Toward GPU Accelerated Data Stream Processing

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Background and Motivation

Fundamentals, Windowing, GPU Acceleration in DBMS/SPS

Data Stream Processing
Application requirements

Examples

- **System Monitoring and Fraud Prevention** — Log files about load, network activity, storage
- **Social Media** — Identify topics of interest online, such as *top-k* hash tags on Twitter
- ...

Requirements

- Real-time response
- Continuous processing and analysis
- High-volume data, potentially infinite
- High-velocity data (many changes)

Data Stream Processing

Data Stream Processing
Processing Model and Windowing

Infinite streams of data, but…

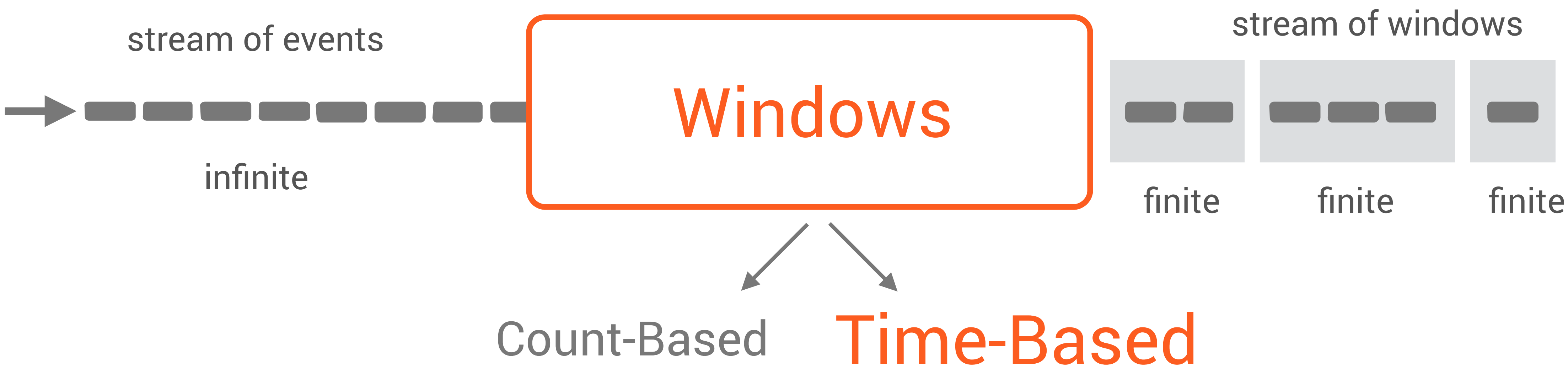
- **Limited** main **memory** and
- Only **sequential access**

Solutions

- Reduction of data amount (e.g., sampling) or
- Buffering (**windowing**)

Data Stream Processing

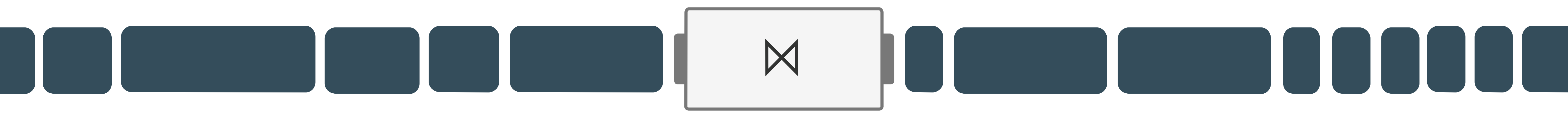
Processing Model and Windowing



- More common for real applications
- Variable number of events per window
- Problematic due to limited GPU memory

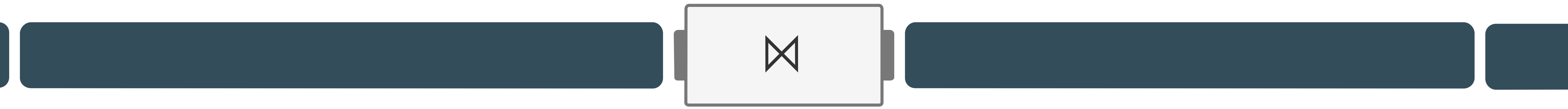
Data Stream Processing
Bottleneck — Example Join Algorithm

- Number of join candidates depends on number of events inside window



Data Stream Processing
Bottleneck — Example Join Algorithm

- Number of join candidates depends on number of events inside window
- Many events in the same instant for time-based windows
  - Decrease of throughput



Data Stream Processing
Bottleneck — Back Pressure

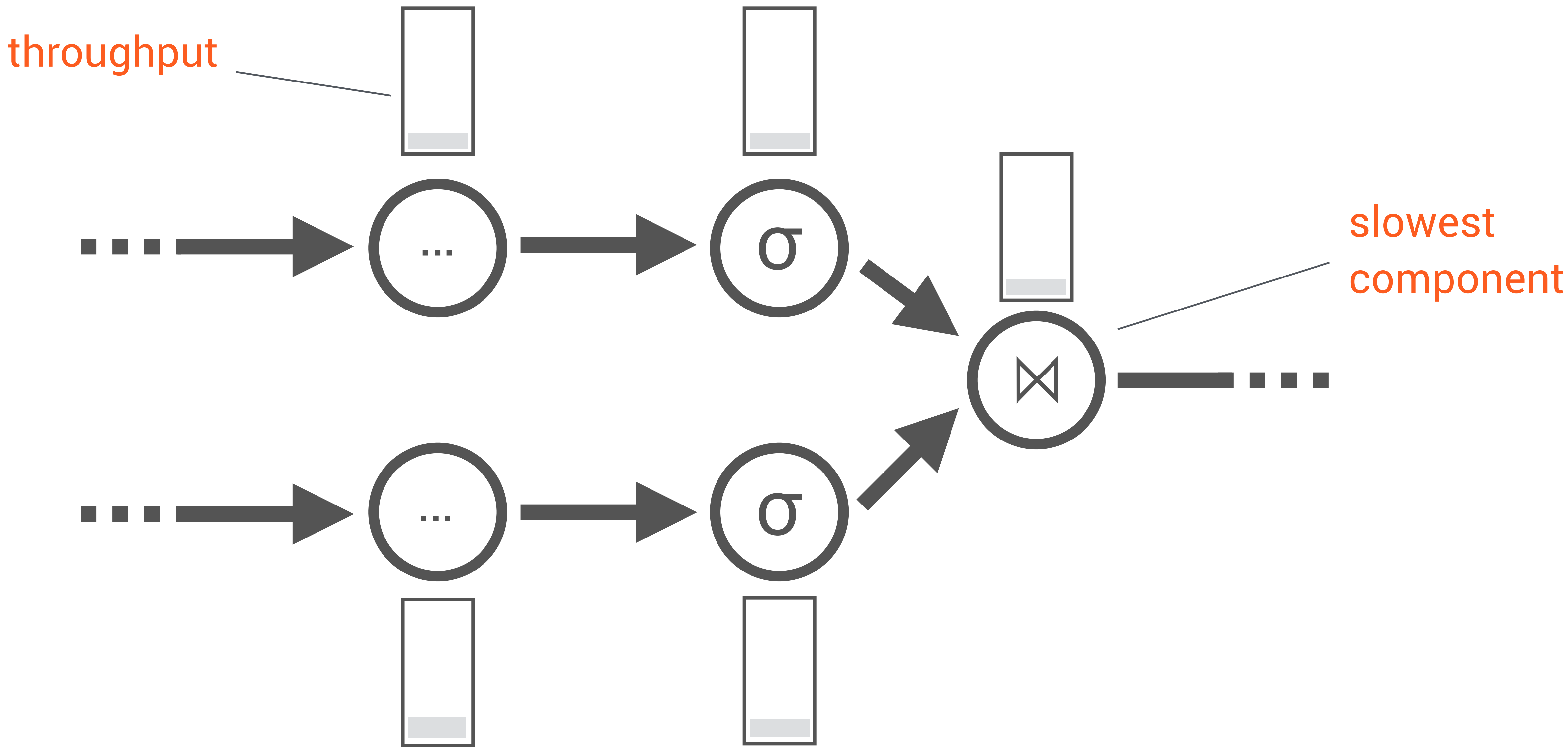
Data flow systems (e.g., stream processing) suffer of **back pressure**

Back pressure

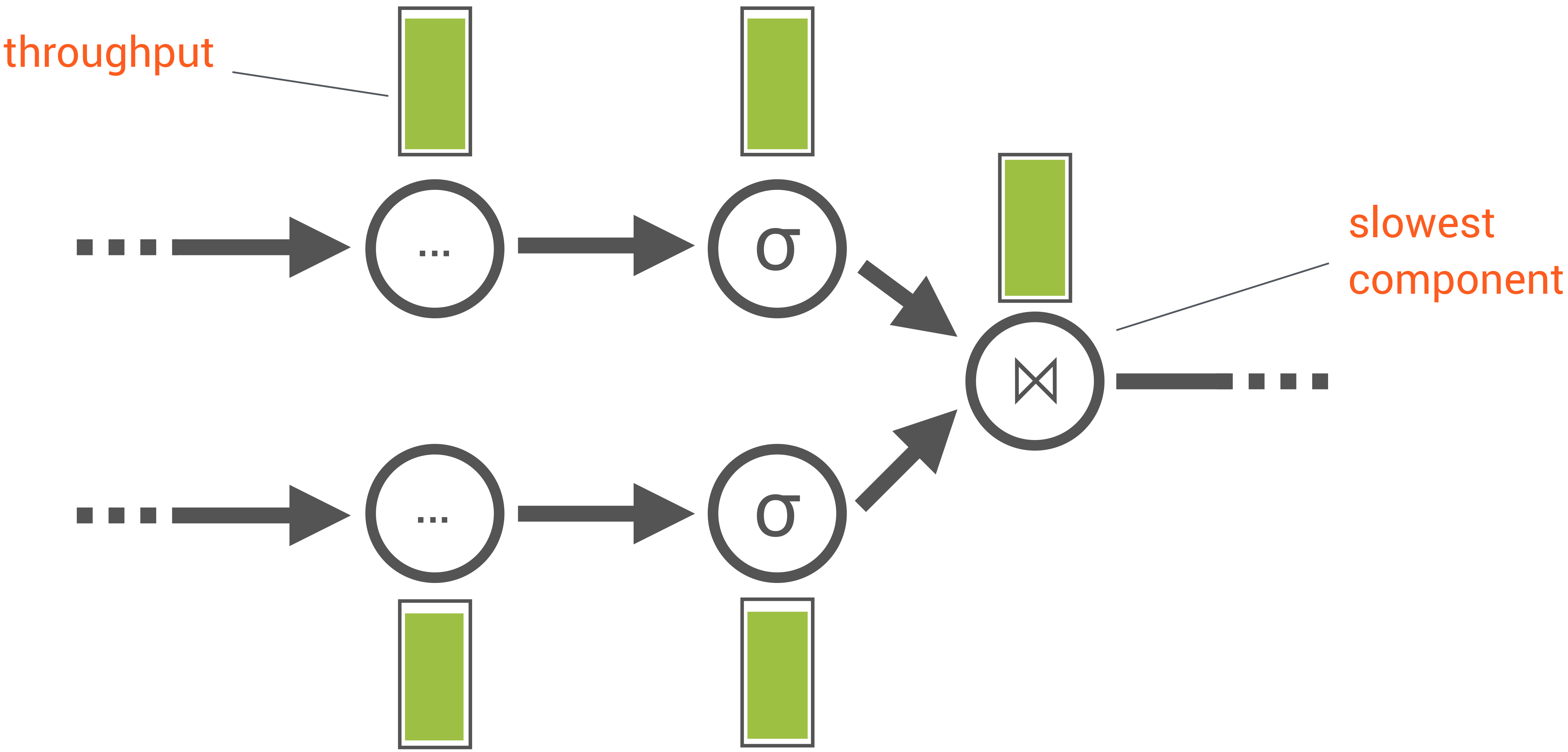
- Upwards-propagated decrease of throughput
- To the level of the slowest component

Results is need for load shedding.

