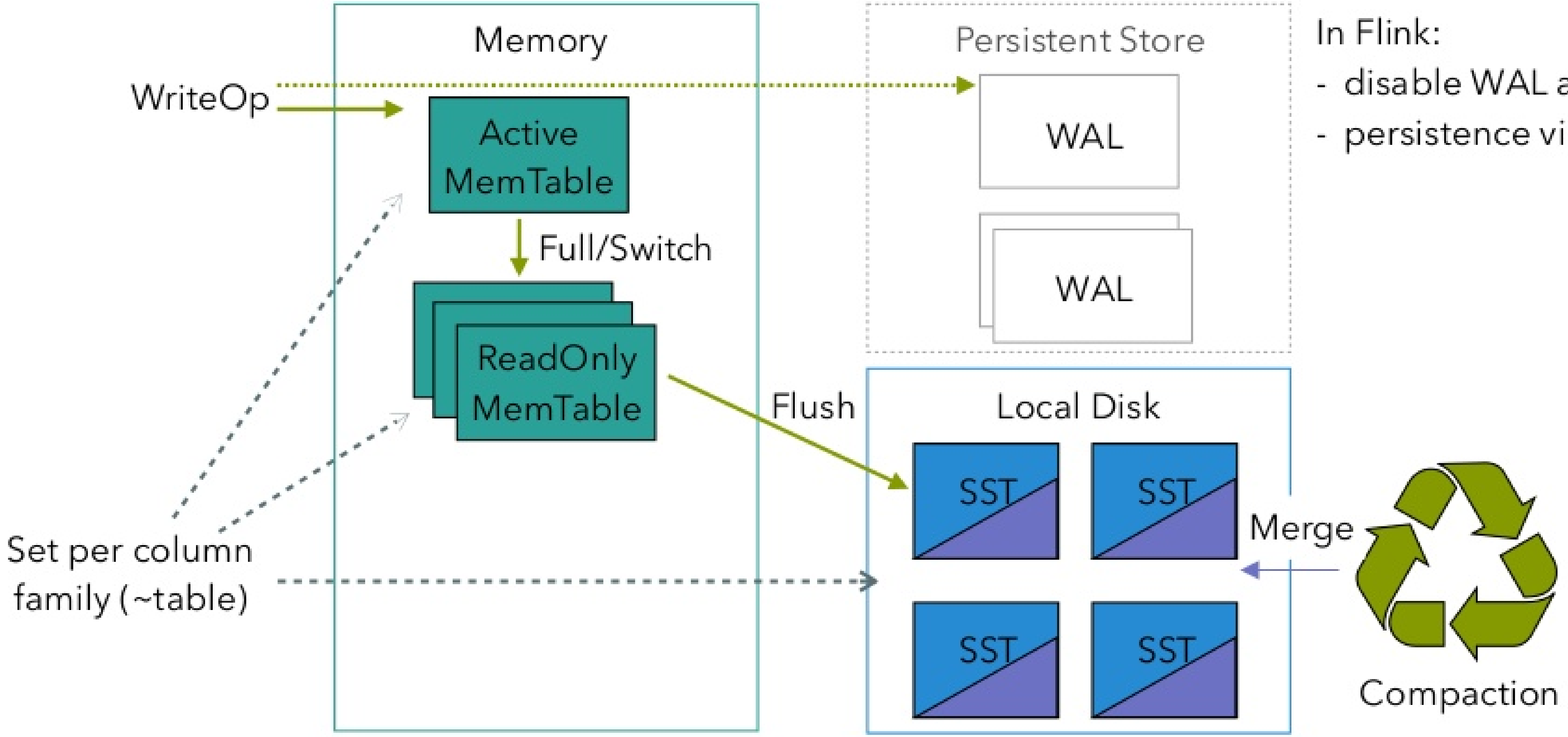

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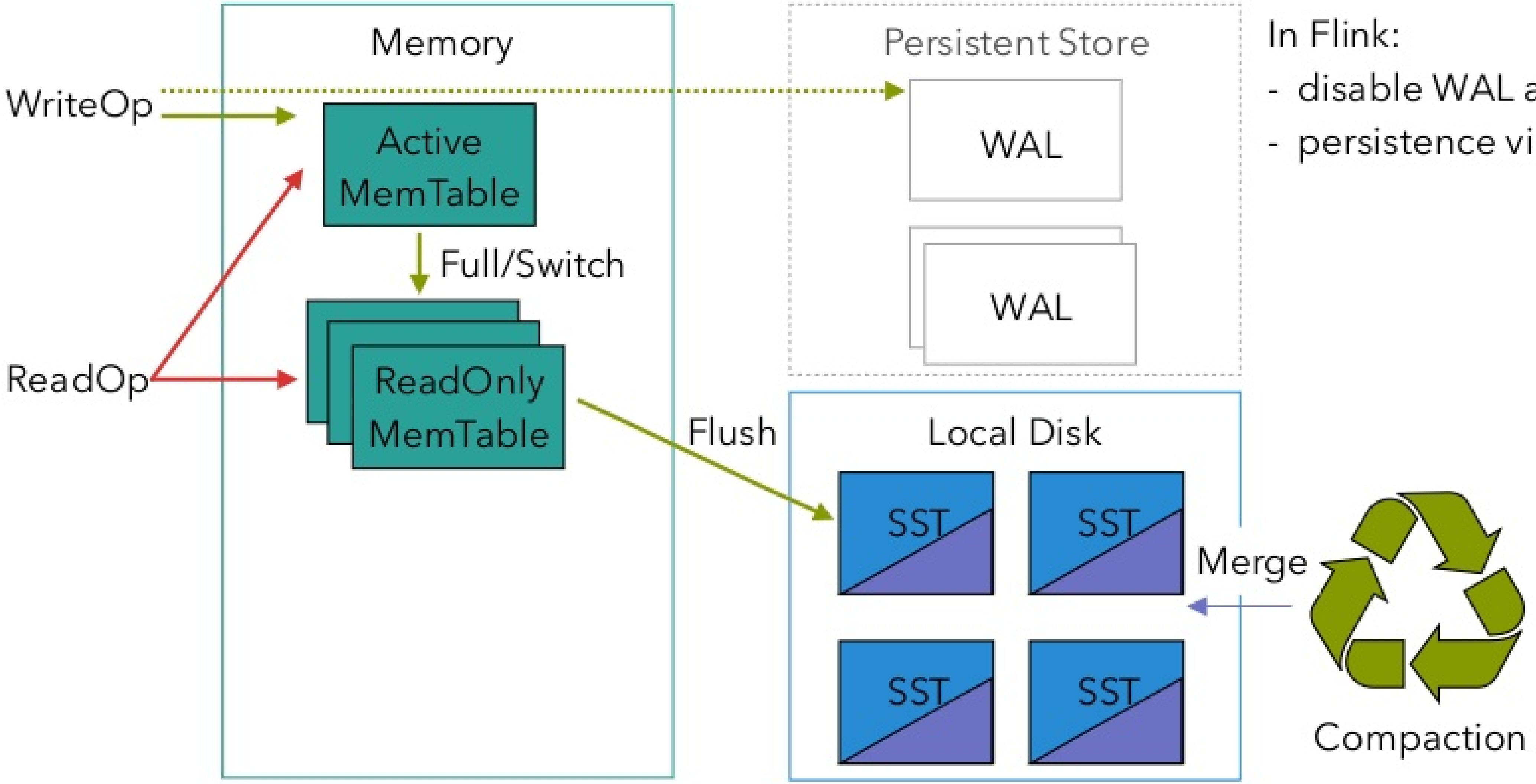

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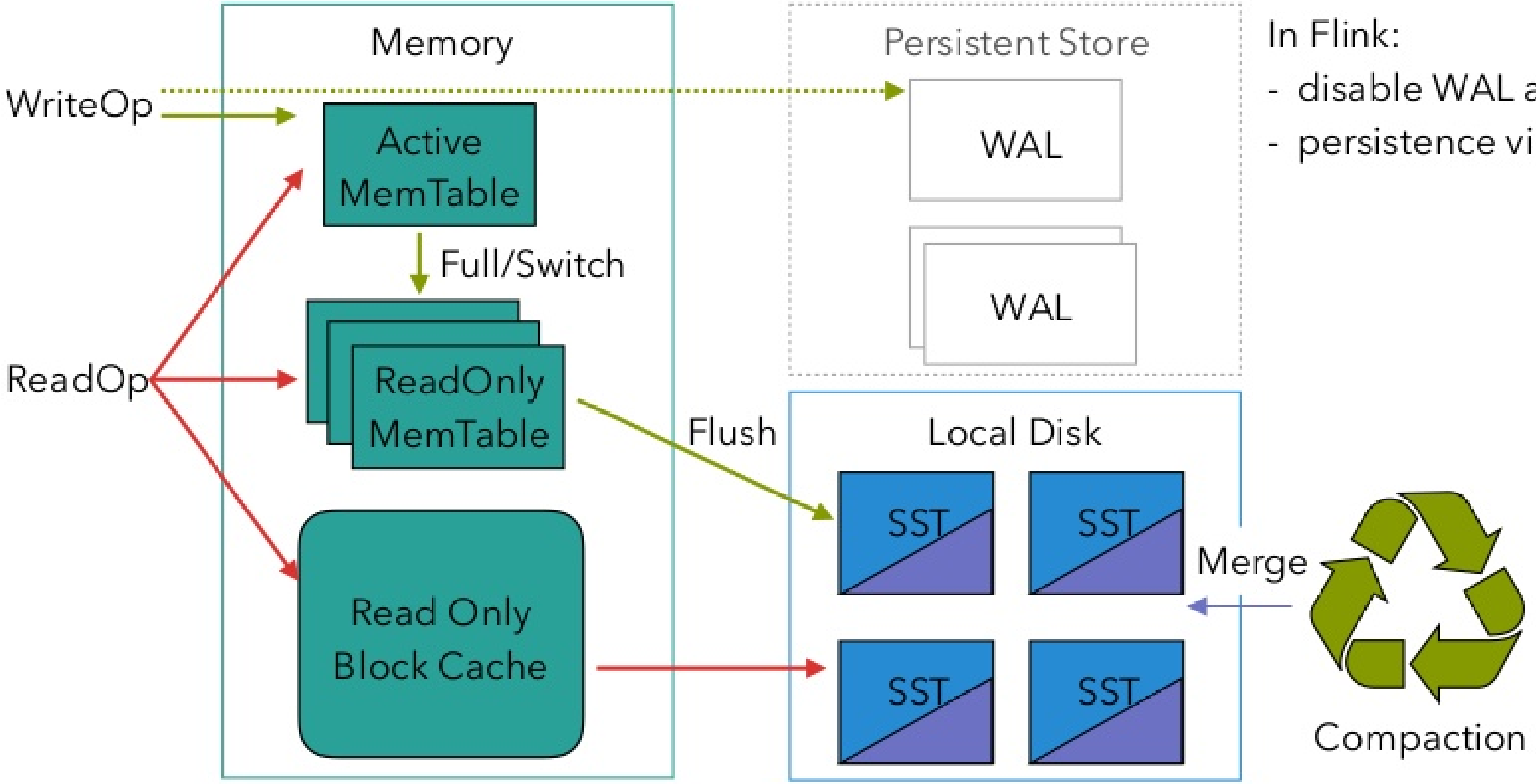


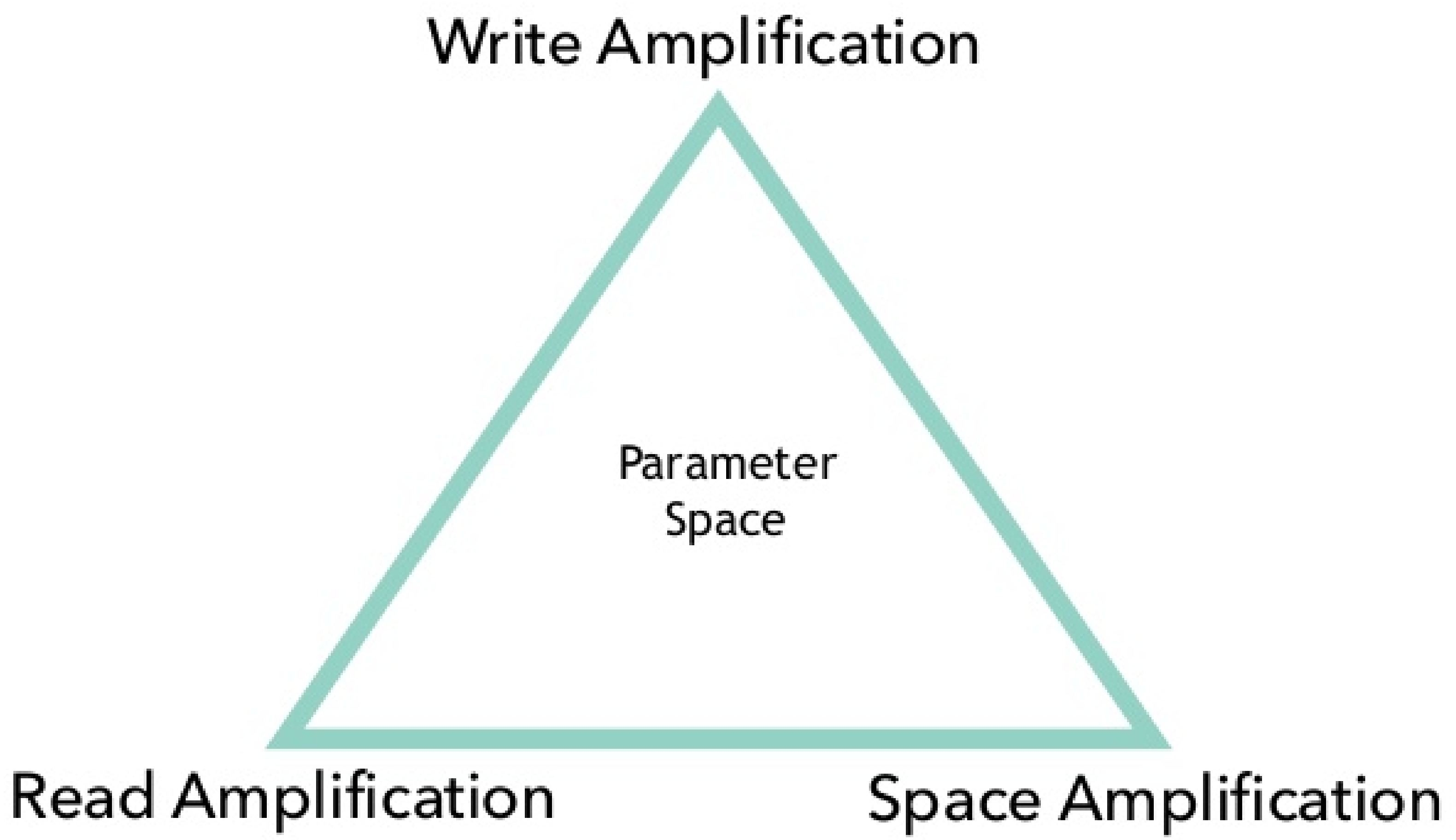
In Flink:

- disable WAL and sync
- persistence via checkpoints

ROCKSDB RESOURCE CONSUMPTION

- One RocksDB instance per keyed operator subtask.
- **block_cache_size**:
  - Size of the block cache.
- **write_buffer_size**:
  - Max. size of a MemTable.
- **max_write_buffer_number**:
  - The maximum number of MemTables in memory before flush to SST files.
- **Indexes and bloom filters** (optional).
- **Table Cache**:
  - Caches open file descriptors to SST files. Default: unlimited!

