StreamBox: Modern Stream Processing on a Multicore Machine

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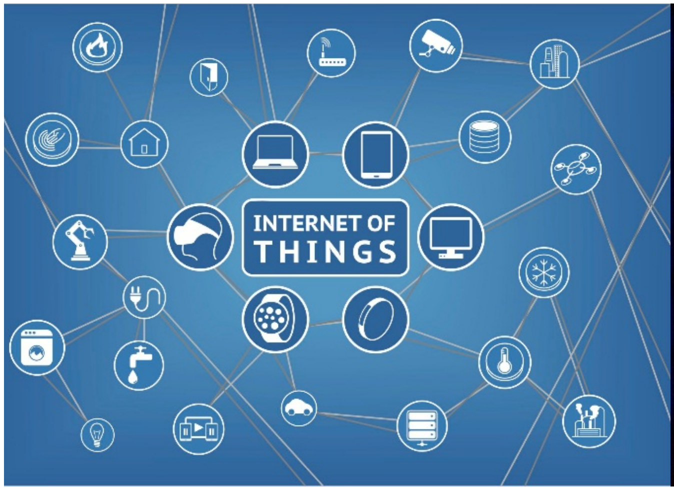
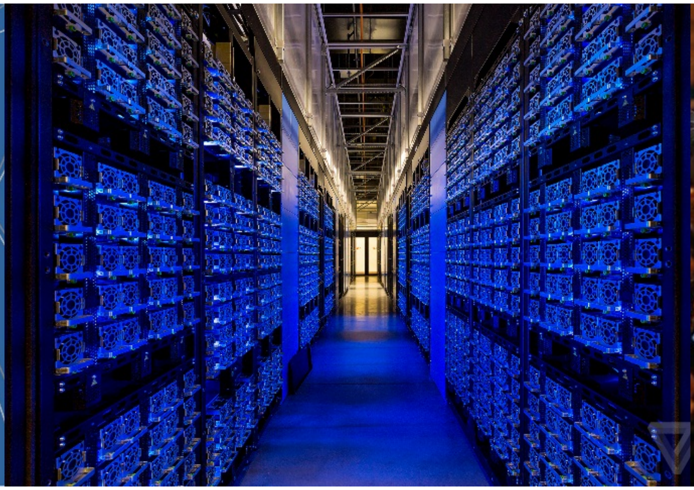
http://xsel.rocks/p/streambox

Purdue University
Microsoft Research
Google
NSF



IoT

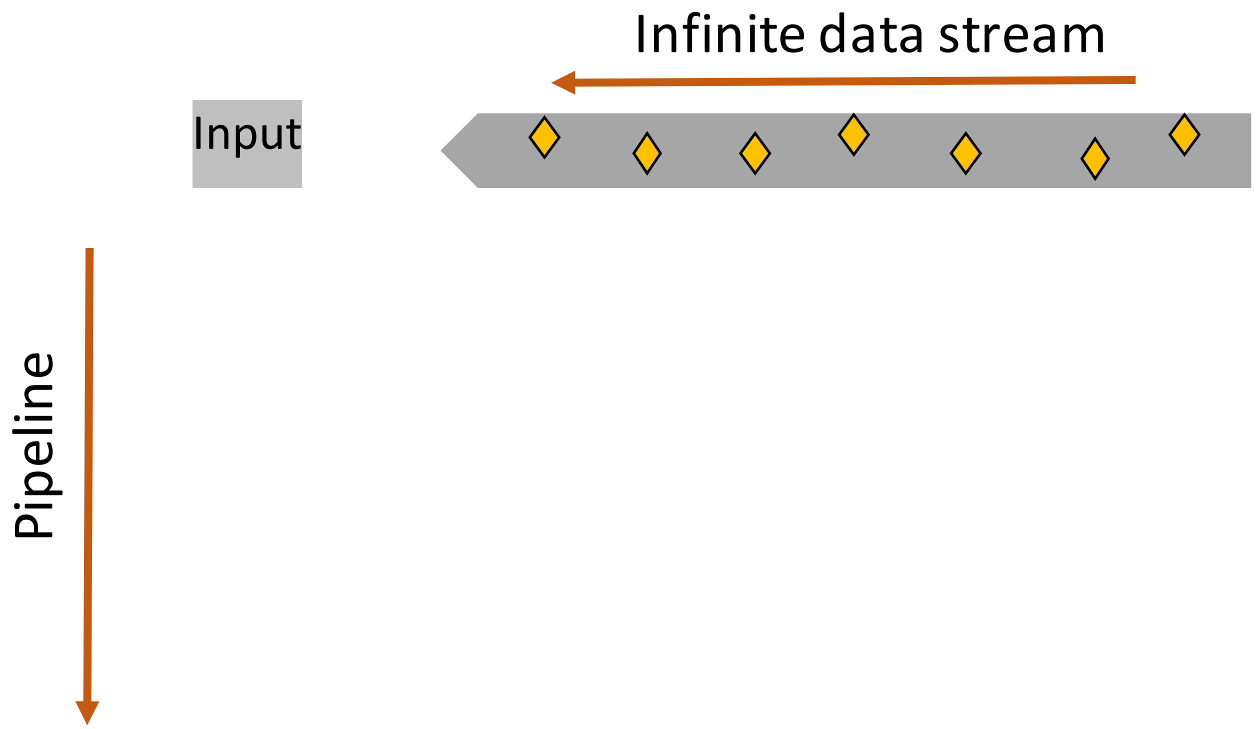


Data centers

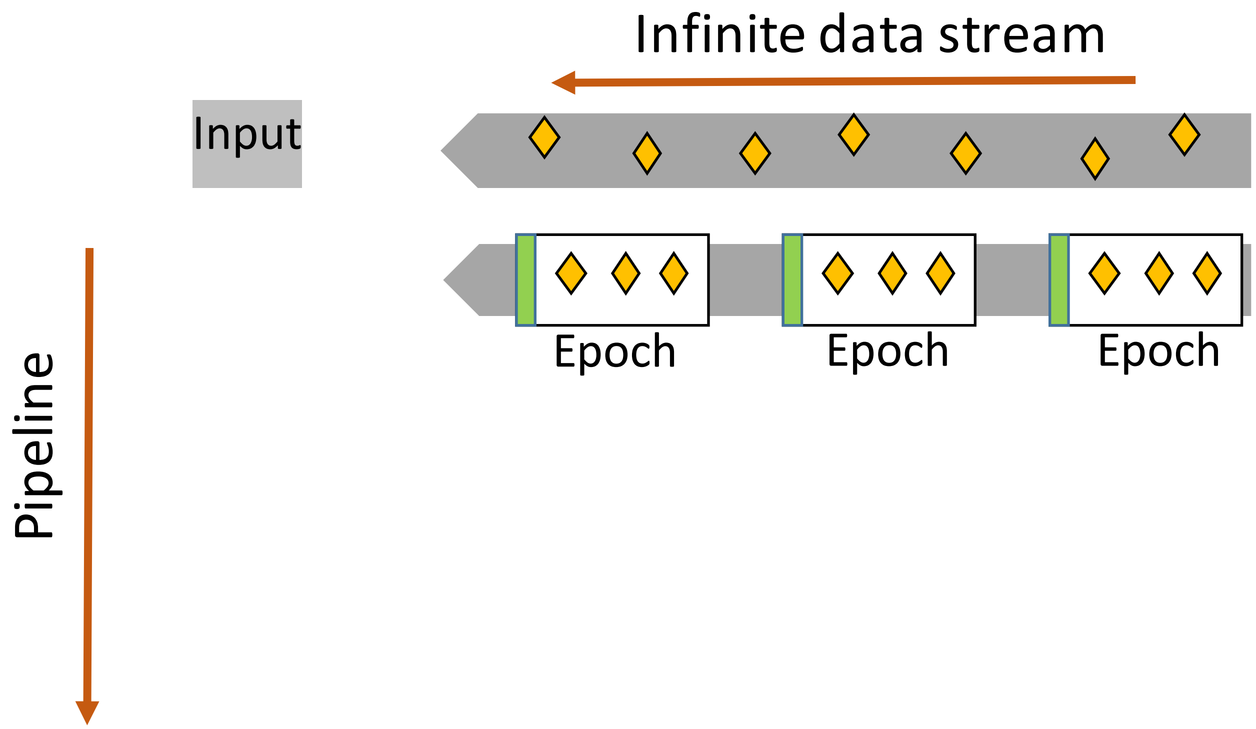
Humans

High velocity of streaming data requires real-time processing

Streaming Pipeline



Streaming Pipeline



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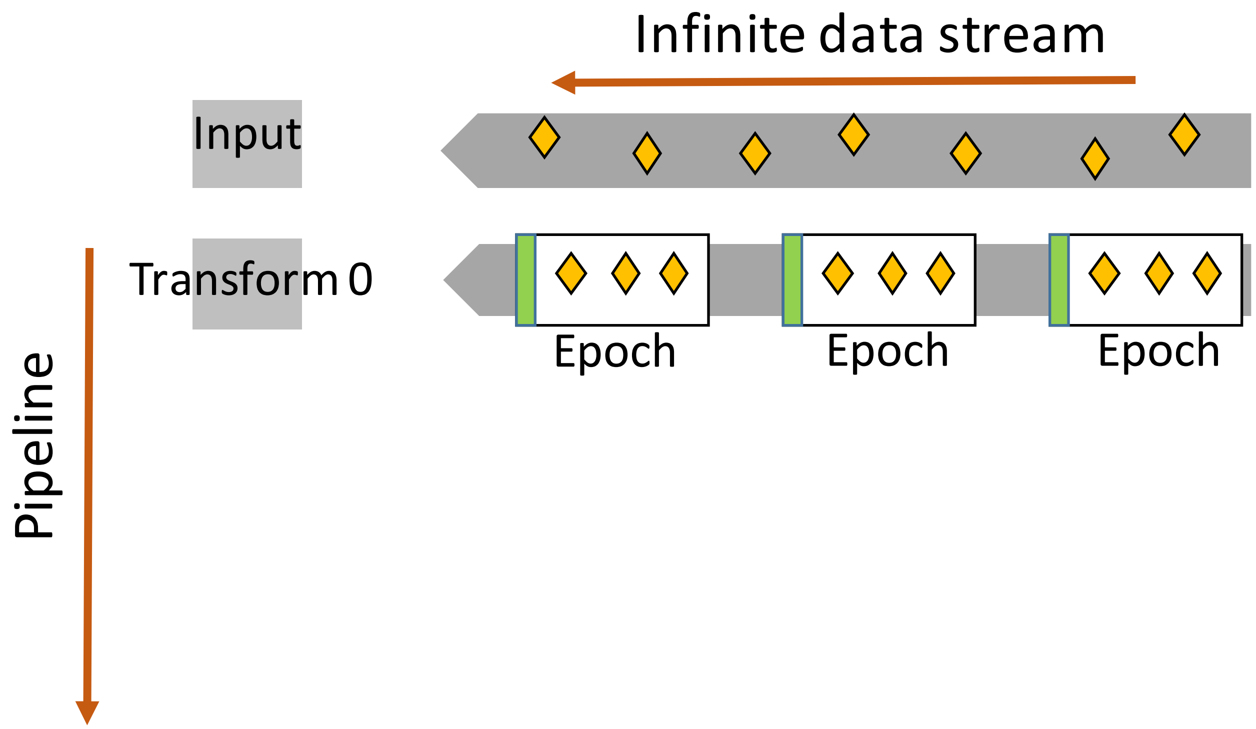

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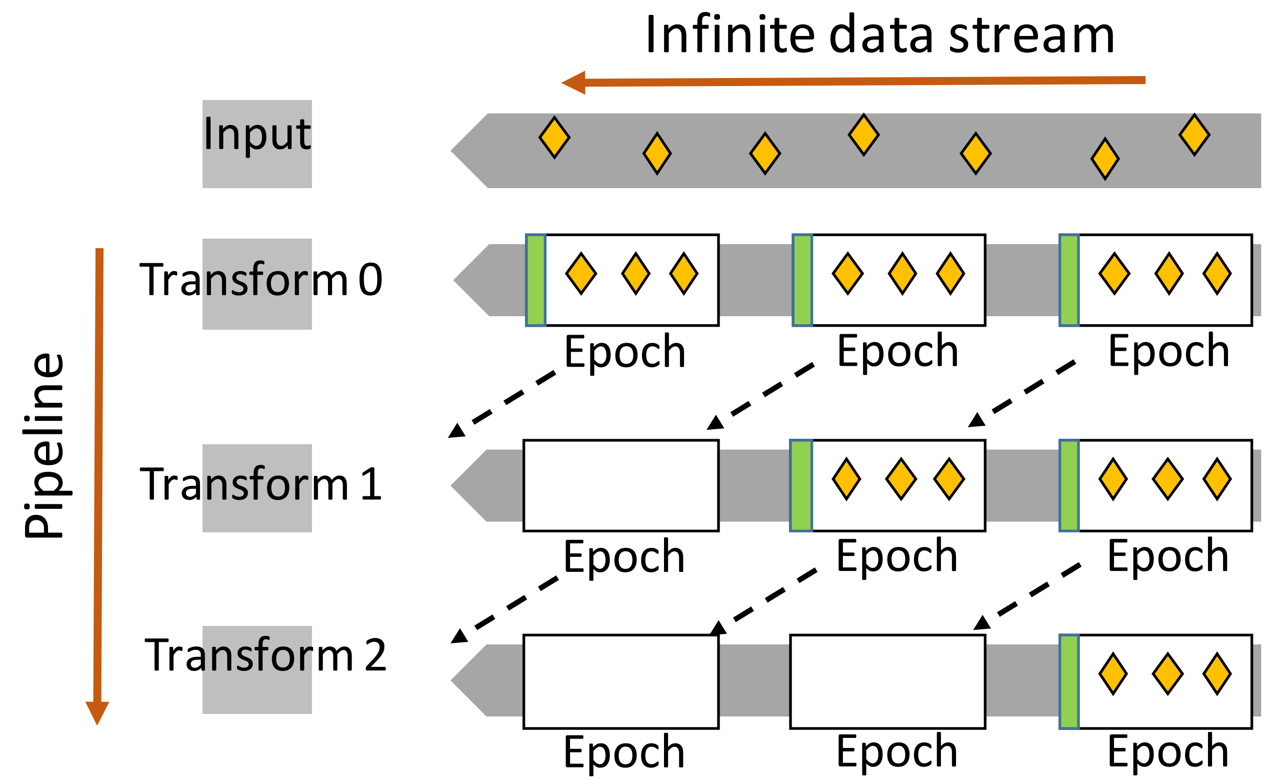