Data Stream Processing
Bottleneck



Data Stream Processing
Bottleneck



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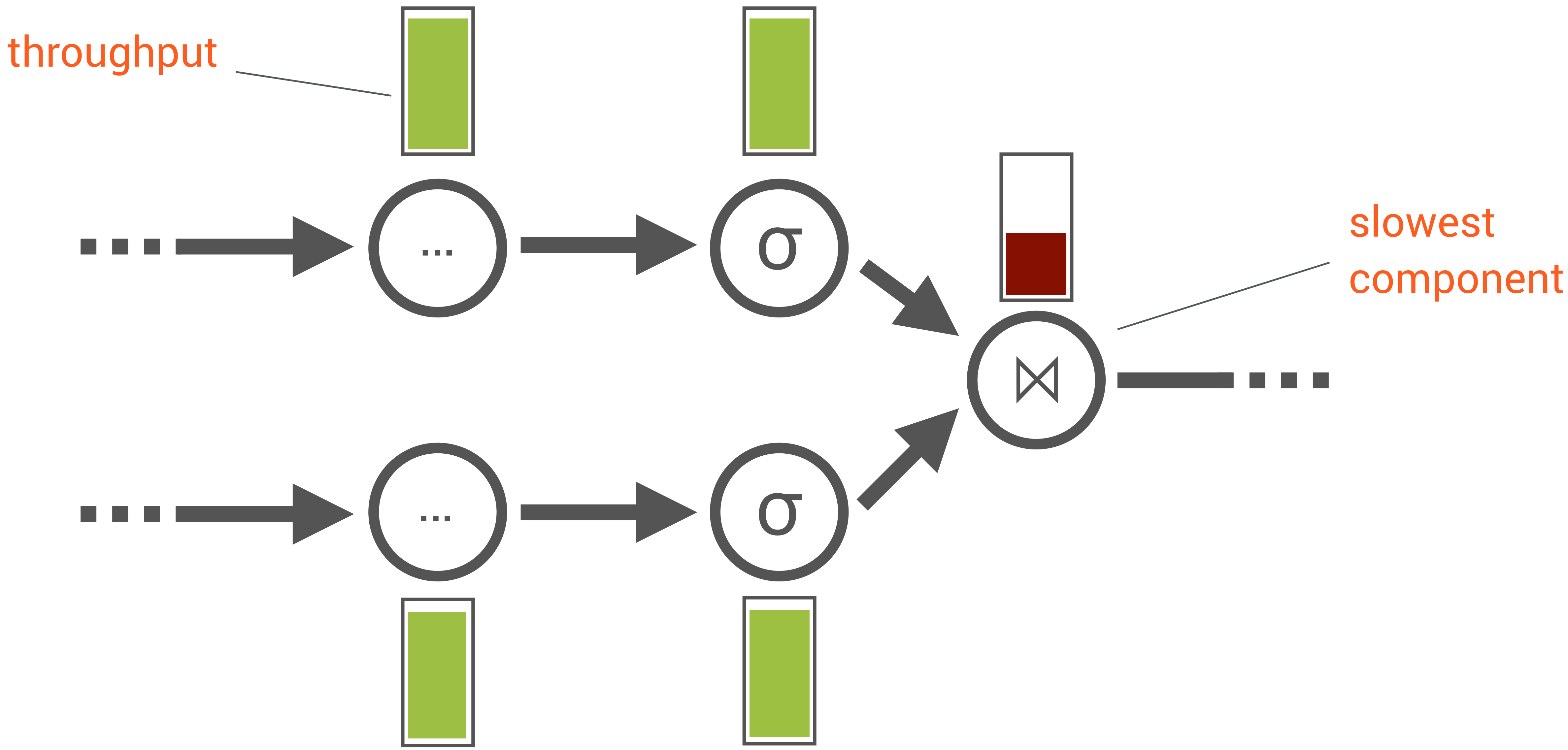
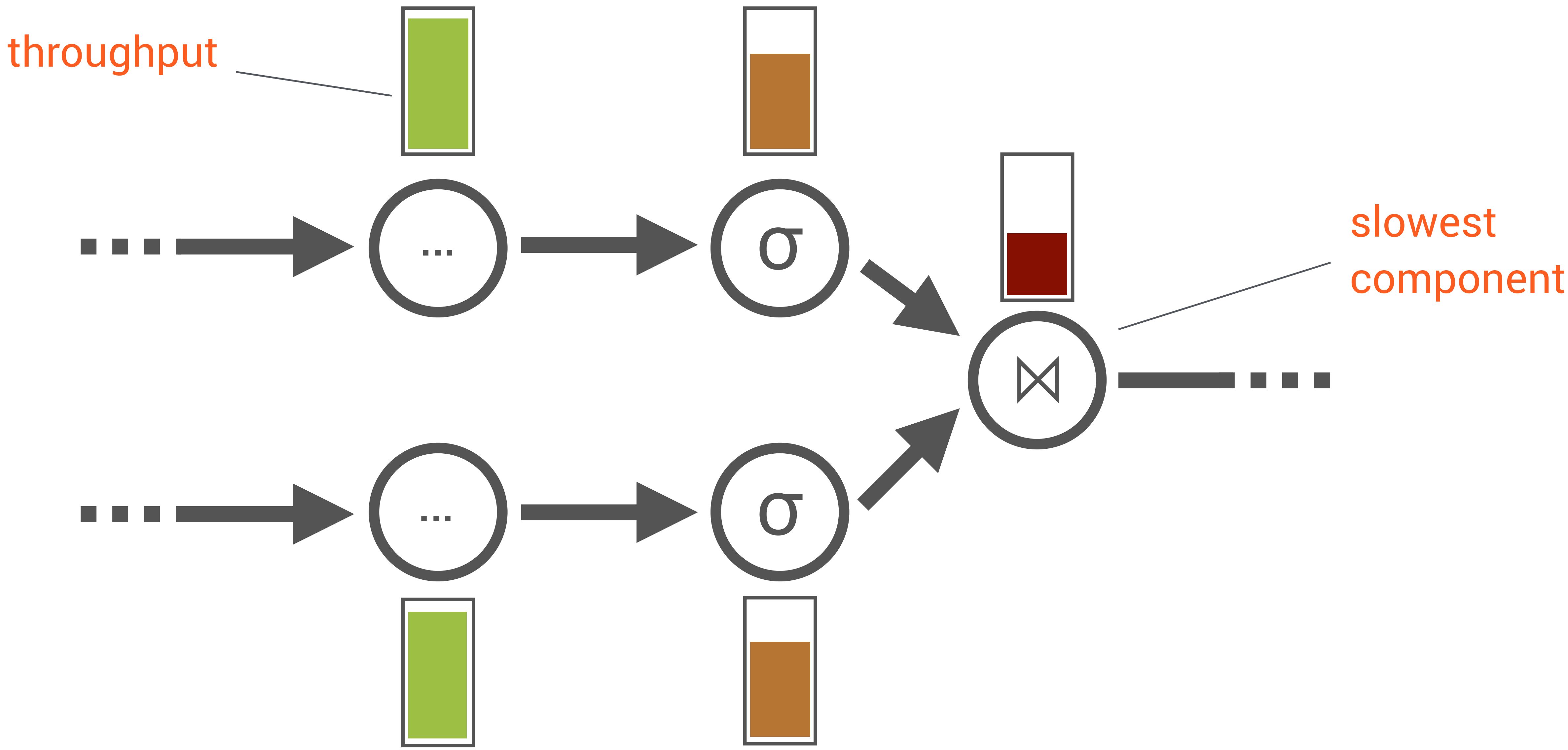
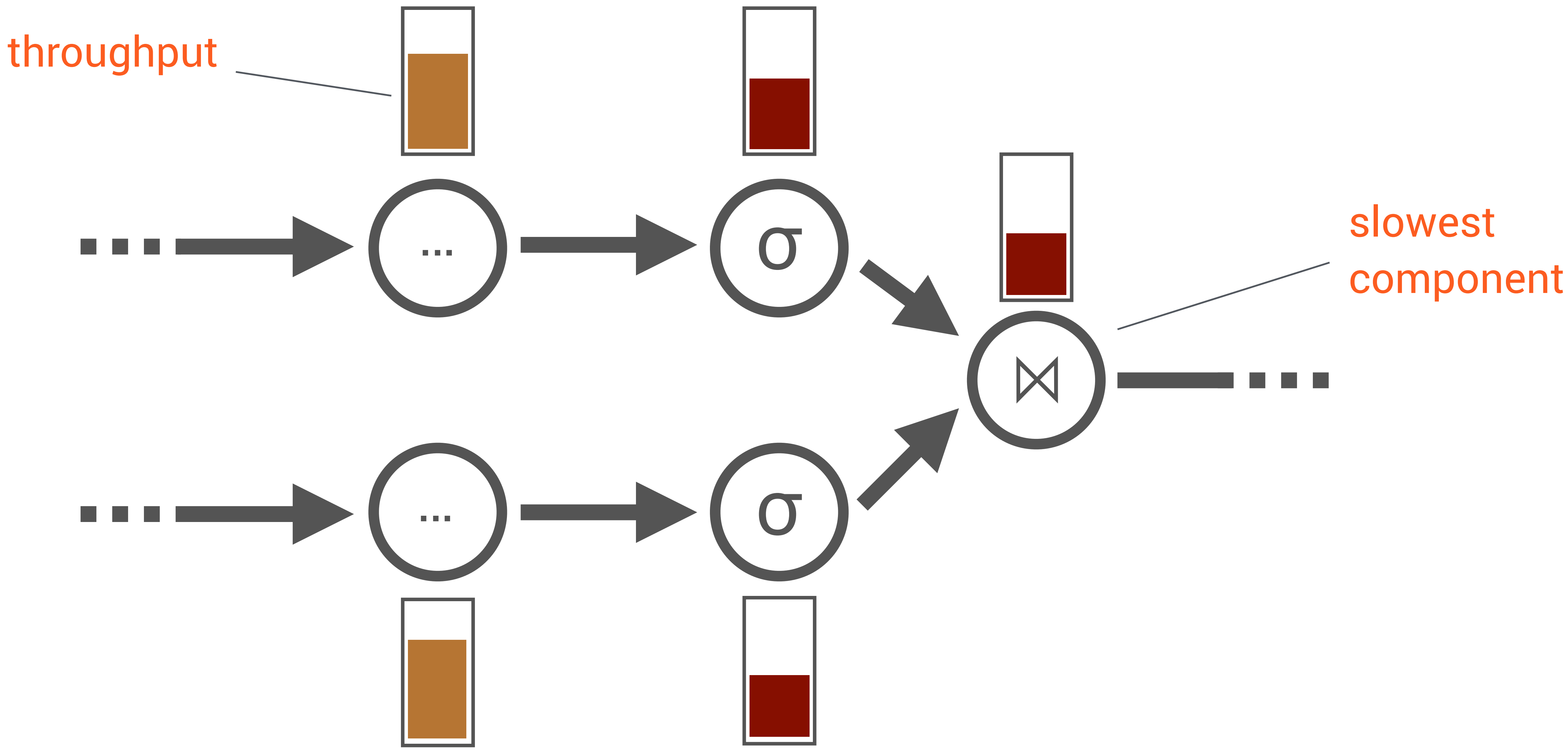


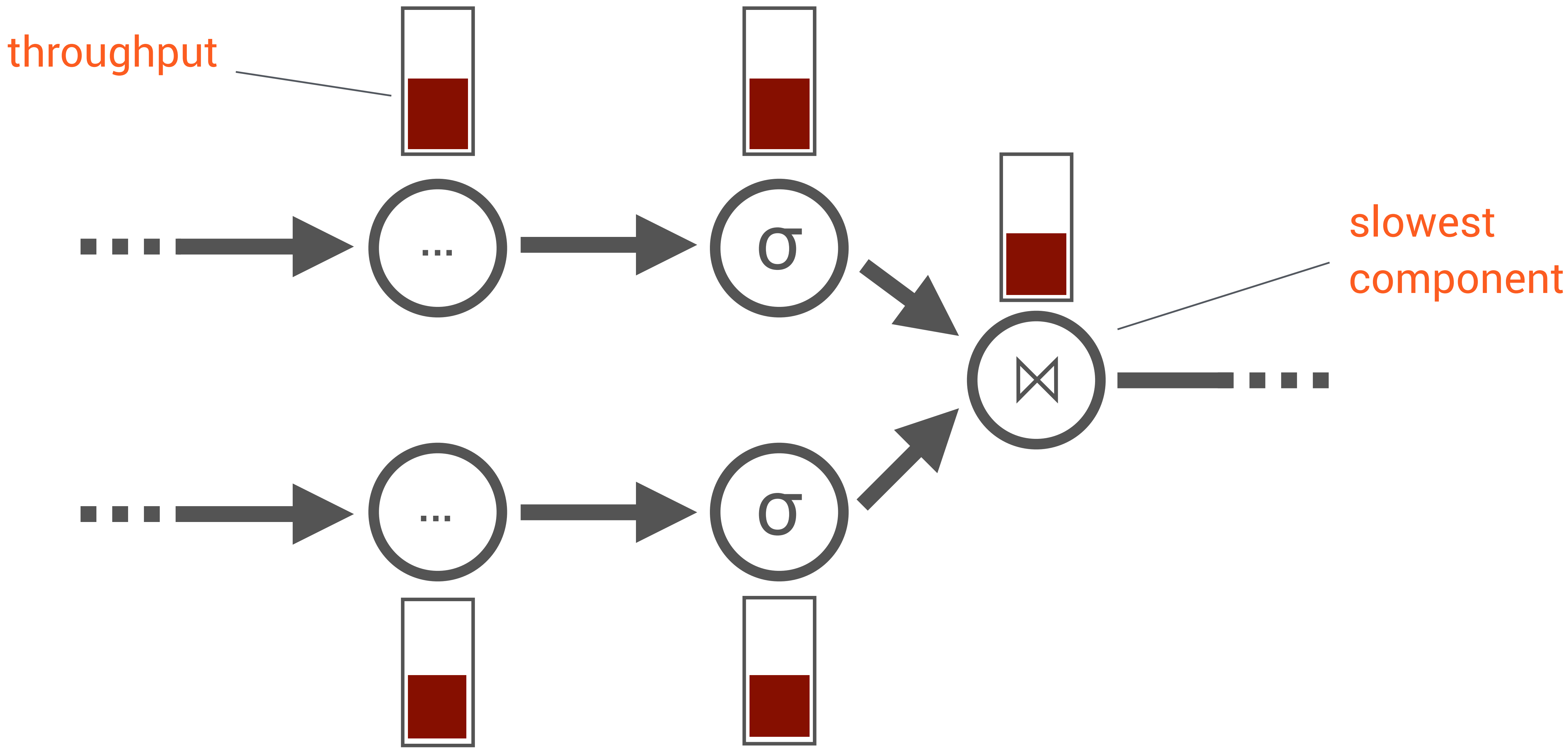
Data Stream Processing
Bottleneck



Data Stream Processing
Bottleneck

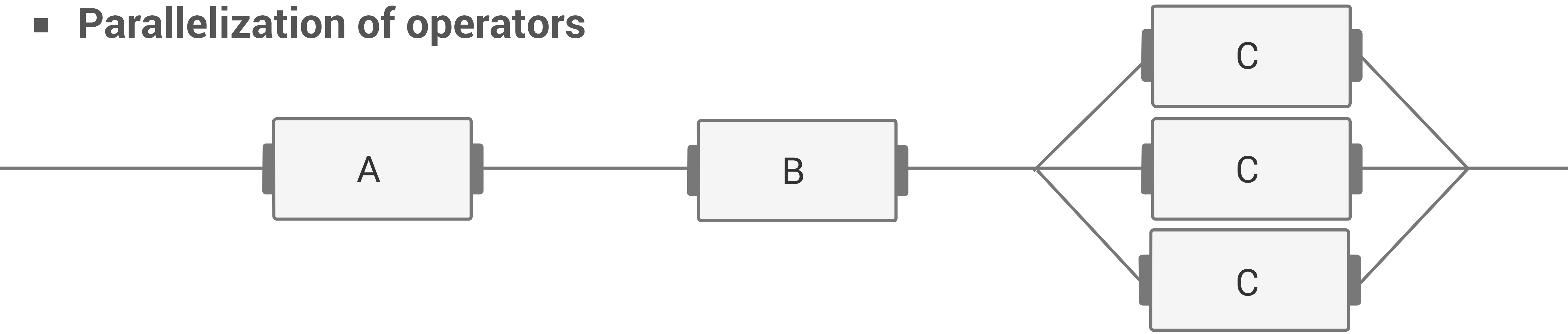


Data Stream Processing
Bottleneck

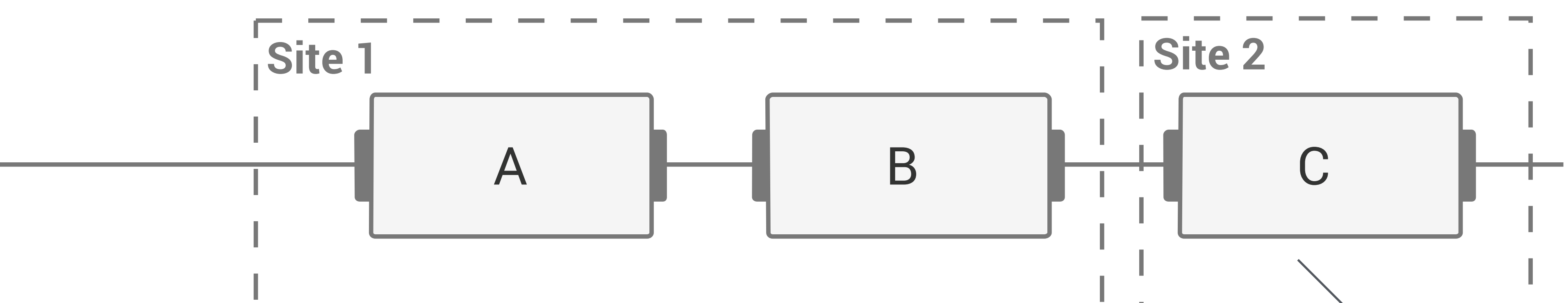


Data Stream Processing
Bottleneck – Solutions

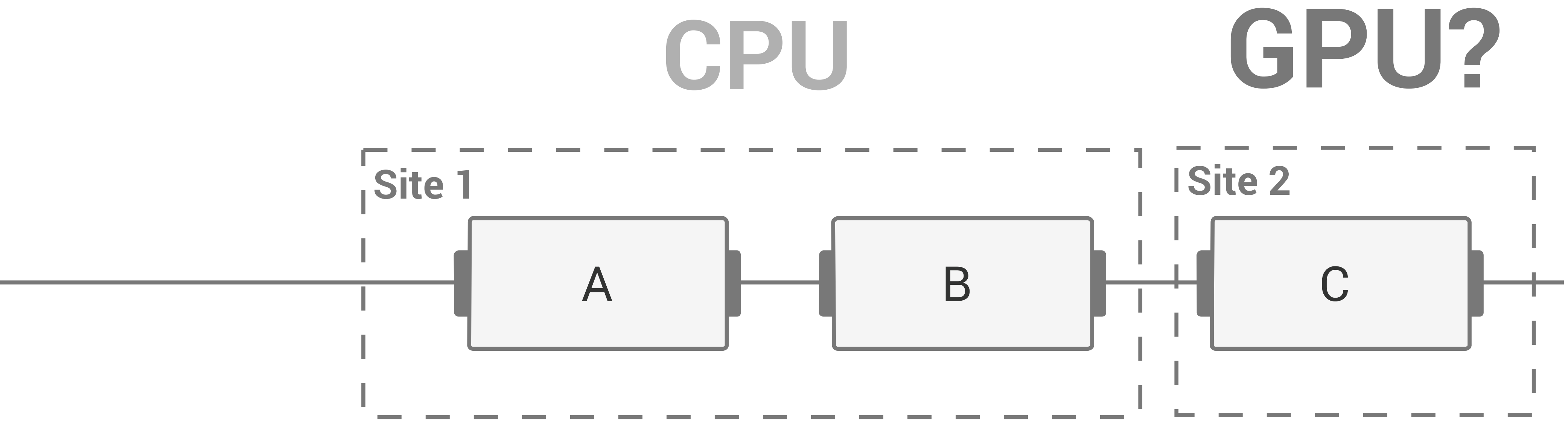
- **Parallelization of operators**



- **Distributed computation**



more computation resources



In DBMS?