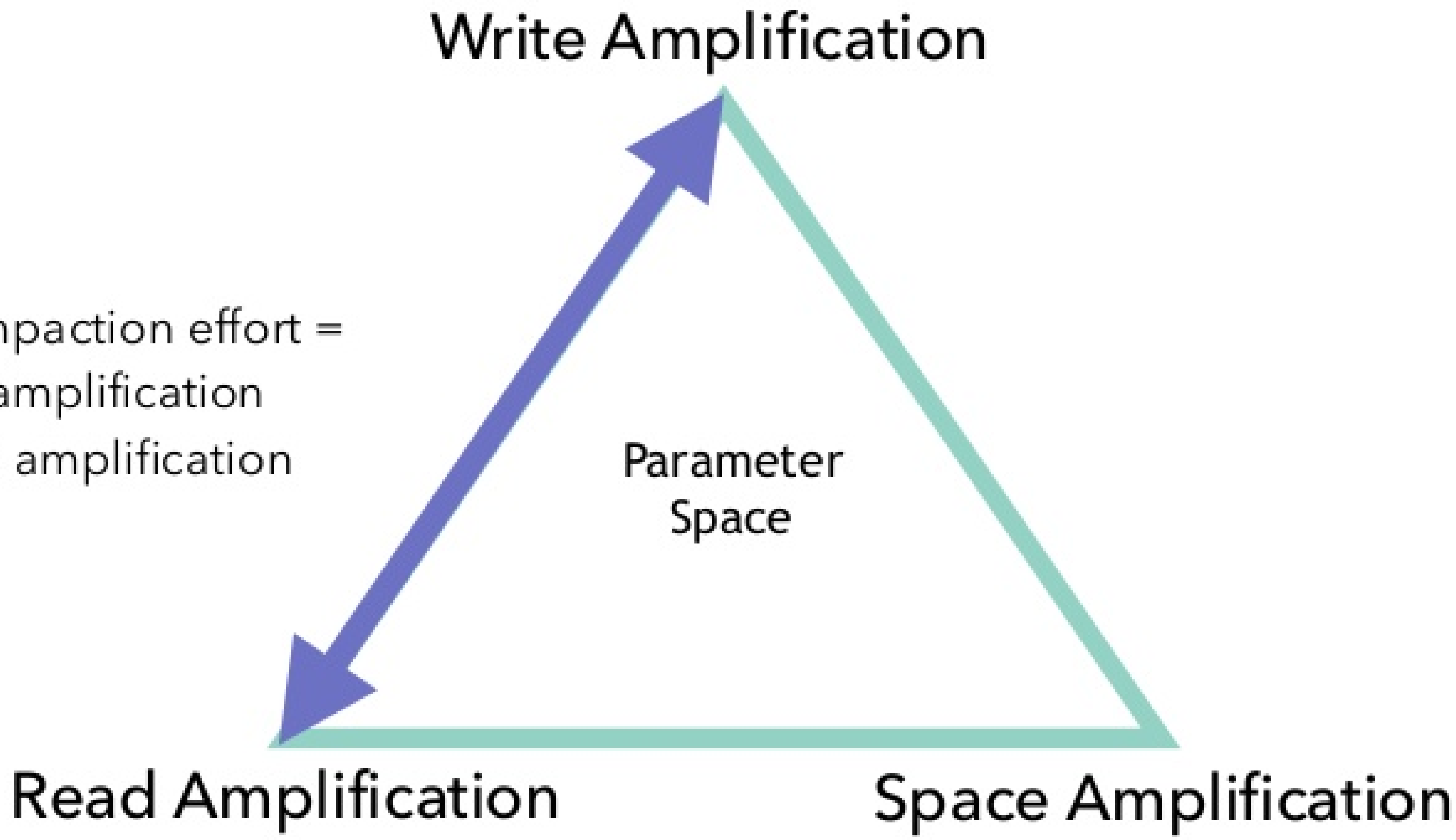
PERFORMANCE TUNING - AMPLIFICATION FACTORS



More details: https://github.com/facebook/rocksdb/wiki/RocksDB-Tuning-Guide

PERFORMANCE TUNING - AMPLIFICATION FACTORS

Example: More compaction effort = increased write amplification and reduced read amplification



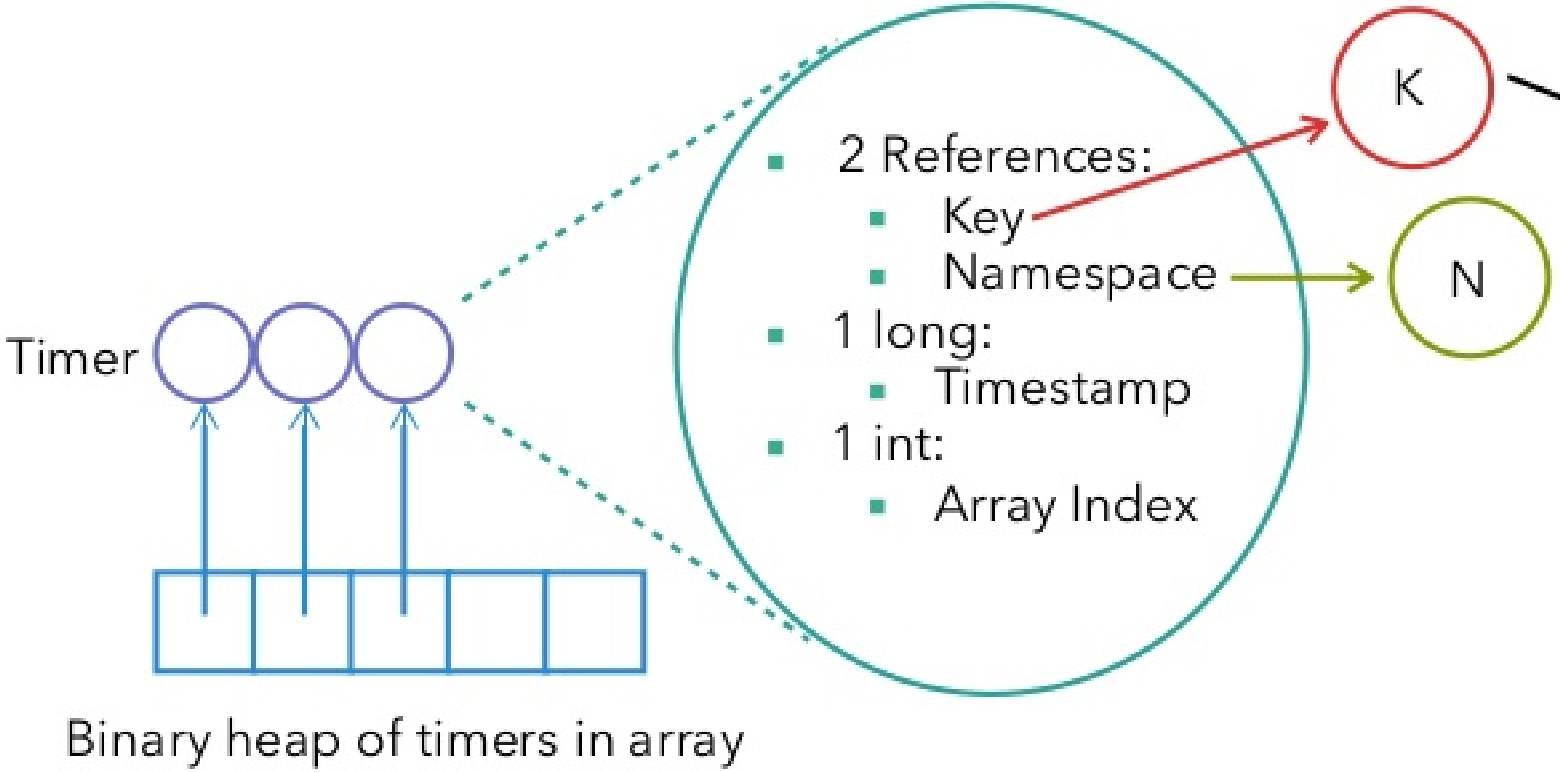
More details: https://github.com/facebook/rocksdb/wiki/RocksDB-Tuning-Guide

GENERAL PERFORMANCE CONSIDERATIONS

- Efficient type serializer and serialization formats.
- Decompose user-code objects: business logic / efficient state representation.
- Extreme: „Flightweight Pattern“, e.g. wrapper object that interprets/manipulates stored byte array on the fly and uses only byte-array type serializer.
- File Systems:
    - Working directory on fast storage, ideally local SSD. Could even be memory file system because it is transient for Flink. EBS performance can be problematic.
    - Checkpoint directory: Persistence happens here. Can be slower but should be fault tolerant.

TIMER SERVICE

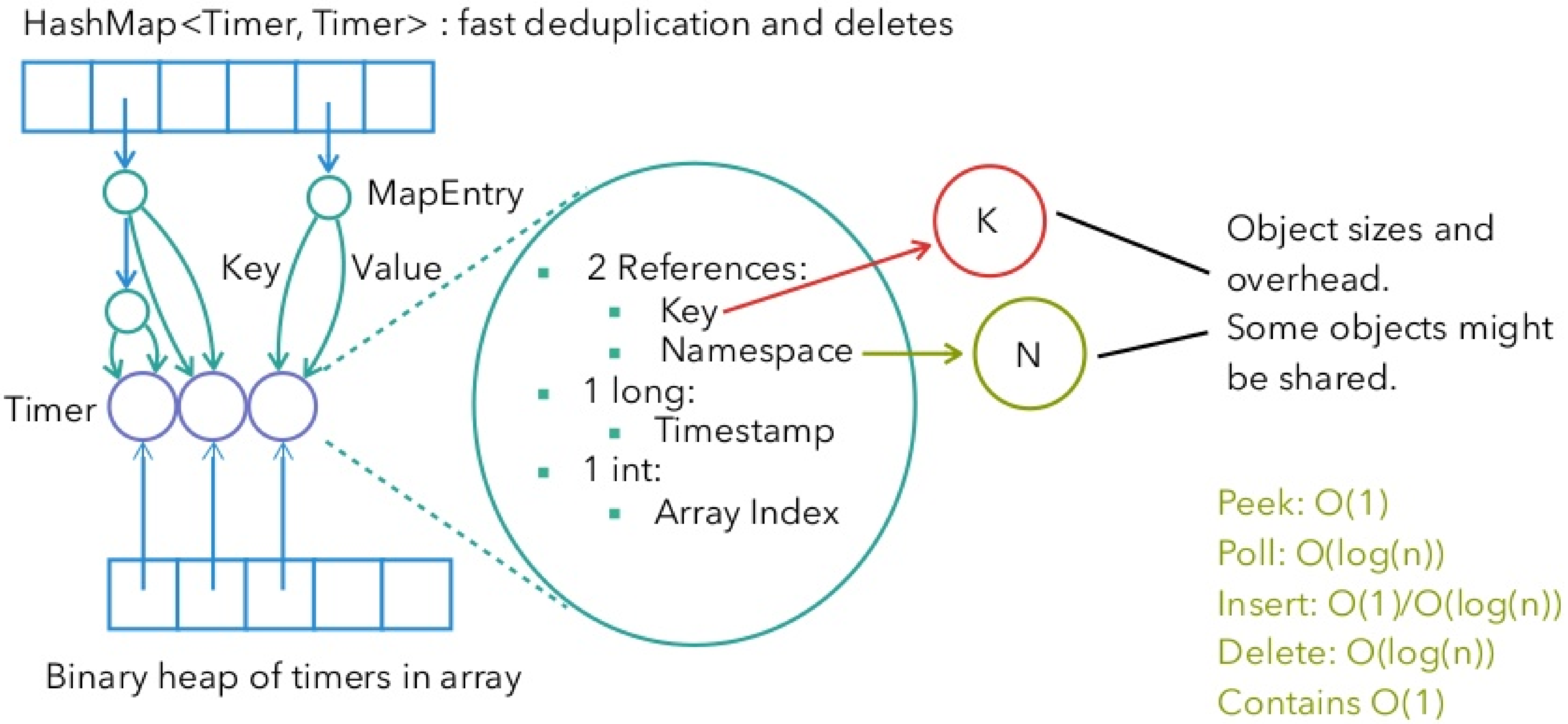
HEAP TIMERS



Object sizes and overhead.
Some objects might be shared.

