Naiad (Timely Dataflow) & Streaming Systems

CS 848: Models and Applications of Distributed Data Systems

Mon, Nov 7th 2016

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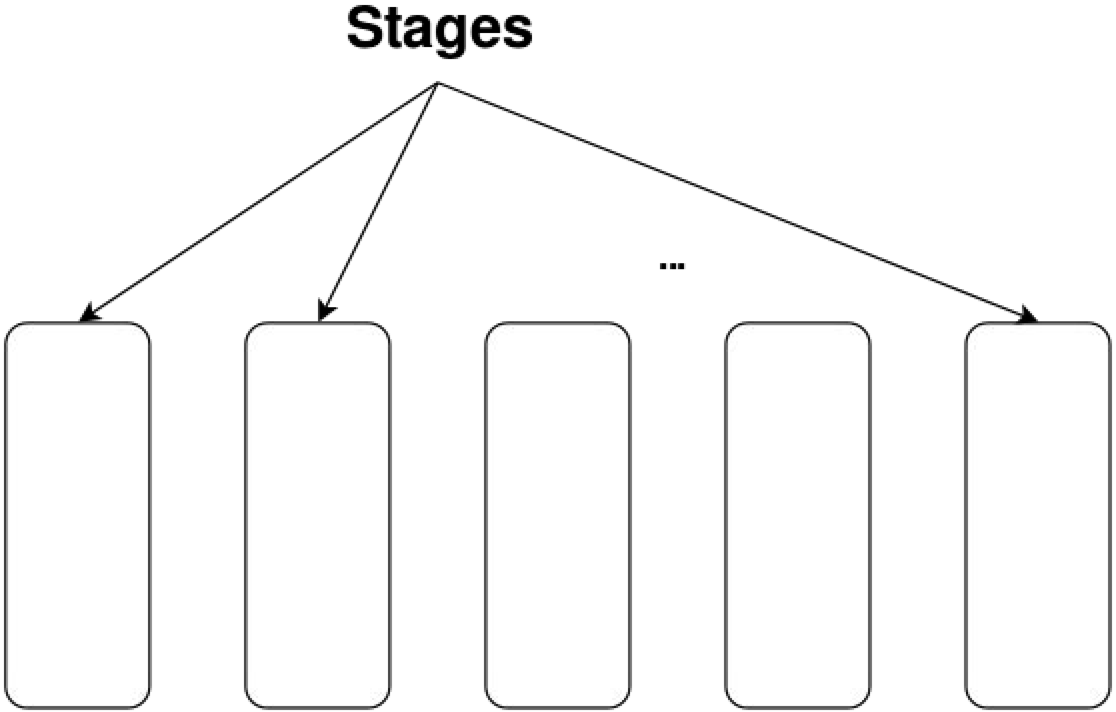
What is 'Timely' Dataflow ?!
What is its significance?

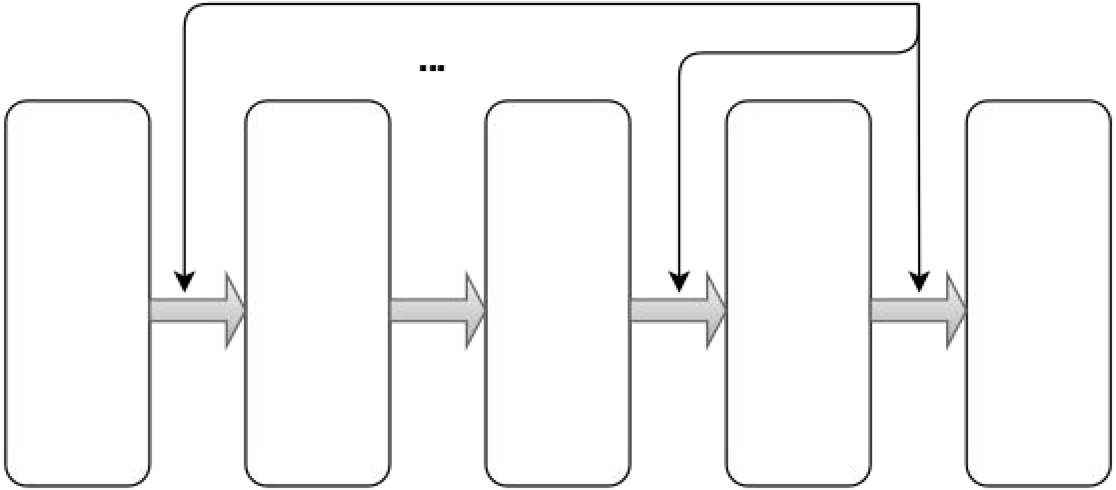
Dataflow ?!

Dataflow?!