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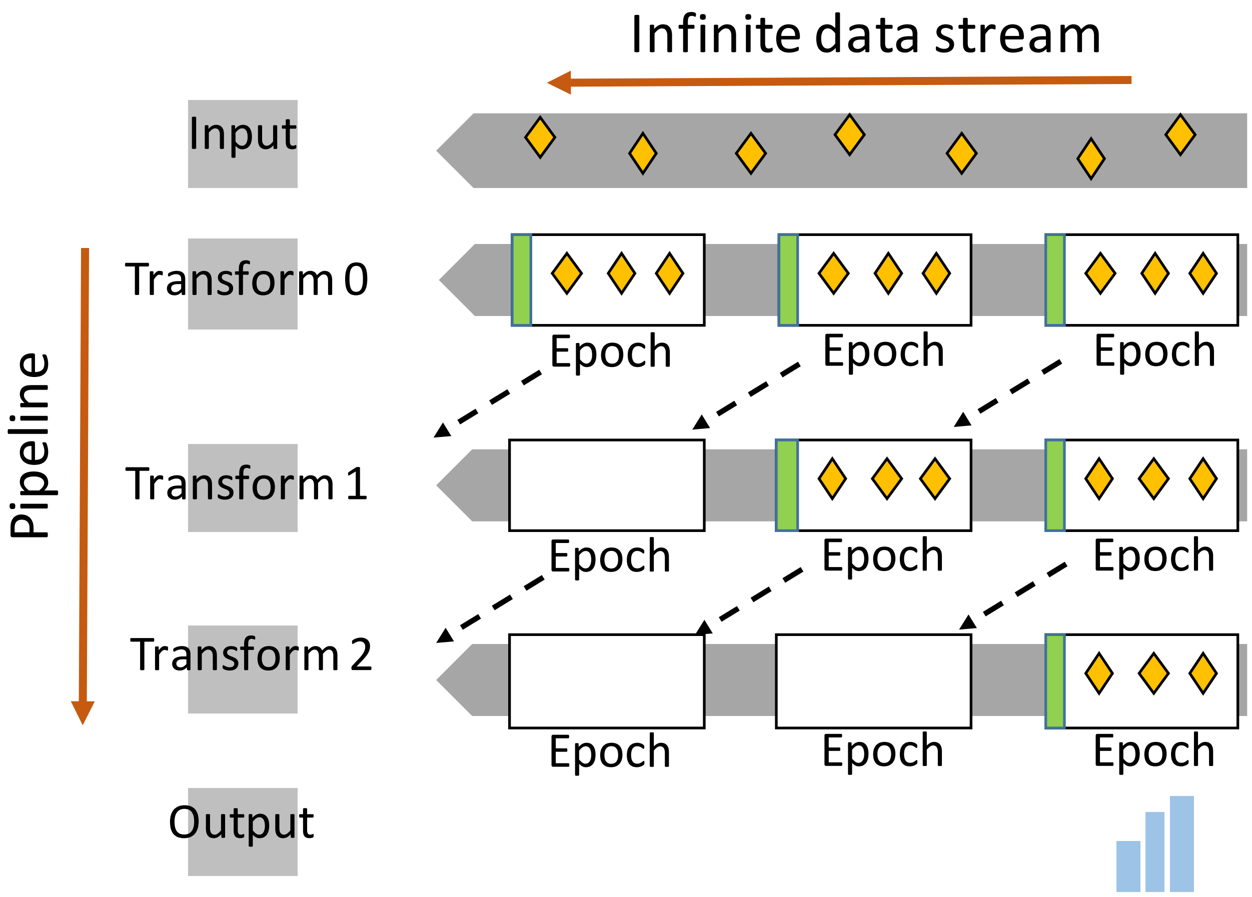
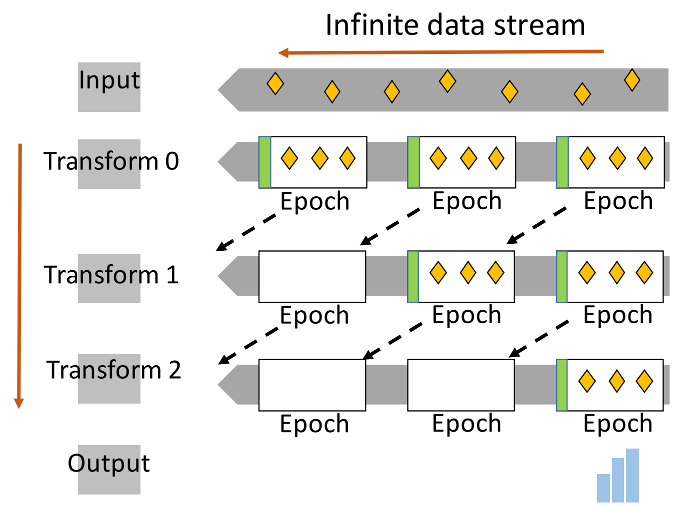


Why is it hard?

Records arrive out-of-order

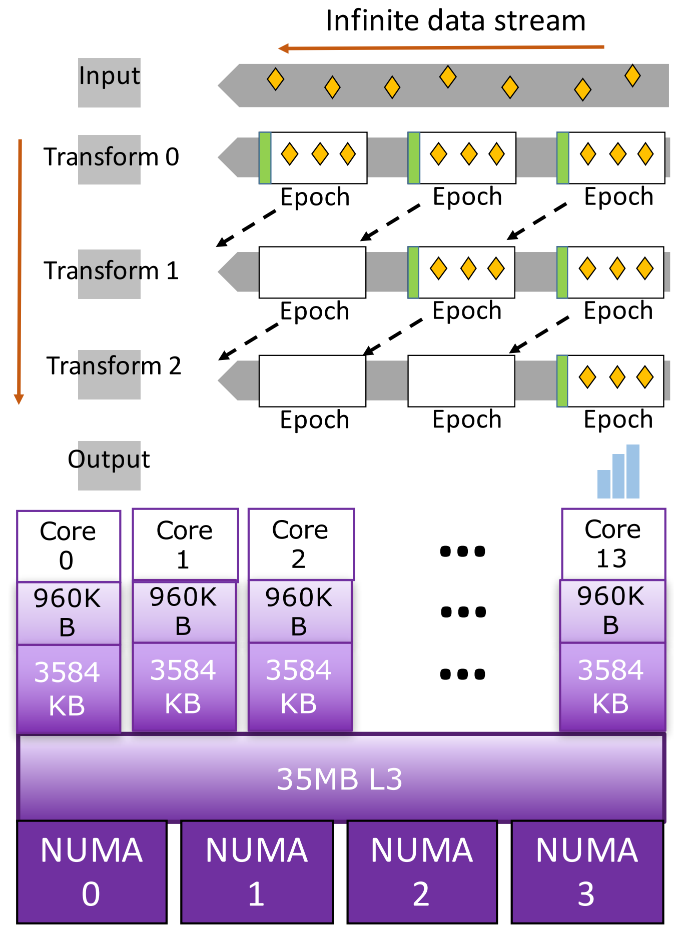


Why is it hard?

Records arrive out-of-order

High Performance on Multicore

- Data parallelism
- Pipeline parallelism
- Memory locality

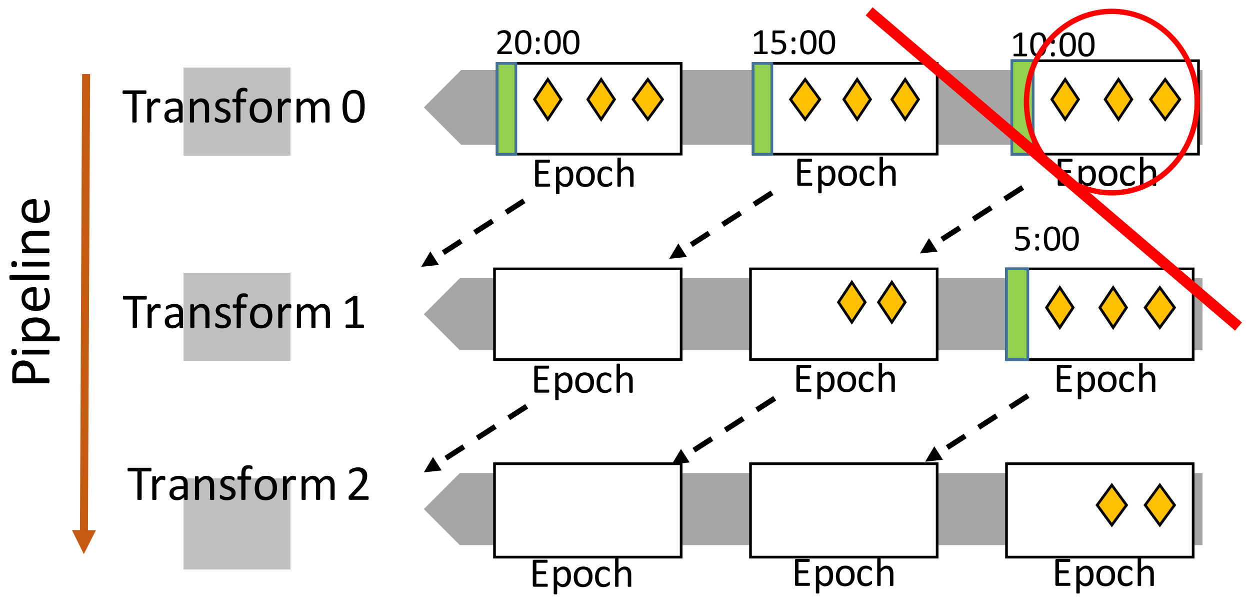


Intel Xeon E7-4830 v4

Prior work

Out-of-order processing within epochs

Processes only one epoch in each transform at a time



Prior work

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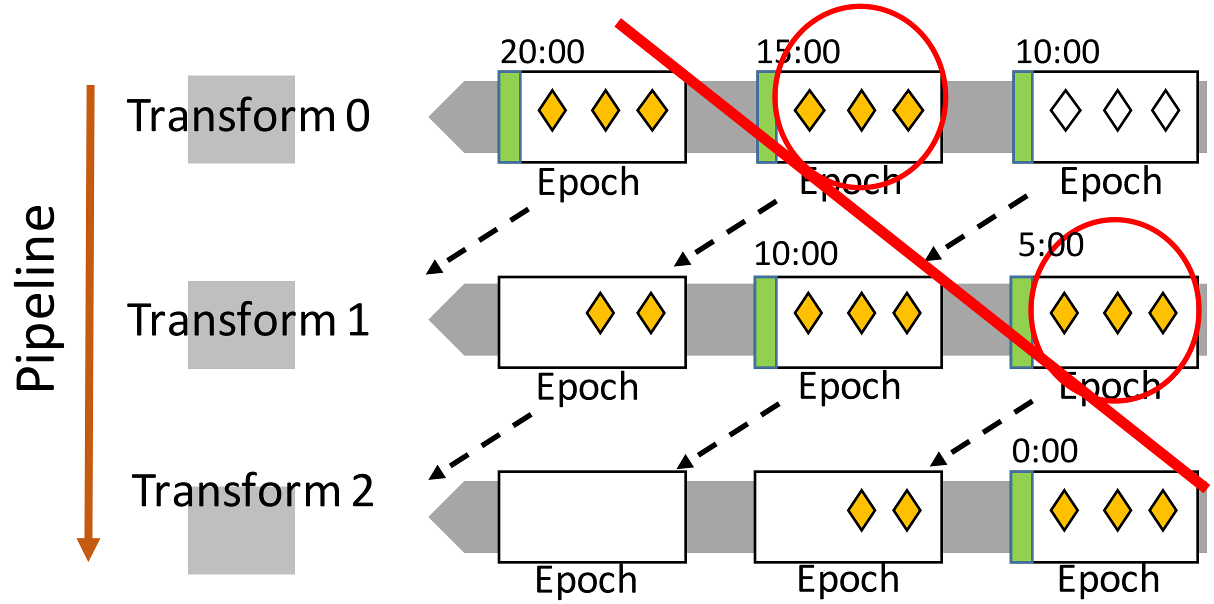

Prior work

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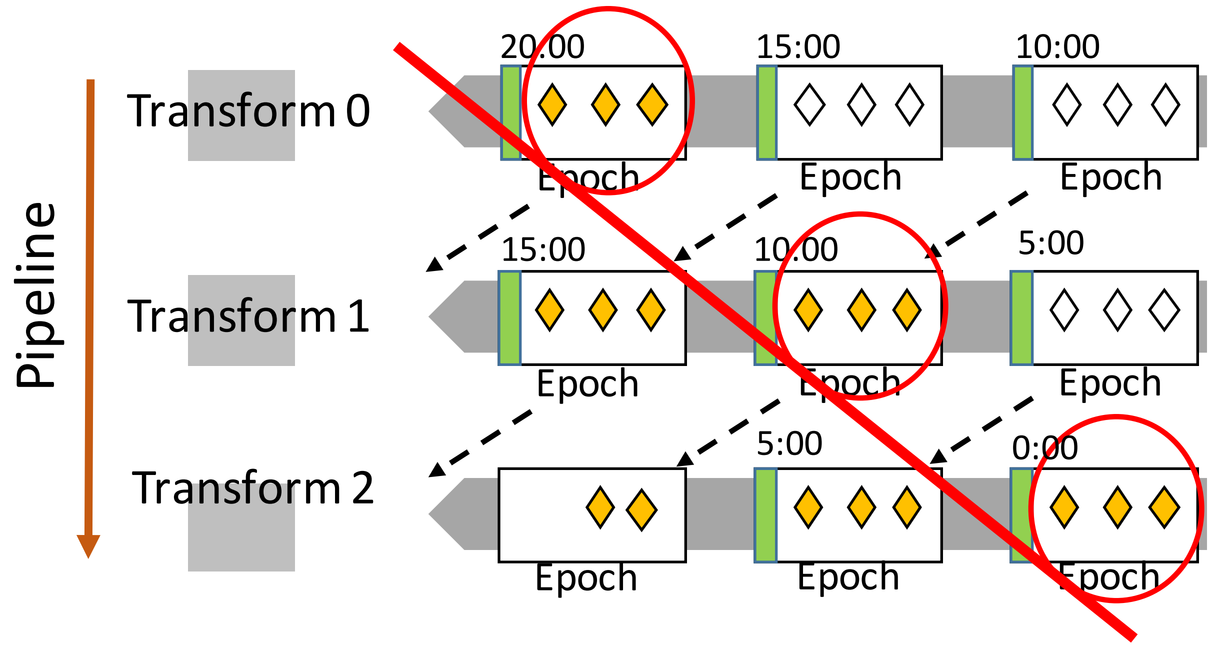
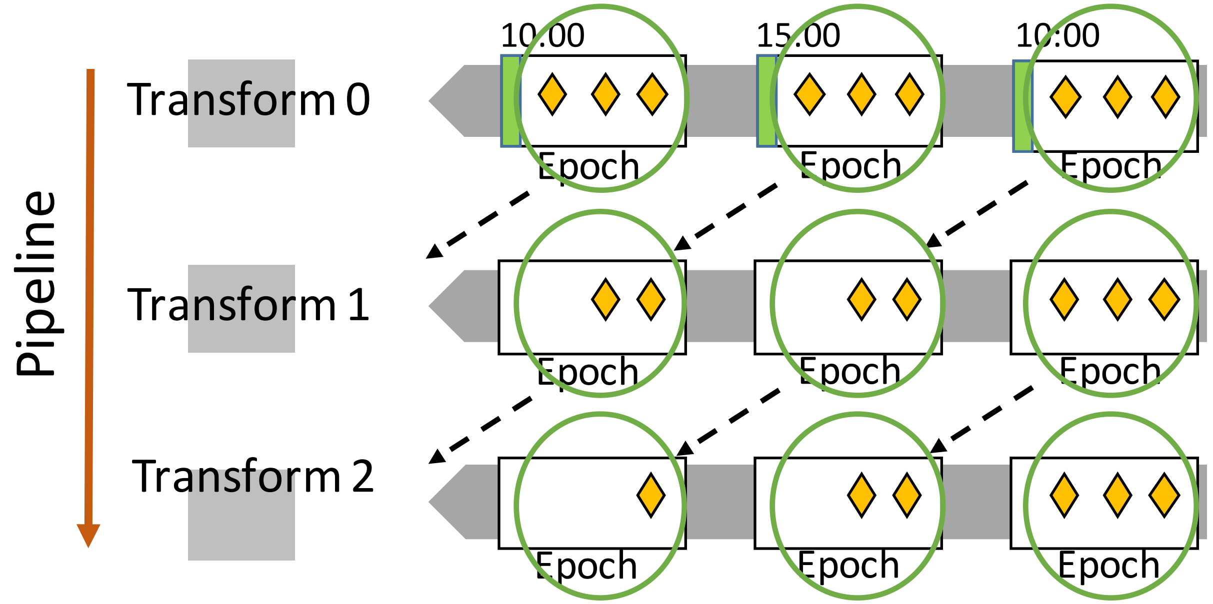