Peek: O(1)
Poll: O(log(n))
Insert: O(1)/O(log(n))
Delete: O(n)
Contains O(n)

HEAP TIMERS


HashMap<Timer, Timer> : fast deduplication and deletes
MapEntry
Key
Value
Timer
Binary heap of timers in array
2 References:
Key
Namespace
1 long:
Timestamp
1 int:
Array Index
K
N
Object sizes and overhead.
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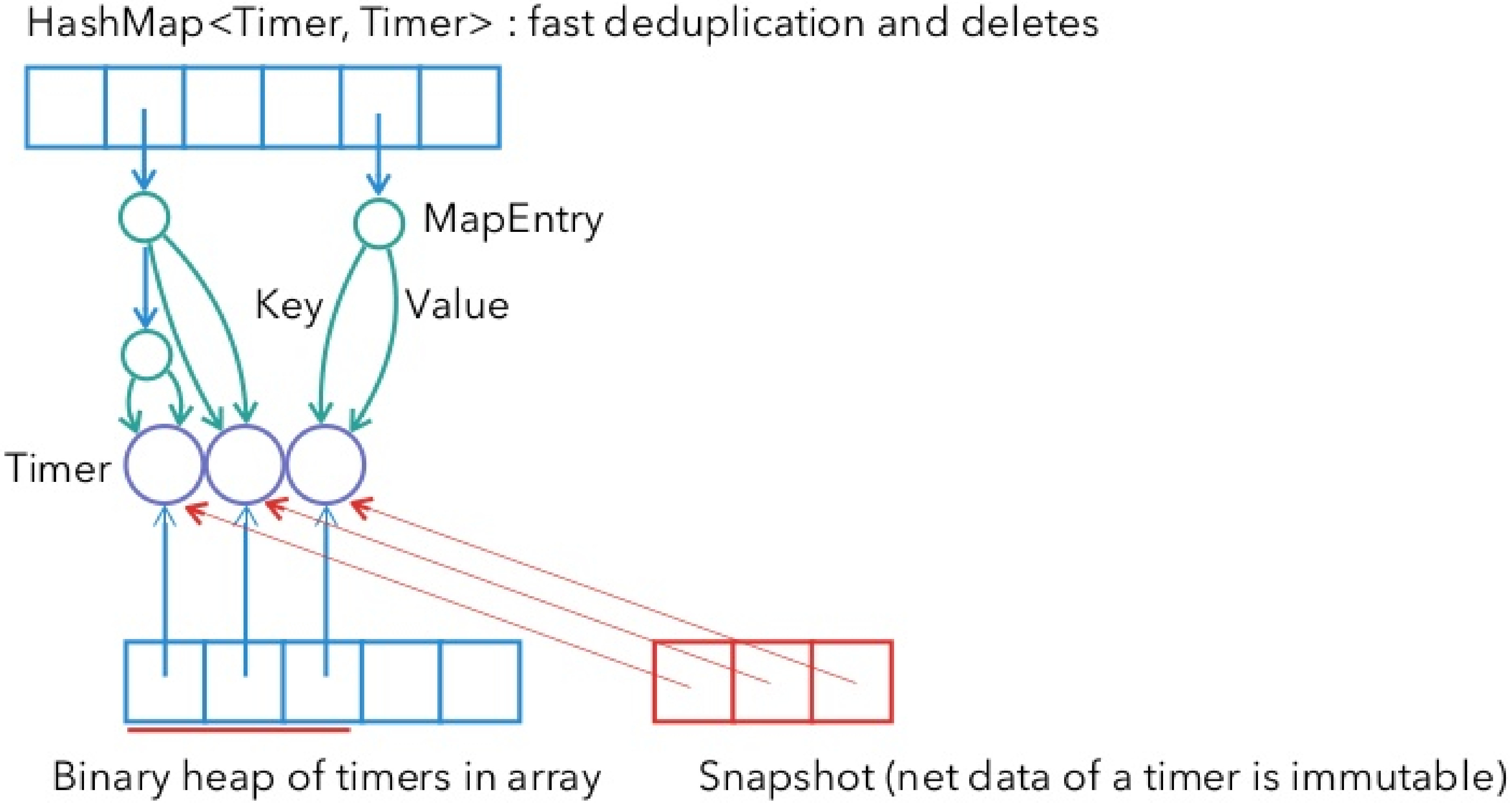
Delete: O(log(n))
Contains O(1)

HEAP TIMERS


HashMap<Timer, Timer> : fast deduplication and deletes
MapEntry
Key
Value
Timer
Binary heap of timers in array
Snapshot (net data of a timer is immutable)

ROCKSDB TIMERS

Column Family - only key, no value

Key Group	Time stamp	Key	Name space
0	20	A	X
0	40	D	Z

...

1	10	D	Z
1	20	C	Y

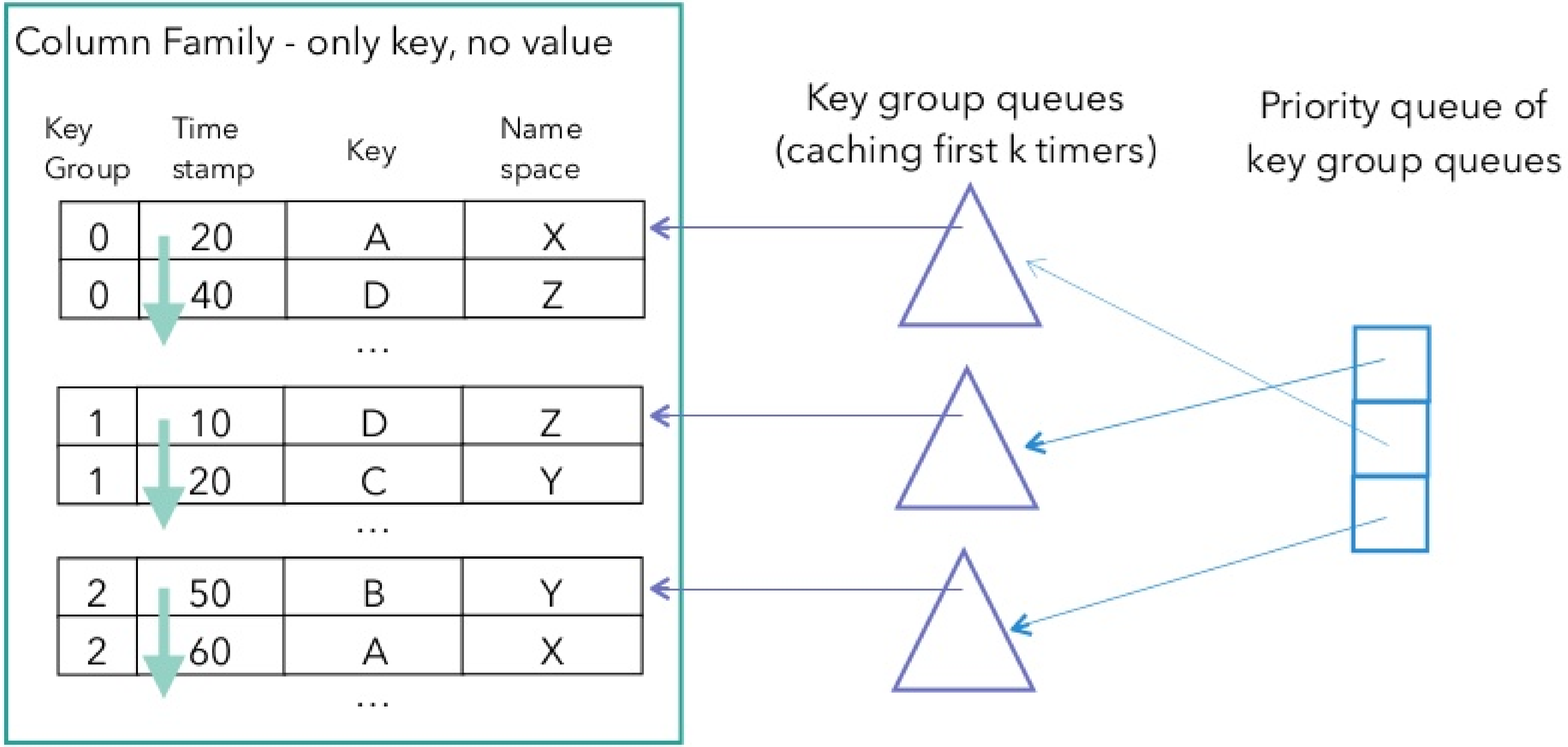
...

2	50	B	Y
2	60	A	X

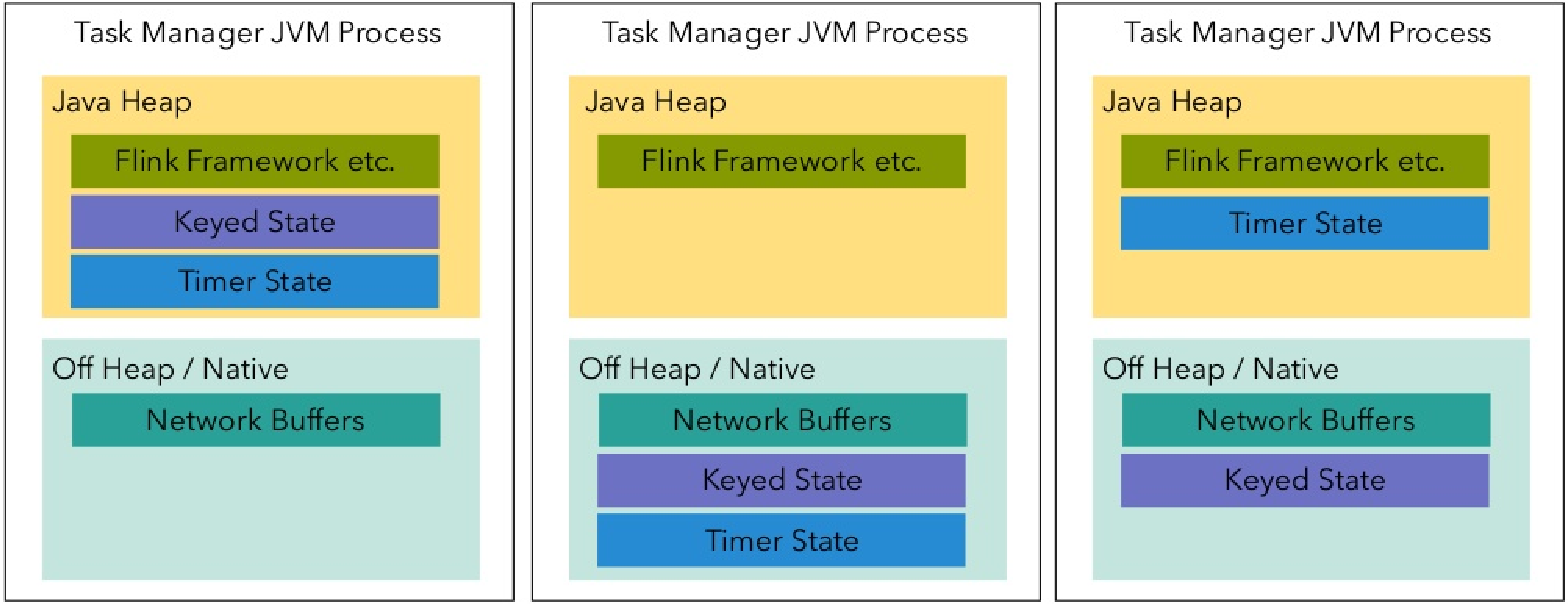
...