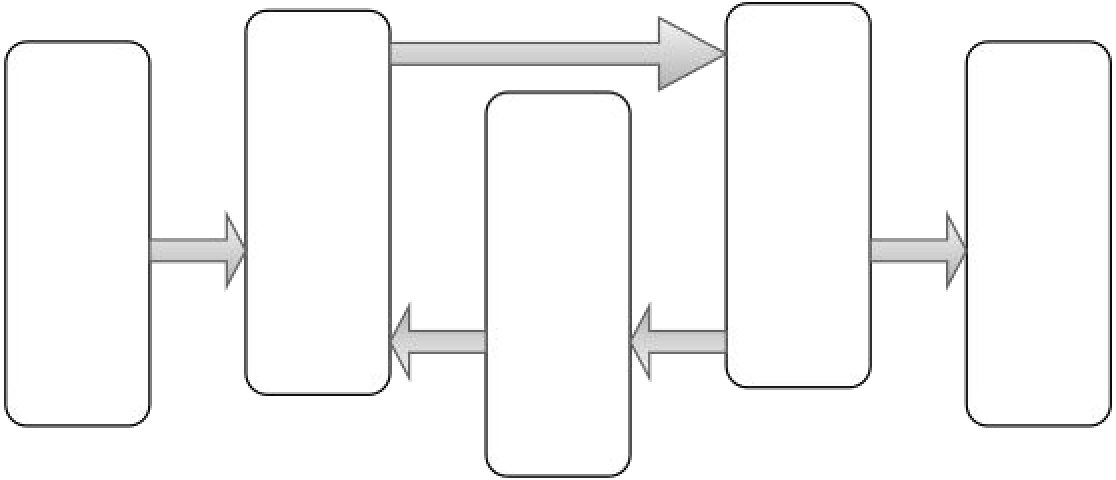
Dataflow?!

Stages makeup a directed graph where data flows along **connectors**

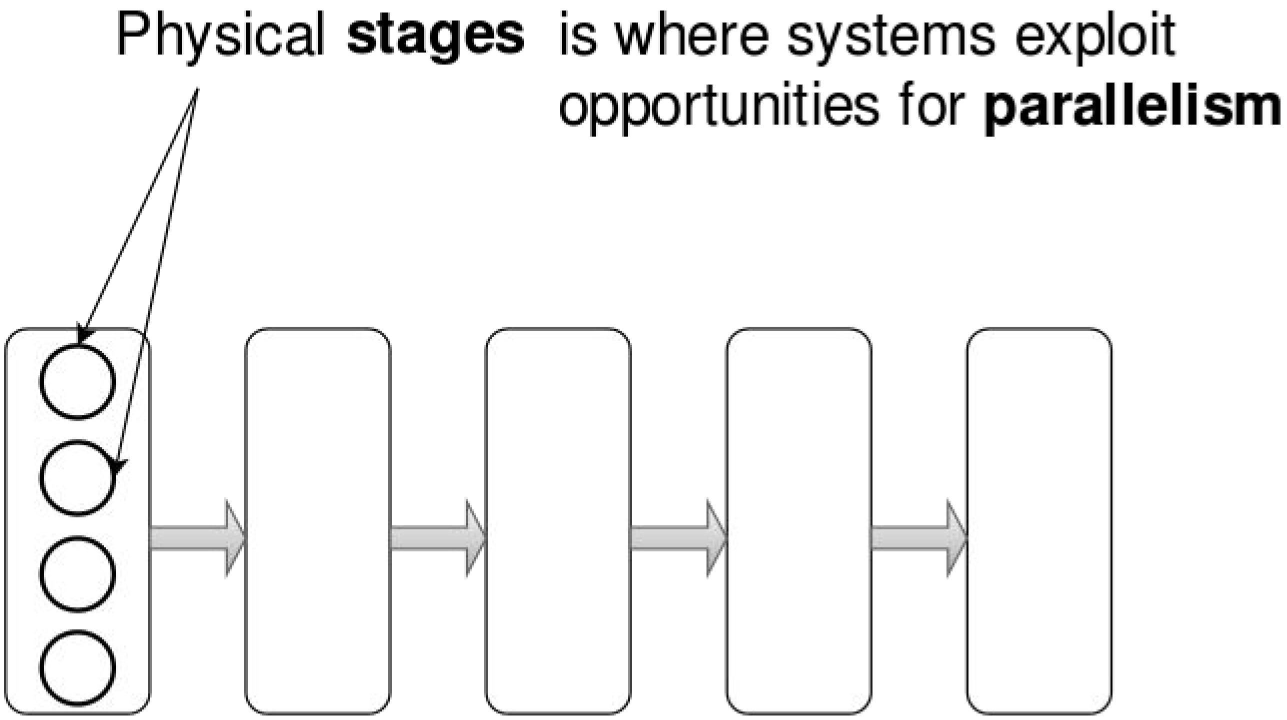


Dataflow?!