StreamBox insight

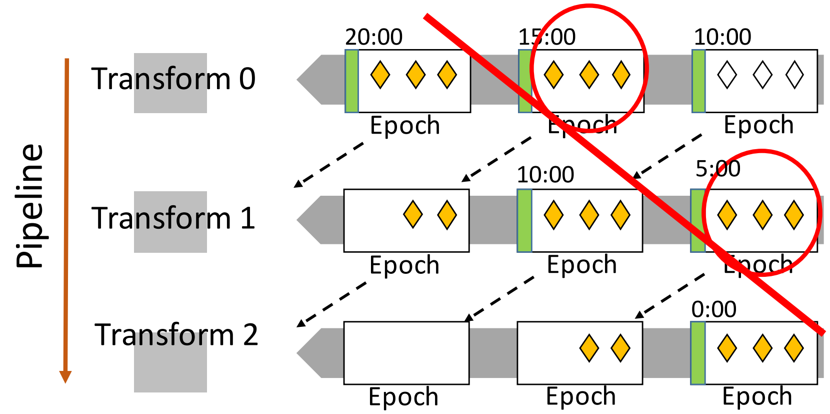
Out-of-order processing across epochs

Process all epochs in all transforms in parallel

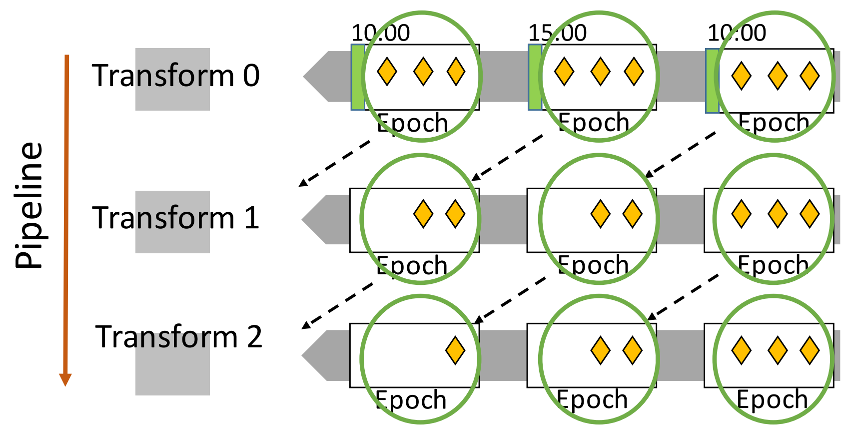


Prior work vs. StreamBox

Processes only one epoch in each transform at a time



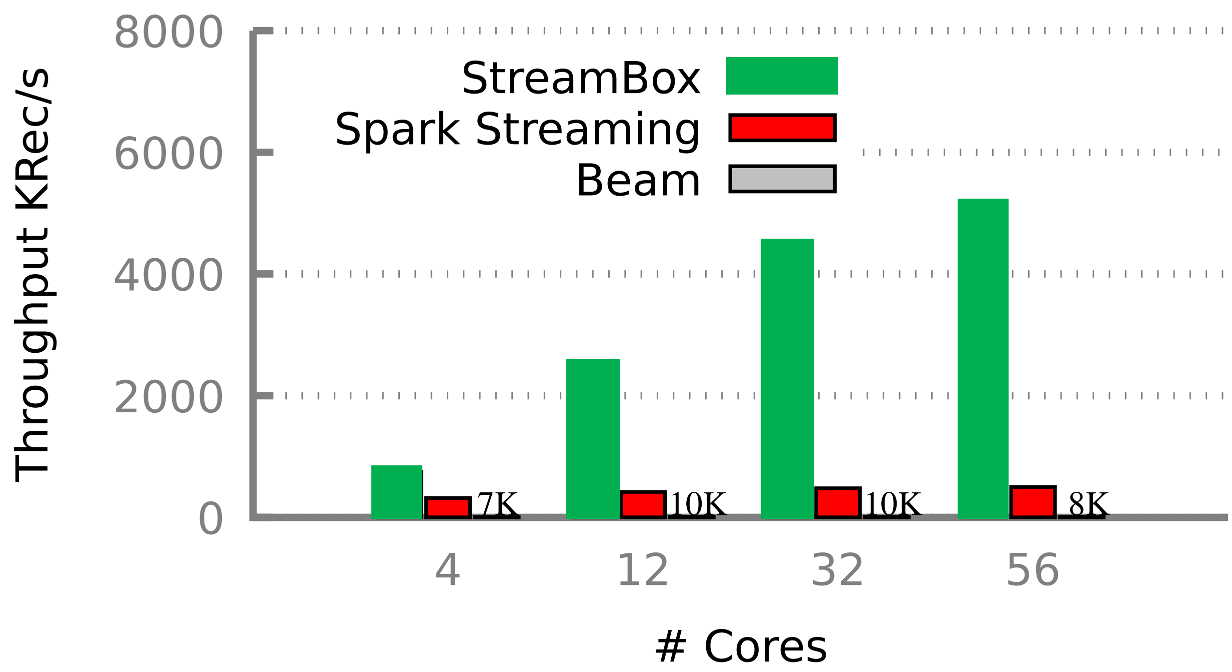
Process all epochs in all transforms in parallel



StreamBox: High pipeline and data parallel processing system

Result: StreamBox vs. existing systems on multicore

High throughput & utilization of multicore hardware



Roadmap

Background

Stream pipeline, streaming data, window, watermark, and epoch

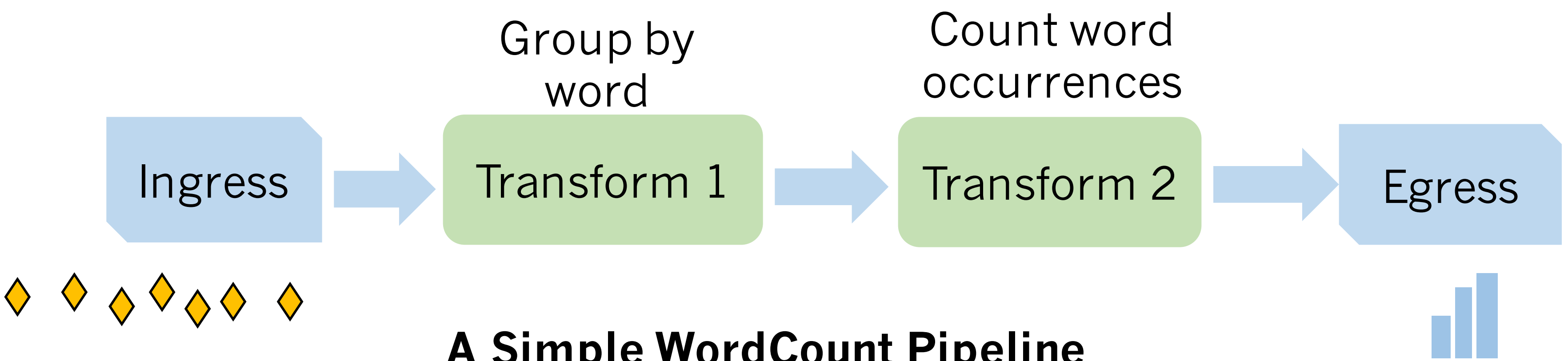
StreamBox Design

- Invariants to guarantee correctness
- Out-of-order epoch processing

Evaluation

Streaming pipeline for data analytics

Transform a computation that consumes and produces streams
Pipeline a dataflow graph of transforms

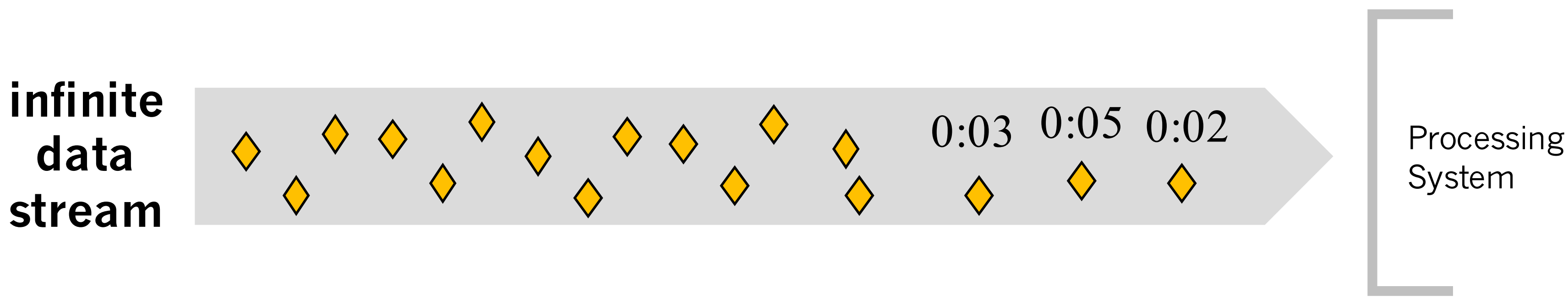


A Simple WordCount Pipeline

Stream records = data + event time

Records arrive out of order

- Records travel diverse network paths
- Computations execute at different rates

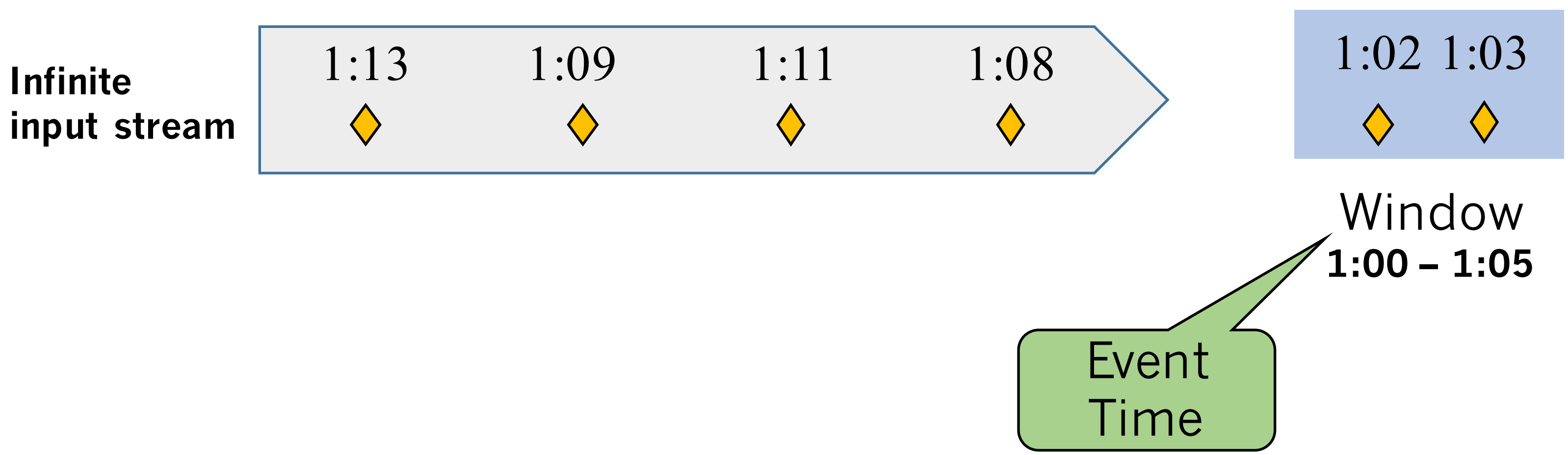


Window

A temporal processing scope of records

Chopping up infinite data into finite pieces along temporal boundaries

Transforms do computation based on windows



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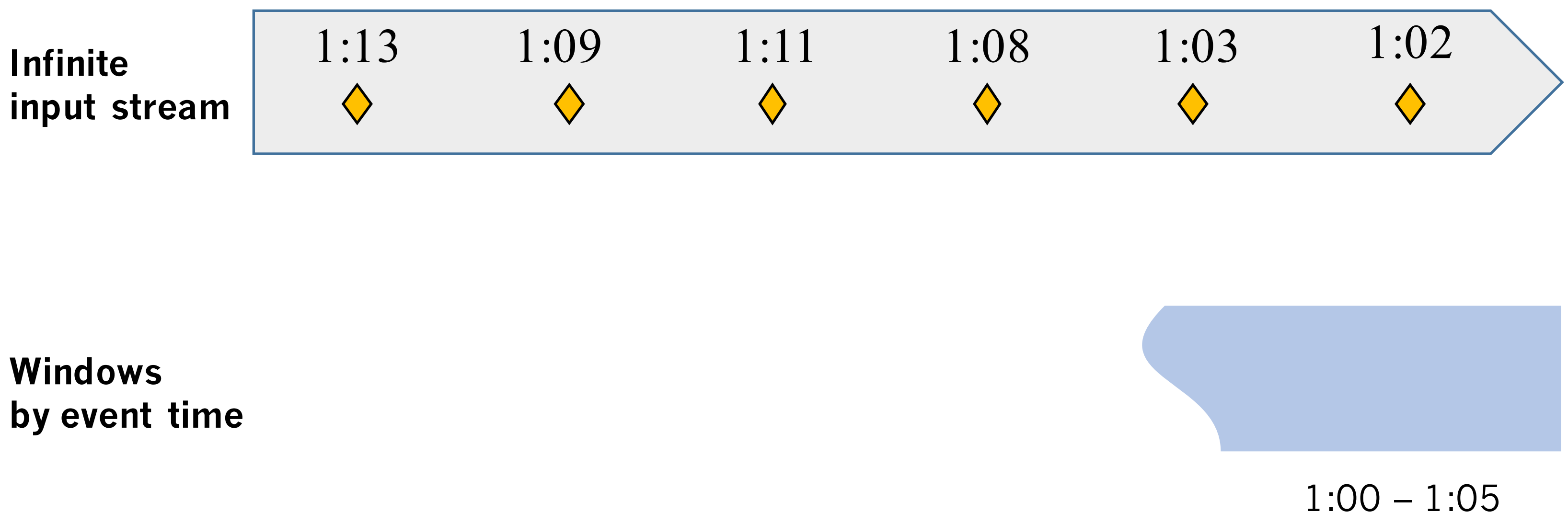

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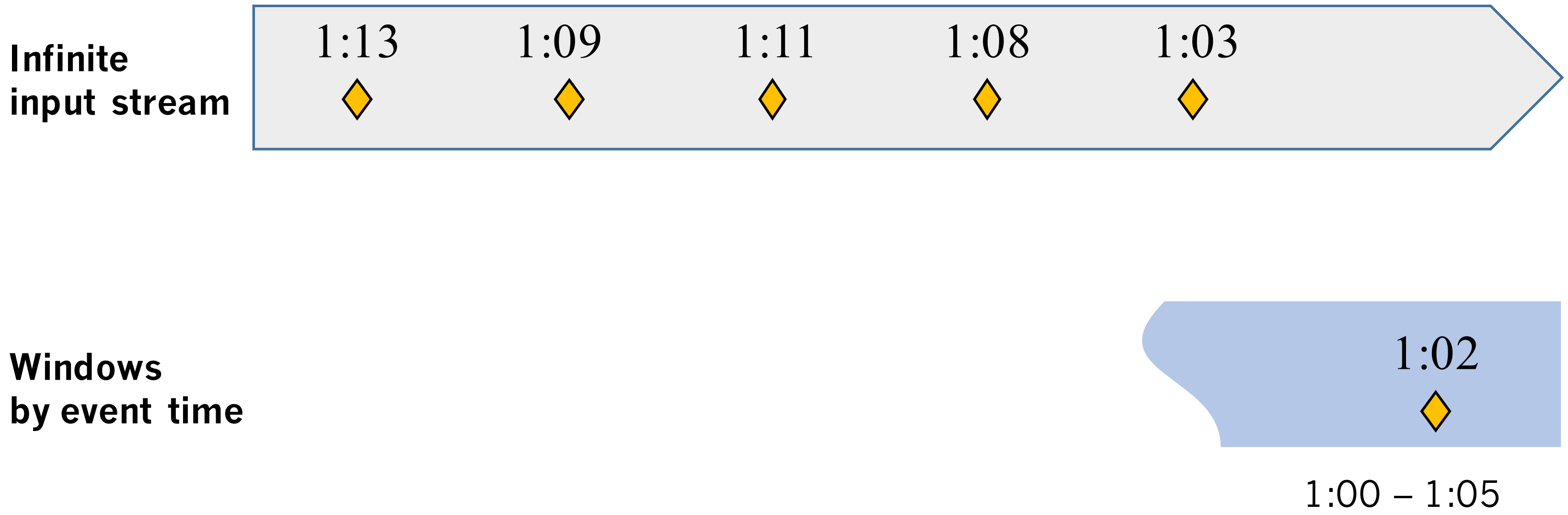

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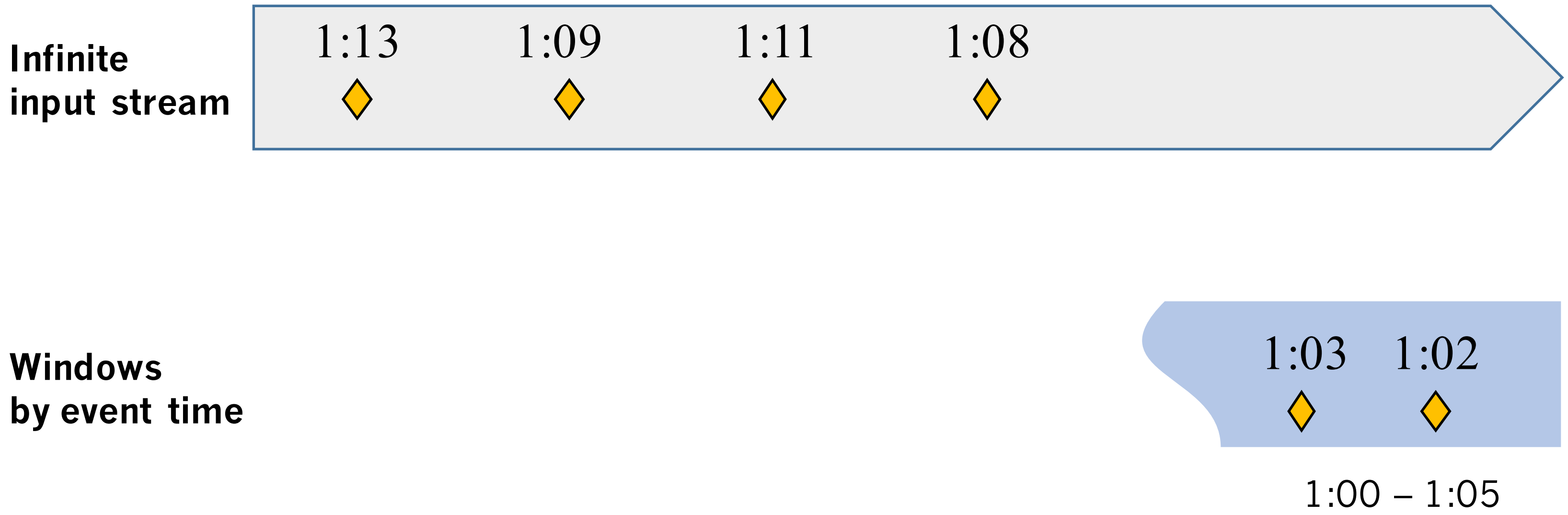