Lexicographically ordered
byte sequences as key, no value

ROCKSDB TIMERS



3 TASK MANAGER MEMORY LAYOUT OPTIONS

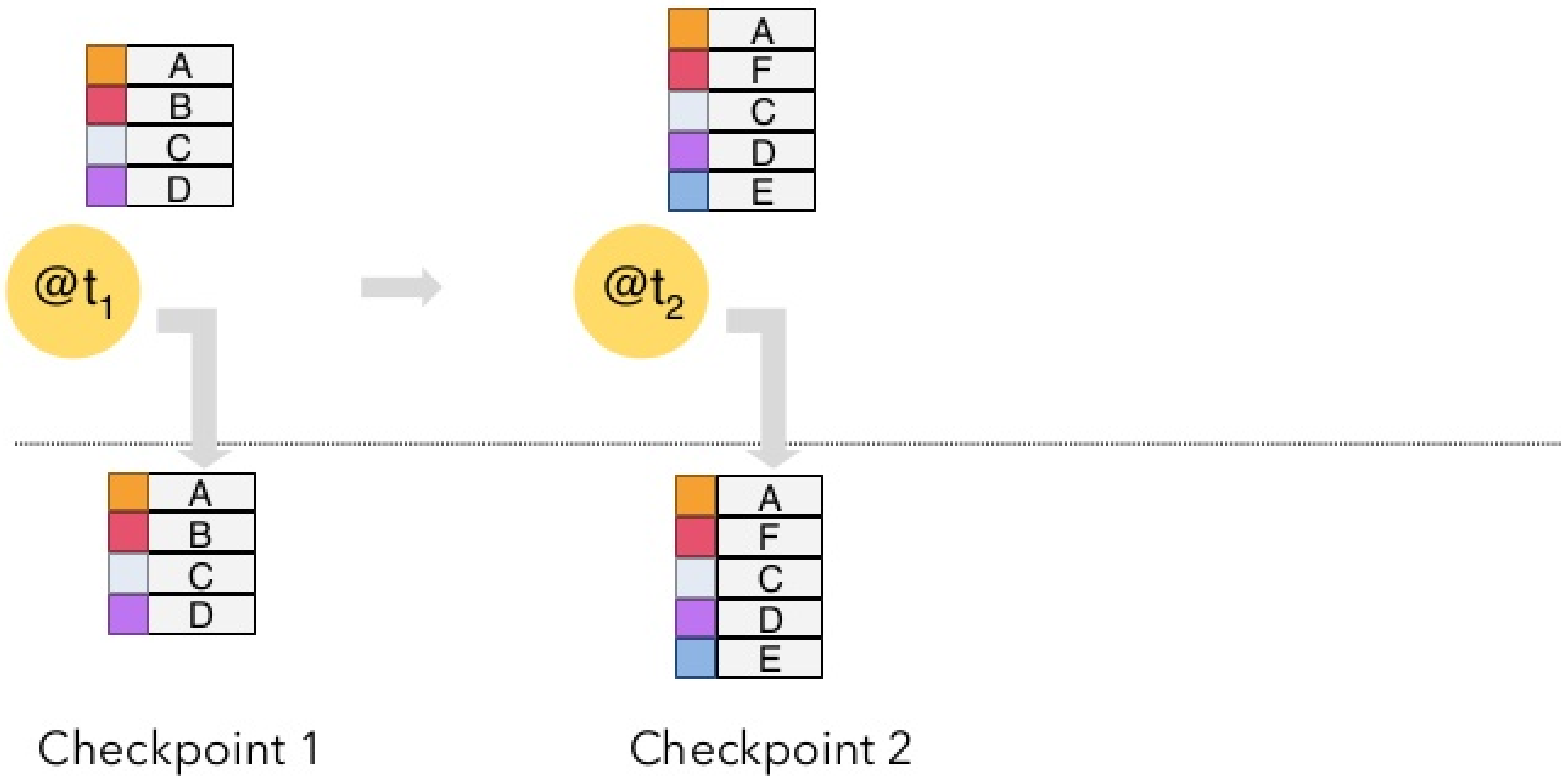


FULL / INCREMENTAL CHECKPOINTS

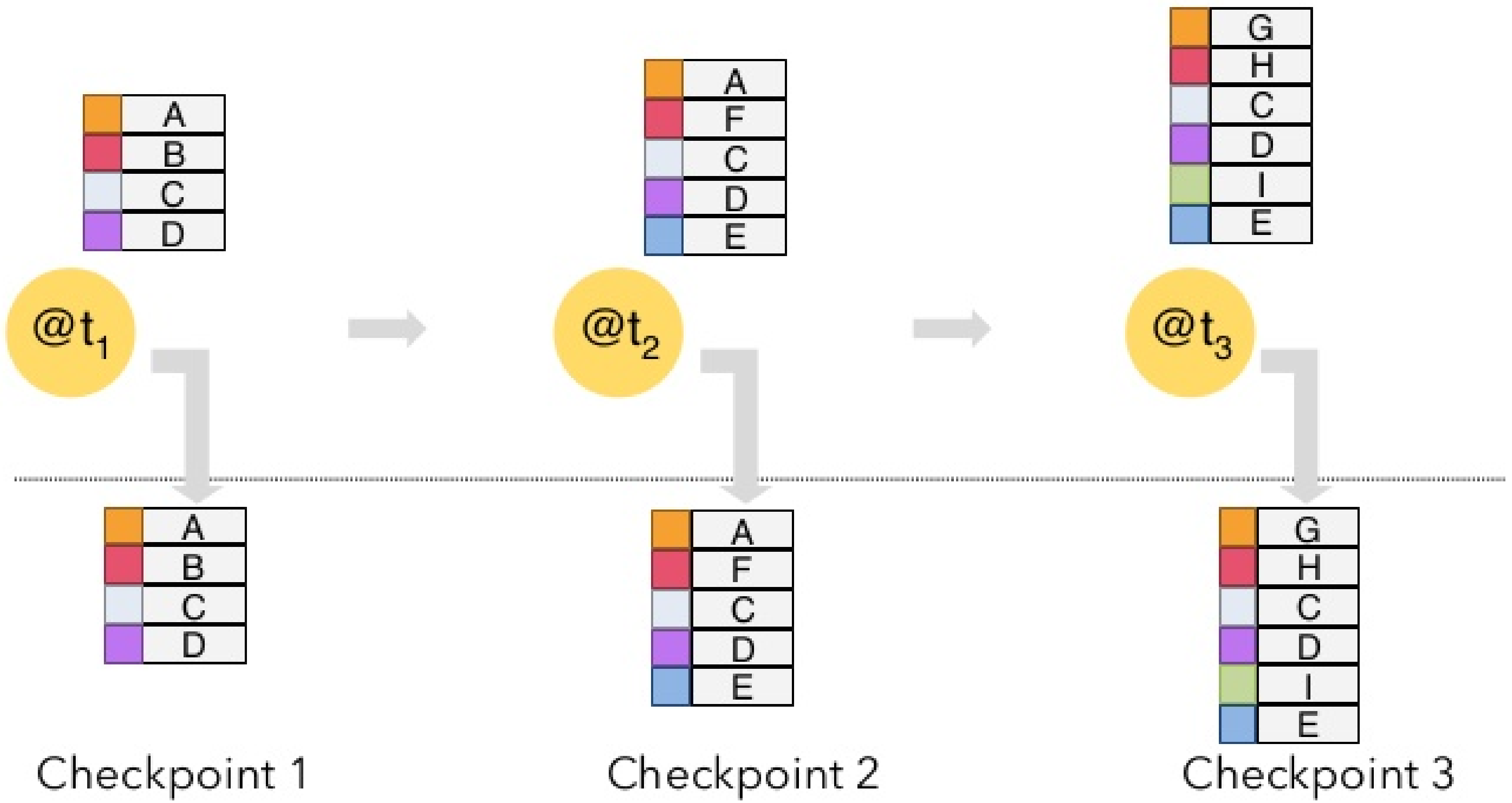
FULL CHECKPOINT

Checkpoint 1

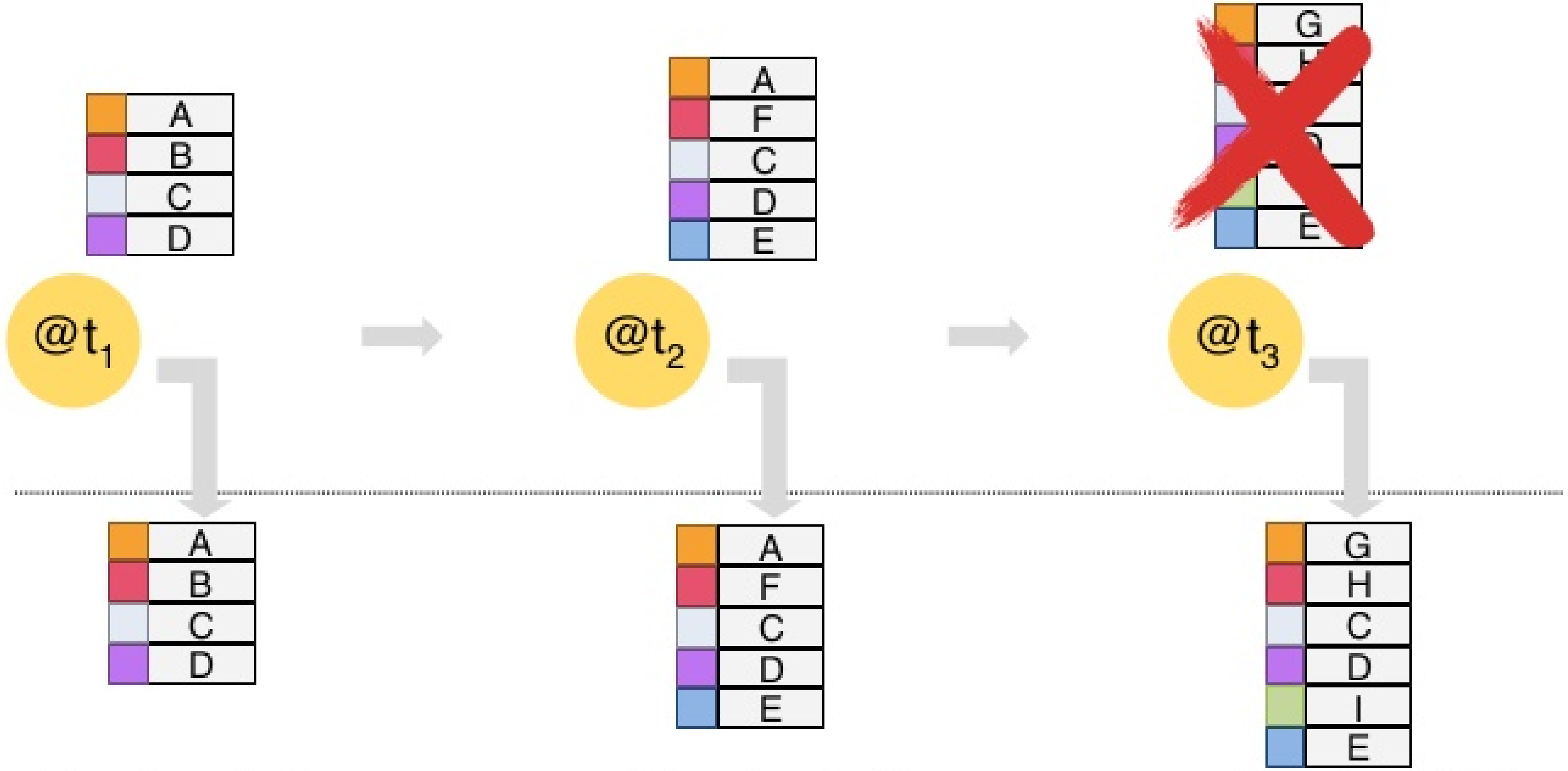
FULL CHECKPOINT



FULL CHECKPOINT



FULL CHECKPOINT

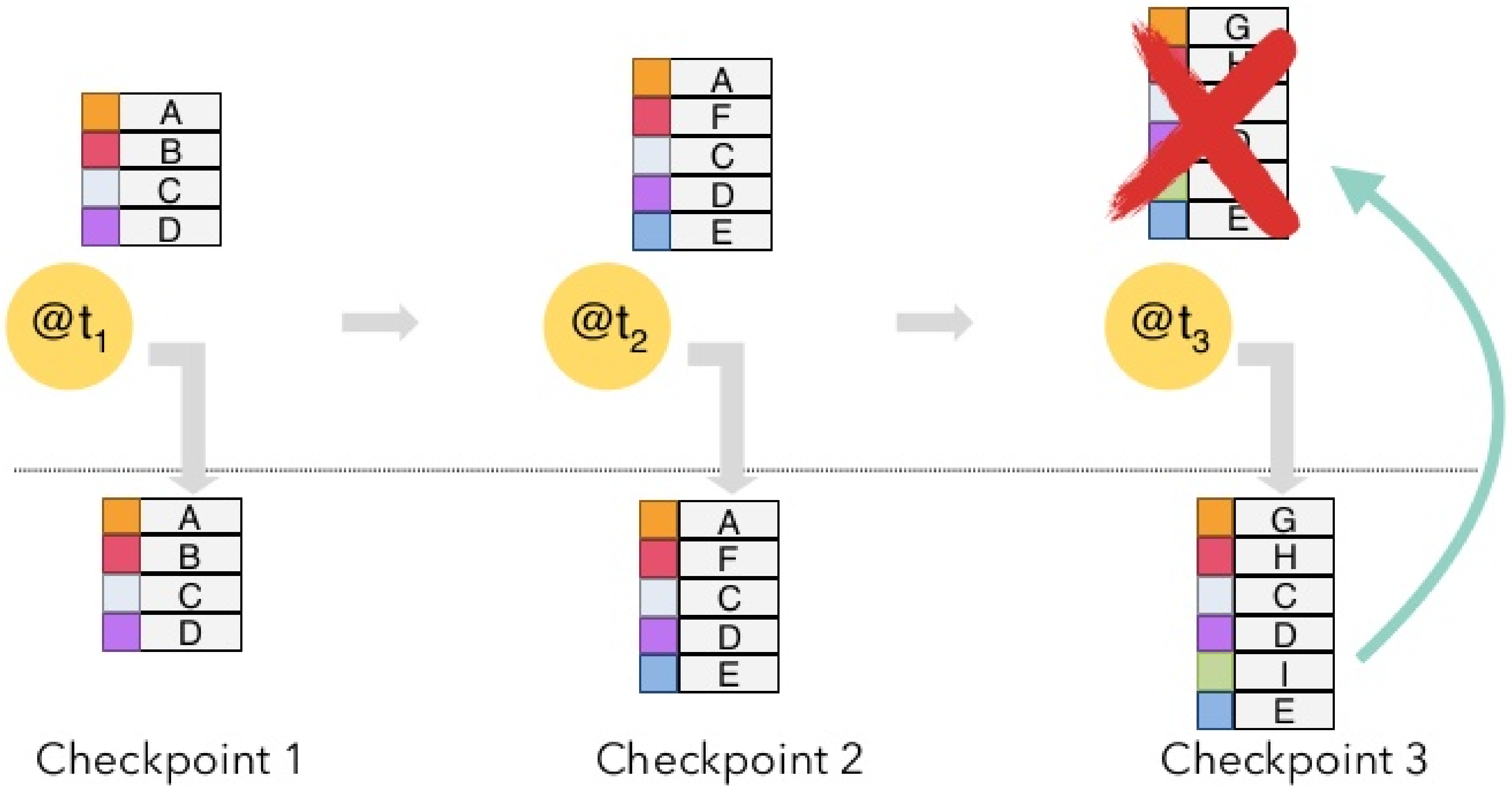


Checkpoint 1

Checkpoint 2

Checkpoint 3

FULL CHECKPOINT



FULL CHECKPOINT OVERVIEW

- Creation iterates and writes full database snapshot as stream to stable storage.
- Restore reads data as stream from stable storage and re-inserts into backend.
- Each checkpoint is self contained, size is proportional to size of full state.
- Optional: compression with Snappy.