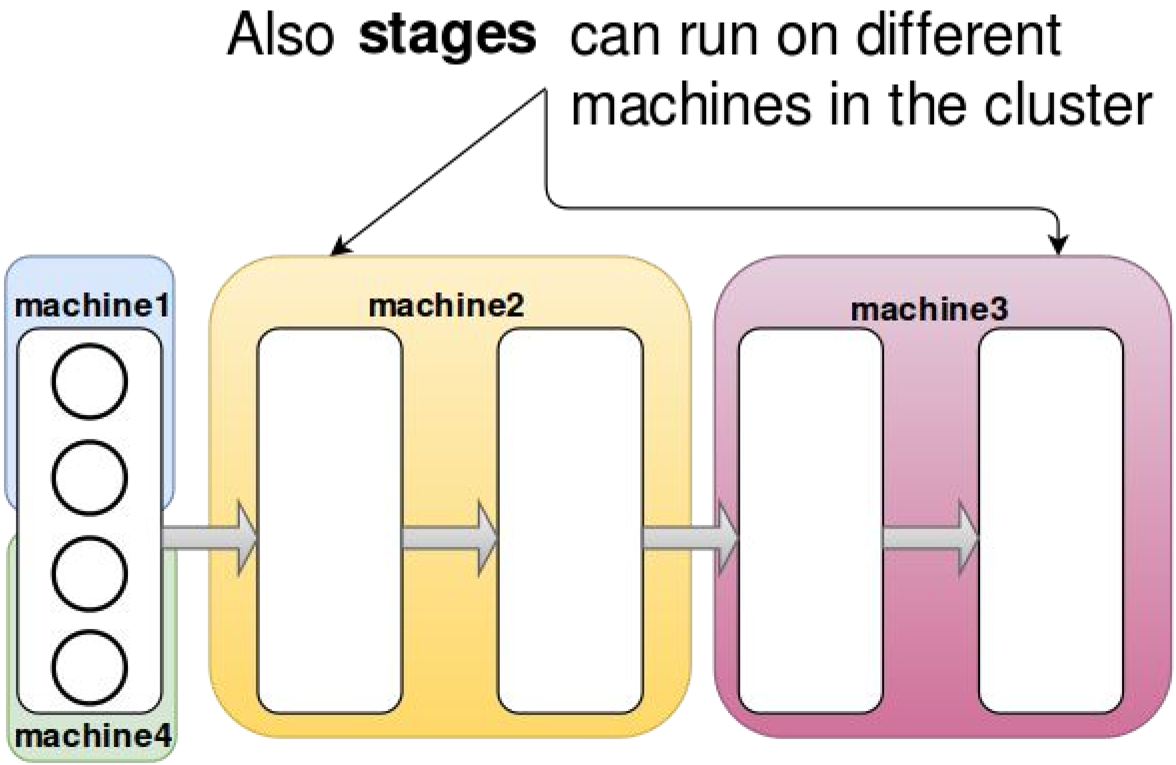
Stages makeup a directed graph
so it allows **iterations**



Dataflow?!

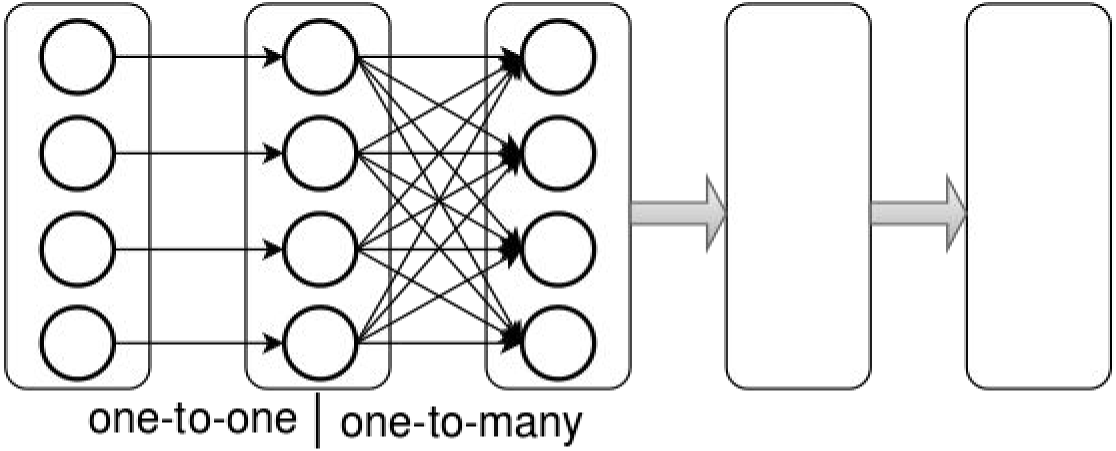

Physical **stages** is where systems exploit opportunities for **parallelism**

Dataflow?!


Also **stages** can run on different machines in the cluster
machine1
machine2
machine3
machine4

Dataflow?!