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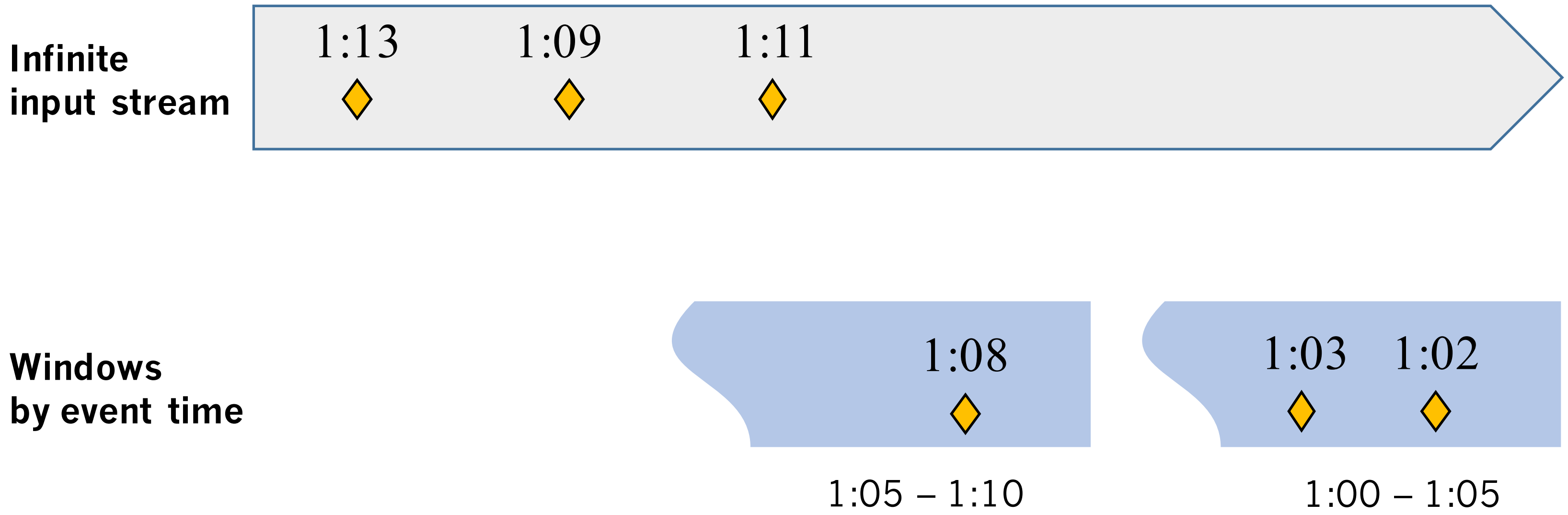

Window

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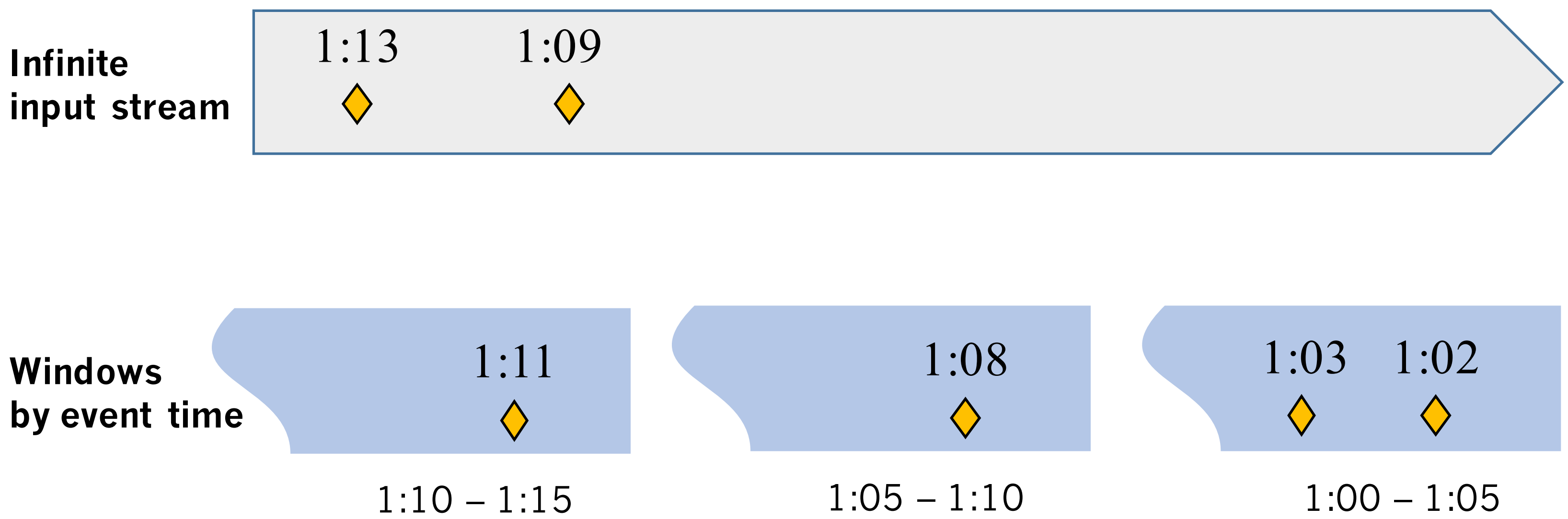

Window

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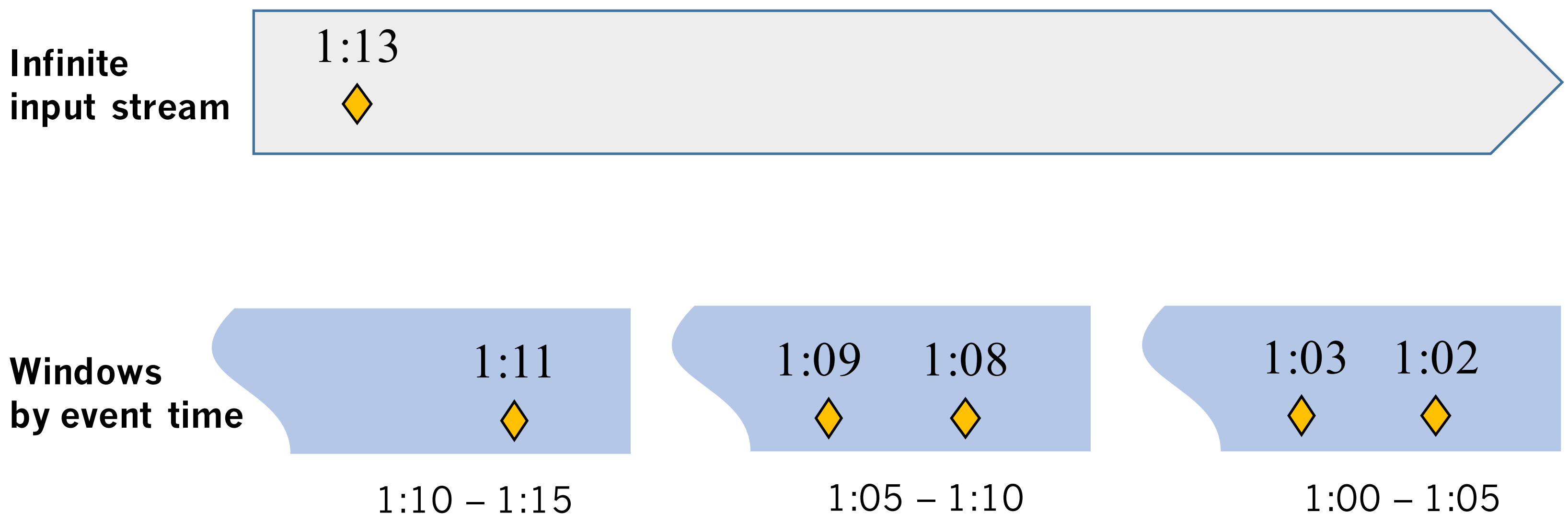

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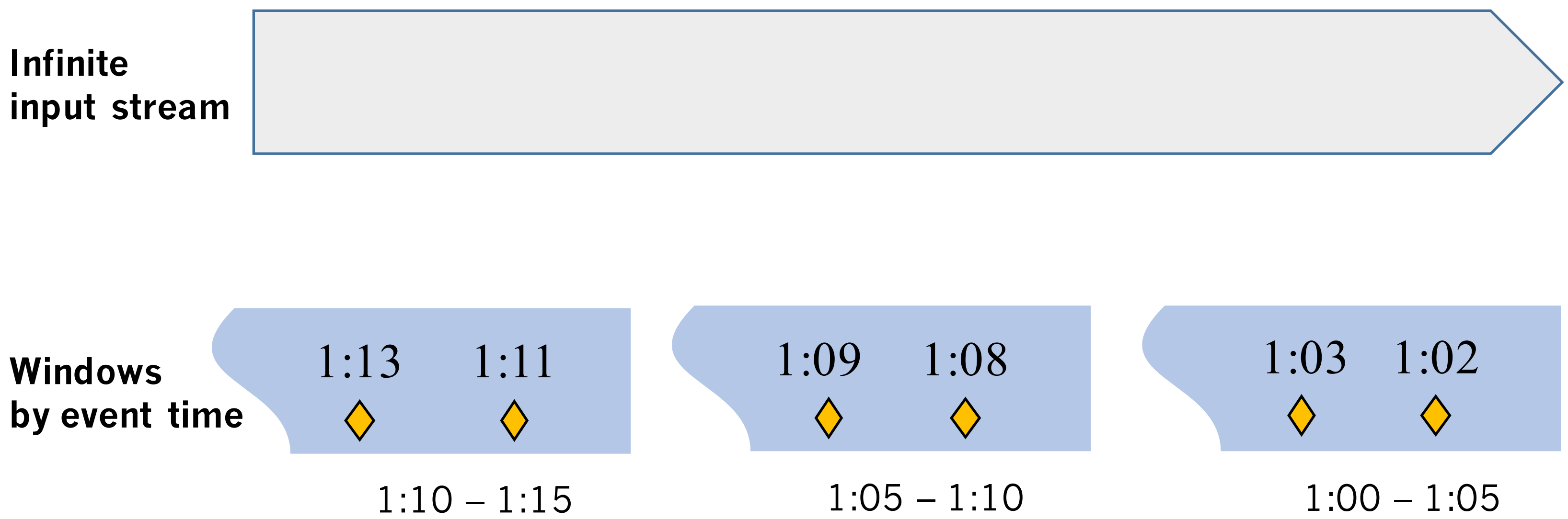
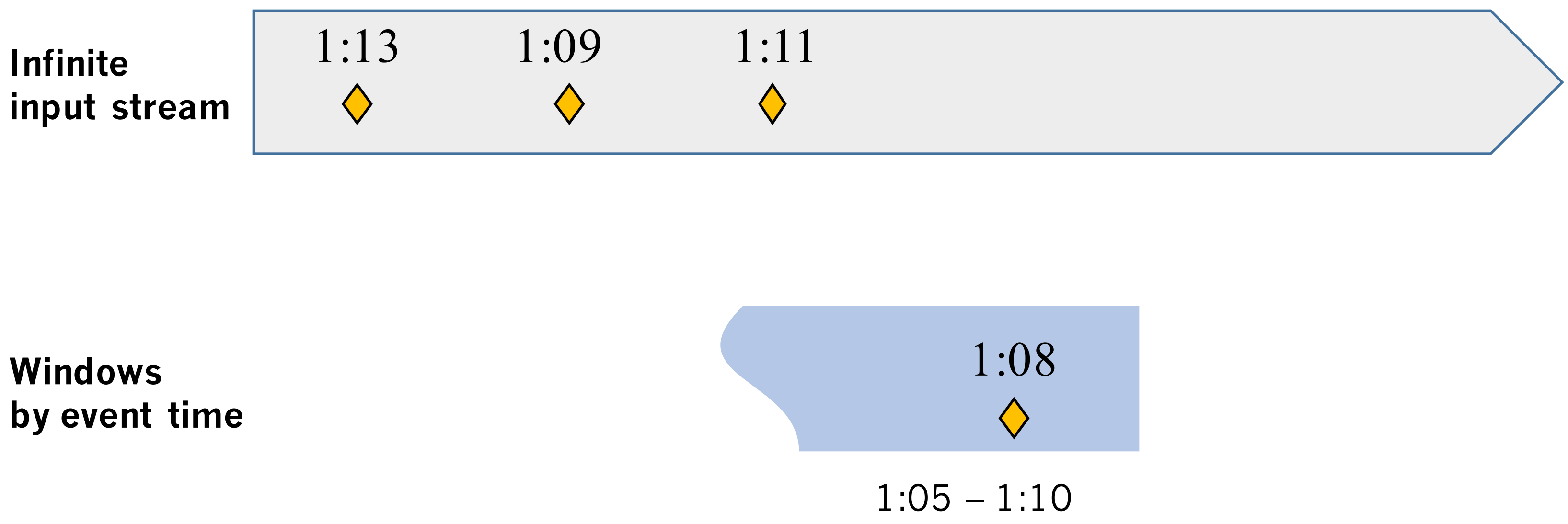
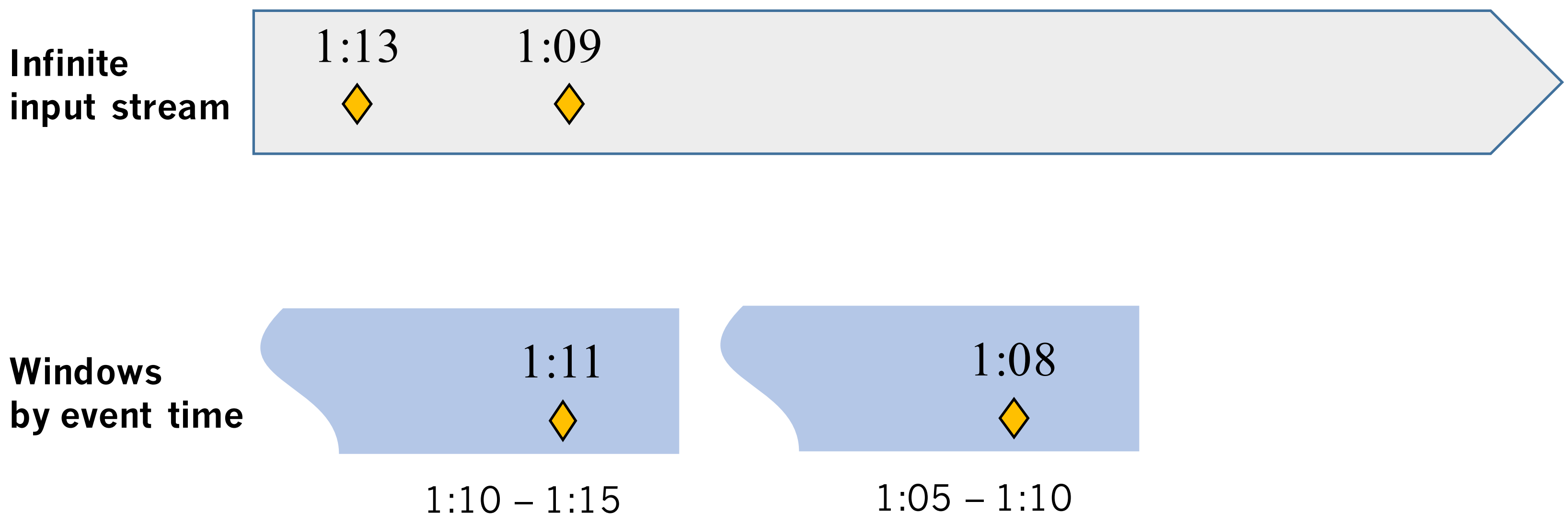


Out-of-order records



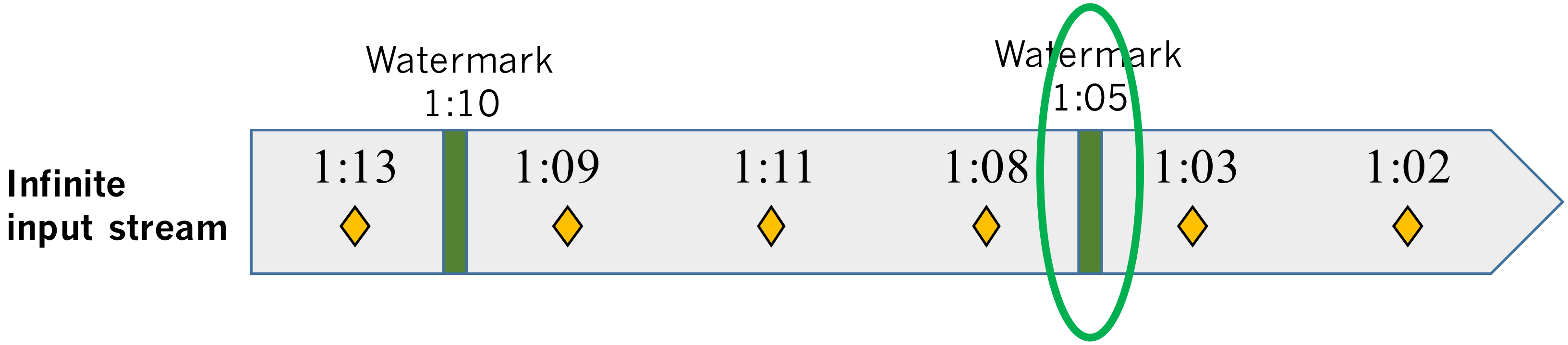
When a window is complete?