INCREMENTAL CHECKPOINT

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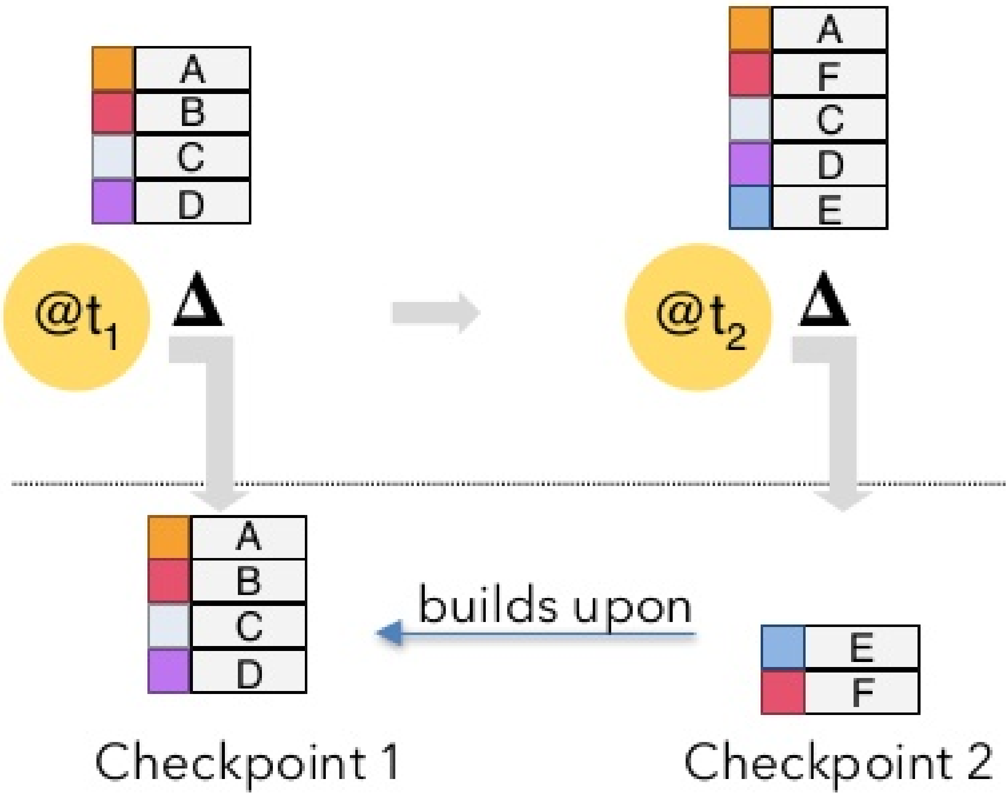

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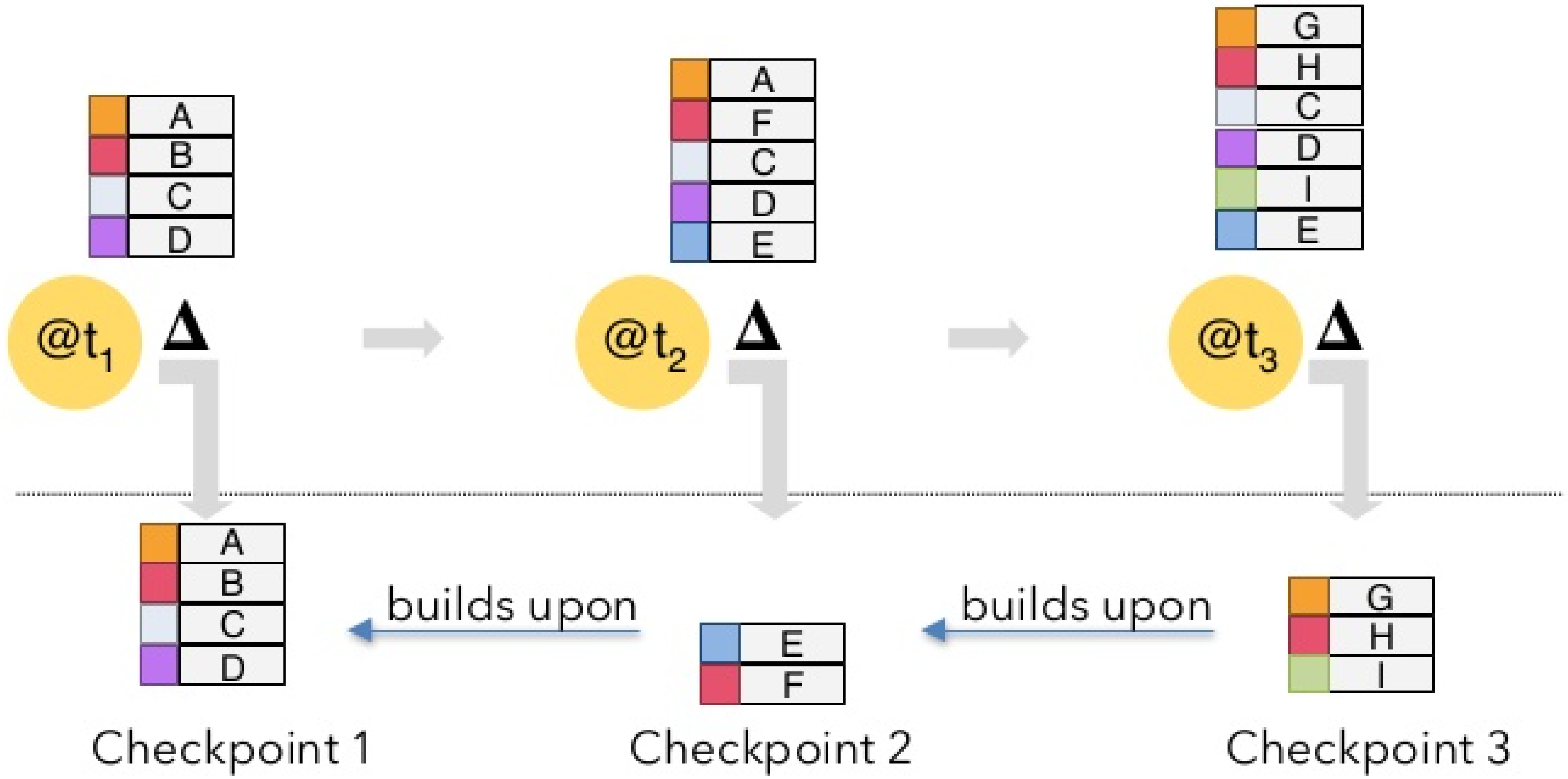

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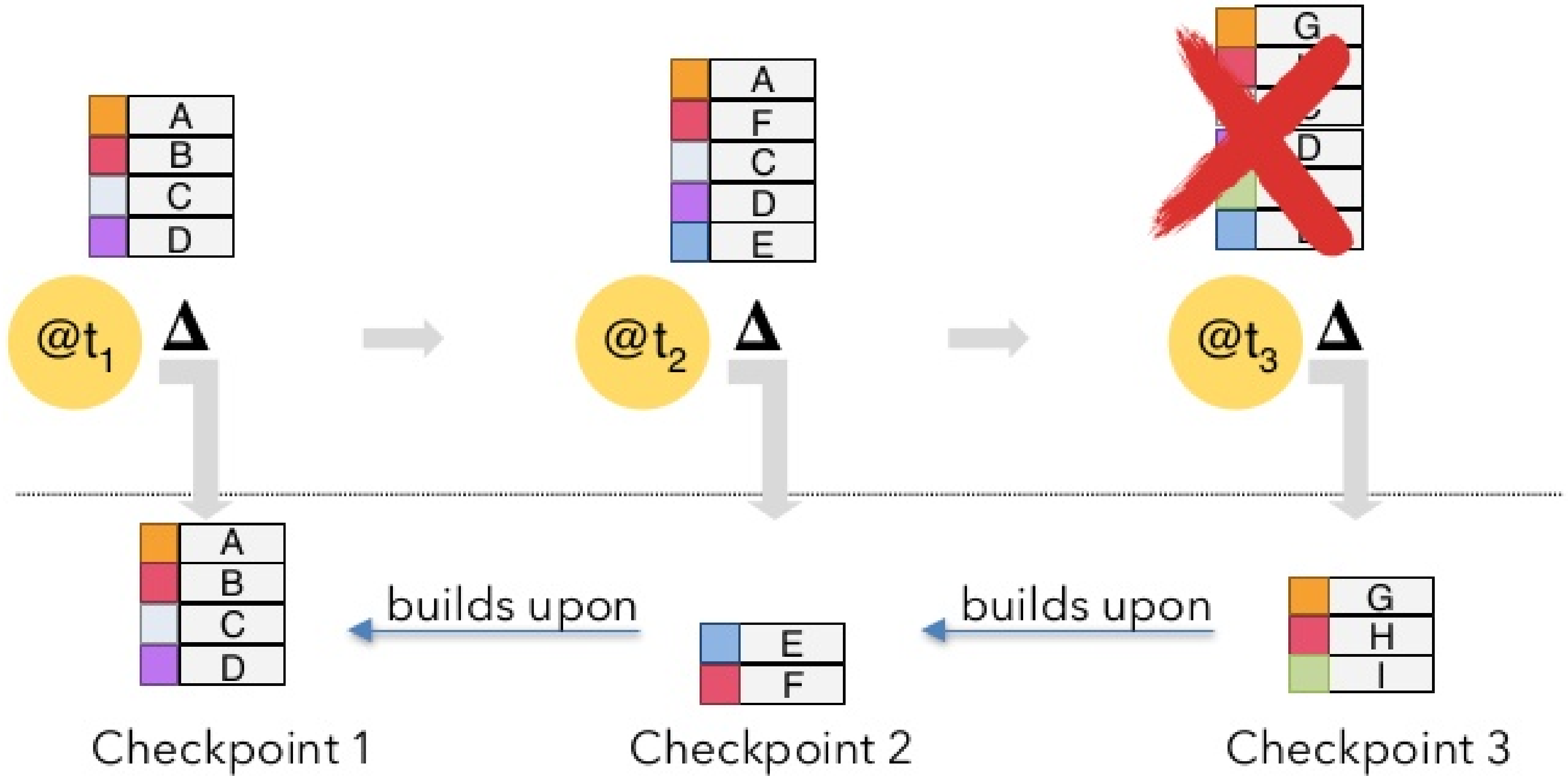

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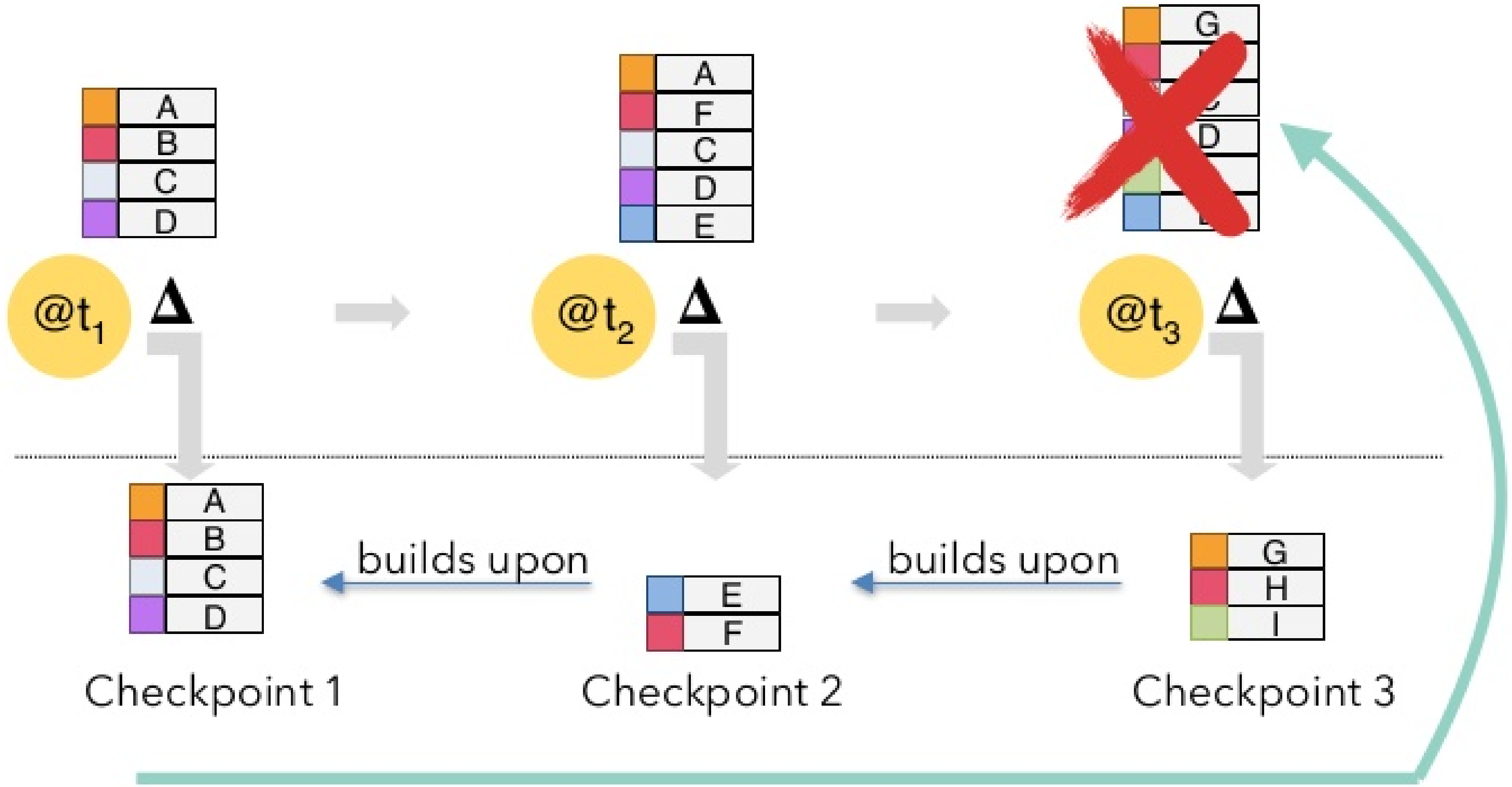
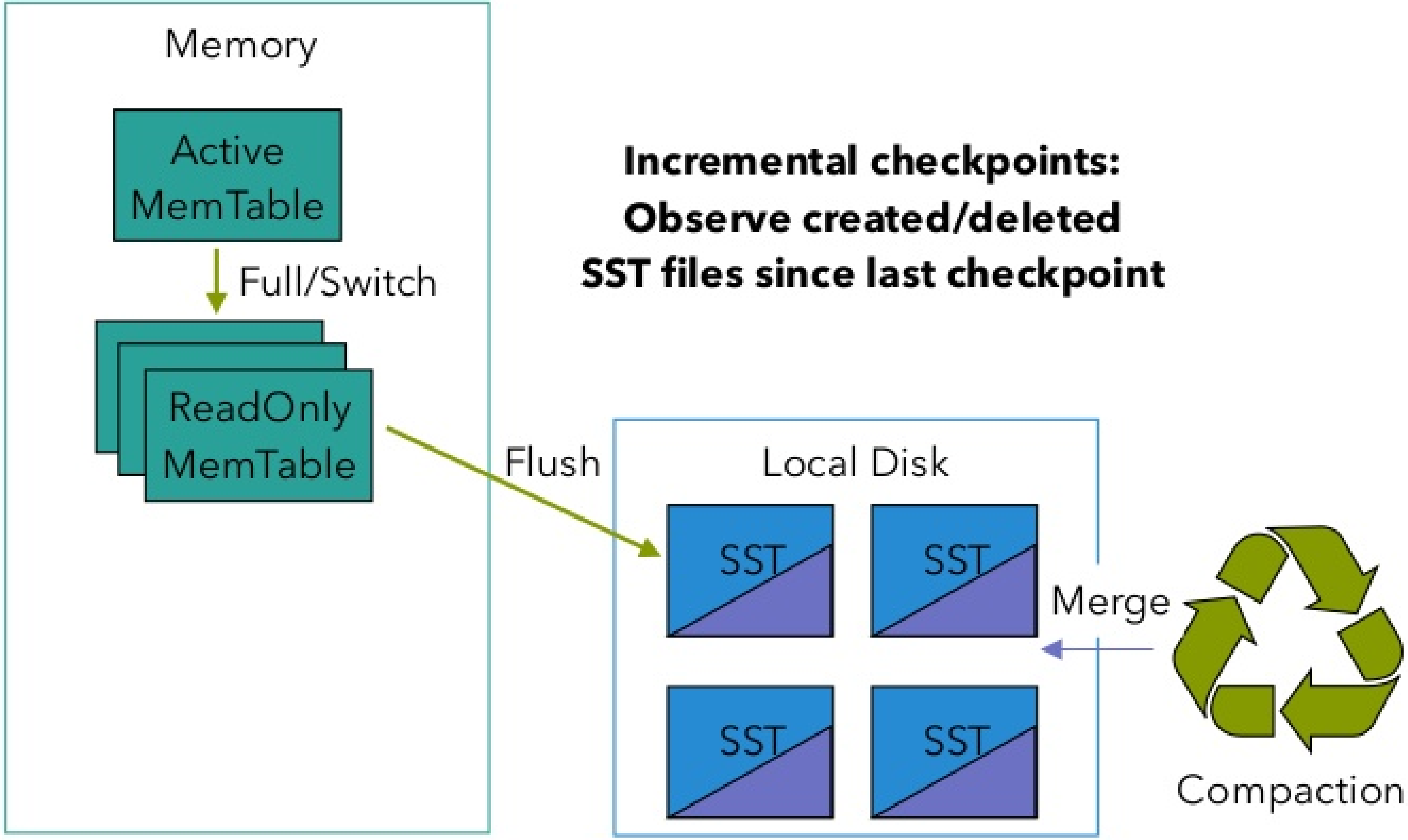