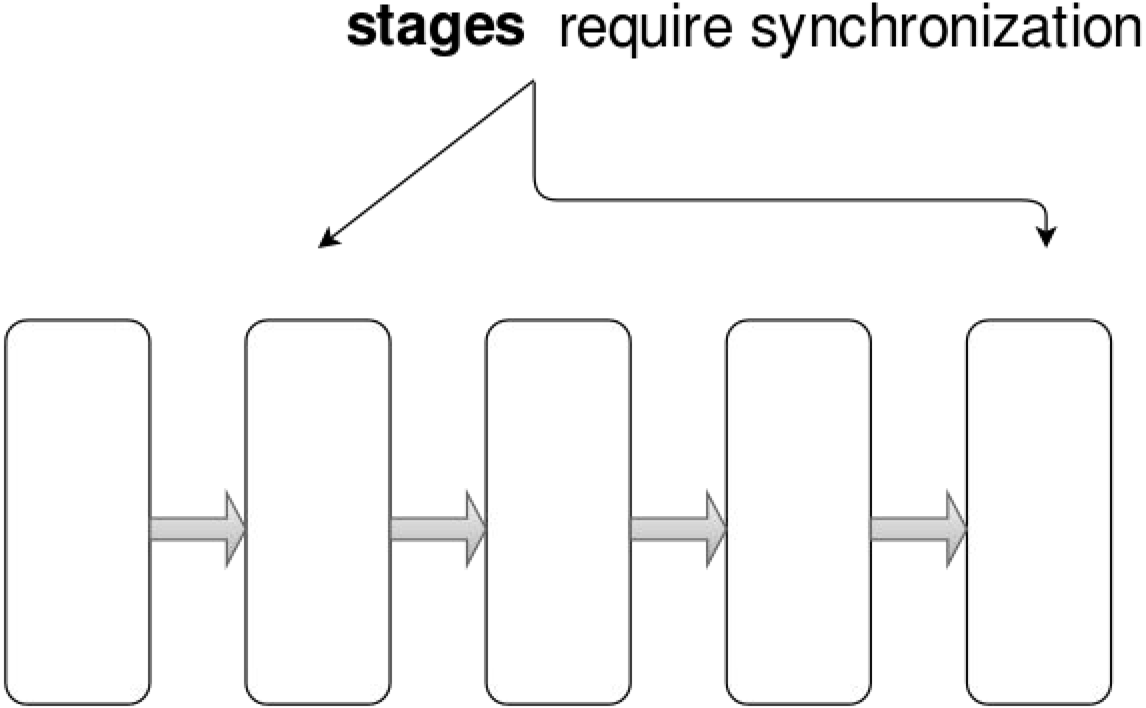
With **stages** parallelized as such.
connectors presenting the flow,
have different types of **mapping**



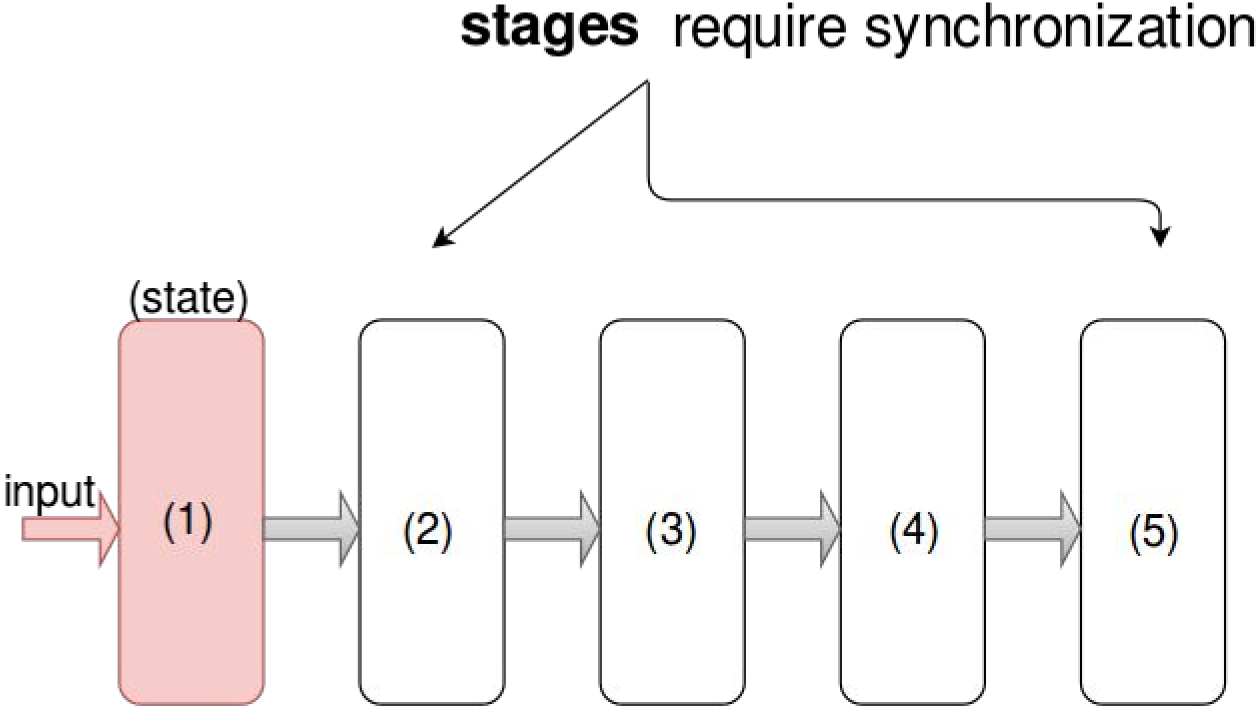
Dataflow

- Batch Processing e.g. MapReduce, Spark
- Asynchronous Processing e.g. Storm, MillWheel
- Variations for Graph Processing e.g. Pregel, GraphLab