Database Management Systems

GPUs in DMBS

- … Efficient co-processor
- … Might outperform CPUs for certain operations
- … Computations are highly parallel (SIMD)
- … Huge corpus on research results

Some conclusions

- Data **transfer costs** to and from graphic card **are critical**
- **Operation** should match GPU architecture (e.g., branch free)
- **Operation must be expensive** enough to amortize transfer costs
- **Column-oriented** architectures **save transfer costs**

GPU Acceleration for Data Stream Processing

Challenges

Limited memory on graphic cards

VS

(time-based) windows can be huge

event representation (tuple) does not match

the GPU architecture

GPU-ready Stream Processing

Our 1st contribution: Handle graphic card memory limitation for very large windows via *bucketing*

GPU-ready Stream Processing
Bucketing

We suggest

Portioning streams of variable-length window of tuples

into a stream of "*Buckets*"

Bucket: fixed-size window portions with column-oriented event representation

GPU-ready Stream Processing
Bucketing (2)

Bucketing Operator

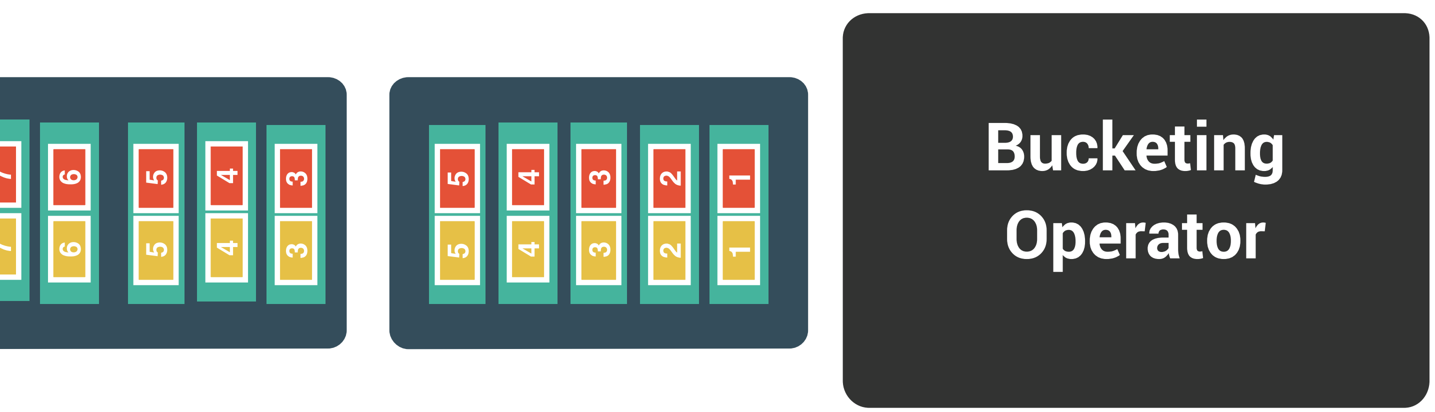
Bucket-at-a-Time
Let’s say bucket size 3

Let’s say bucket size 5

Bucket-at-a-Time

GPU-ready Stream Processing

Bucketing (2)



Bucket-at-a-Time

Let’s say bucket size 3

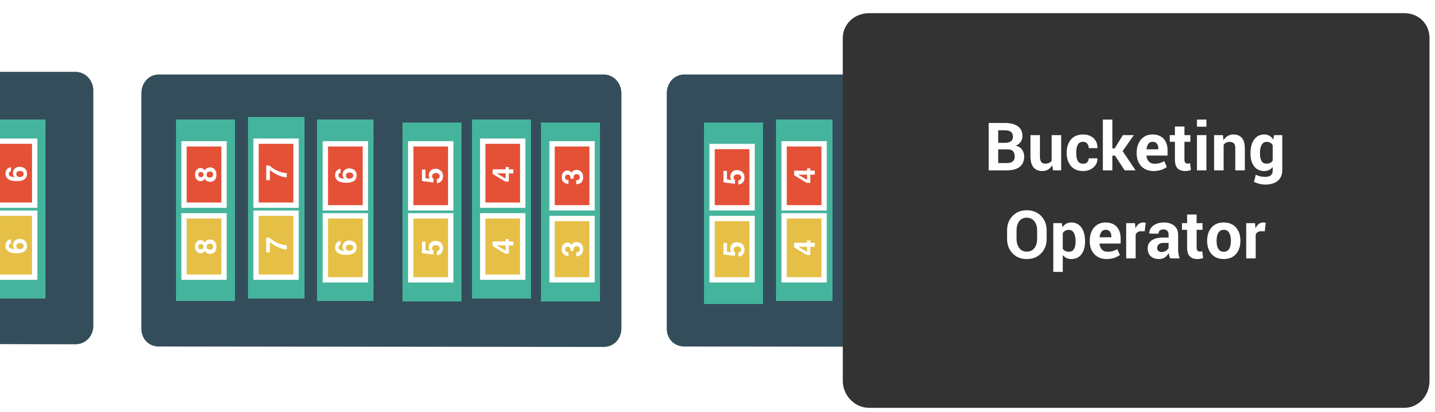
Let’s say bucket size 5

Bucket-at-a-Time

GPU-ready Stream Processing

Bucketing (2)

3 events,
column-oriented



Bucket-at-a-Time

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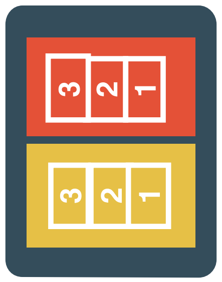
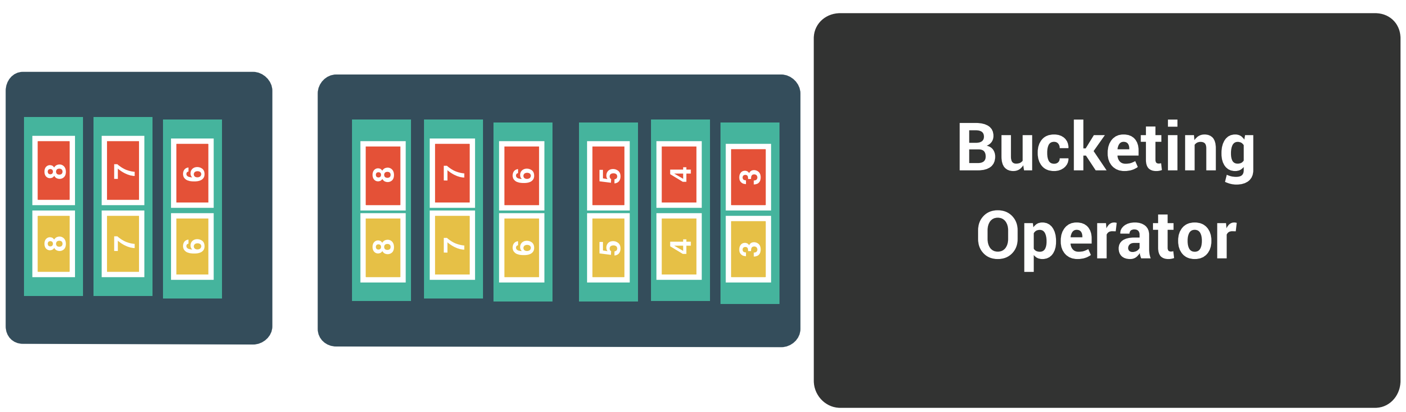


Let’s say bucket size 5

Bucket-at-a-Time

GPU-ready Stream Processing

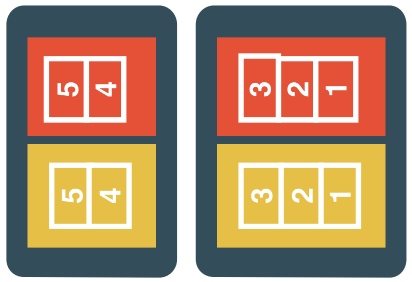
Bucketing (2)

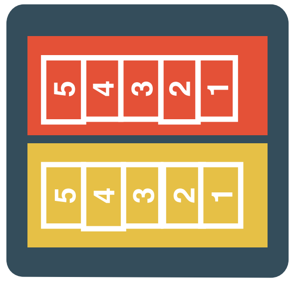


5 events,
column-oriented

Bucket-at-a-Time

Let’s say bucket size 3





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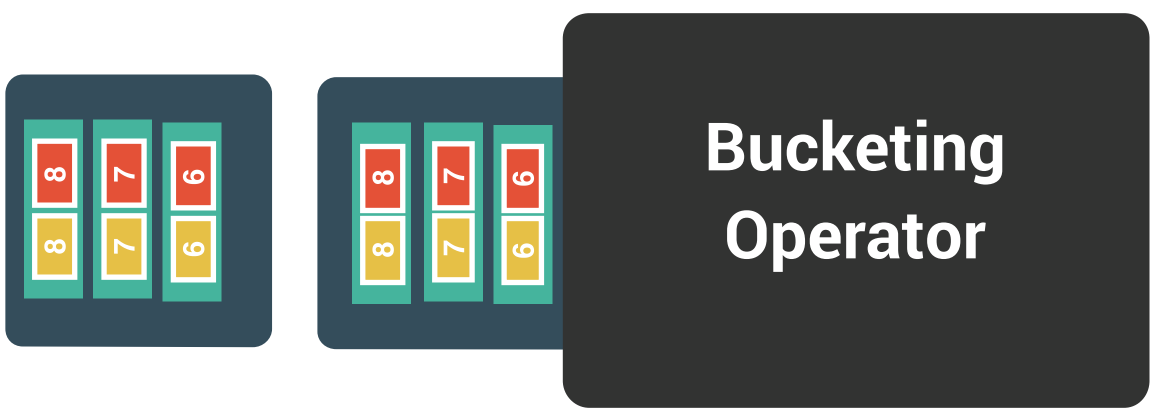
Bucket-at-a-Time

GPU-ready Stream Processing
Bucketing (2)



Bucket-at-a-Time
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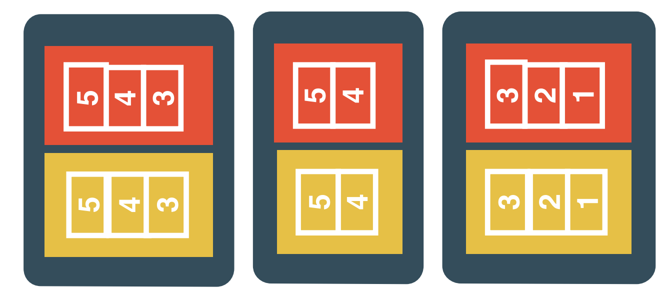

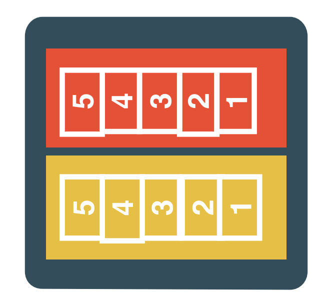

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Bucket-at-a-Time

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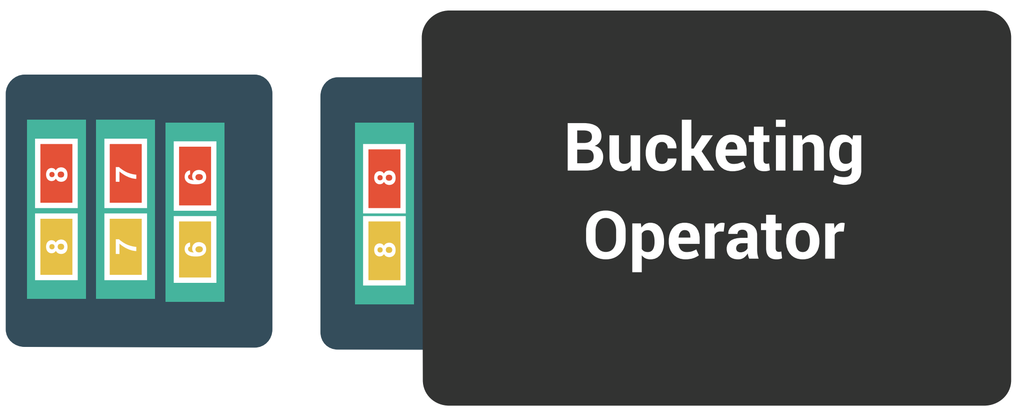
Bucketing (2)



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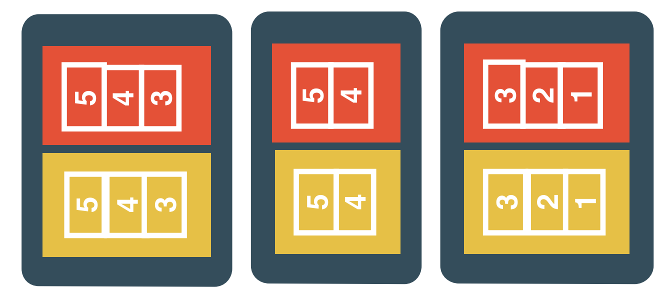