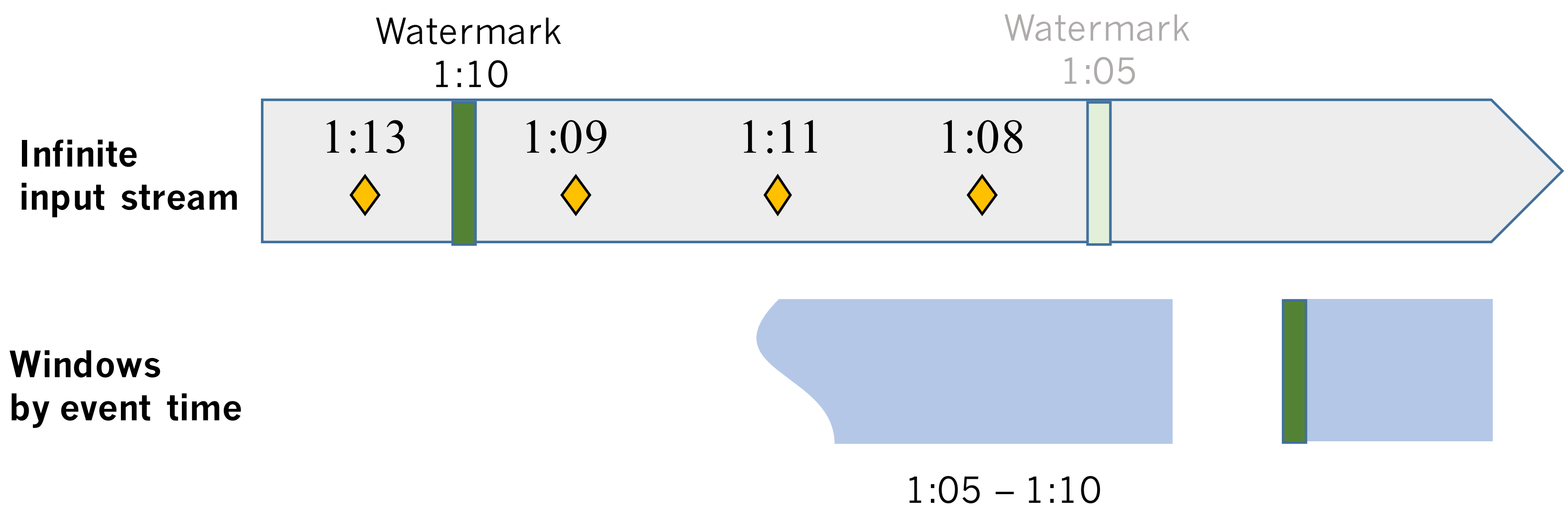
Watermark

Input completeness indicated by data source

Watermark X all input data with event times less than X have arrived



Handling out-of-order with watermarks



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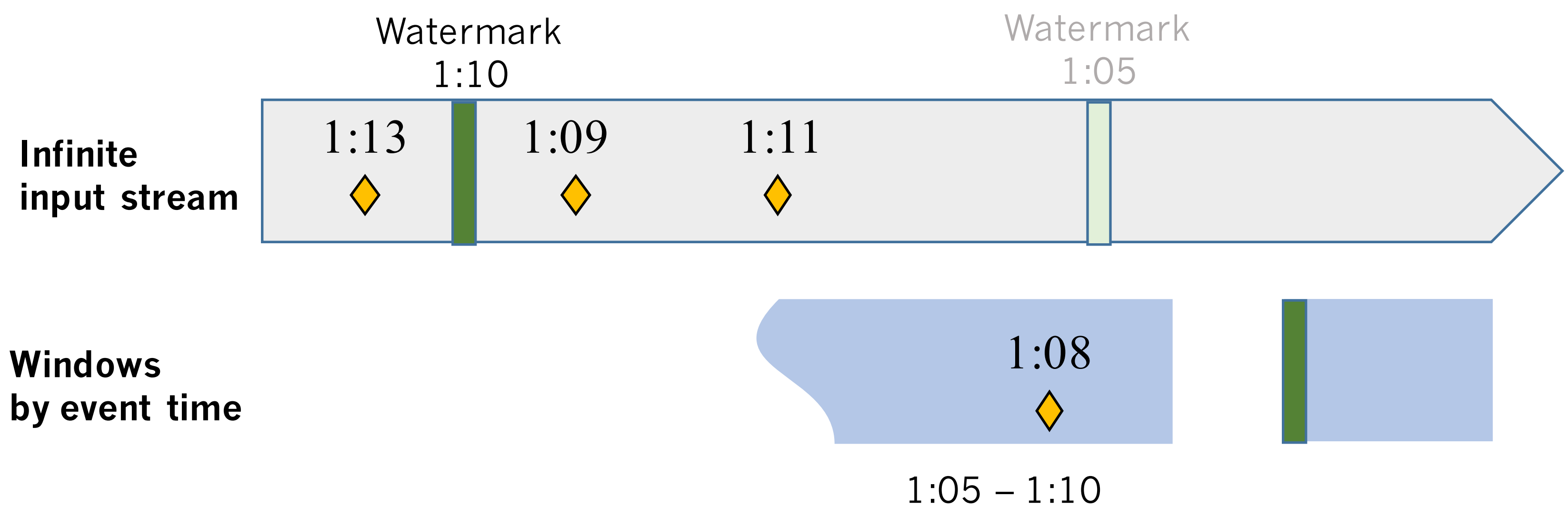

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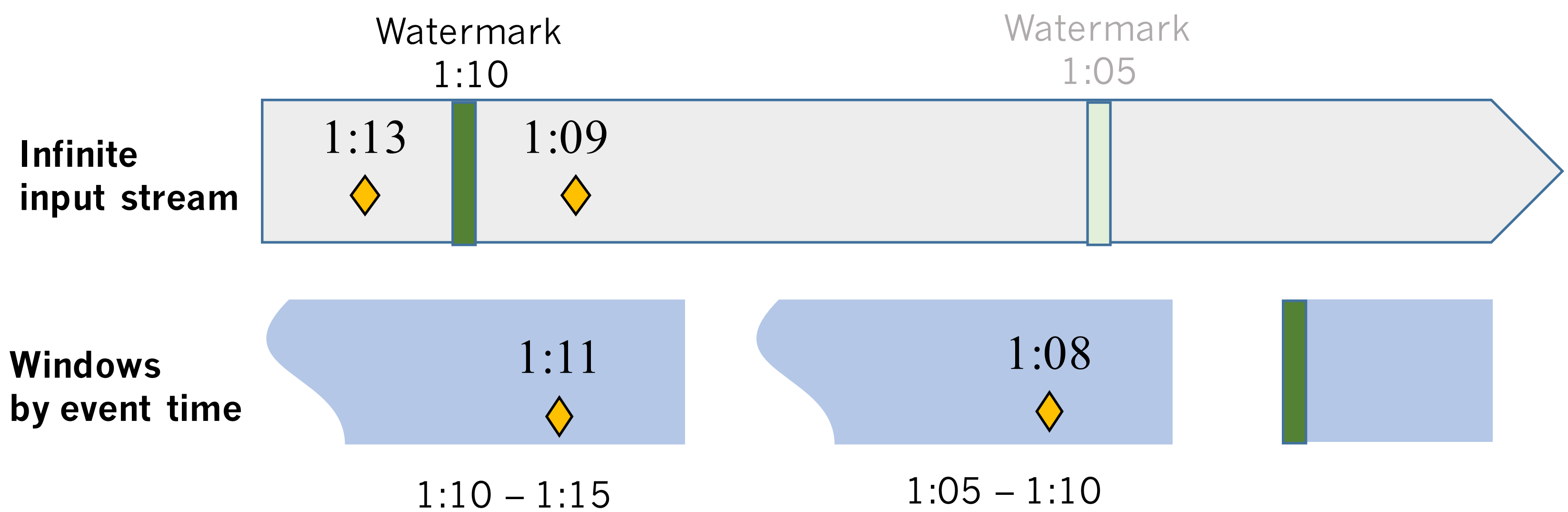

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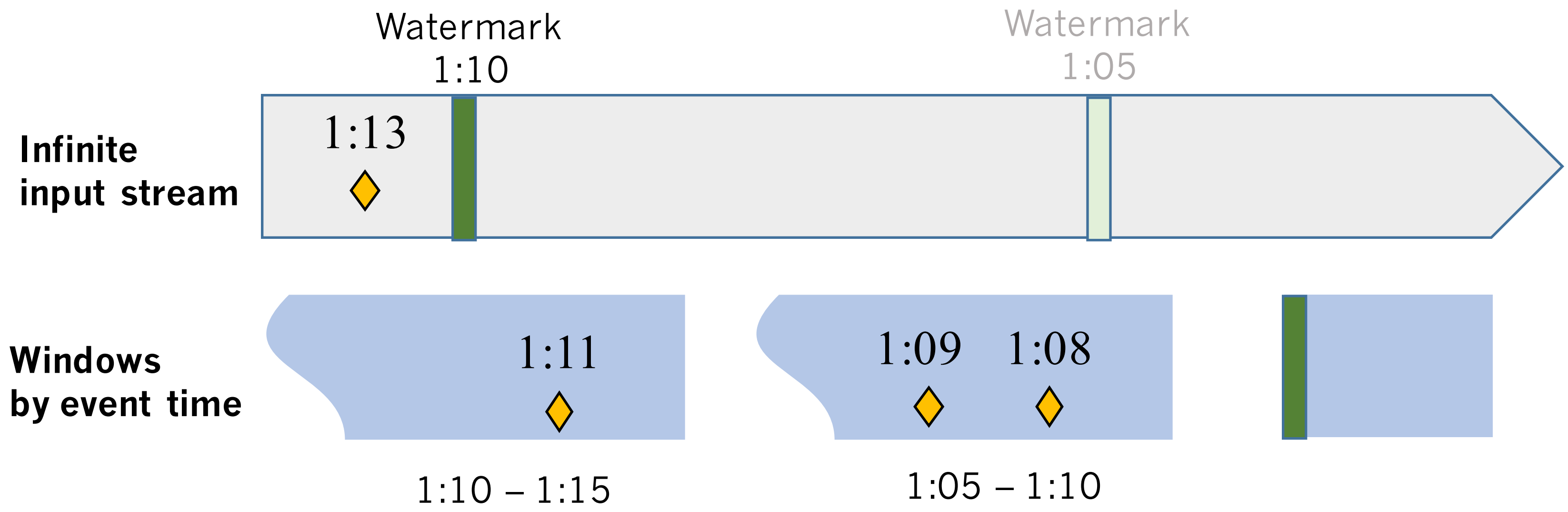

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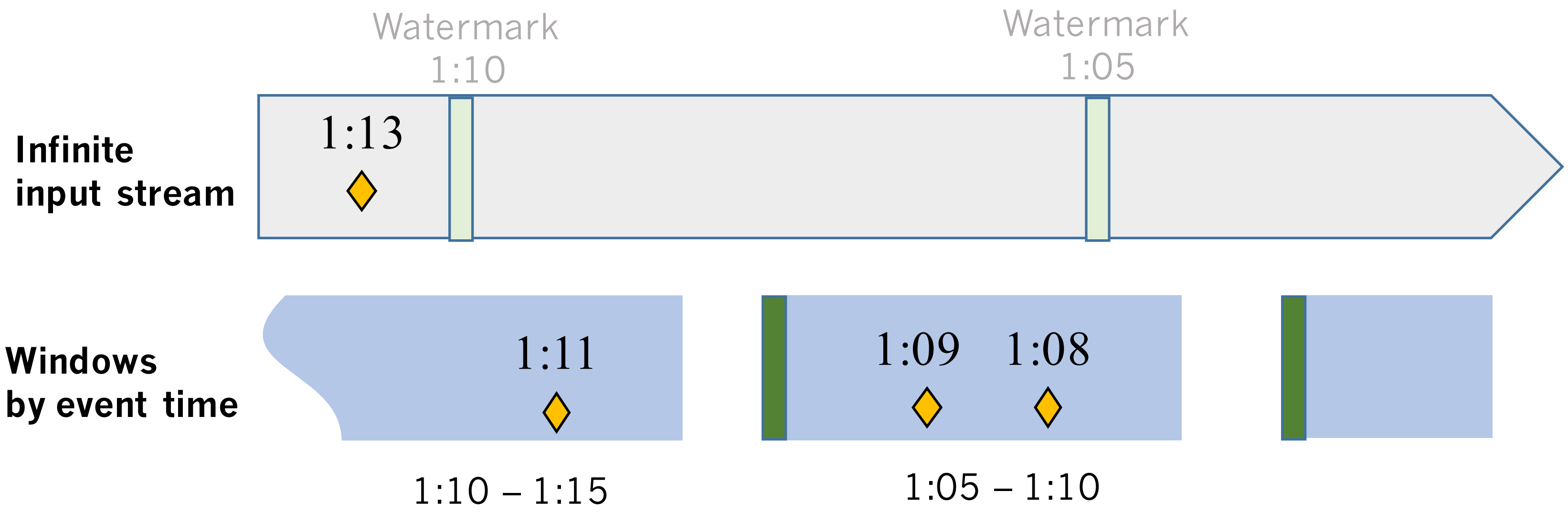
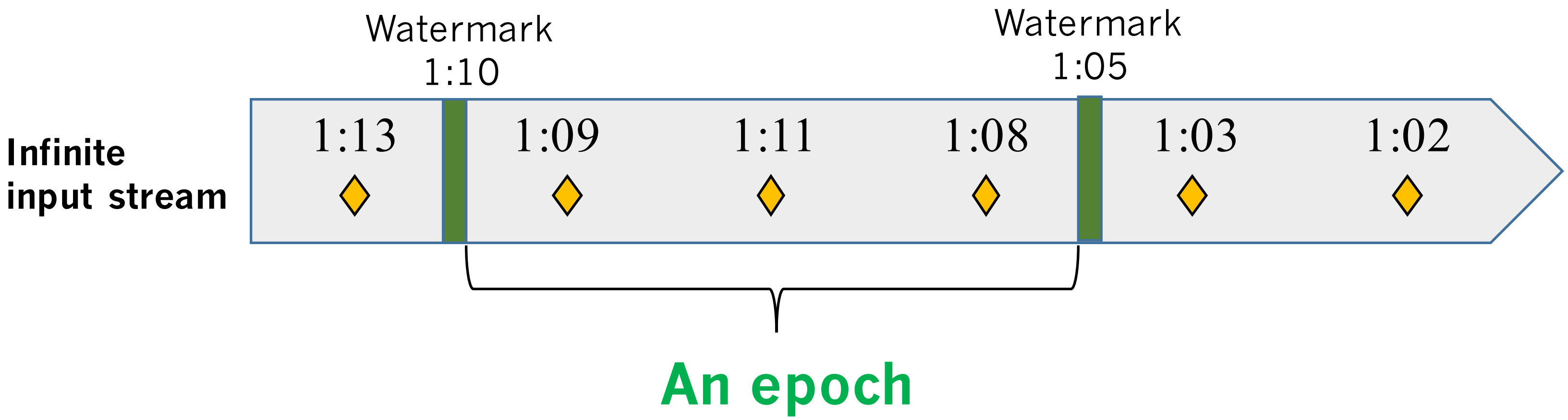