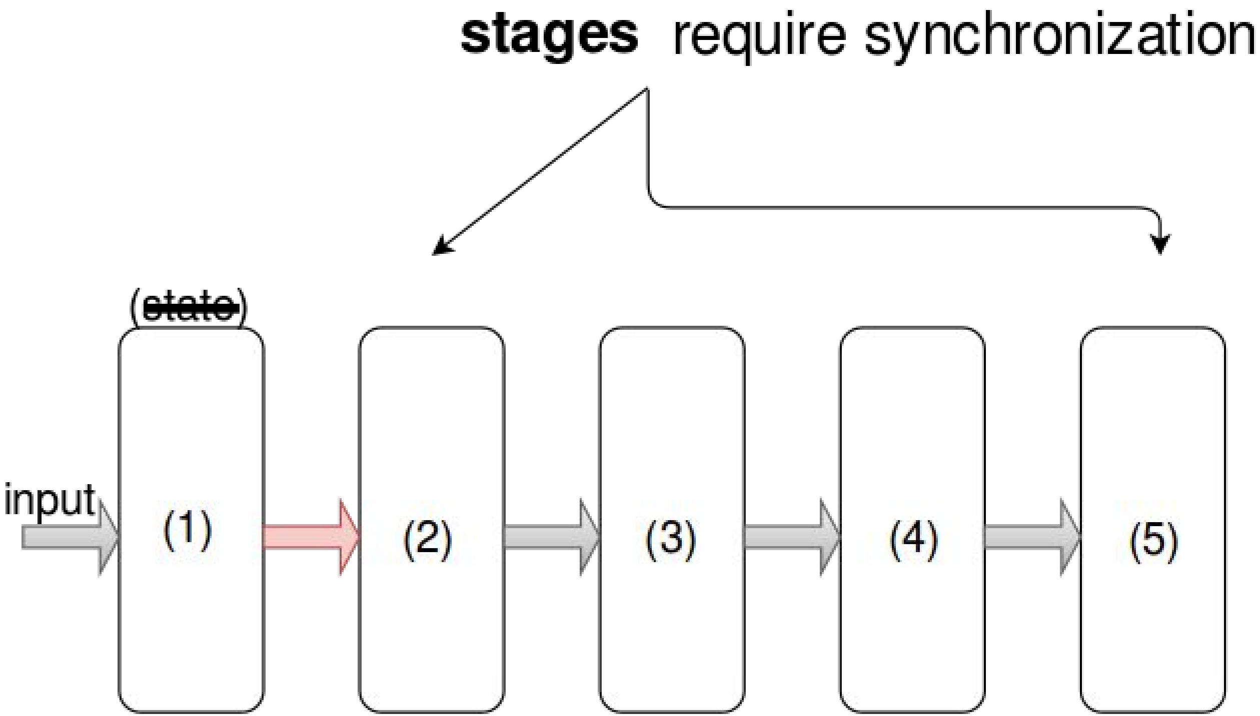
Dataflow: Batch Processing



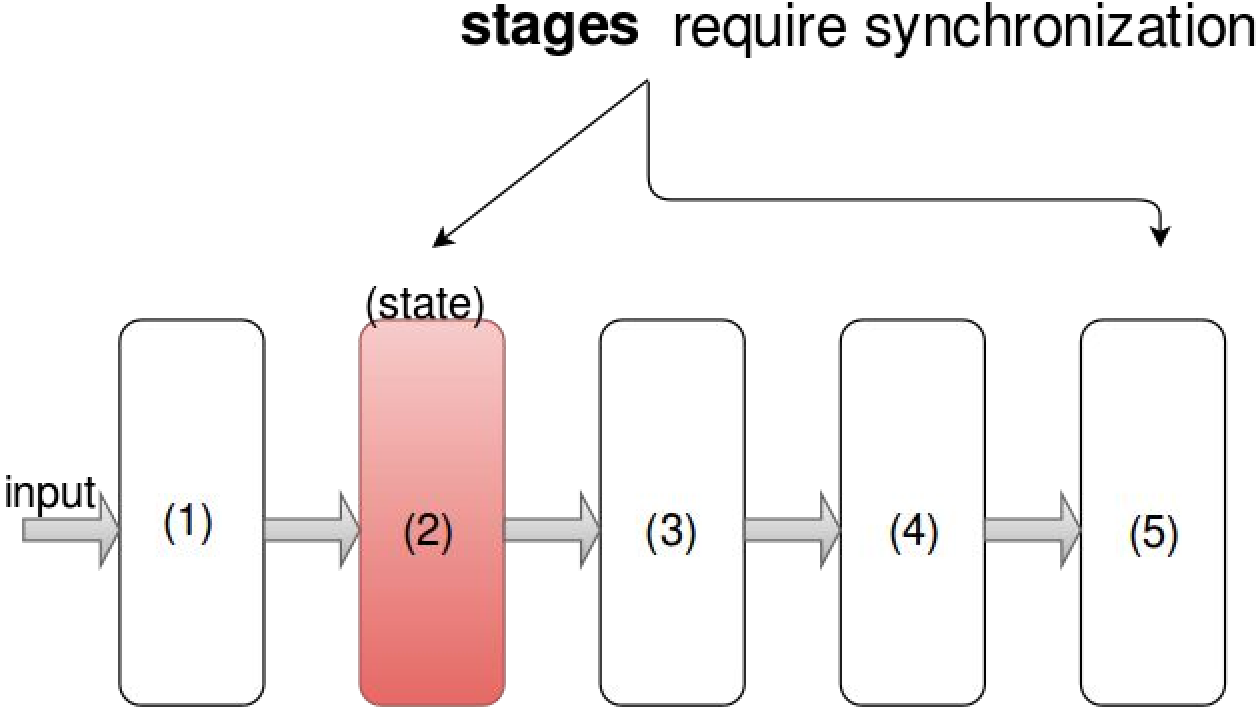
Dataflow: Batch Processing



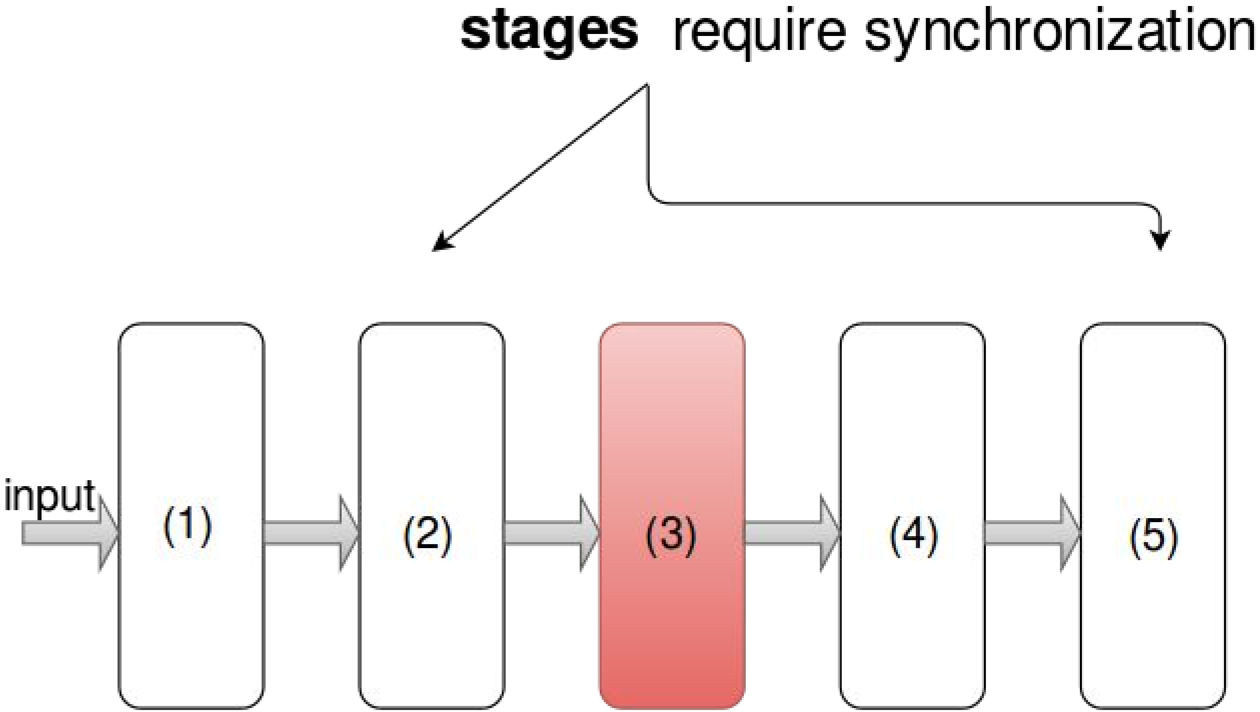
Dataflow: Batch Processing