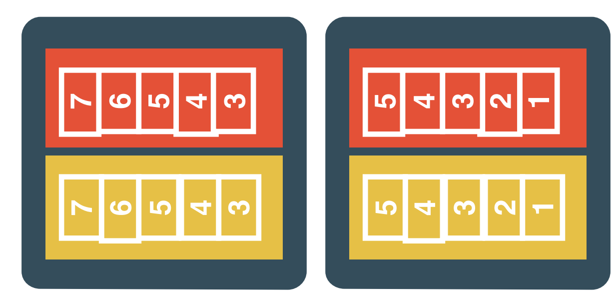

Let’s say bucket size 5

Bucket-at-a-Time

GPU-ready Stream Processing

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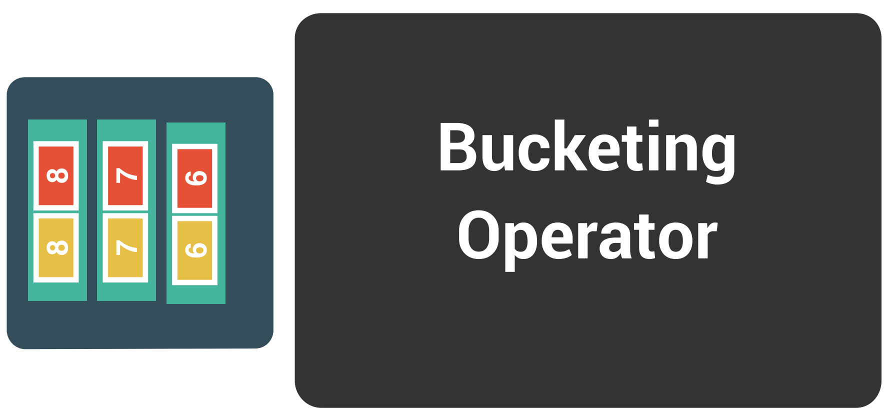

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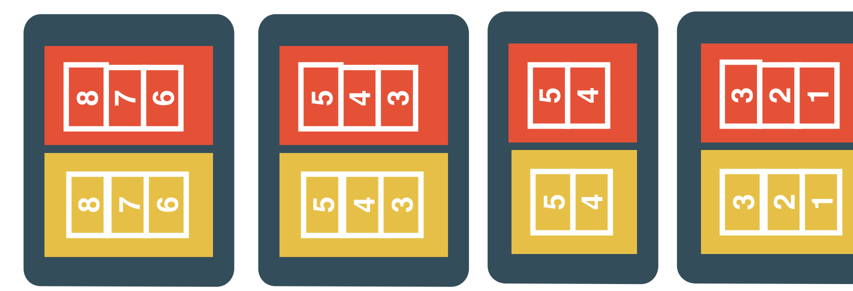

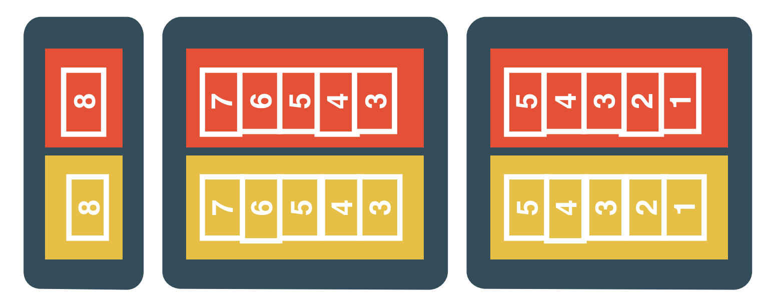

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Bucket-at-a-Time

GPU-ready Stream Processing
Bucketing (2)

Bucket-at-a-Time
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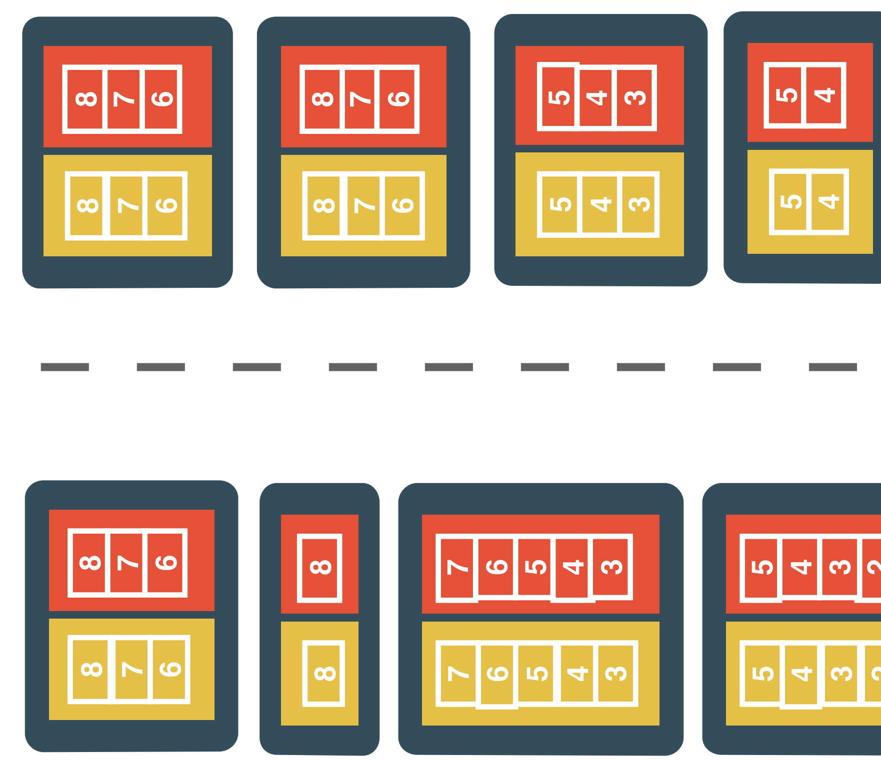


Let’s say bucket size 5
Bucket-at-a-Time

GPU-ready Stream Processing
Benefits through Bucketing

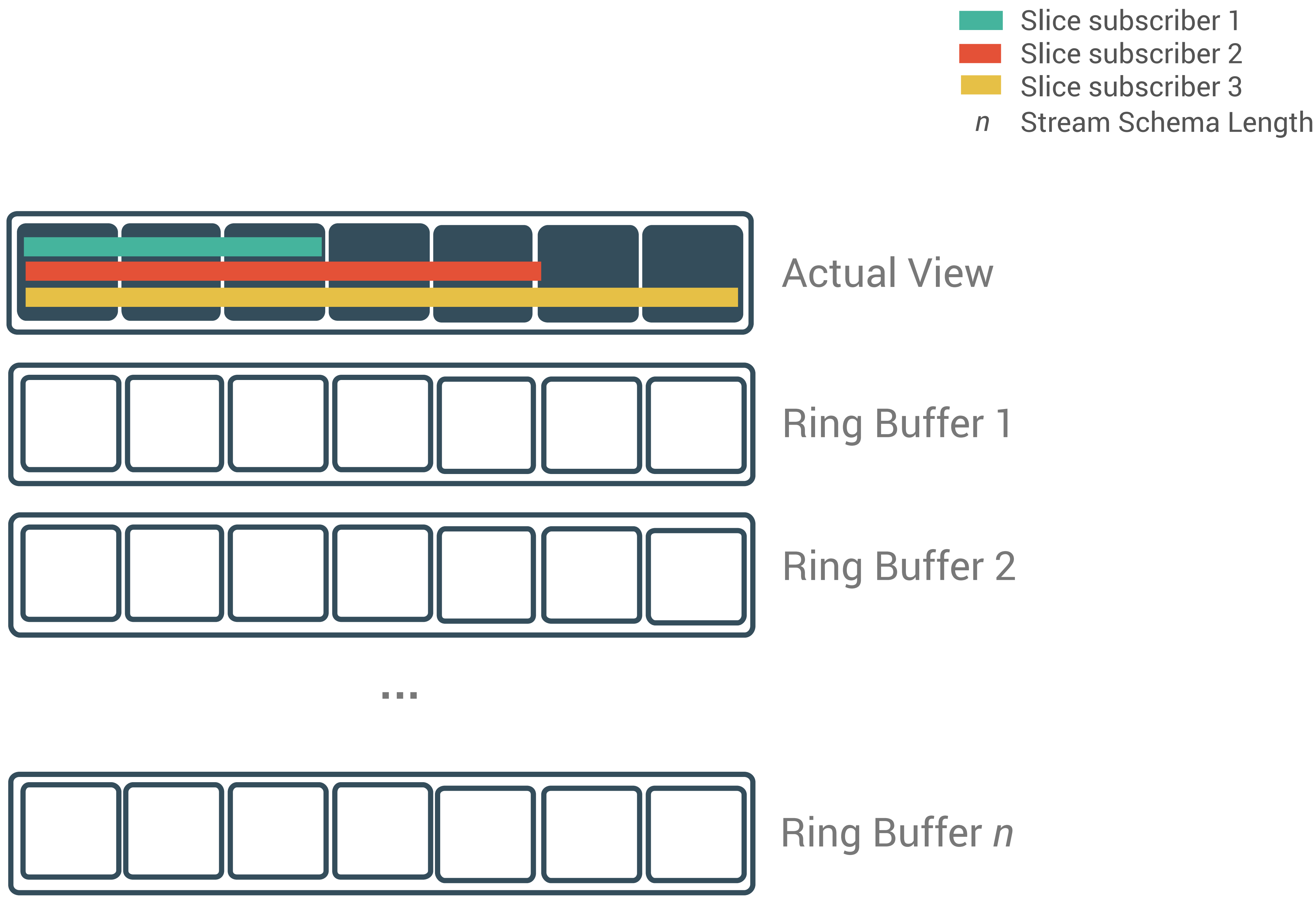
- **Each operator** requests its **own bucket size *k***
- The bucket size is **independent of** the actual **window length**
    - Memory allocation on graphic card has an upper bound for input
- Bucketing **flips event representation**
    - Processing entire columns
- **Window length > bucket size,** the **window is split** into portions
- **Single bucketing-operator** can be **subscribed by many** operators

GPU-ready Stream Processing
Buckets versus Windows

	Windowing	Bucketing
Purpose	▪ **Bounding** infinite **stream**	▪ **Portioning windows**
Consumes	▪ Stream of **events**	▪ Stream of **windows**
Produces	▪ Stream of **windows**	▪ Stream of **buckets**
#Events	▪ **Might be huge**	▪ **Has upper bound**
Events Represention	▪ **Tuples**	▪ **Column-wise**

GPU-ready Stream Processing

Achieve bucketing



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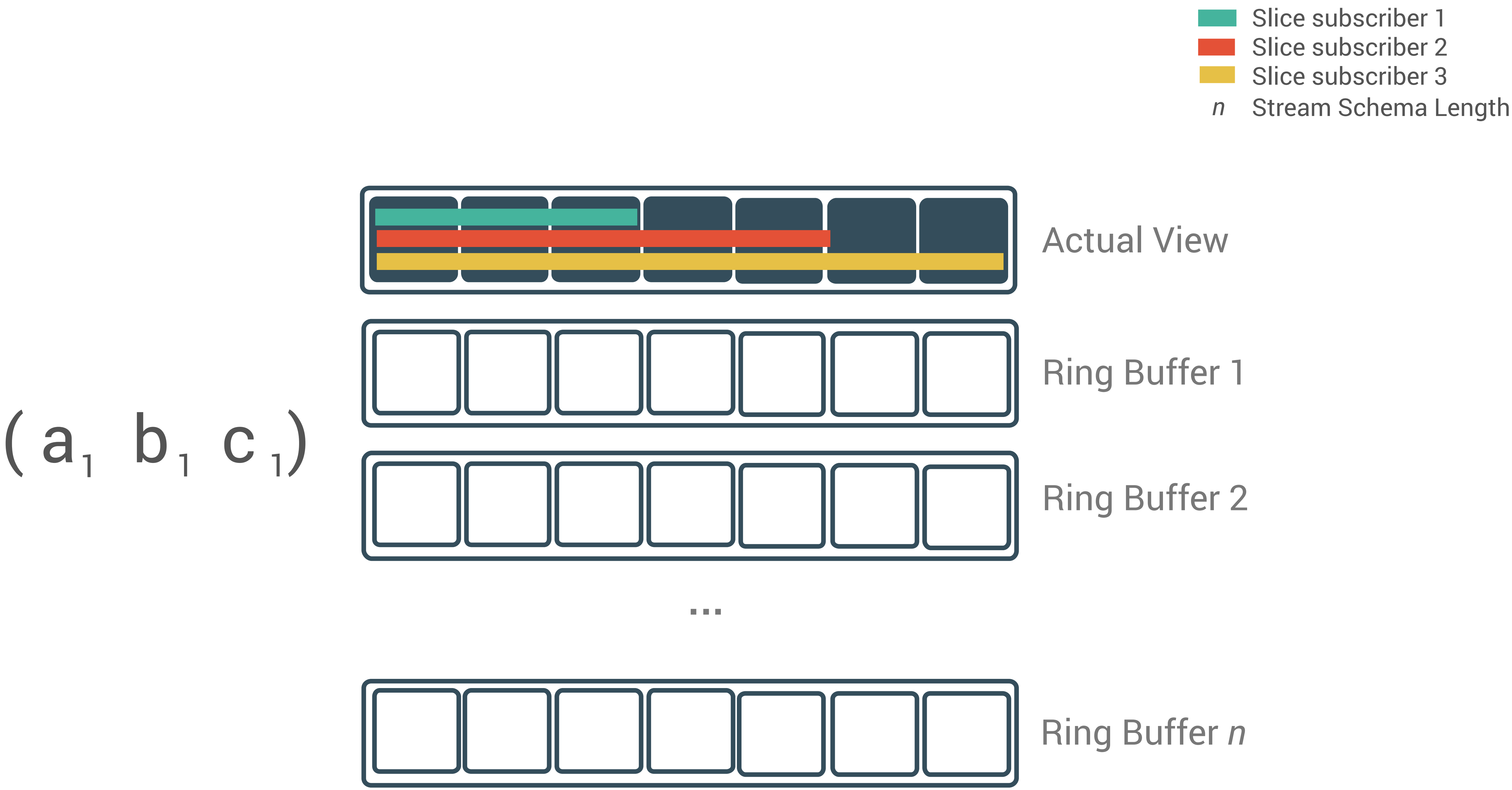