Epoch

A set of records arriving between two watermarks

A window may span multiple epochs



Roadmap

Background

StreamBox Design

- **Invariants to guarantee correctness**
- **Out-of-order epoch processing**

Evaluation

Stream processing engines

Most of stream engines optimize for a distributed system

- Neglected efficient multicore implementation
- Assume a single machine incapable of handling stream data

Spark Streaming

beam

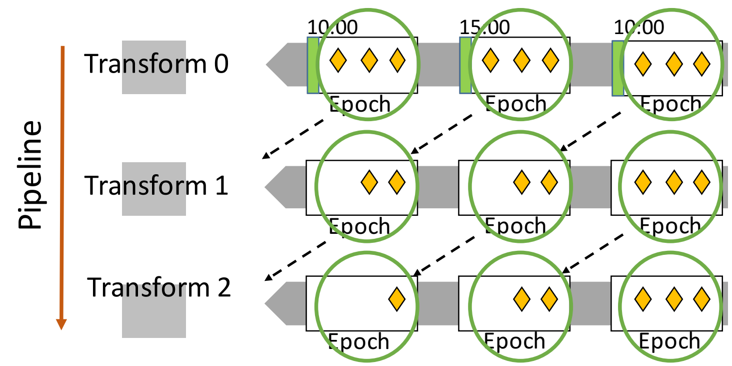
Goal A stream engine for multicore

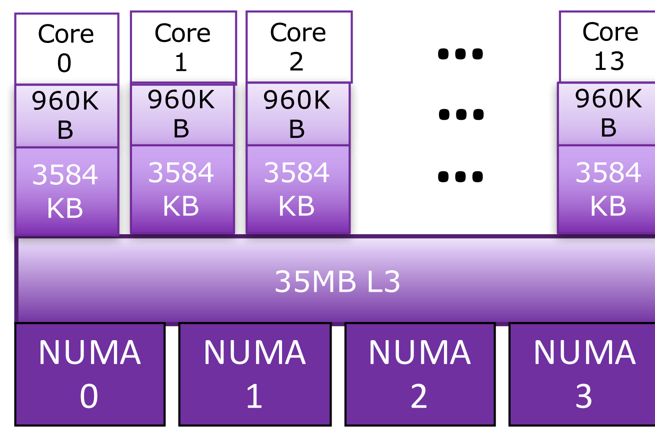
Multicore hardware with

- High throughput I/O
- Terabyte DRAMs
- A large number of cores

A stream engine for multicore

- **Correctness** respect dependences with minimal synchronization
- **Dynamic parallelism** processes any records in any epochs
- **Target** throughput & latency





Challenges

Correctness

- Guarantee watermark semantics by meeting two invariants

Throughput

- Never stall the pipeline

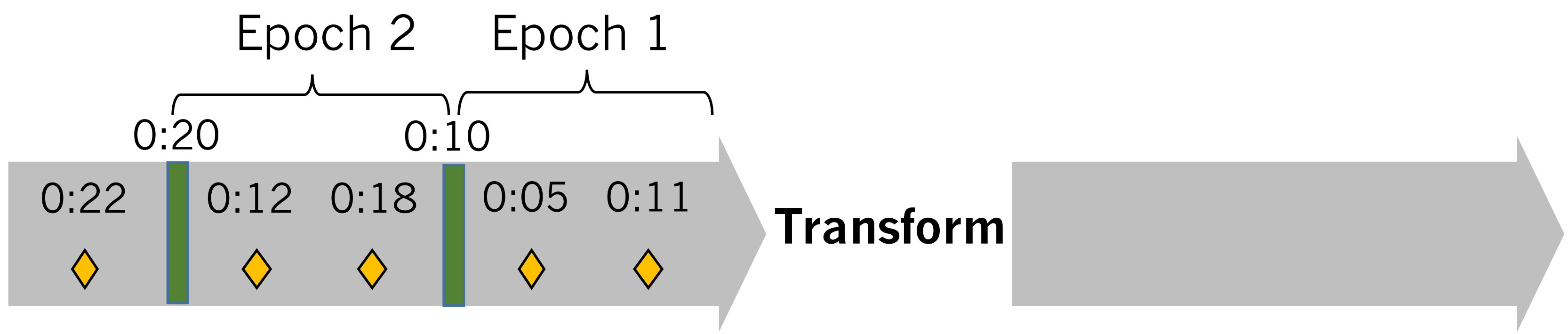
Latency

- Do not relax the watermark
- Dynamically adjust parallelism to relieve bottlenecks

Invariant 1 Watermark ordering

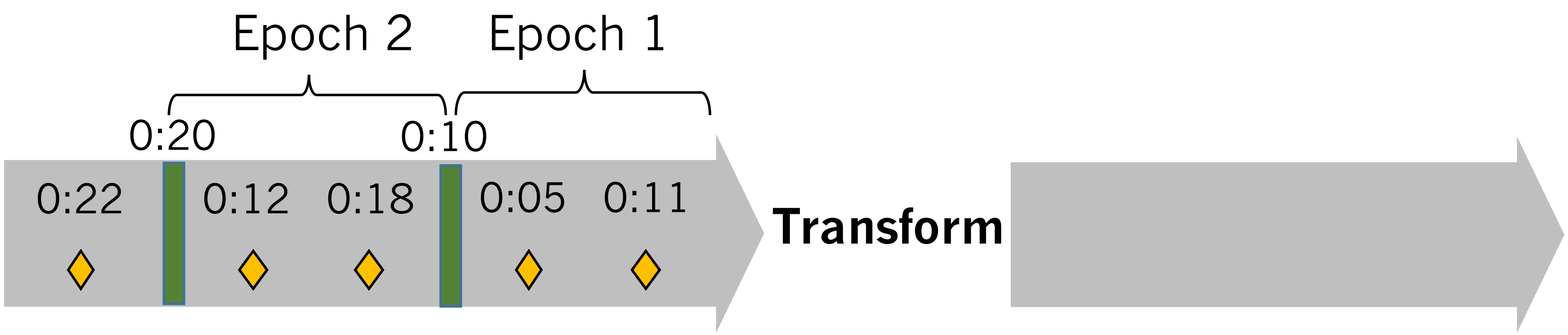
Transforms consume watermarks in order

Transforms consume all records in an epoch before consuming the watermark



Invariant 2 Respect epoch boundaries

Once a transform assigns a record an epoch, the record never changes epochs



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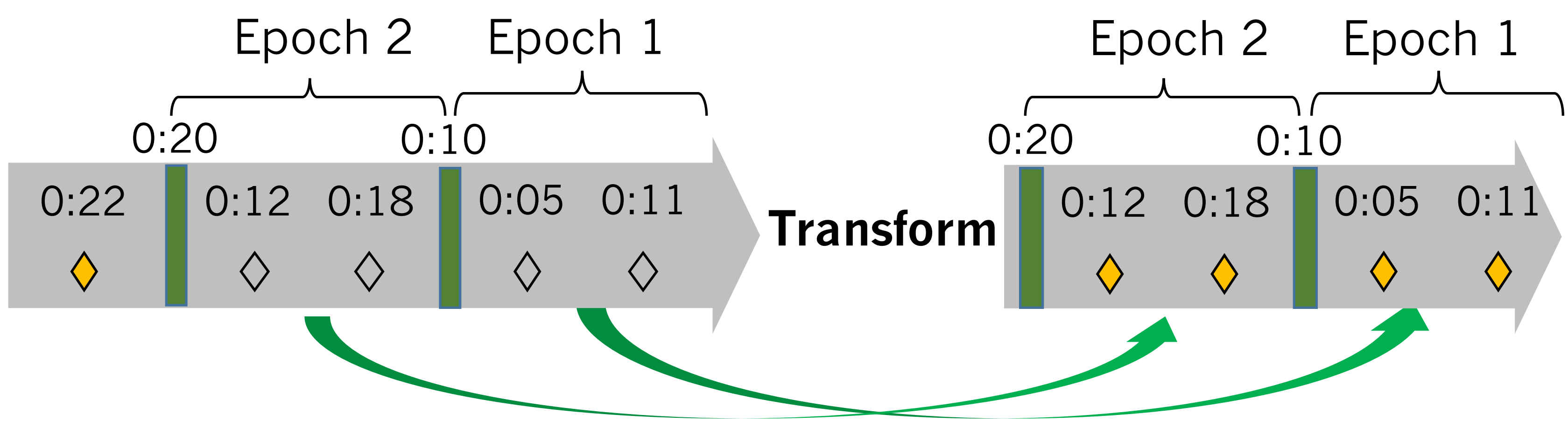
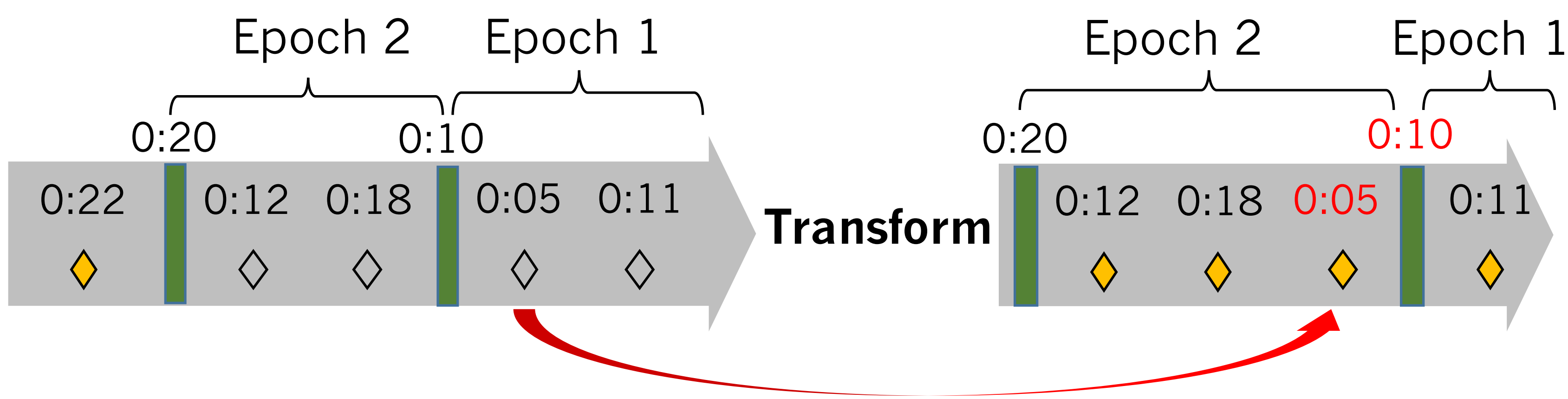


Invariant 2 Respect epoch boundaries

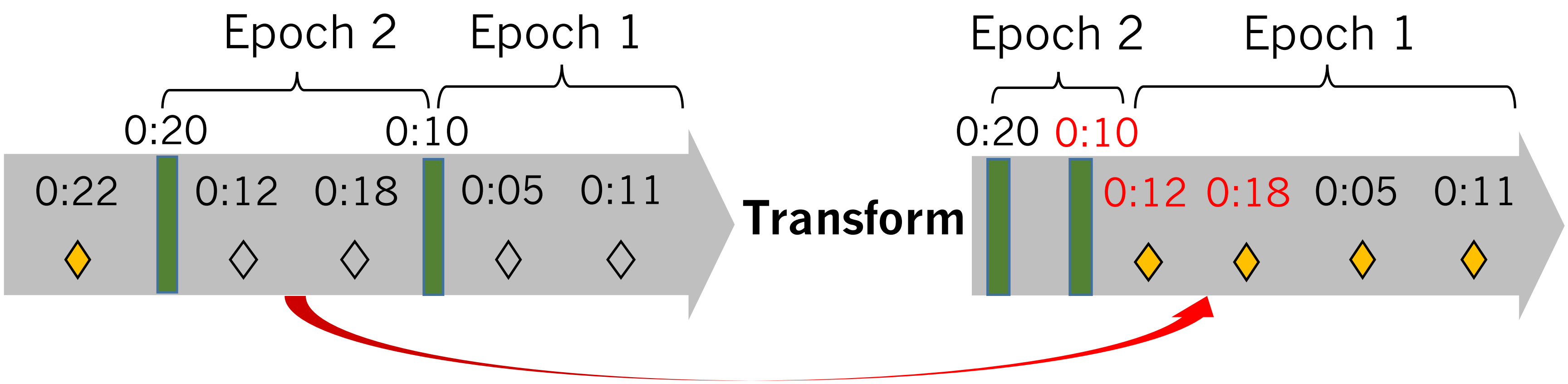
What if a record changes to a later epoch?



Violate watermark guarantee!

Invariant 2 Respect epoch boundaries

What if records change to an earlier epoch?

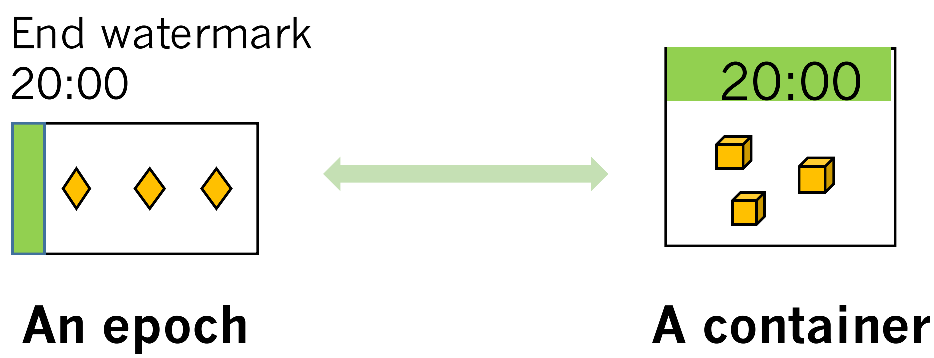


Relax watermark, and delay window completion!