Dataflow: Batch Processing



Dataflow: Batch Processing

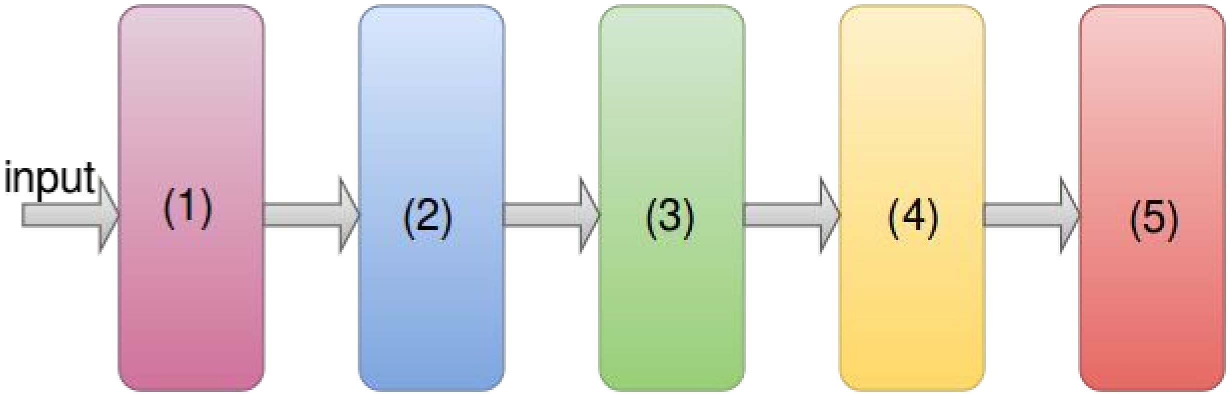


Dataflow: Batch Processing

- Iterations make use of synchronization.
- The cost is latency.