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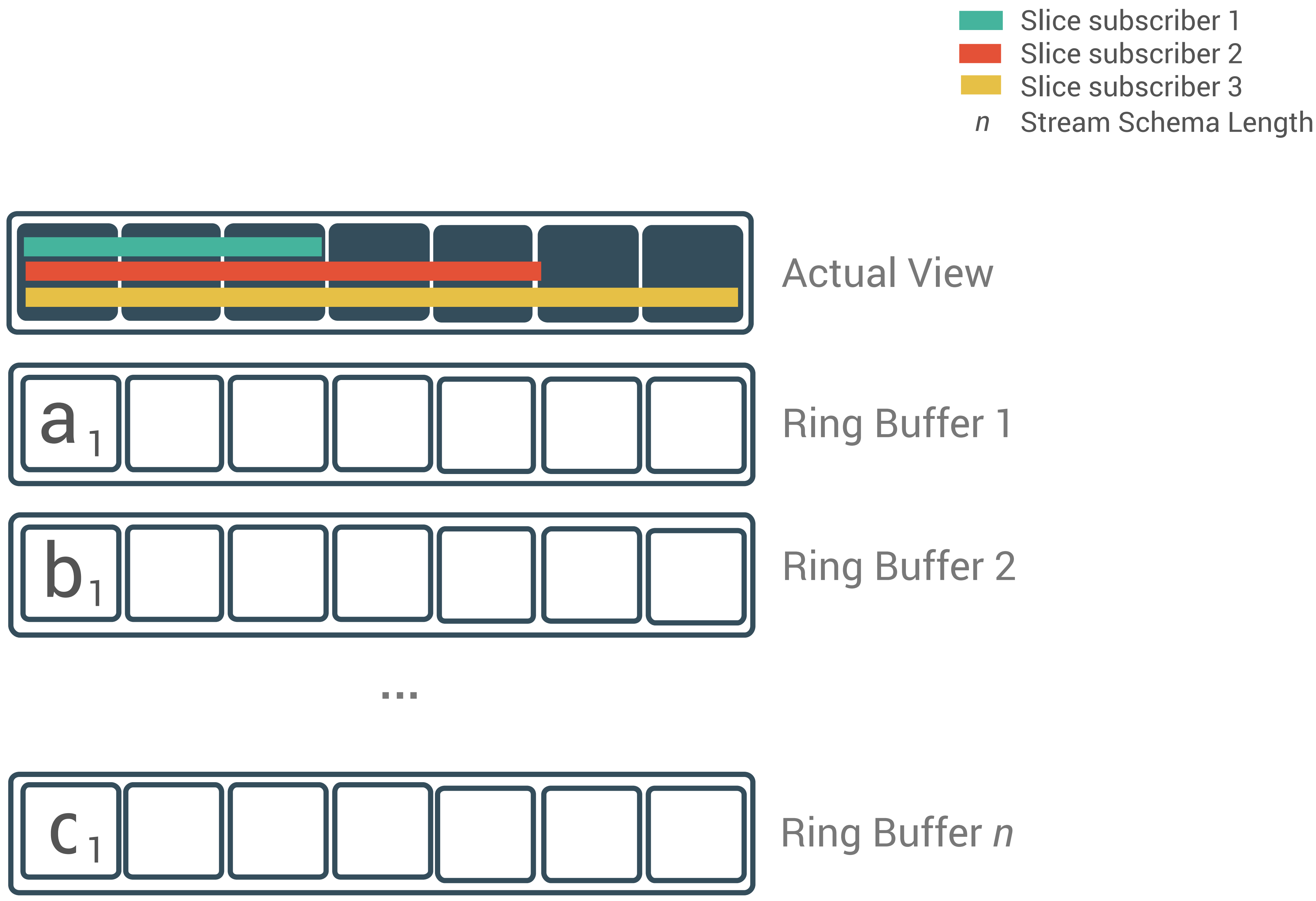

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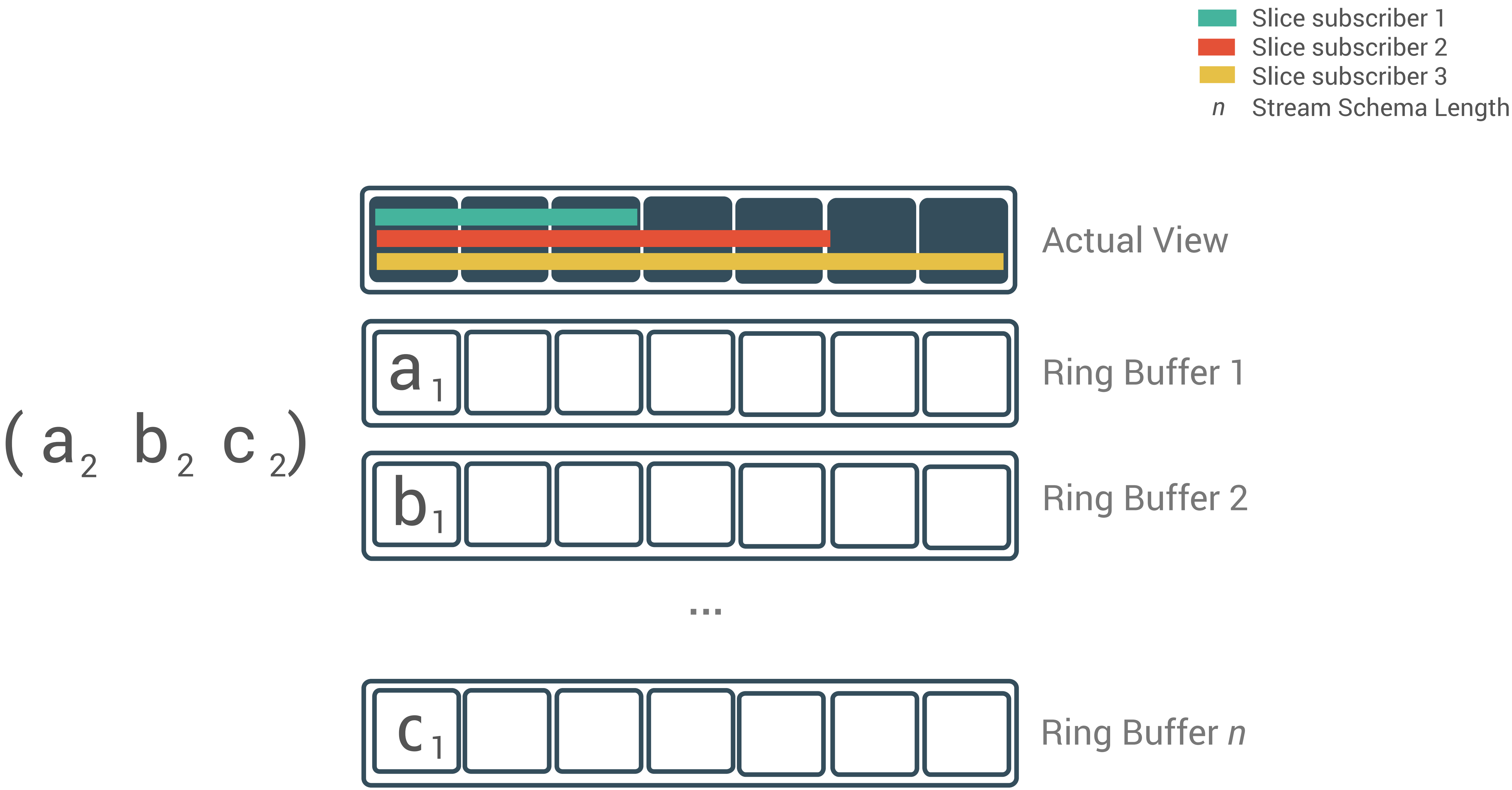

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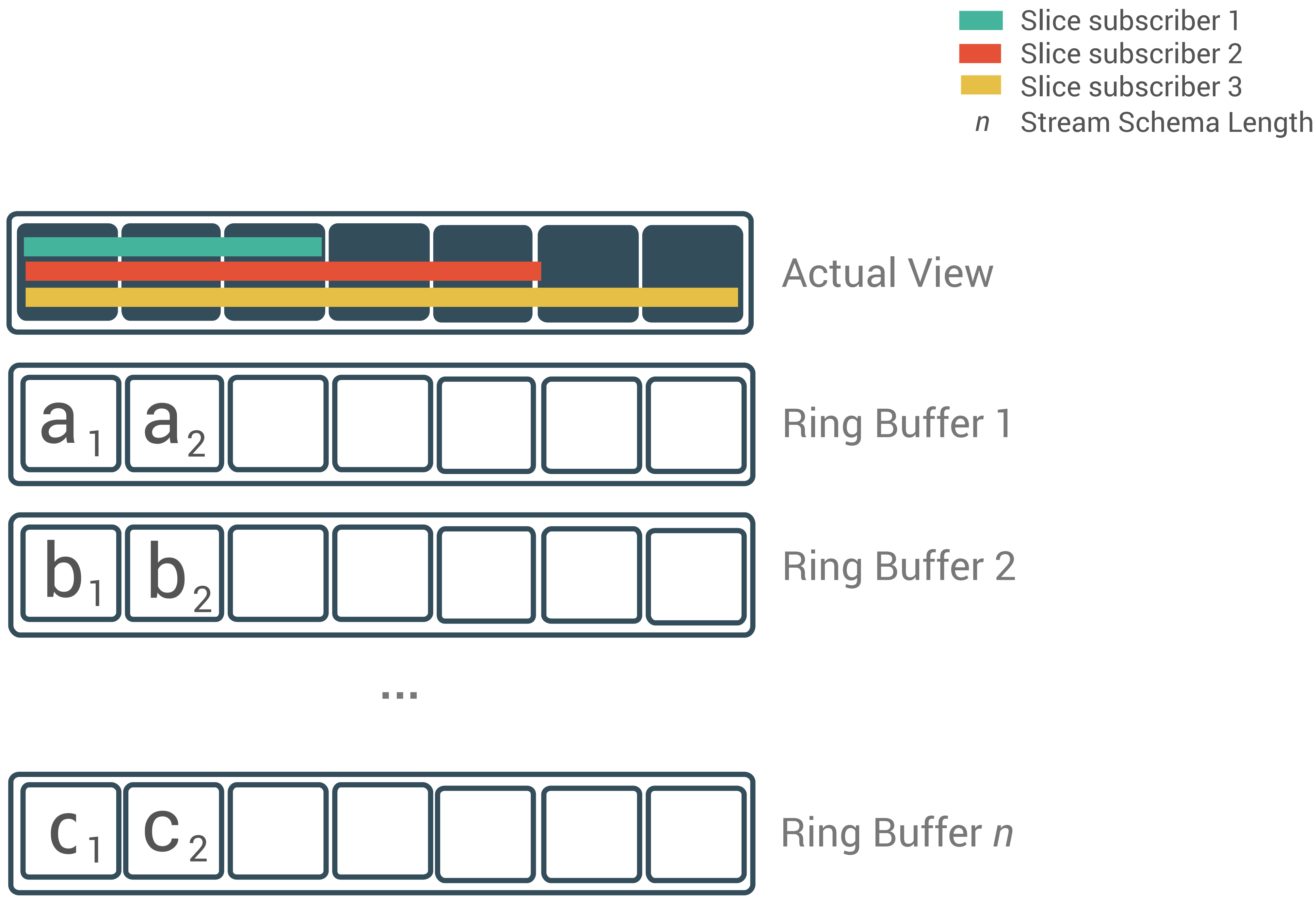

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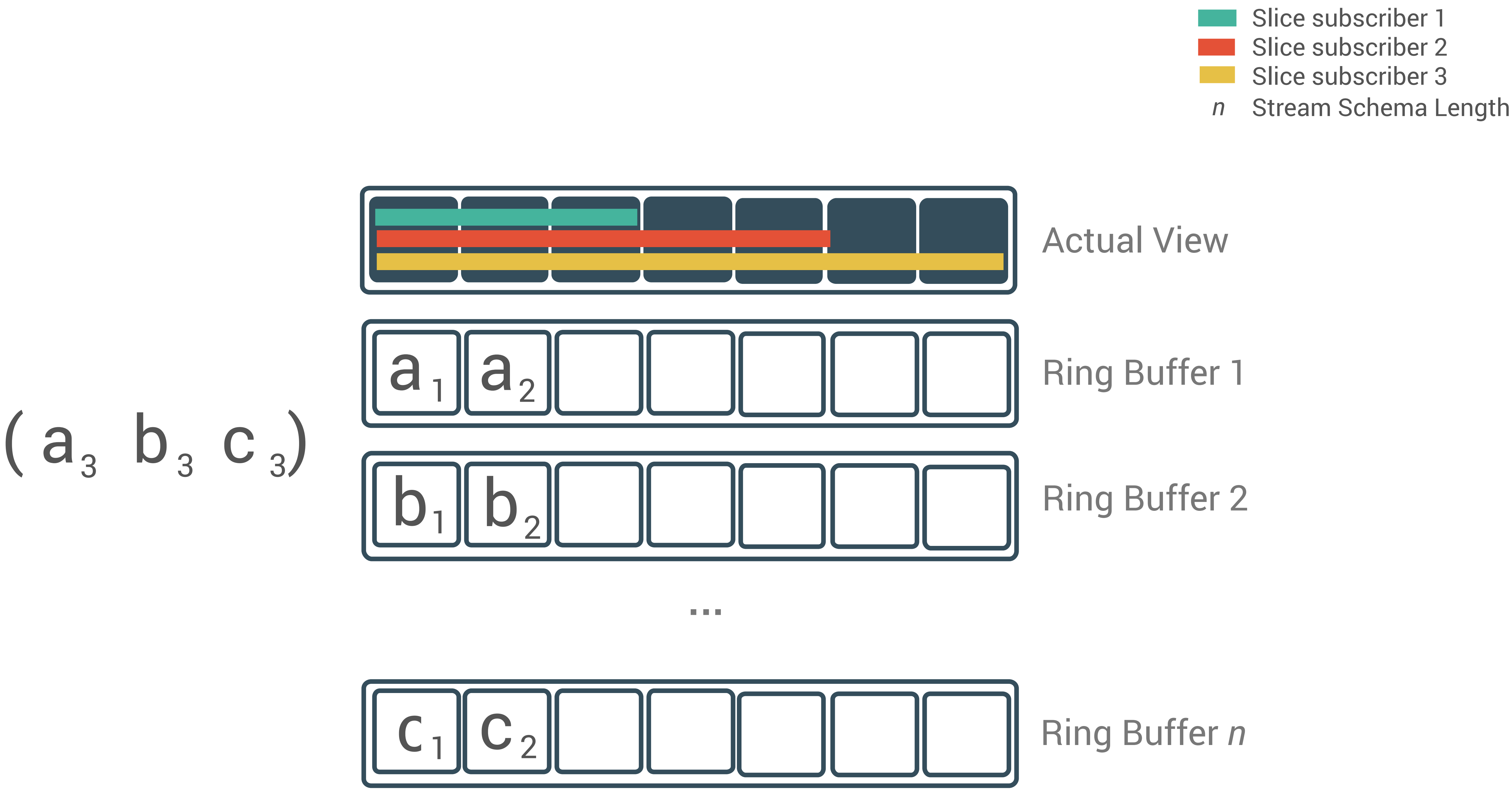