Our solution: **Cascading containers**

Each cascading container

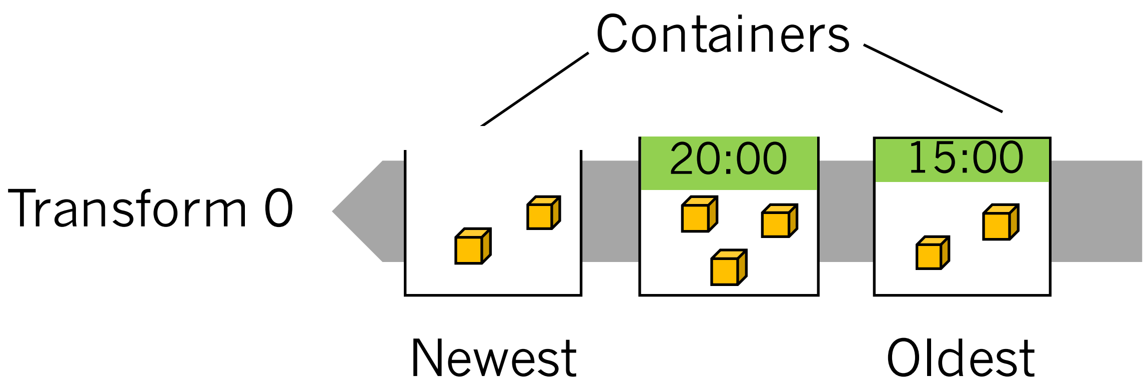
- Corresponds to an **epoch**
- Tracks an epoch state and the relationship between records and the watermark
- Orchestrates worker threads to consume watermarks and records



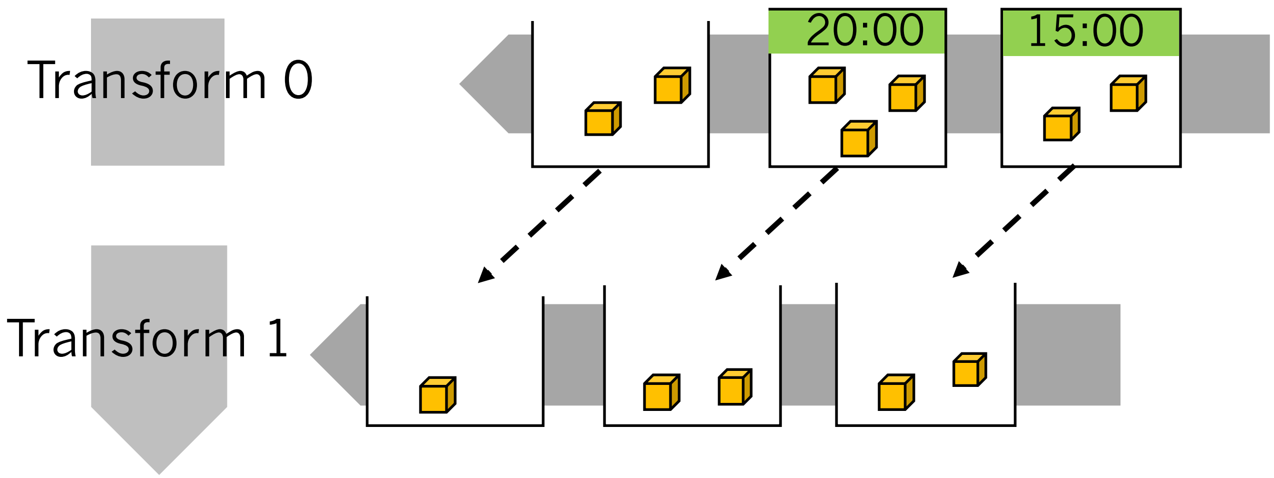
Each transform has multiple containers

A transform has multiple epochs

Each epoch corresponds to a container



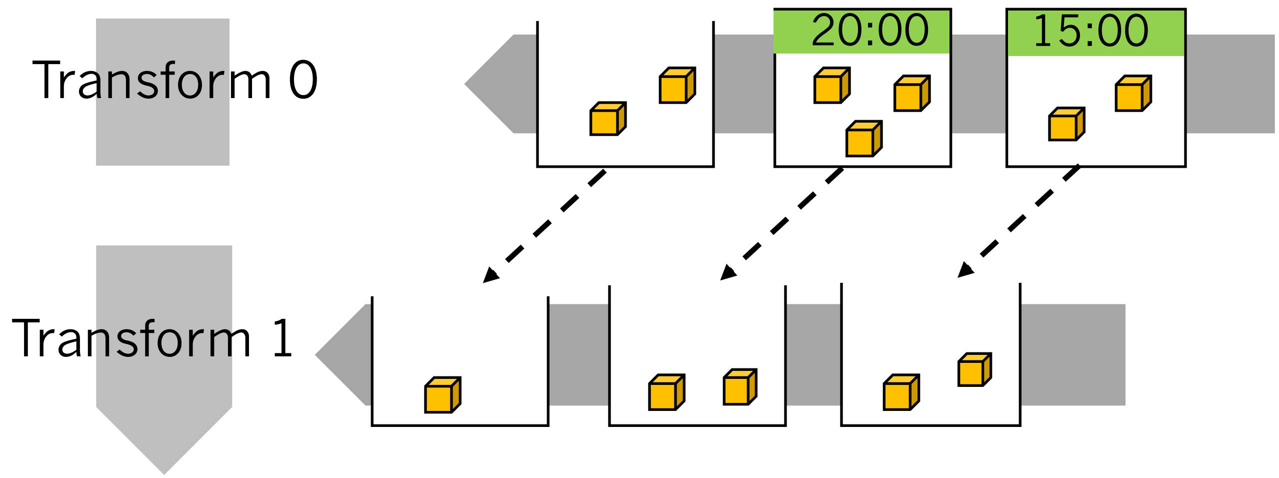
Link each container to a downstream container defined by the transform



Records/watermarks flow through the pipeline by following the links

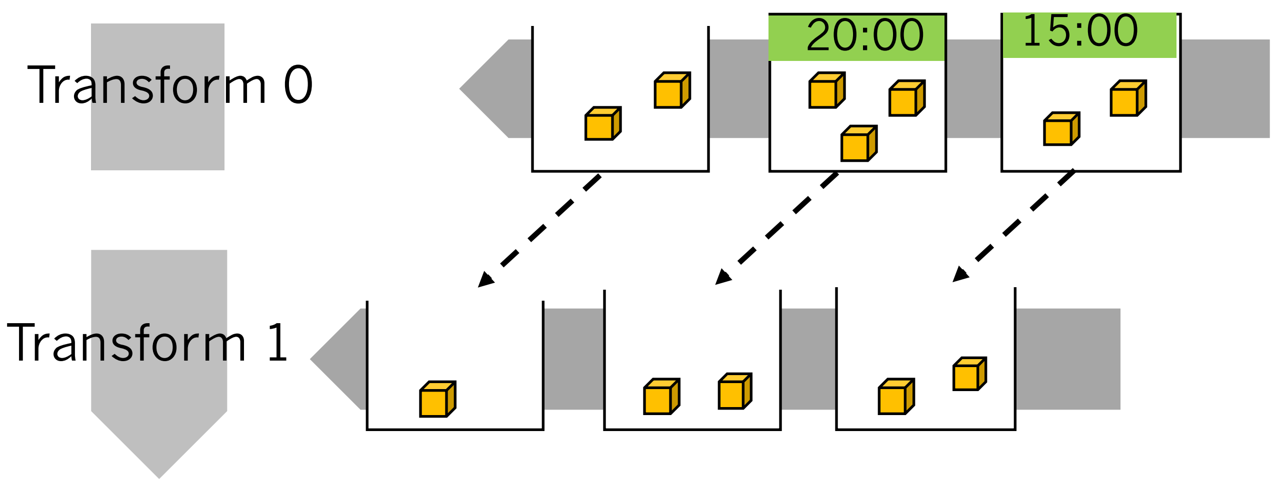
Meets invariant 2: records respect epoch boundary

Avoids relaxing watermark



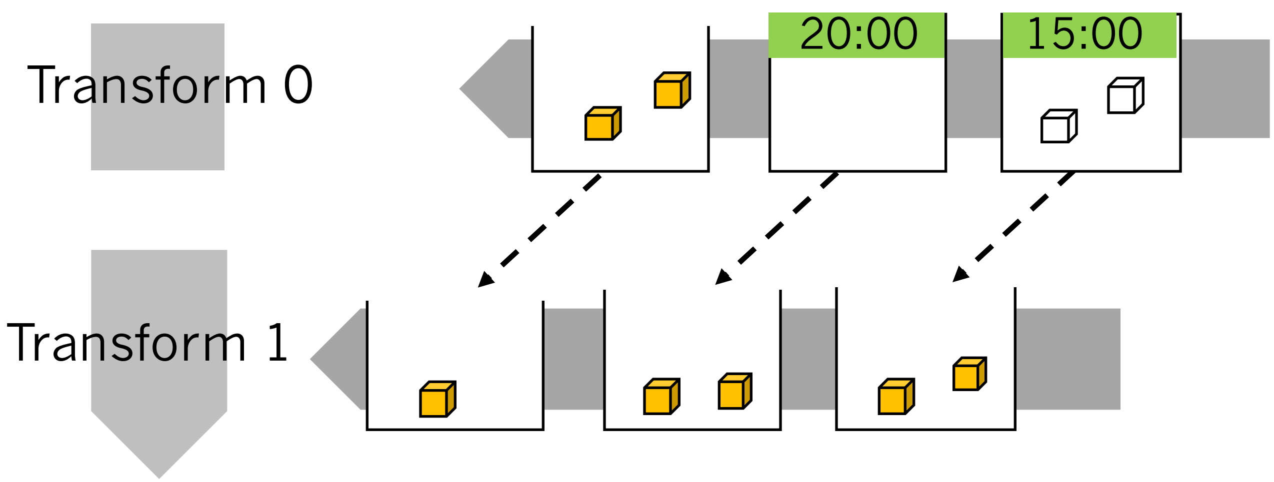
A watermark will be processed after all records within the container have been processed

Guarantees the invariant 1: watermark ordering



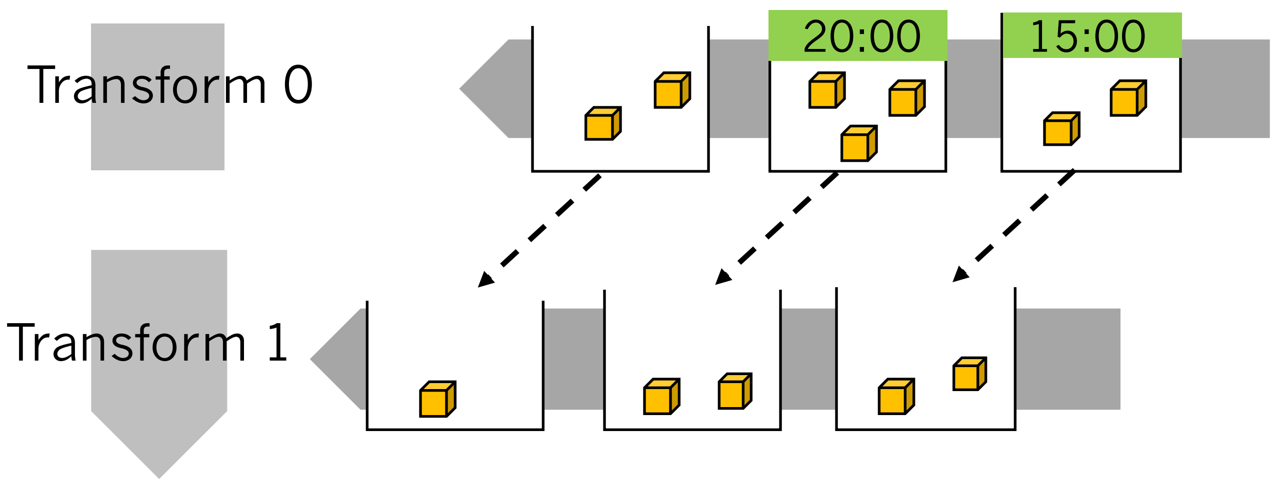
Watermarks will be processed in order

Guarantees the invariant 1: watermark ordering



All records in all containers can be processed in parallel

Avoids stalling pipeline



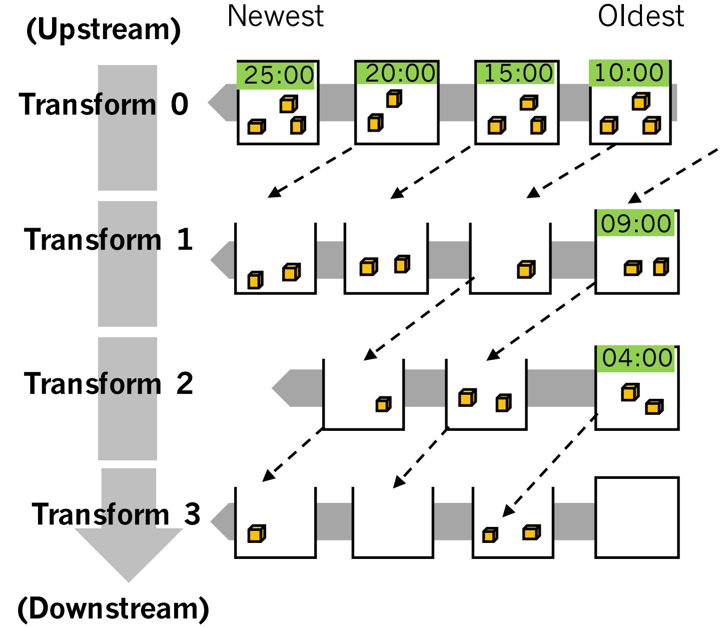
Big picture

A pipeline: multiple transforms

- Containers form a network
- Records/watermarks flow through the links

High parallel pipeline

- Guarantees watermark semantic
- Avoids stalling pipeline (for throughput)
- Avoids relaxing watermark (for latency)



Other key optimizations

Organizing records into bundles

- Minimize synchronization

Multi-input transforms

- Defer container ordering in downstream

Pipeline scheduling

- Prioritize externalization to minimize latency

Pipeline state management

- Target NUMA-awareness and coarse-grained allocation

StreamBox implementation

Built from scratch in 22K SLoC of C++11

- Supported transforms: Windowing, GroupBy, Aggregation, Mapper, Reducer, Temporal Join, Grep…
- Source code @ http://xsel.rocks/p/streambox

C++ libraries

- Intel TBB, Facebook folly, jemalloc, boost…

Concurrent hash tables

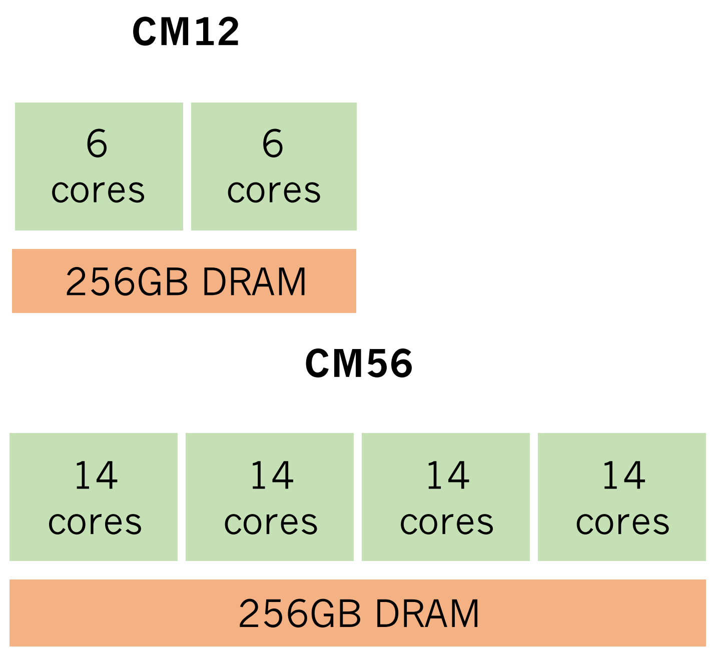
- Wrapped TBB's concurrent hash map

StreamBox implementation

Benchmarks:

- Windowed grep
- Word count
- Counting distinct URLs
- Network latency monitoring
- Tweets sentiment analysis

Machine configurations:



Roadmap

Background

StreamBox Design

Evaluation

Evaluation

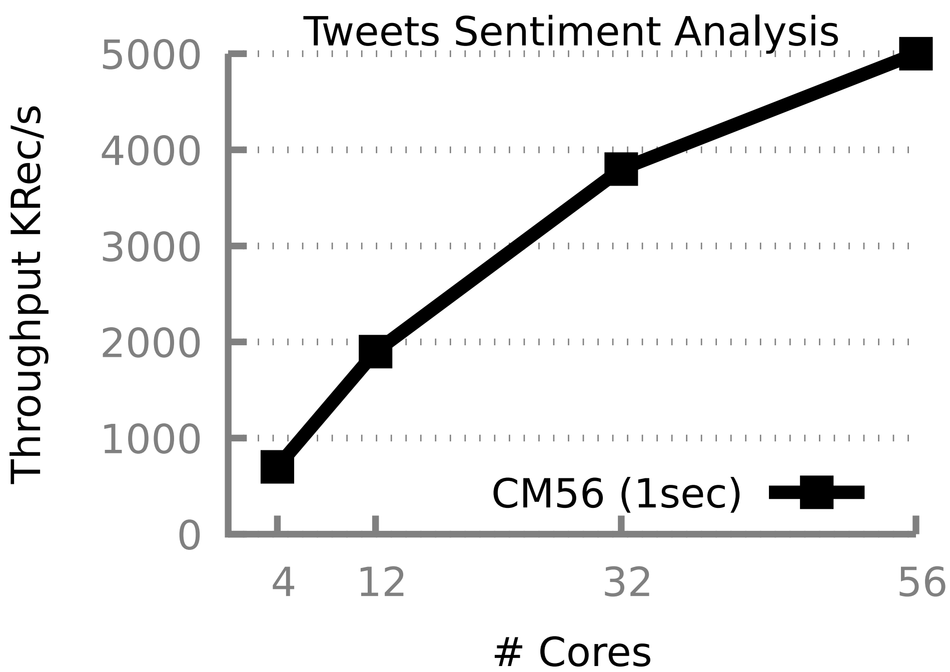
Throughput and scalability

Comparison with existing stream engines

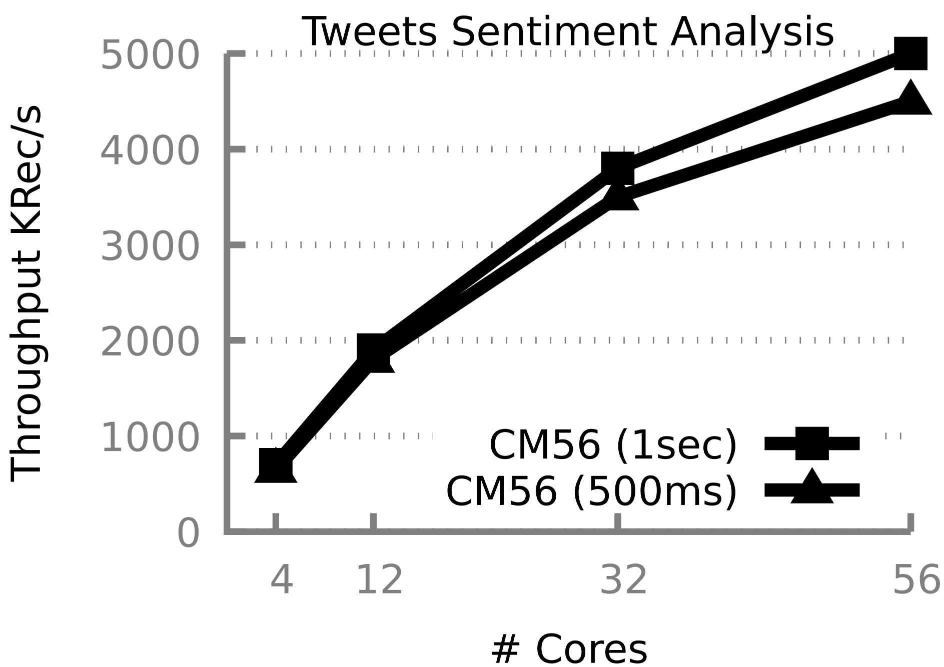
Handling out-of-order input streaming data