INCREMENTAL CHECKPOINTS WITH ROCKSDB



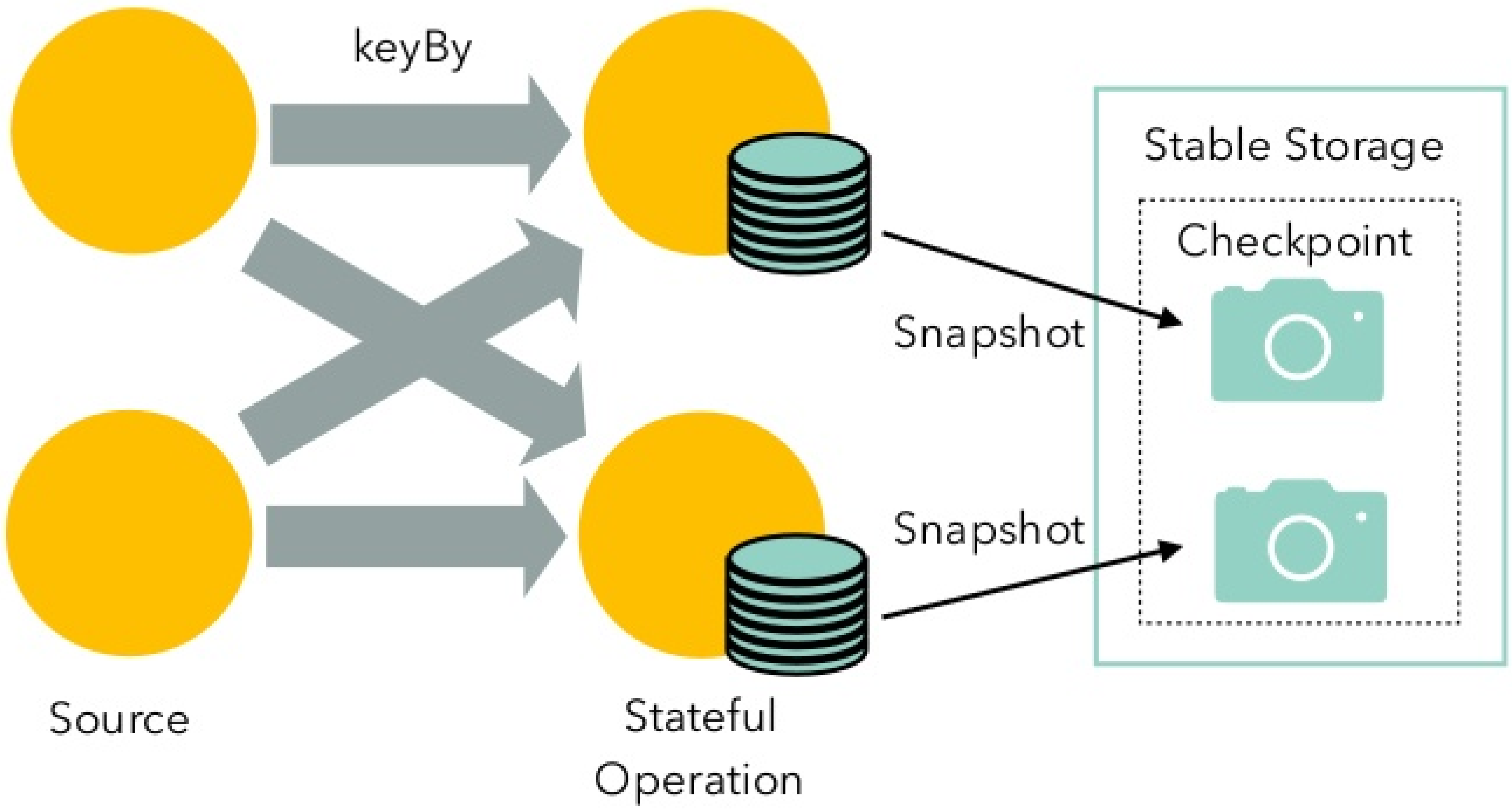
Incremental checkpoints:
Observe created/deleted
SST files since last checkpoint

INCREMENTAL CHECKPOINT OVERVIEW

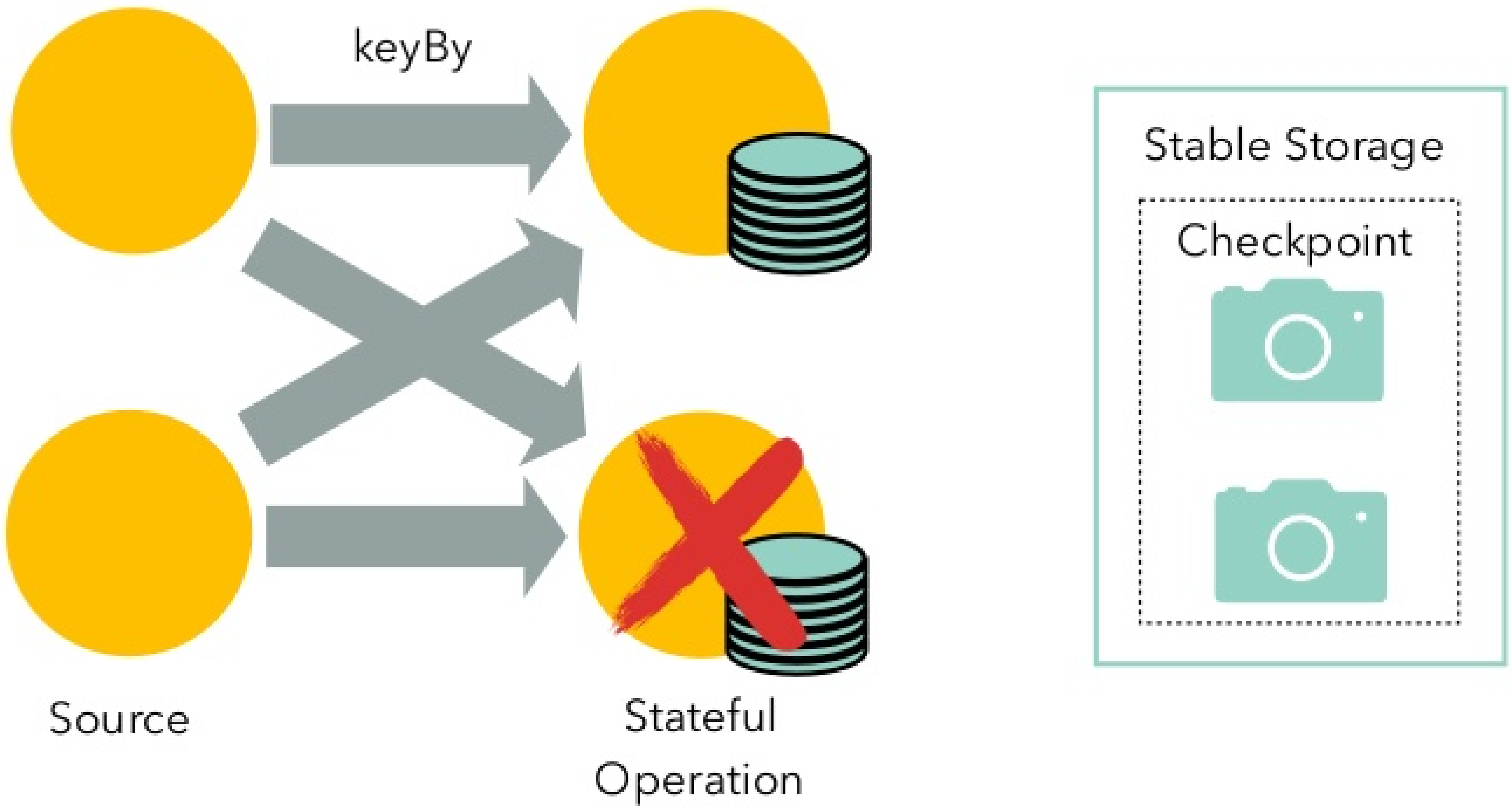
- Expected trade-off: faster* checkpoints, slower* recovery
- Creation only copies deltas (new local SST files) to stable storage.
- Write amplification because we also upload compacted SST files so that we can prune checkpoint history.
- Sum of all increments that we read from stable storage can be larger than the full state size. Deletes are also explicit as tombstones.
- But no rebuild required because we simply re-open the RocksDB backend from the SST files.
- SST files are snappy-compressed by default.