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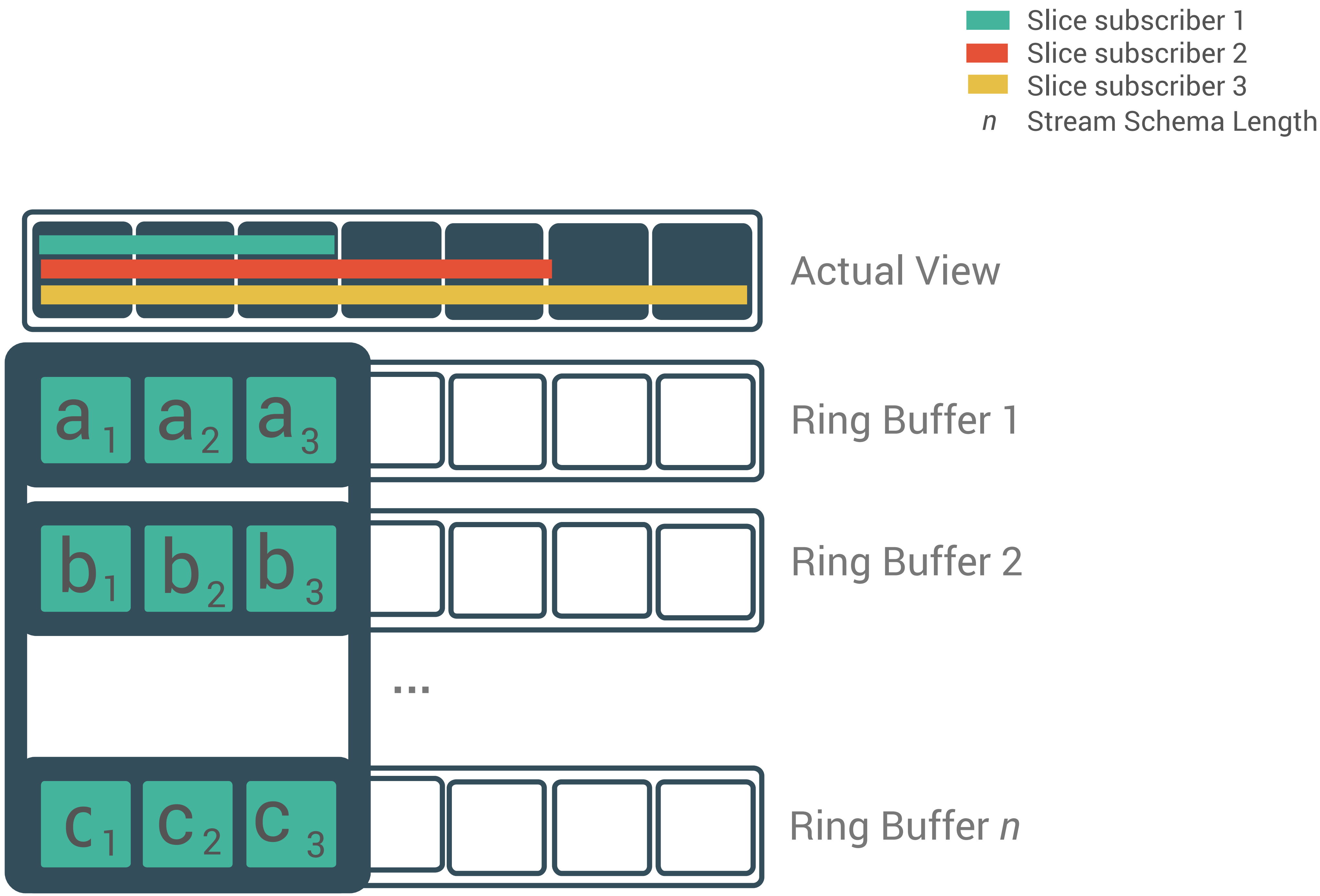

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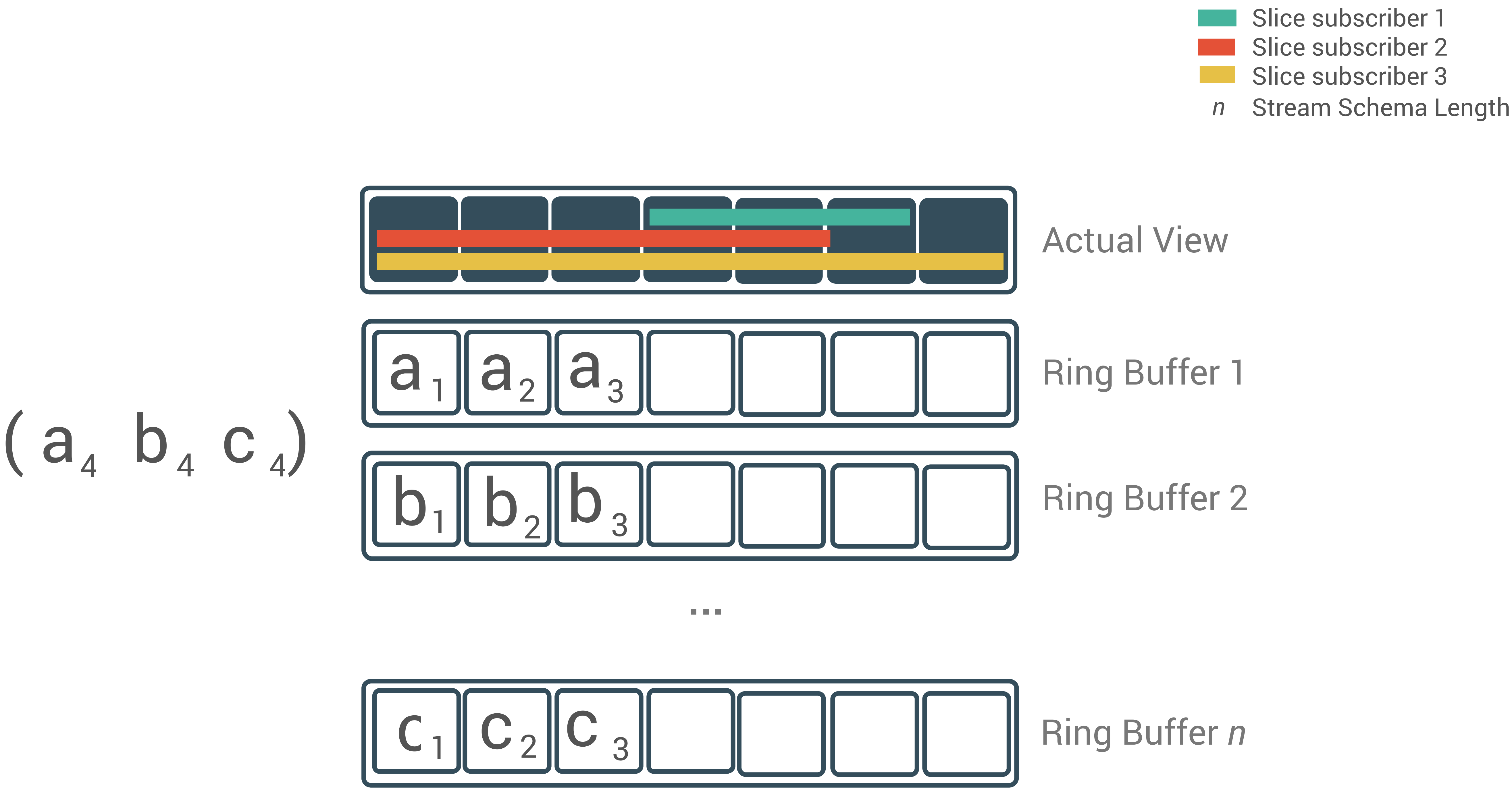

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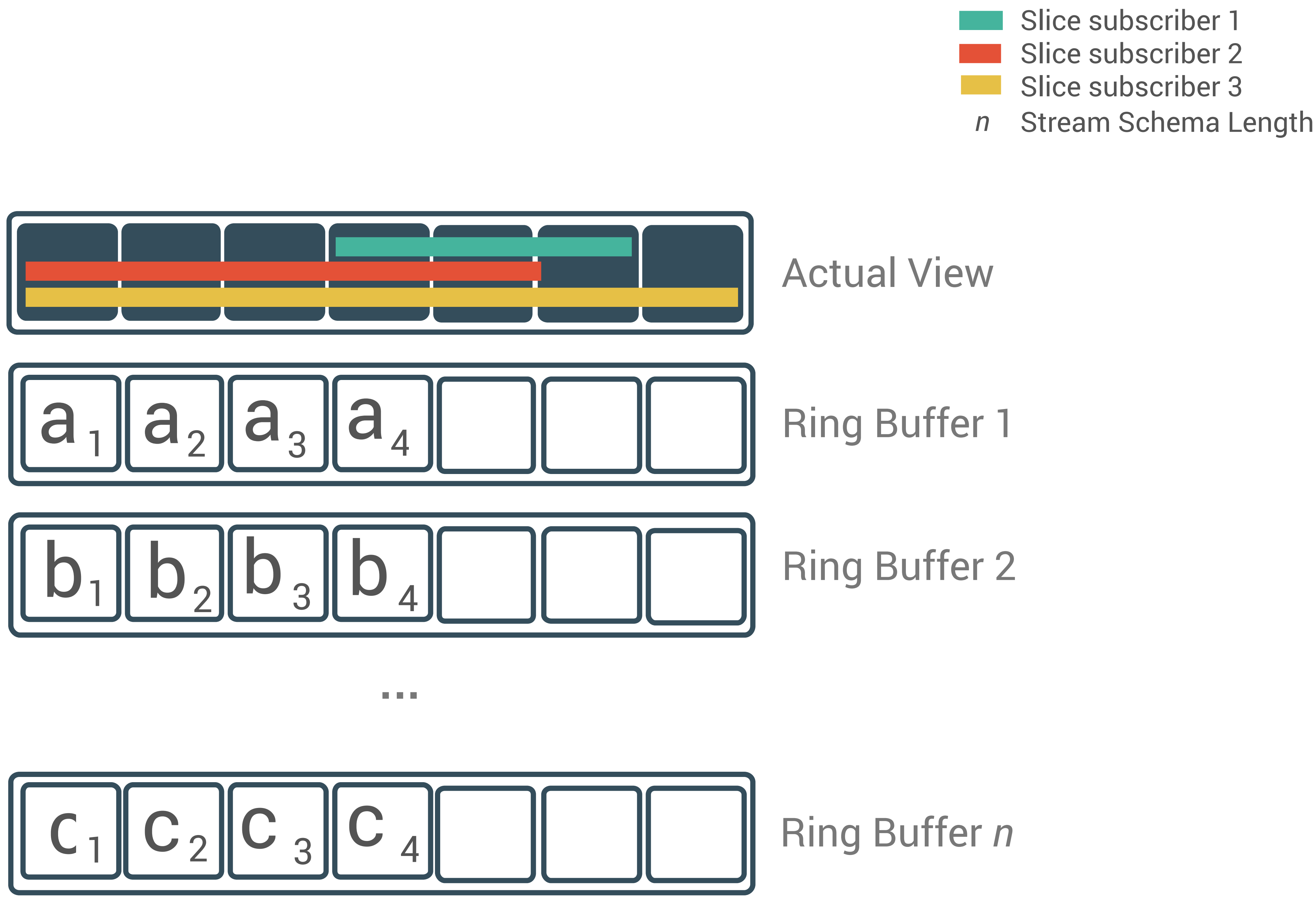

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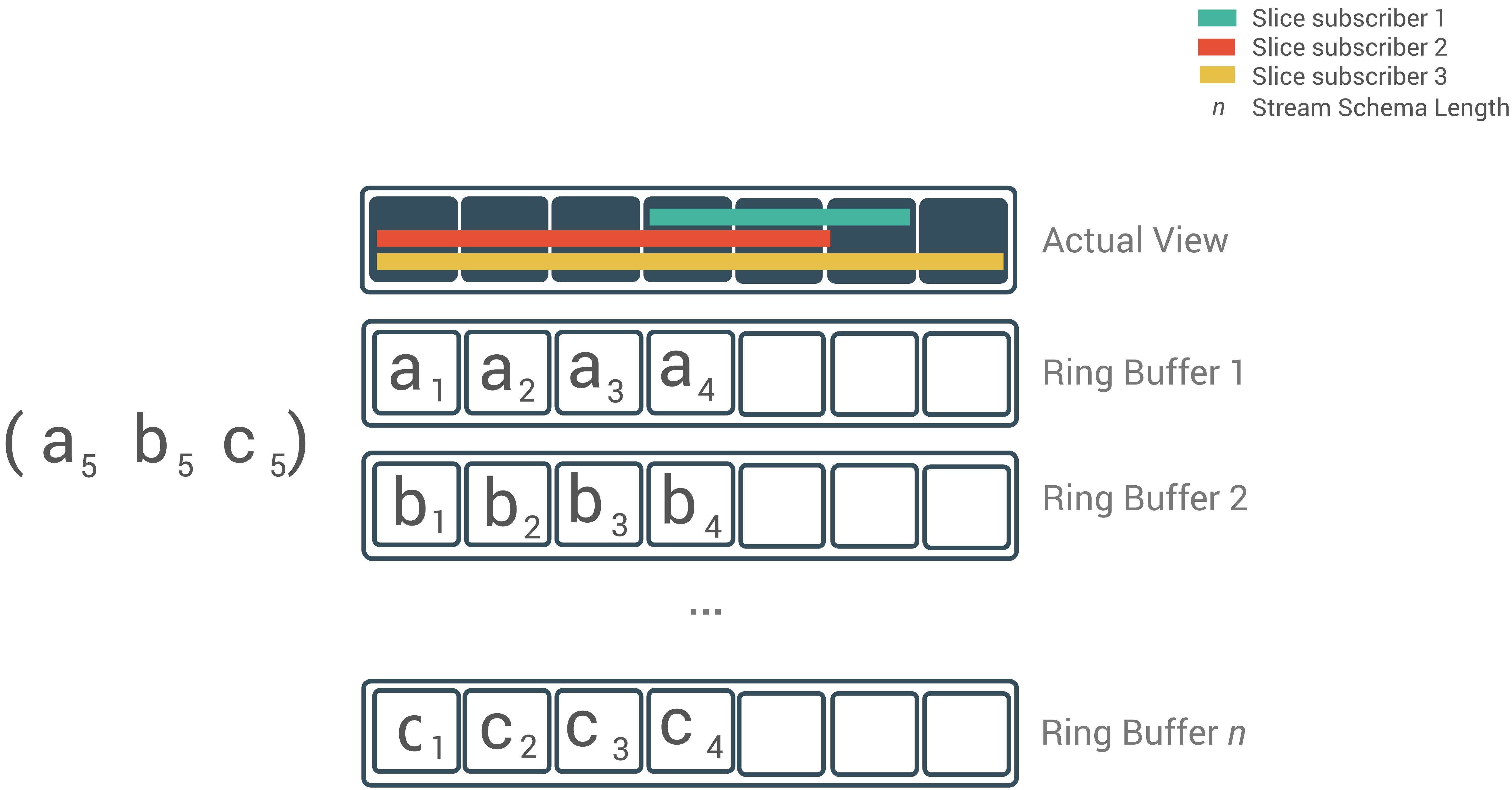