Dataflow: Asynchronous Processing

stages do NOT require synchronization
all stages are active and output data
after processing input data.



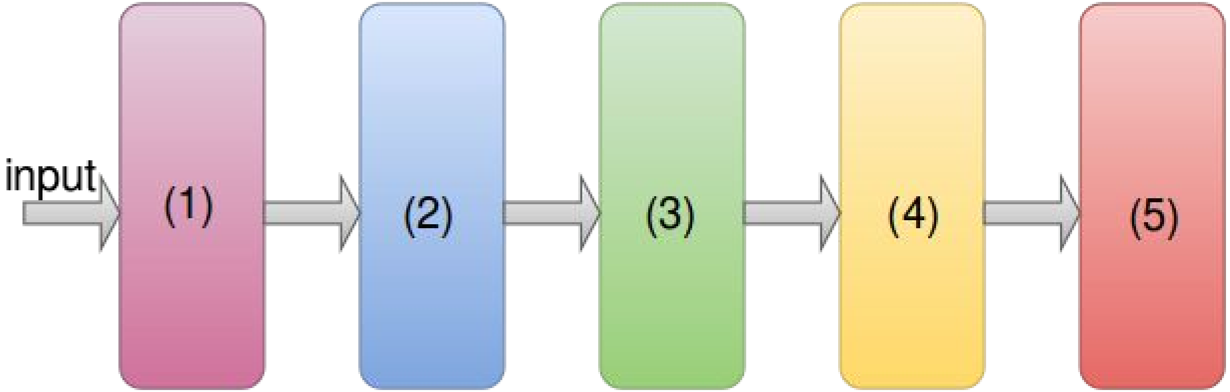
Dataflow: Asynchronous Processing

- Compared with batch:
  - latency is lower.
  - Aggregations are incremental and data changes over time.
- More efficient for distributed systems.
  - Stages do not need coordination.
- Correspondence between input & output is lost.

So, what is (Naiad)
Timely dataflow ?!

Timely Dataflow?!

stages are asynchronous.
They can synchronize if needed.
Make use of **logical timestamps**.



Timely Dataflow

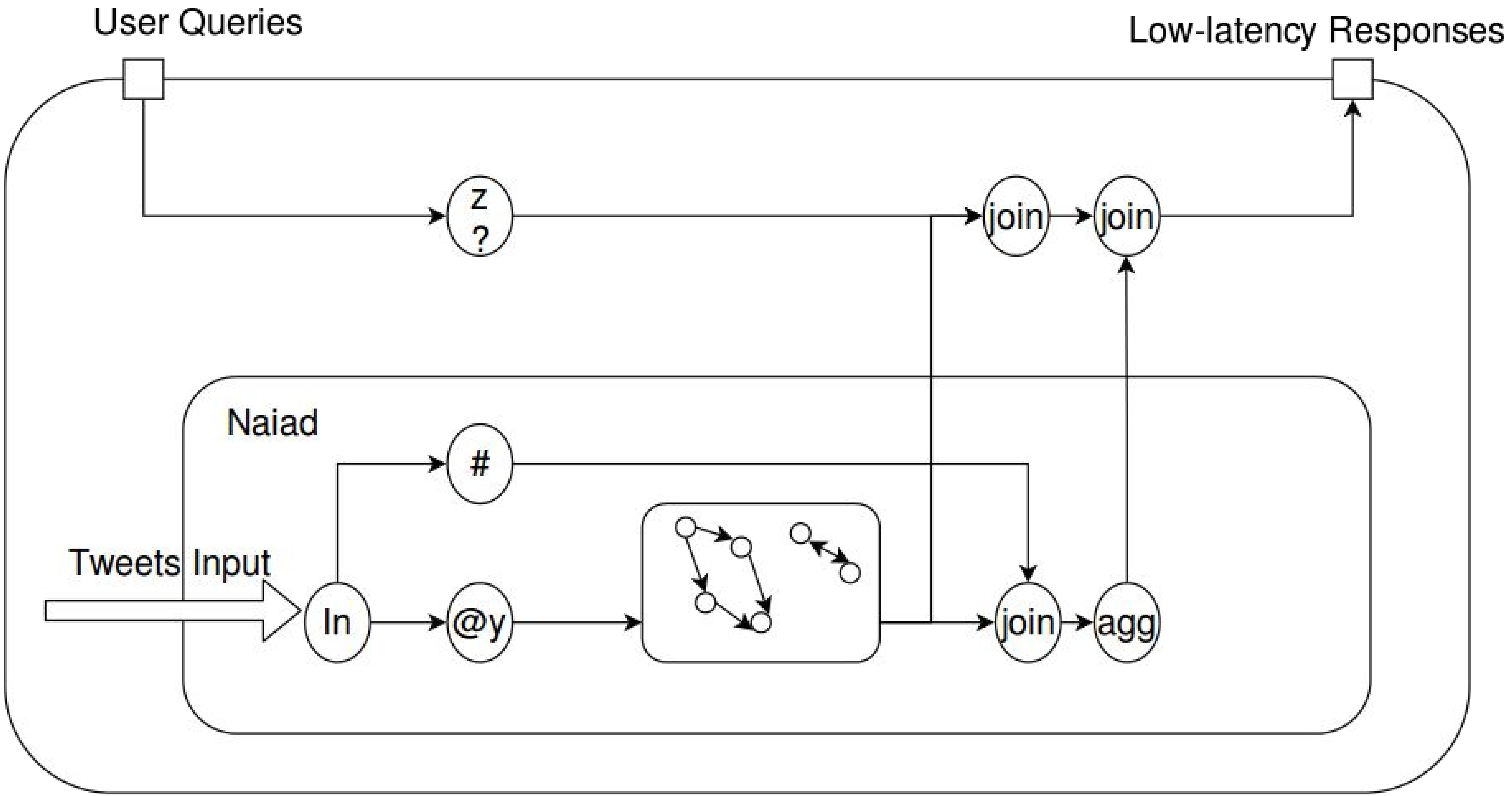
- Reconcile both models batch and async.
- Low-latency and high-throughput.