LOCAL RECOVERY

CHECKPOINTING WITHOUT LOCAL RECOVERY



RESTORE WITHOUT LOCAL RECOVERY



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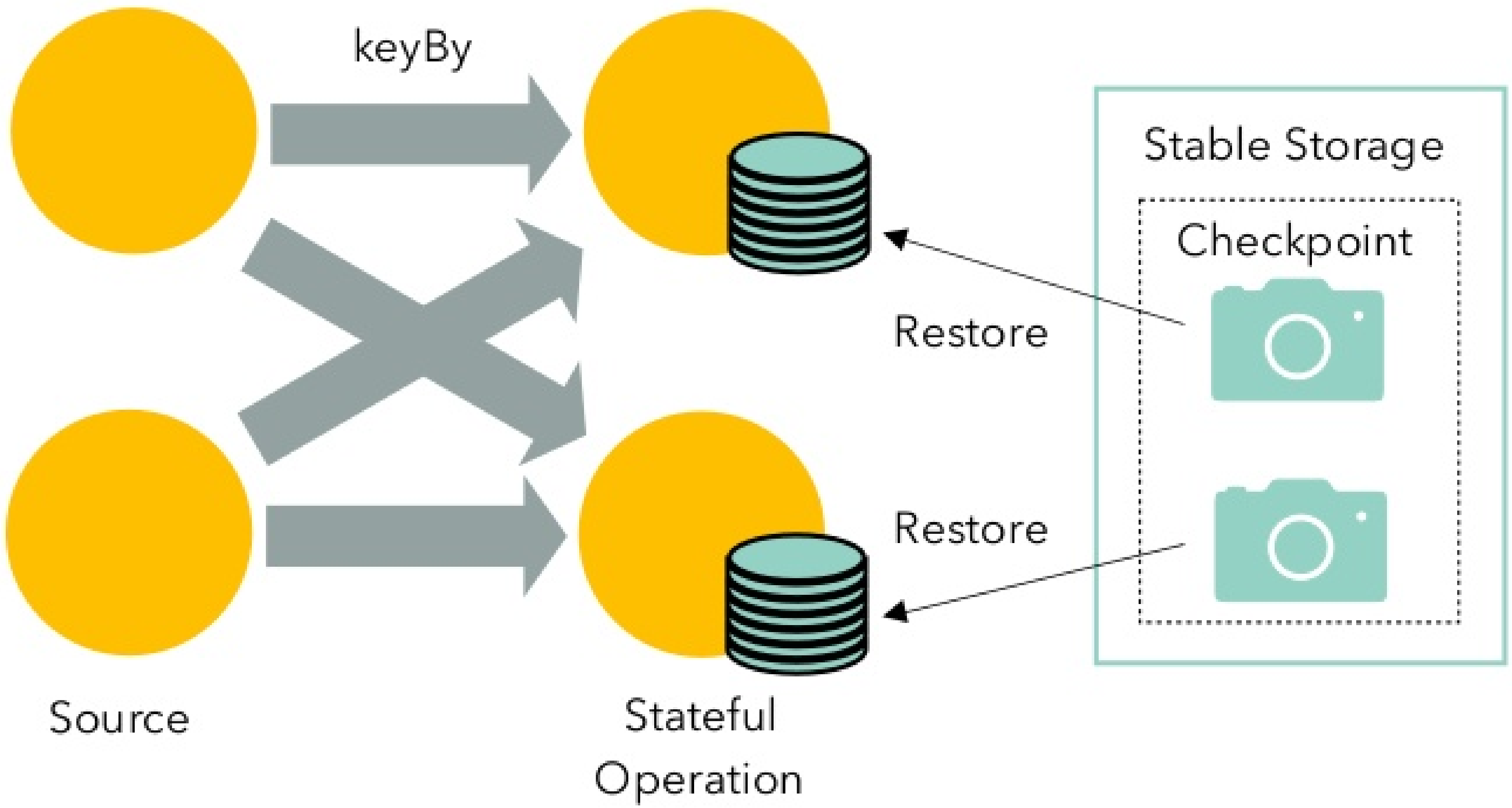
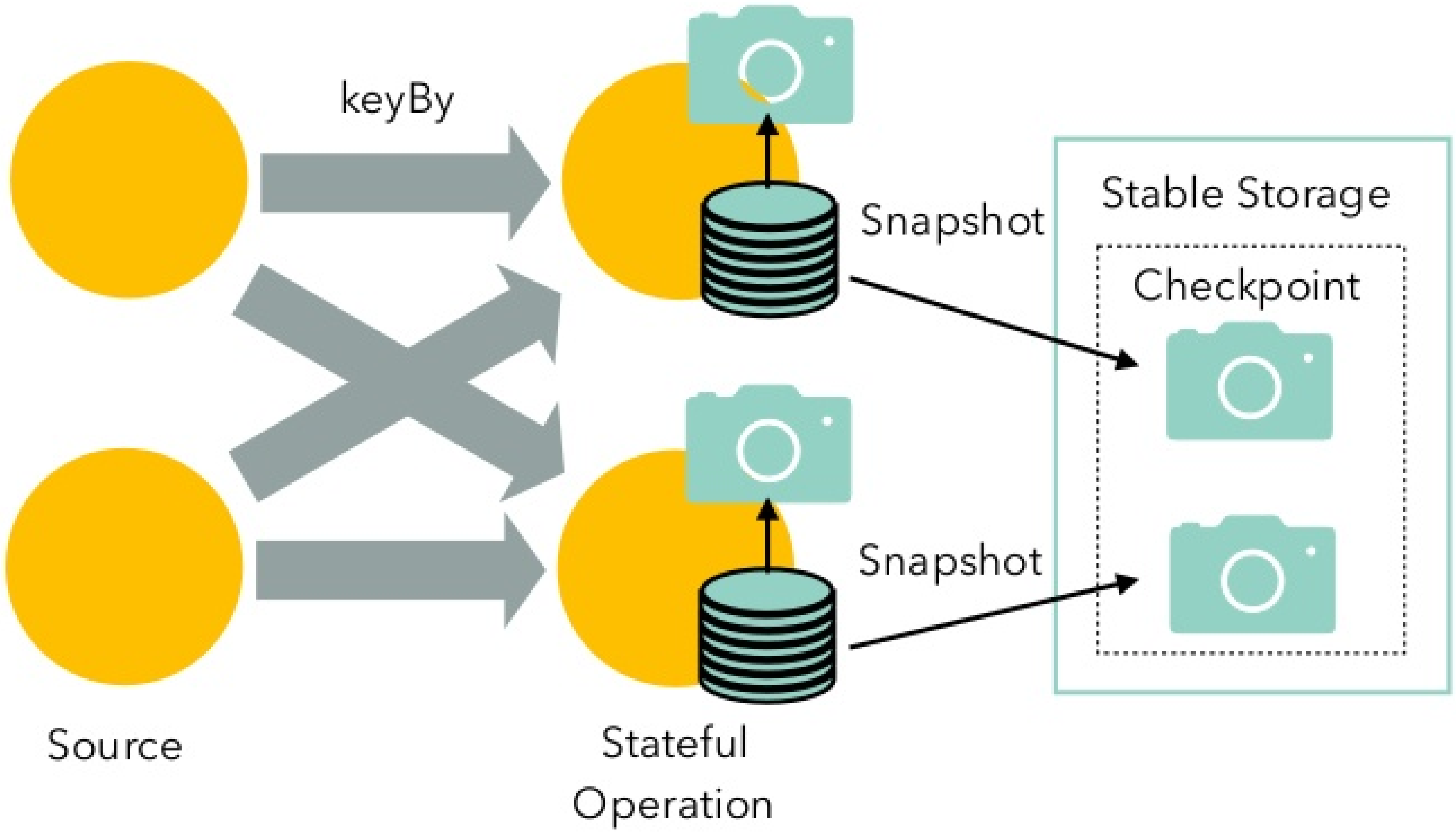
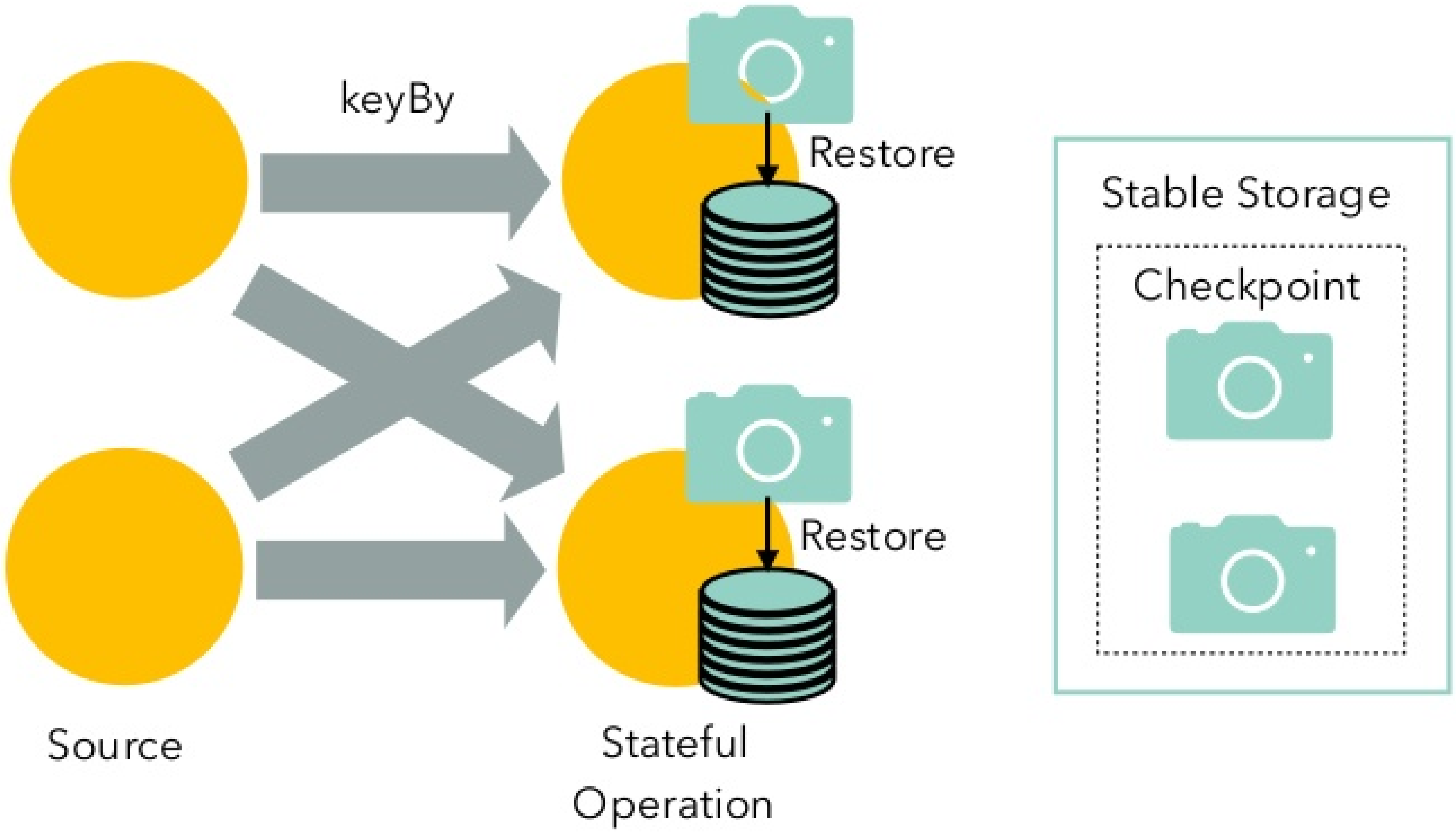


CHECKPOINTING WITH LOCAL RECOVERY



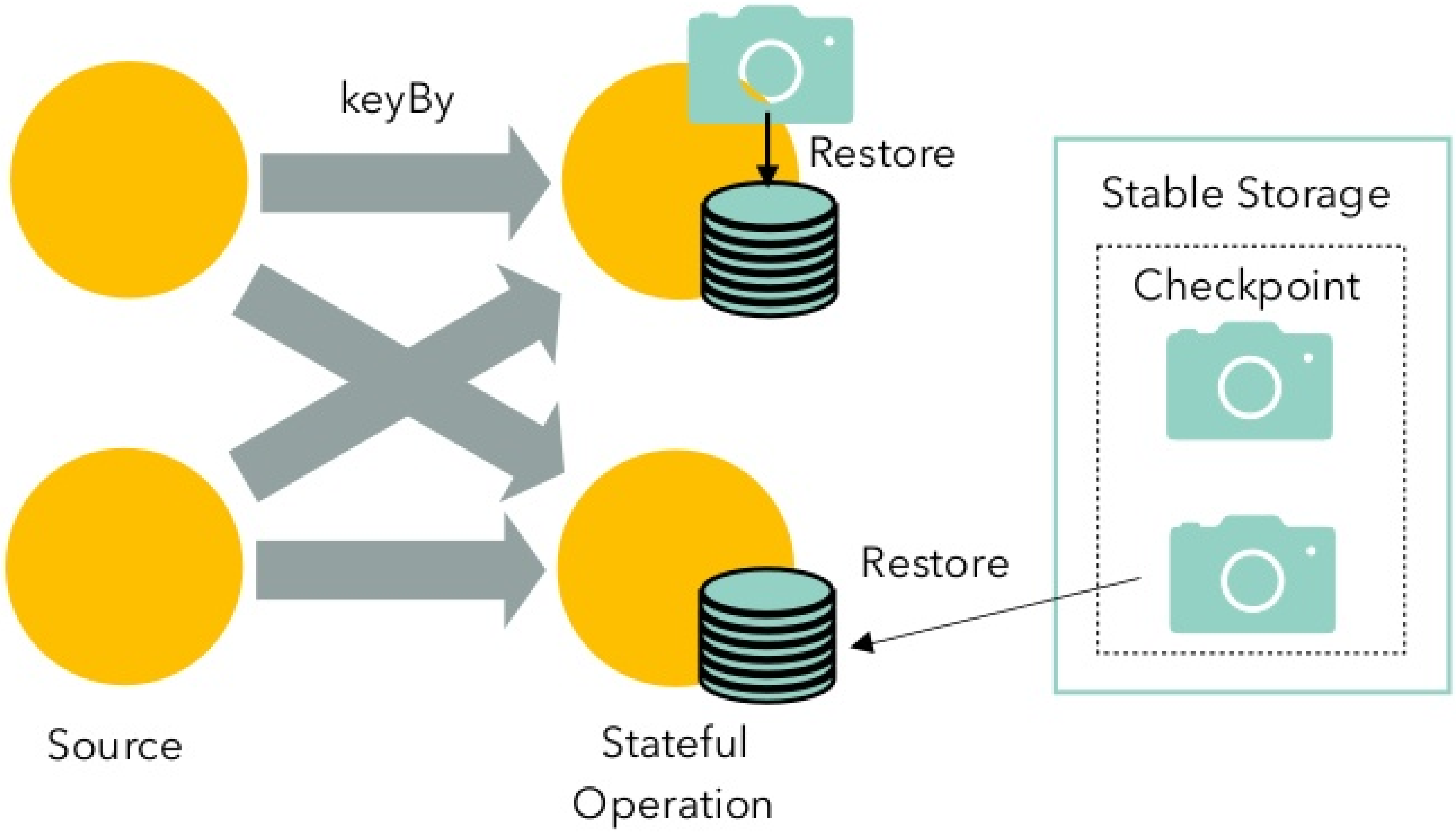
RESTORE WITH LOCAL RECOVERY

Scenario 1: No task manager failures, e.g. user code exception



RESTORE WITH LOCAL RECOVERY

Scenario 2: With task manager failure, e.g. disk failure



LOCAL RECOVERY TAKEAWAY POINTS

- Works with both state backends, for full and incremental checkpoints.
  - Keeps a local copy of the snapshot. Typically, this comes at the cost of mirroring the snapshot writes to remote storage also to local storage.
  - Restore with LR avoids the transfer of state from stable to local storage.

- LR works particularly well with RocksDB incremental checkpoints.
  - No new local files created, existing files might only live a bit longer.
  - Opening database from local, native table files - no ingestion / rebuild.

- Under TM failure recovery still bounded by slowest restore, but still saves a lot of resources!

REINTERPRET STREAM AS KEYED STREAM

REINTERPRETING A DATASTREAM AS KEYED

```
env.addSource(new InfiniteTupleSource(1000))
        .keyBy(0)
        .map((in) -> in)
        .timeWindow(Time.seconds(3));
```

Problem: Will not compile because we can no longer ensure a keyed stream!

REINTERPRETING A DATASTREAM AS KEYED

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```

Problem: Will not compile because we can no longer ensure a keyed stream!