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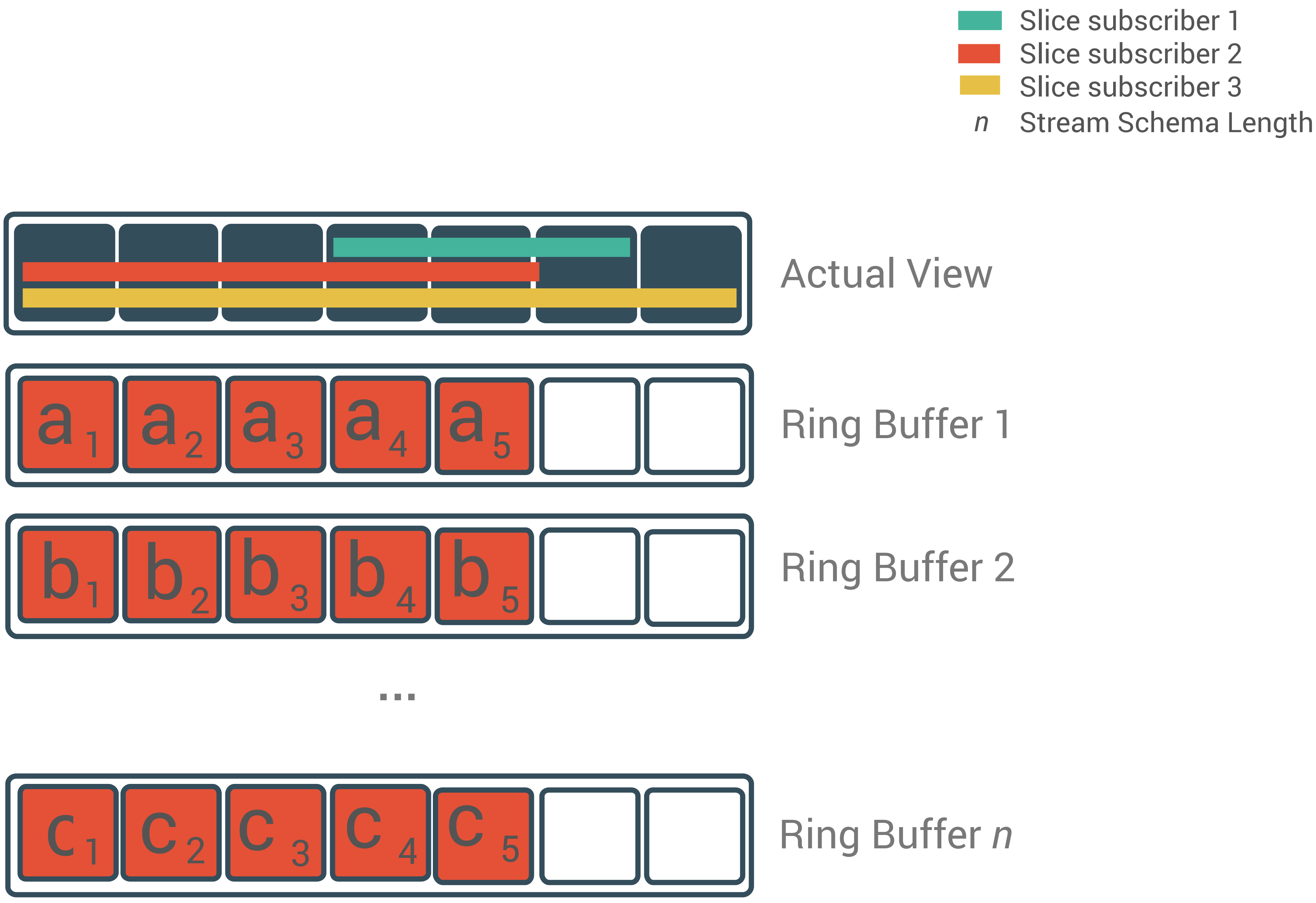

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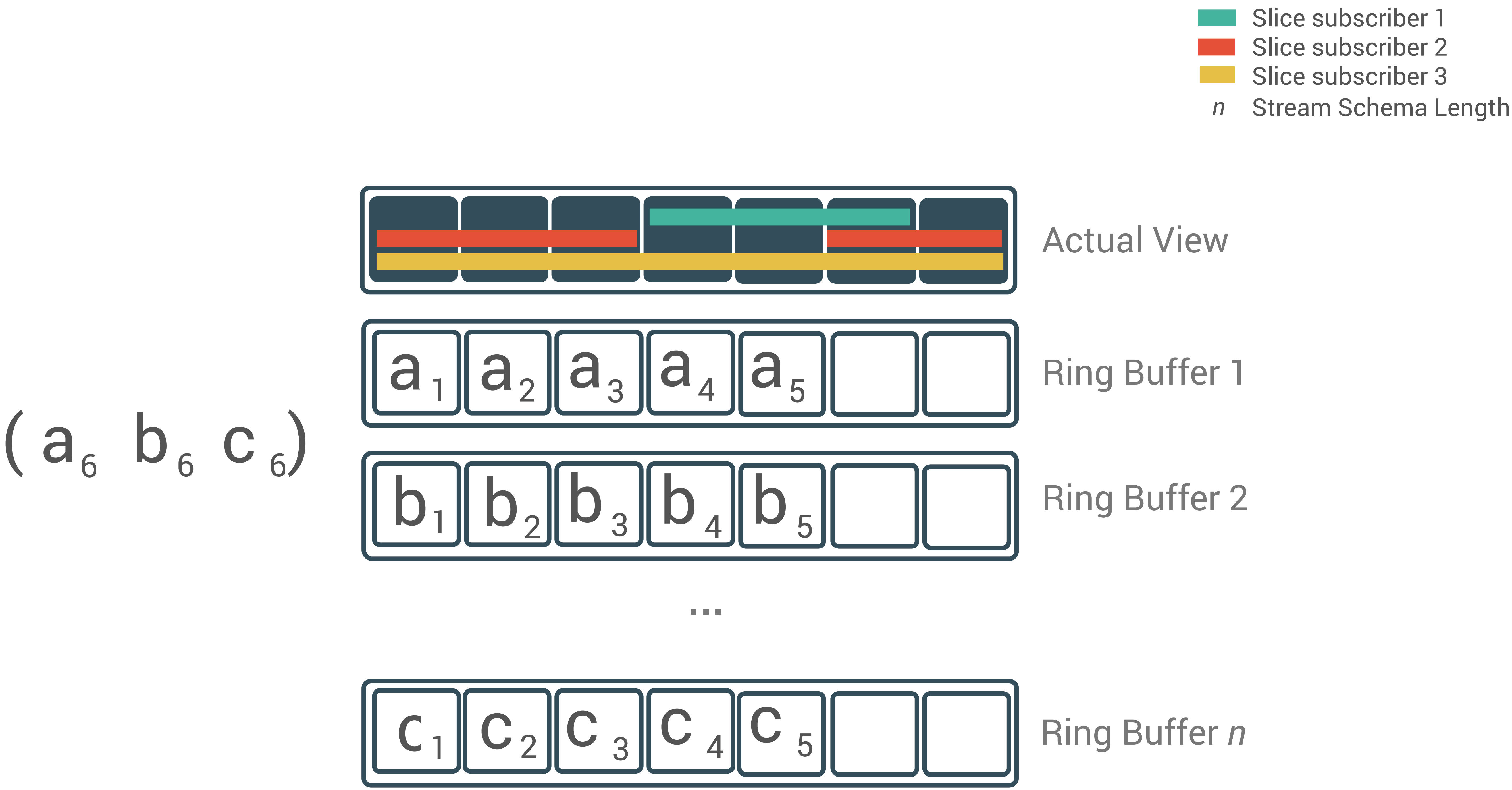

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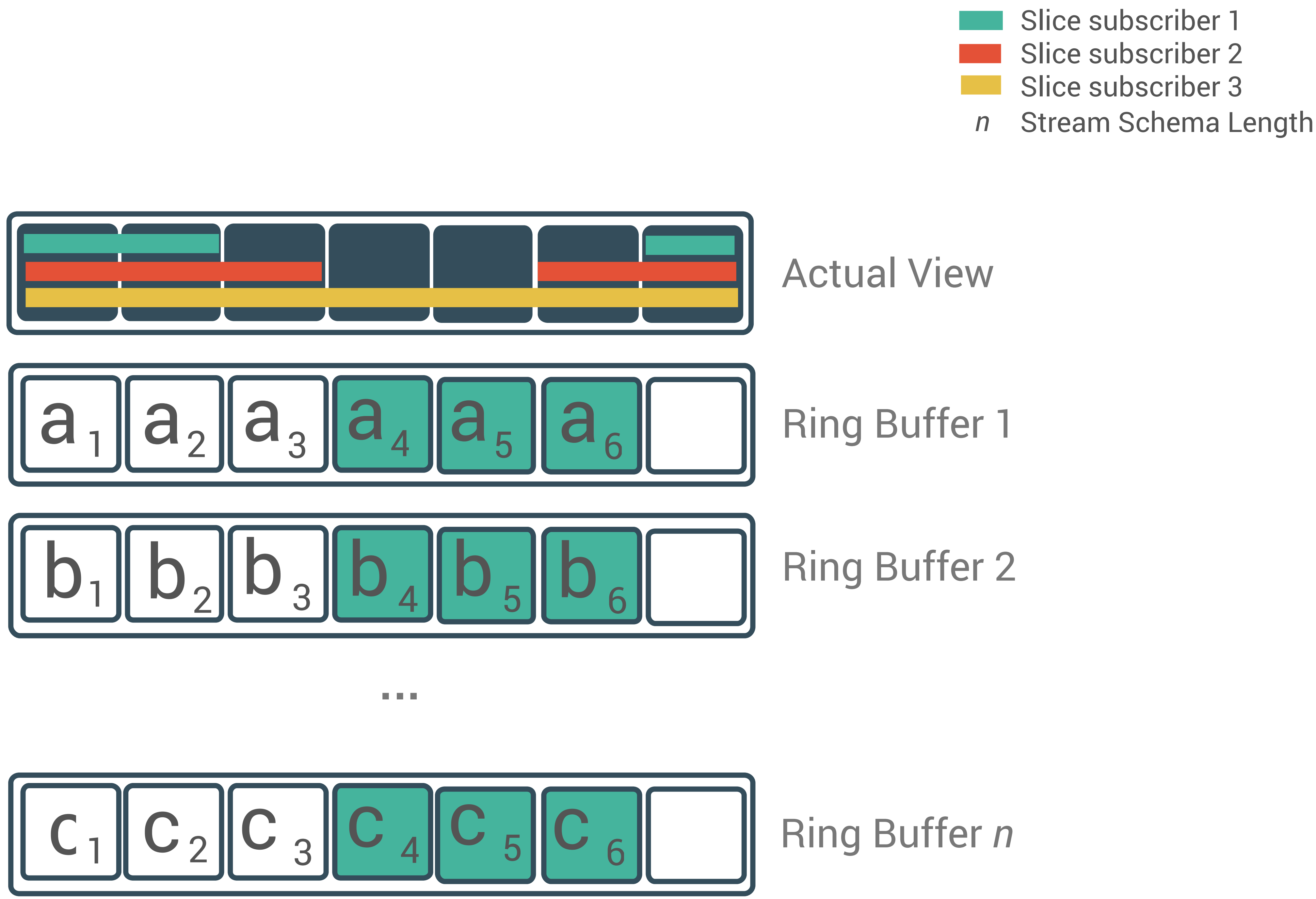

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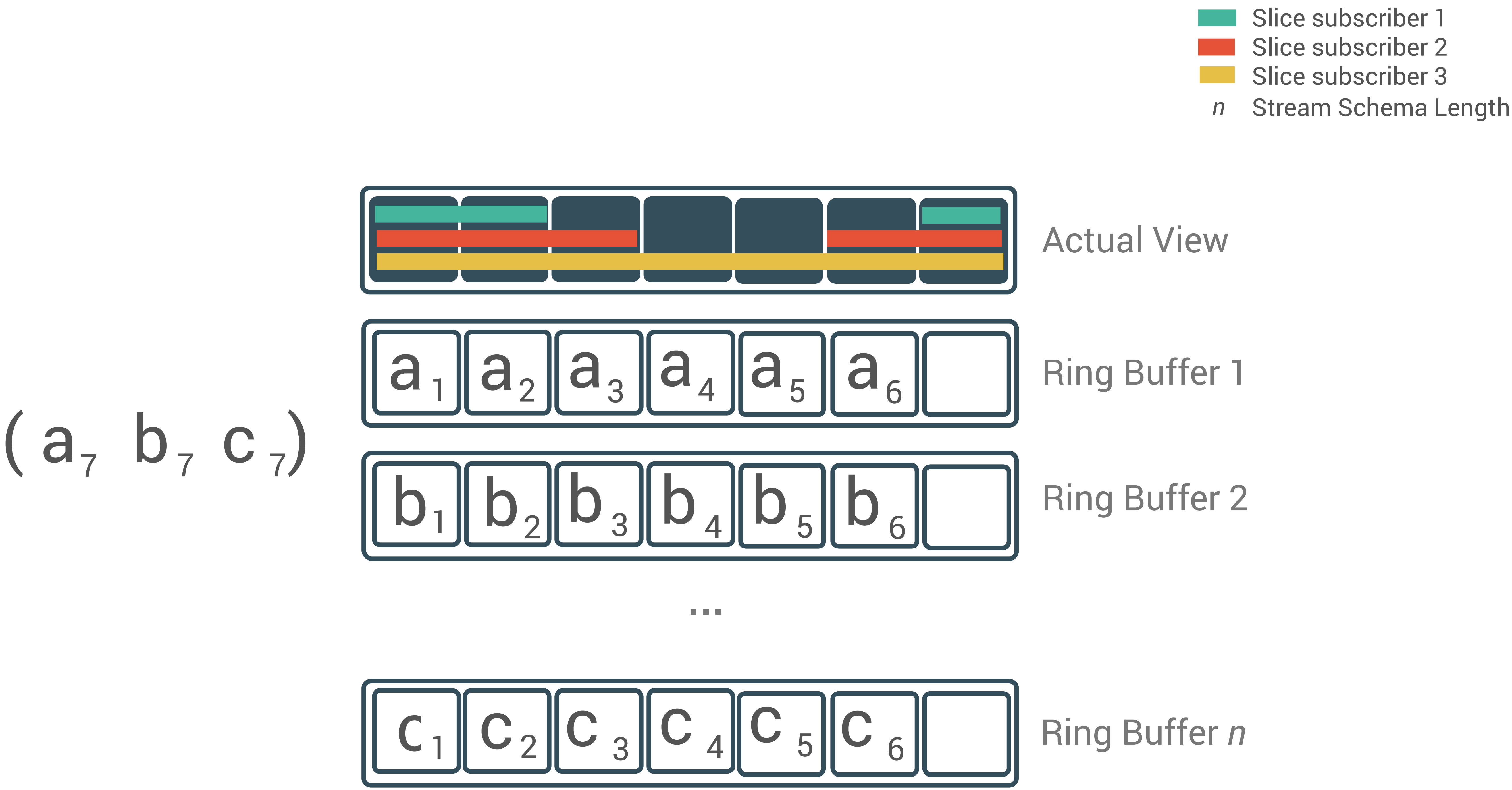