Epoch parallelism effectiveness

Good throughput and scalability



Good throughput and scalability



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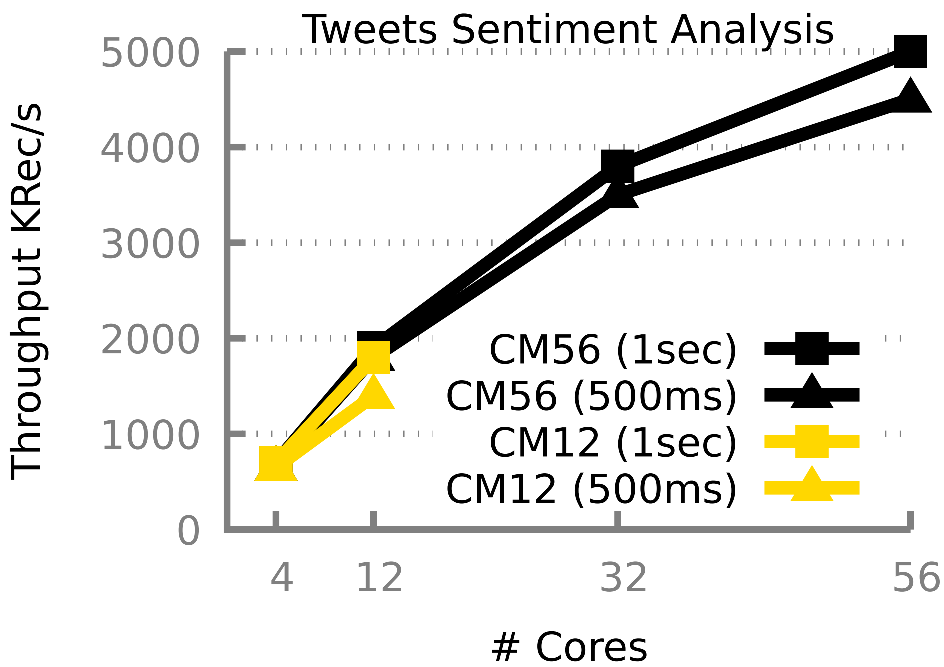

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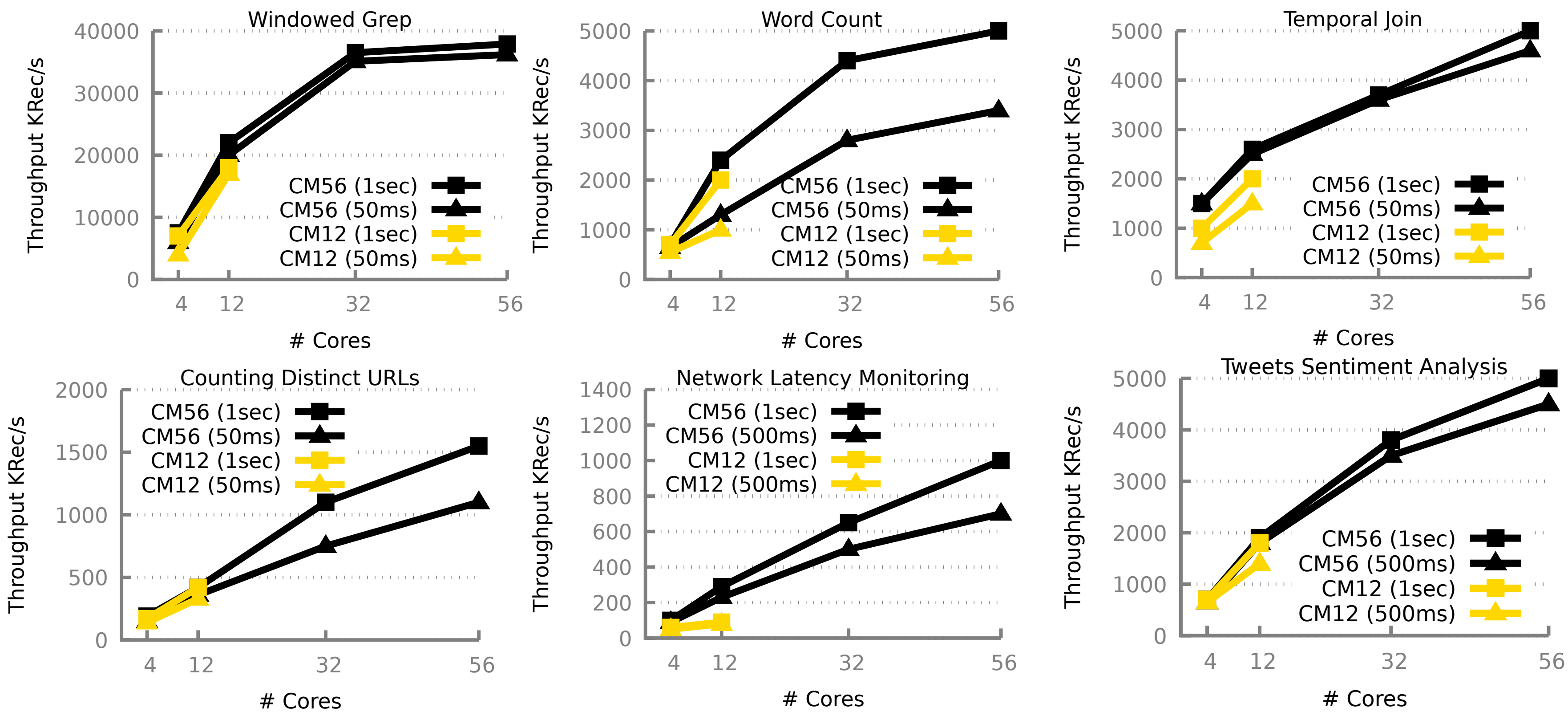
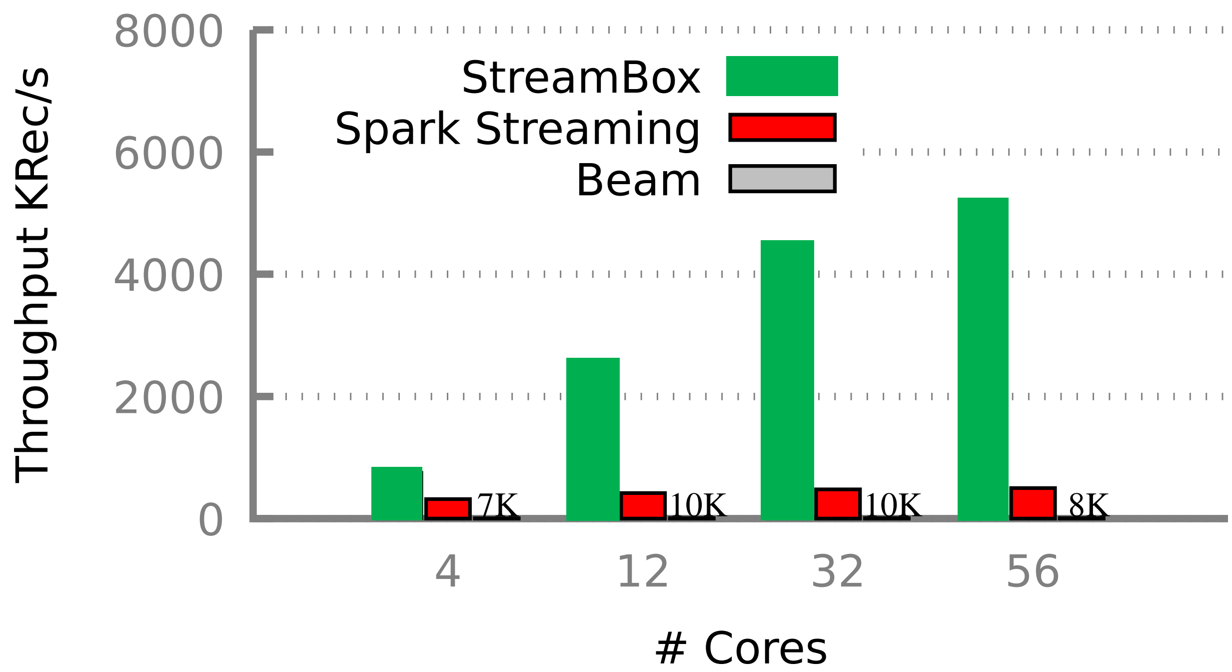


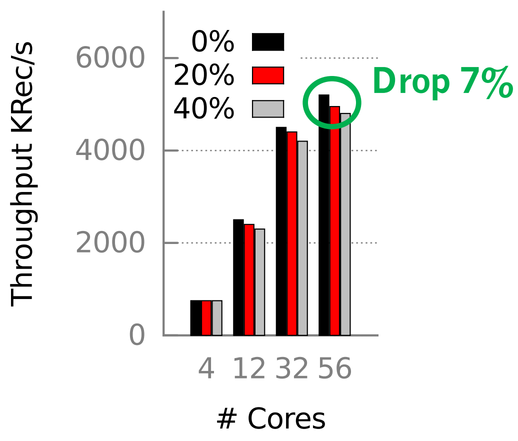
StreamBox vs. existing stream engines



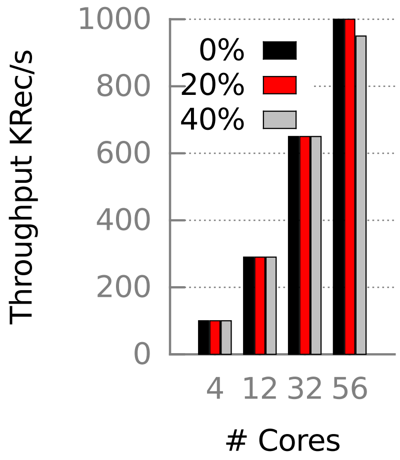
Spark: v2.1.0
Beam: v0.5.0

StreamBox achieves significantly better throughput and scalability

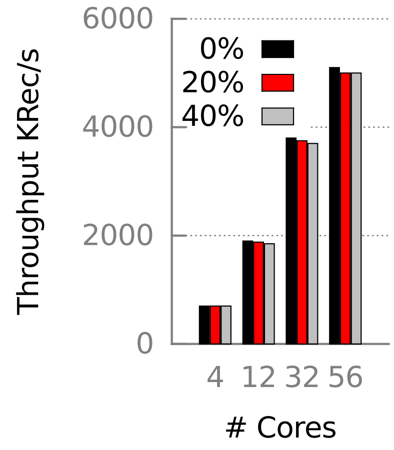
Handling out-of-order records



WordCount



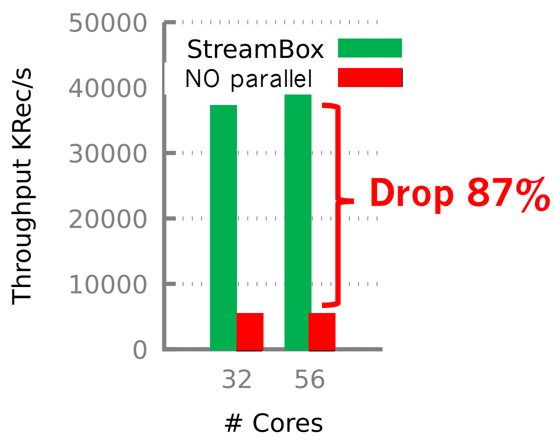
Netmon



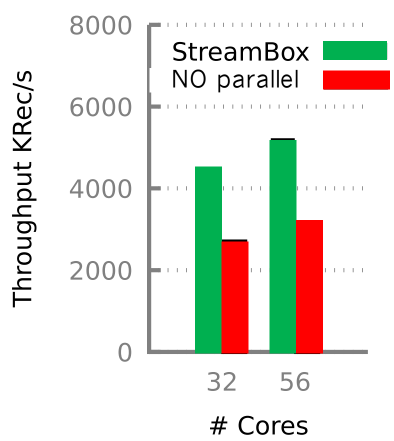
Tweets

StreamBox achieves good throughput even with lots of out-of-order records

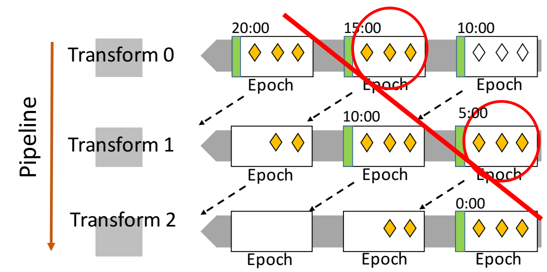
Epoch parallelism is effective



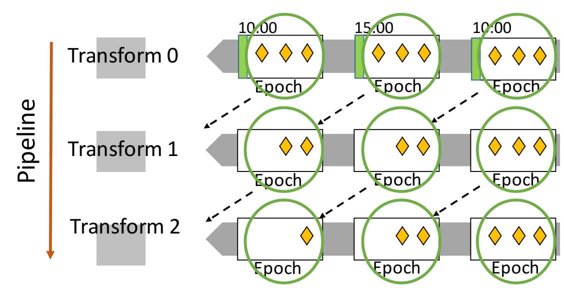
Grep



WordCount



Prior work



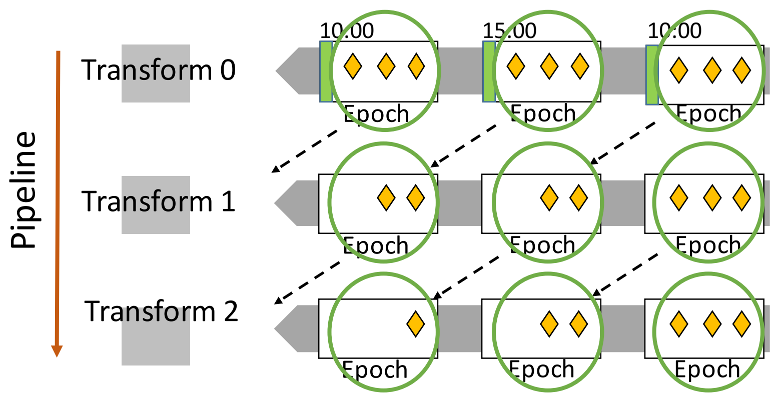
StreamBox

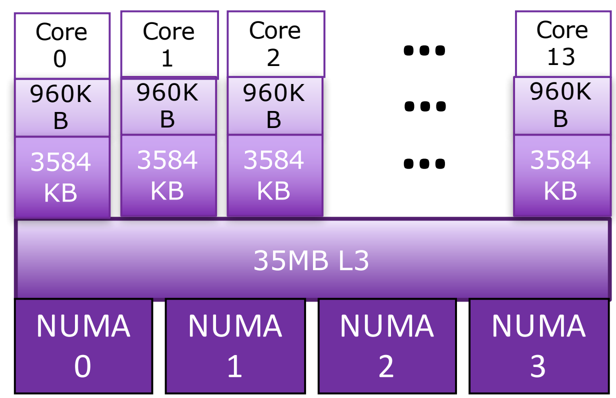
Summary: StreamBox on multicores

Processes any records in any epochs in parallel by using all CPU cores

Achieves high throughput with low latency

- Millions records per second throughput, on a par with distributed engines on a cluster with a few hundreds of CPU cores
- Tens of milliseconds latency, 20x shorter than other large-scale engines





http://xsel.rocks/p/streambox