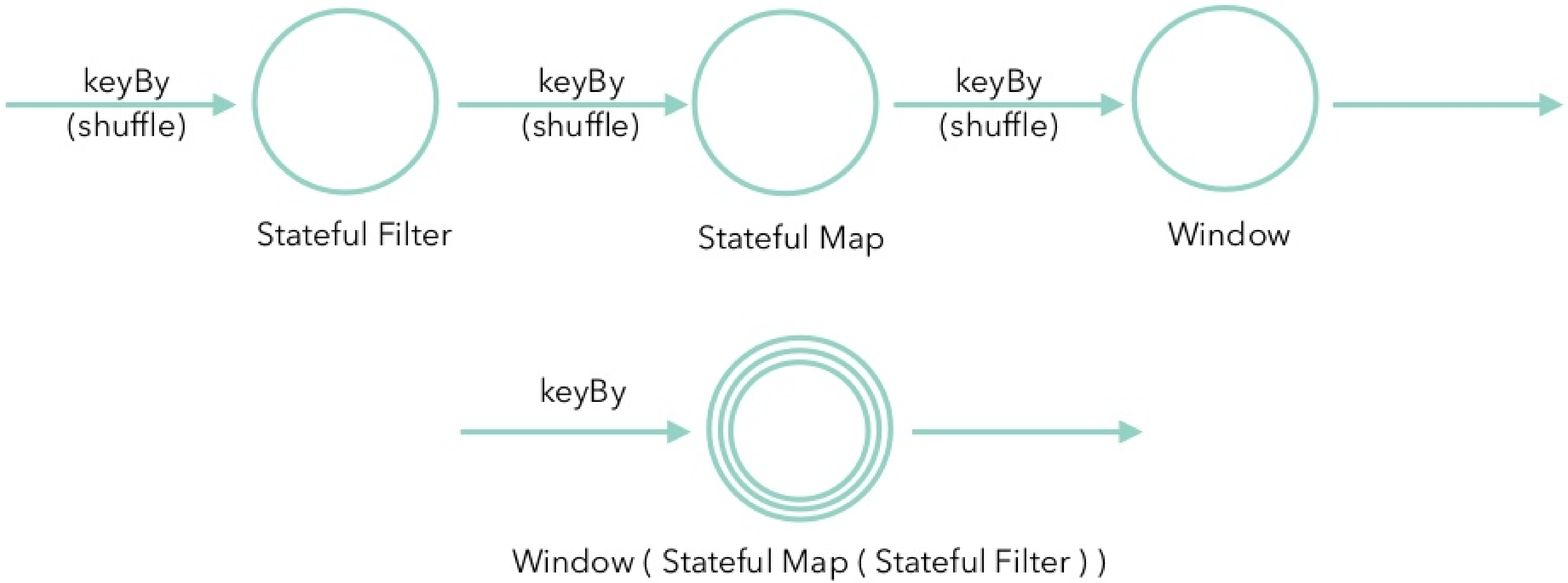
```
KeyedStream<T, K> reinterpretAsKeyedStream(
    DataStream<T> stream,
    KeySelector<T, K> keySelector)
```

Solution: Method to explicitly give (back) „keyed" property to any data stream

```
DataStreamUtils.reinterpretAsKeyedStream(
    env.addSource(new InfiniteTupleSource(1000))
        .keyBy(0)
        .filter((in) -> true), (in) -> in.f0)
    .timeWindow(Time.seconds(3));
```

Warning: Only use this when you are absolutely sure that the elements in the reinterpreted stream follow exactly Flink's keyBy partitioning scheme for the given key selector!

IDEA 1 - REDUCING SHUFFLES



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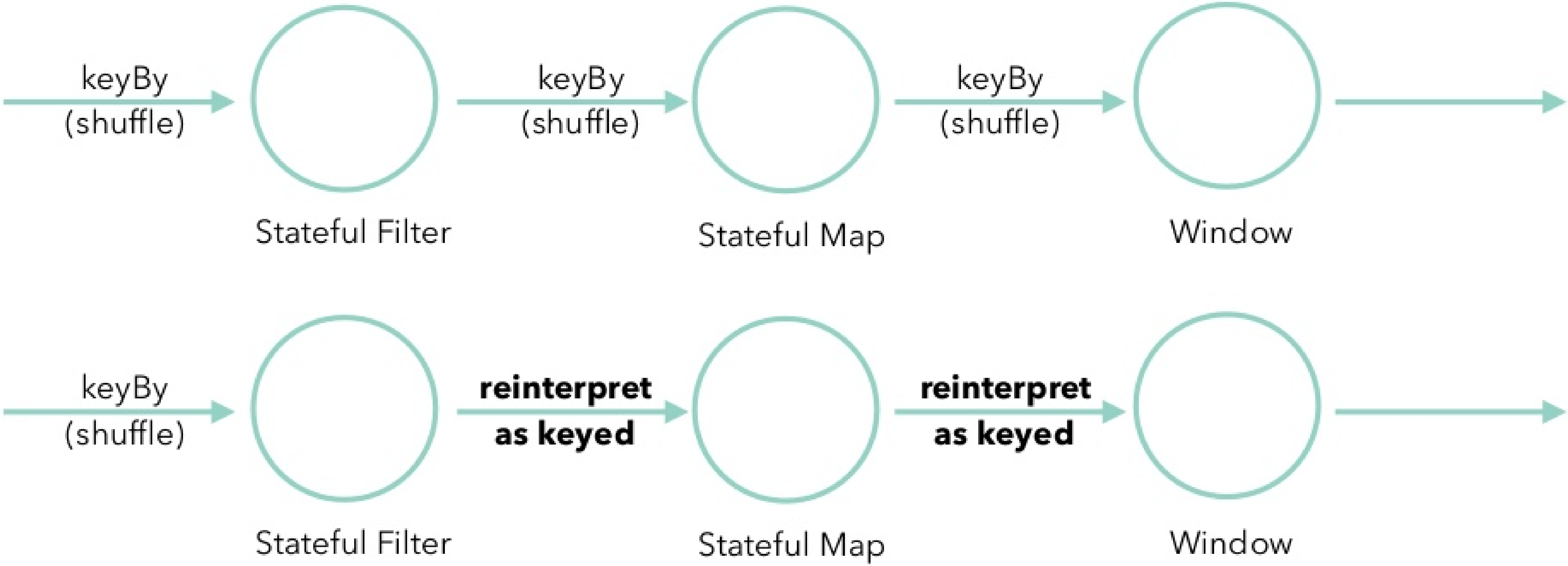
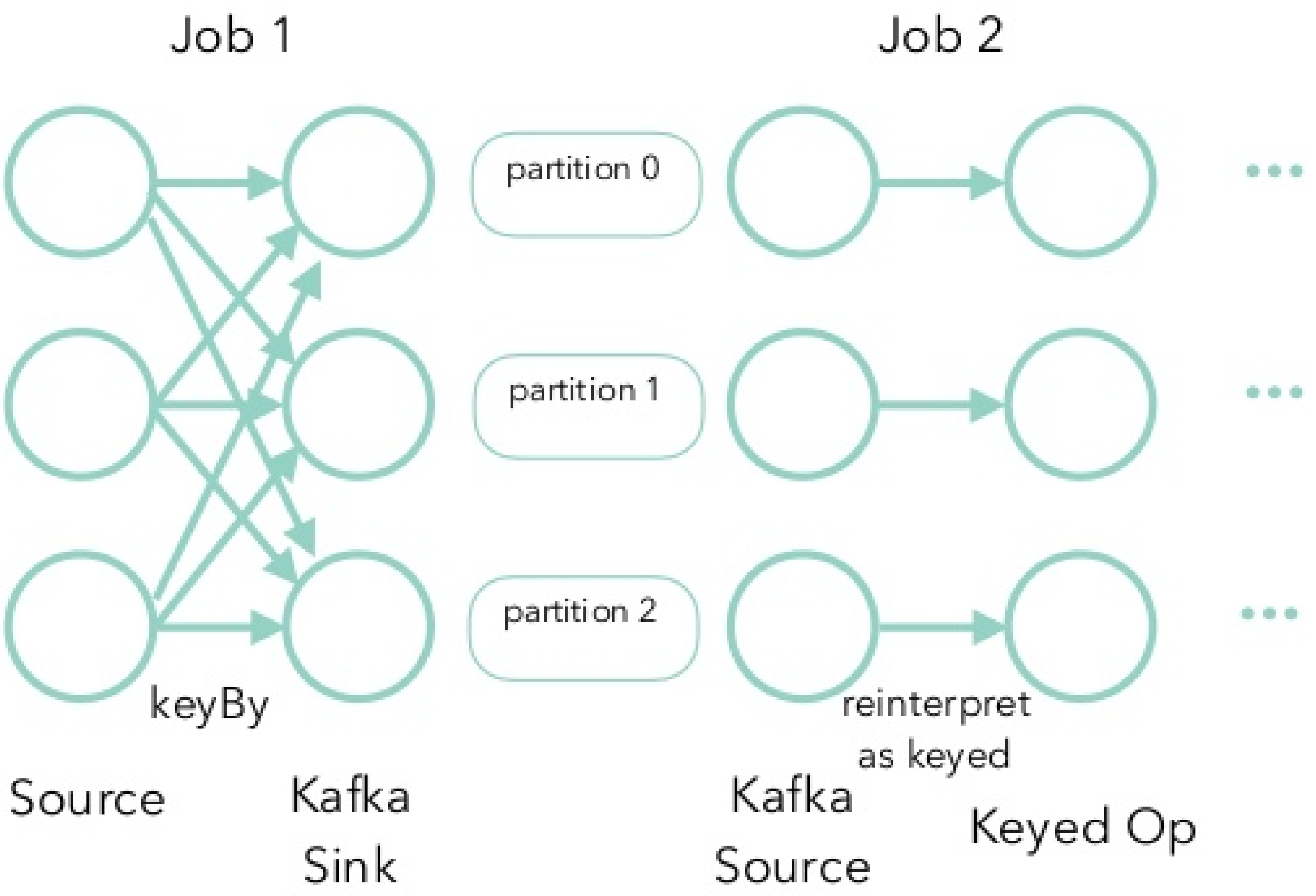


IDEA 2 - PERSISTENT SHUFFLE



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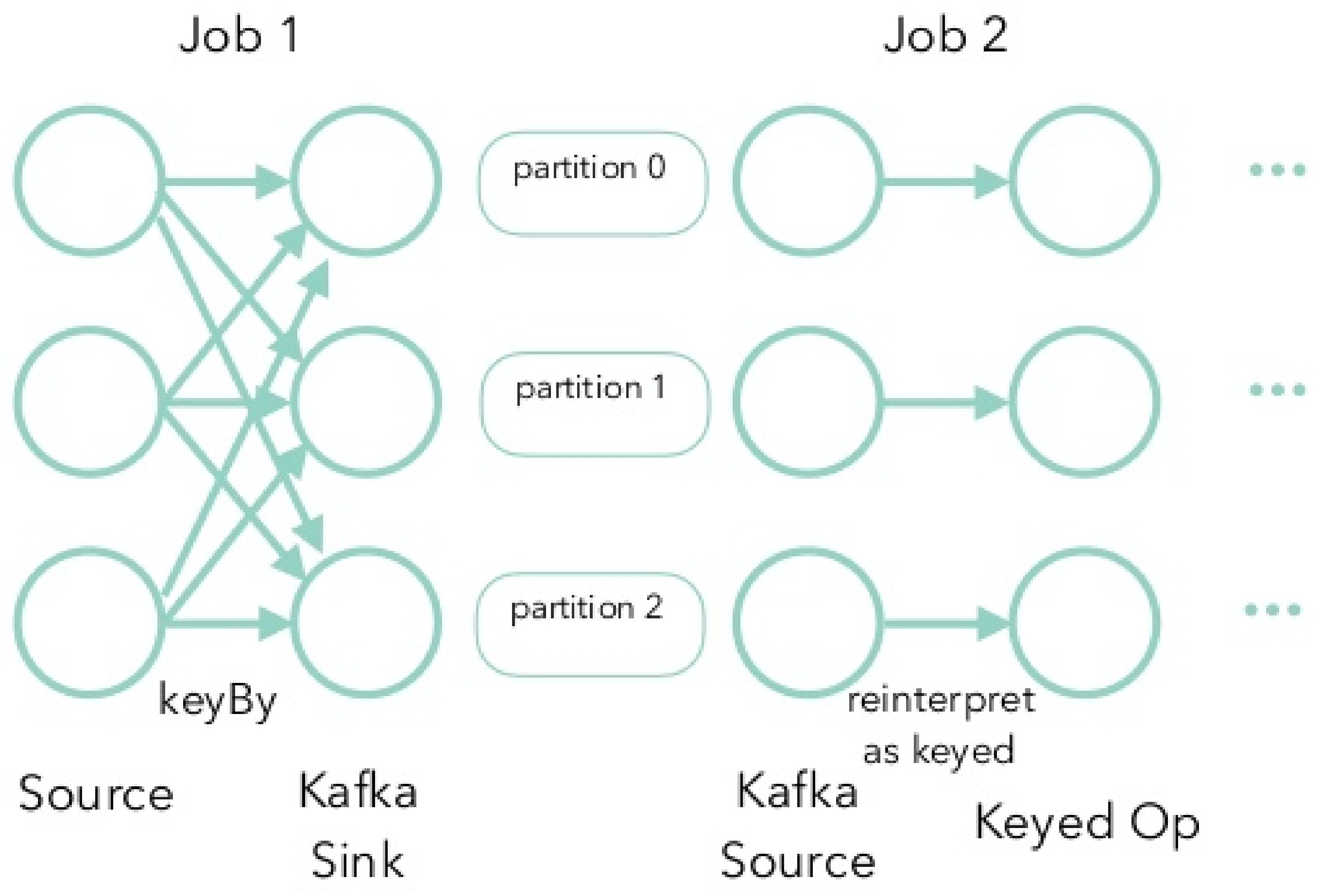

Job 2 becomes embarrassingly parallel and can use fine grained recovery!

THANK YOU!

@StefanRRichter
@dataArtisans
@ApacheFlink

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