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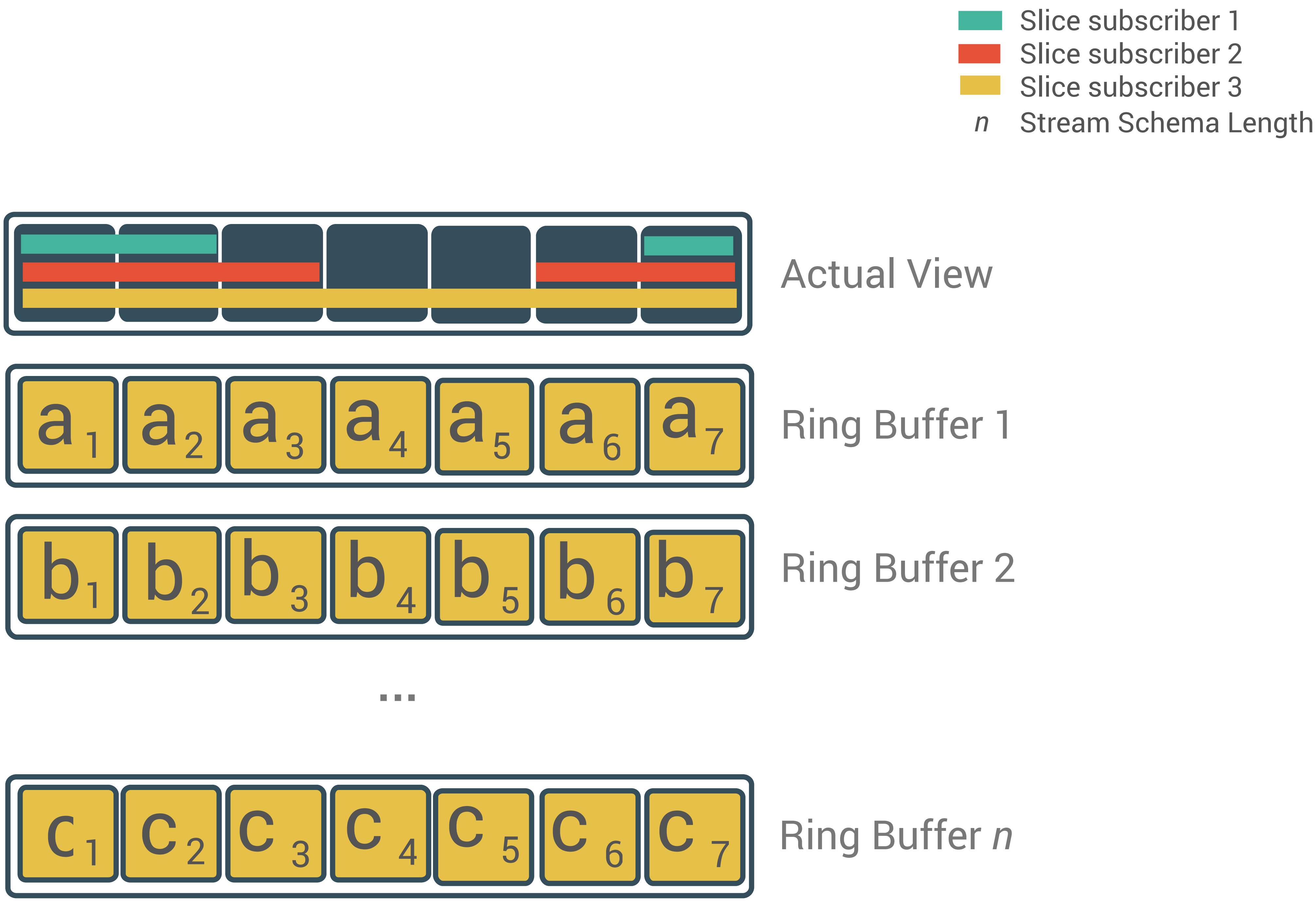

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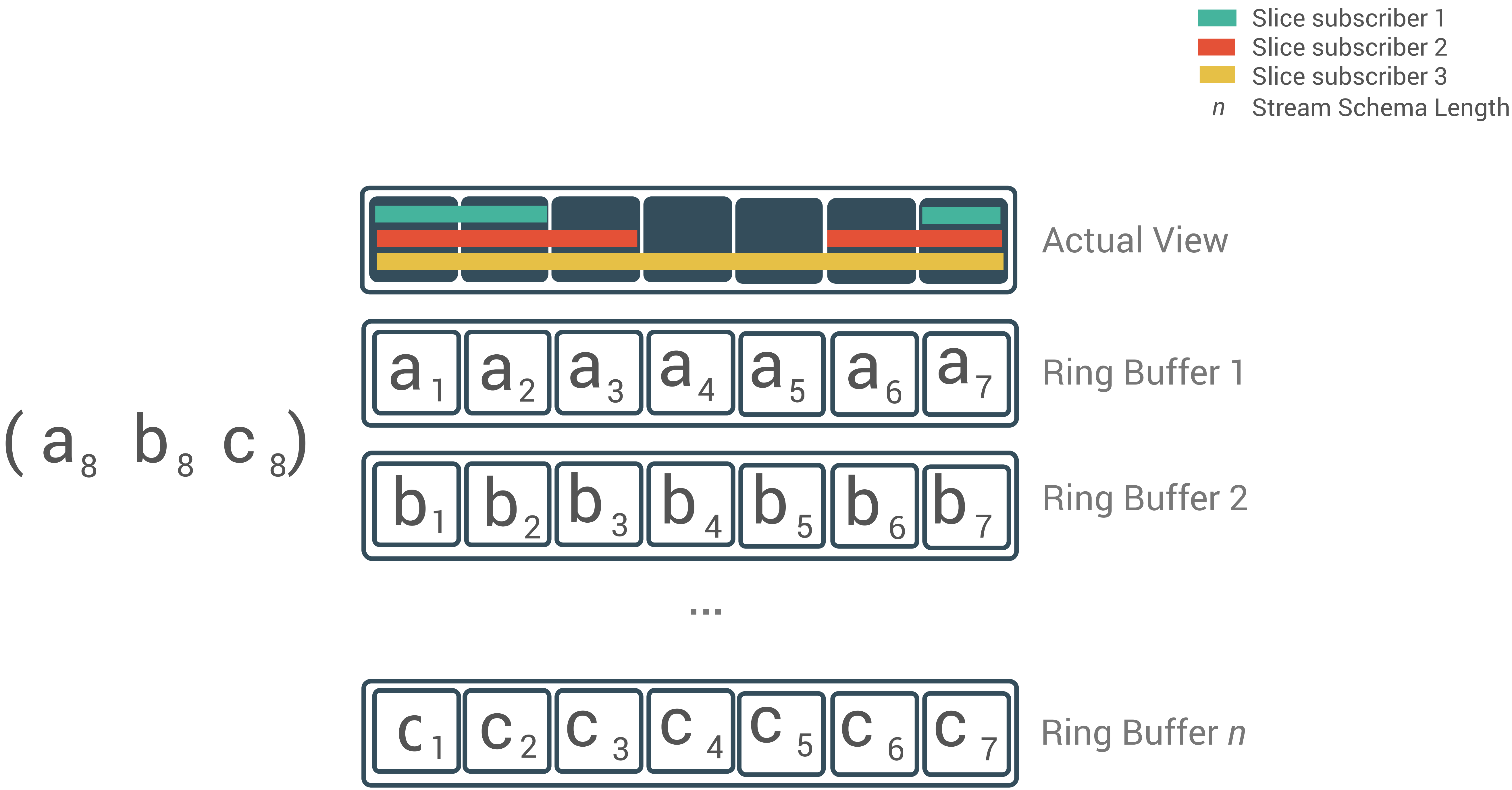

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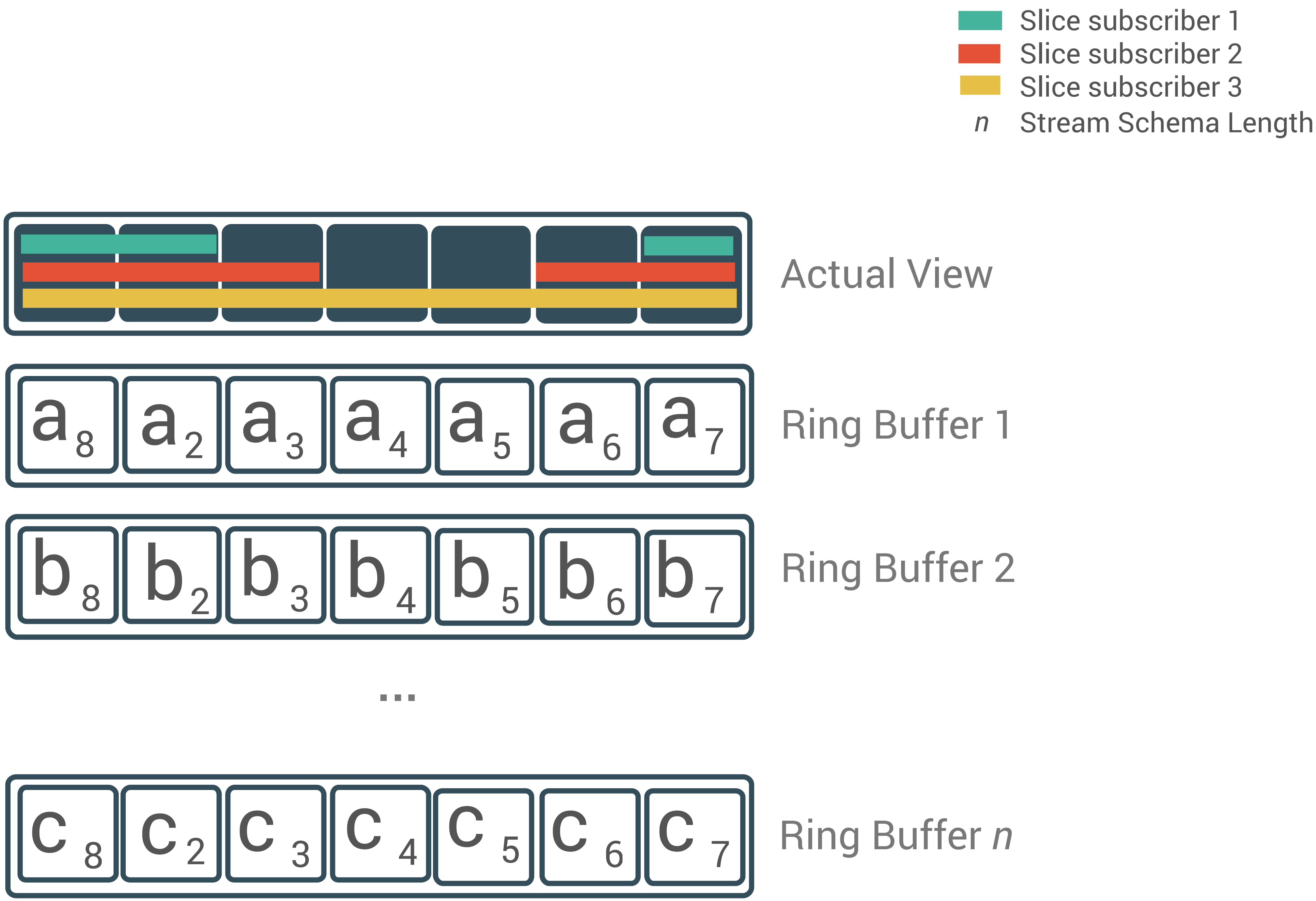

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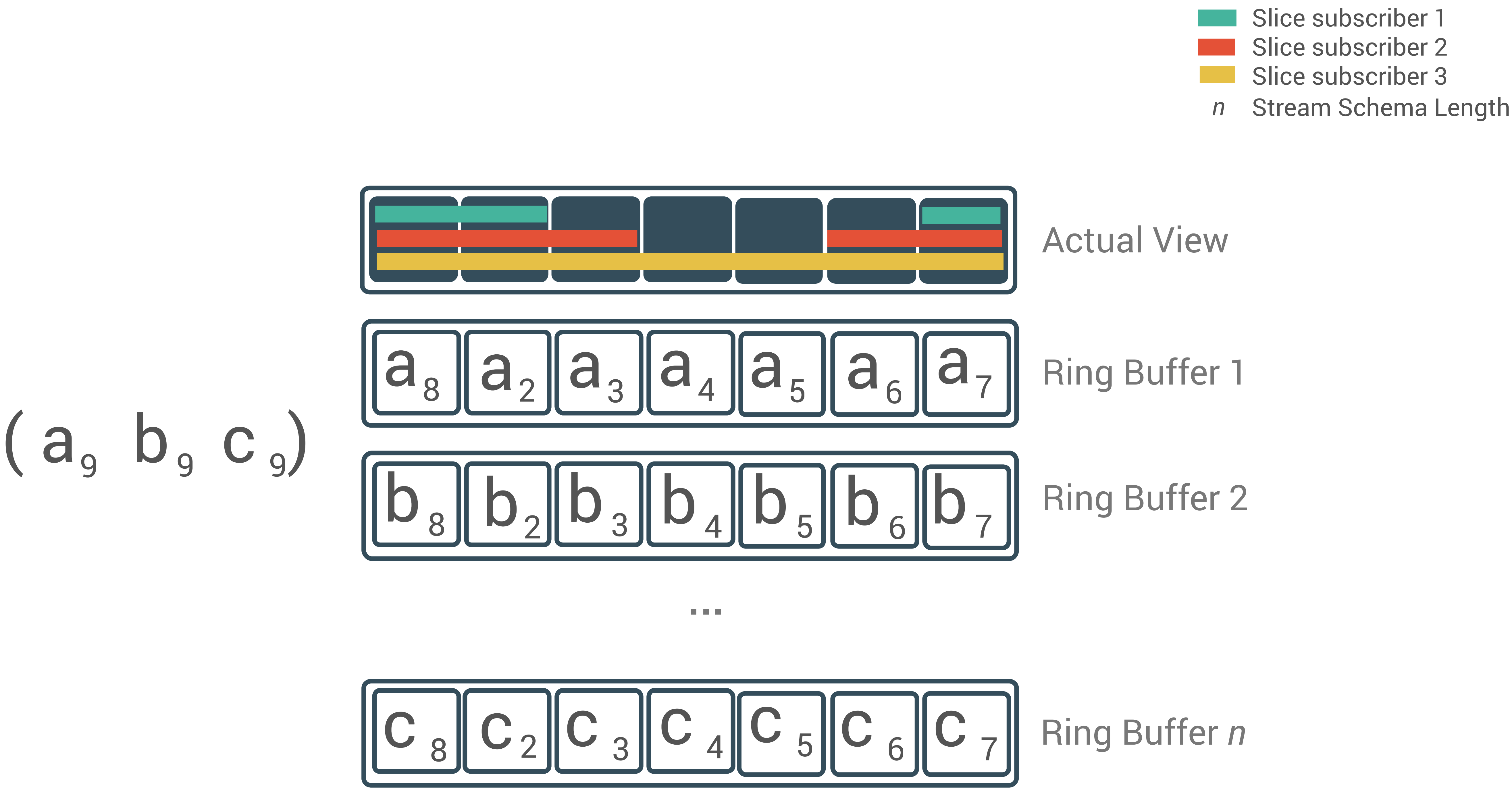

Open Research Challenges

Our 2st contribution: Identification of research challenges related to co-processing for Data Stream Processing

Open Research Challenges

Modern hardware and scheduling in Stream Processing

- **Other** specialized **co-processors** might be possible
  - Intel Xeon Phi or FPGAs for instance
- Optimized **algorithm** and executions **models for** the certain **co-processor**
- More than CPU-only Data Stream Processing:
  - Large physical **query execution plan space**
- **Find** best performance for a
  - **Logic plan** and
  - **Load sharing** between devices

***Further research** should be investigated to **find limitations** and **benefits** for applying modern hardware here*

Conclusion

Conclusion

Bucketing windows enables GPU-ready Data Stream Processing for very large windows

- Memory allocation has upper bound for input (fixed-size)
- Reduces transfer costs (column-selection)

We present an approach to achieve bucketing

- Separat operator, independent of SPS's tuple-at-a-time or batch-at-a-time support
- Ring buffer per attribute plus per-subscriber slice
- Enables processing of large-scale windows on limited graphic card memory
  - No fallback to CPU required

We identify research challenges for further co-processing in this context.

- Other co-processors with specialized algorithm — limitations and benefits
- Large search space for query plans (logical operator — devices — concrete algorithm) — optimizer