Where does Naiad fit?!

Naiad?!

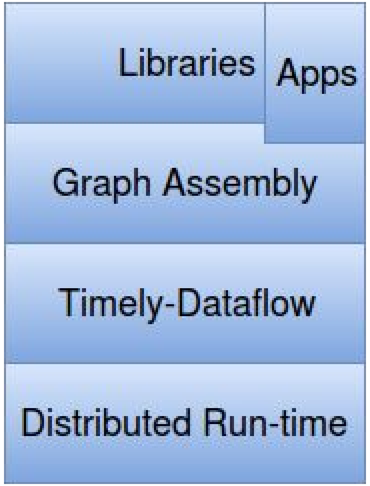
- It is the prototype built by Microsoft Research underlying **Timely dataflow** Computational model.
- Iterative and incremental computations.
- The logical timestamps allow **coordination**.
- Provides efficiency, maintainability and simplicity.

Let's look at a computational example


User Queries
Low-latency Responses
z
?
join
join
Naiad
#
Tweets Input
In
@y
join
agg

Naiad?!

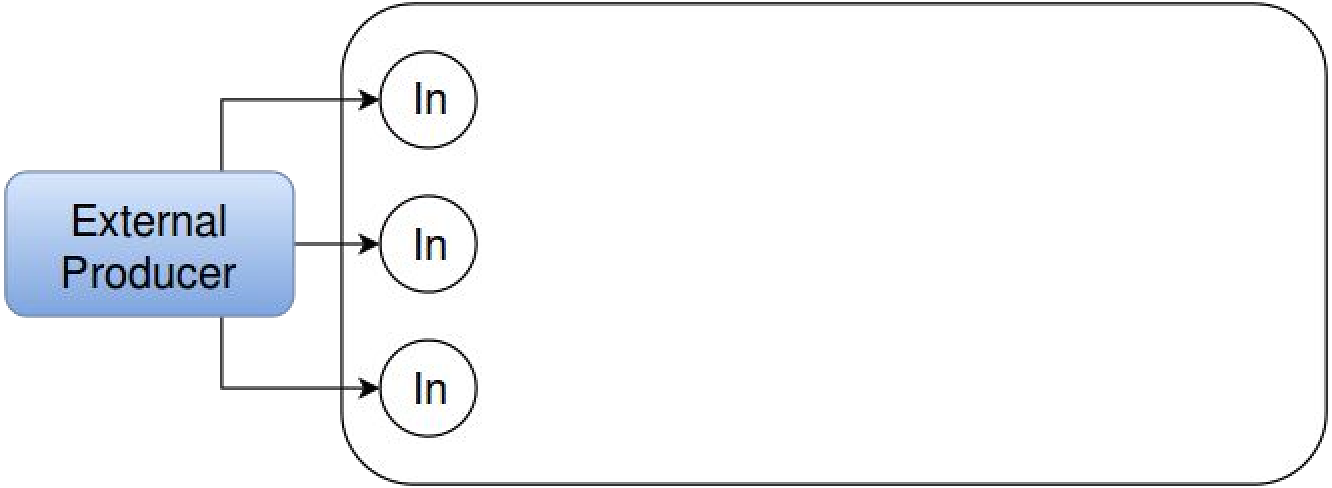
- It is the prototype built by Microsoft Research underlying **Timely dataflow** Computational model.



The Timely Dataflow Graph Structure

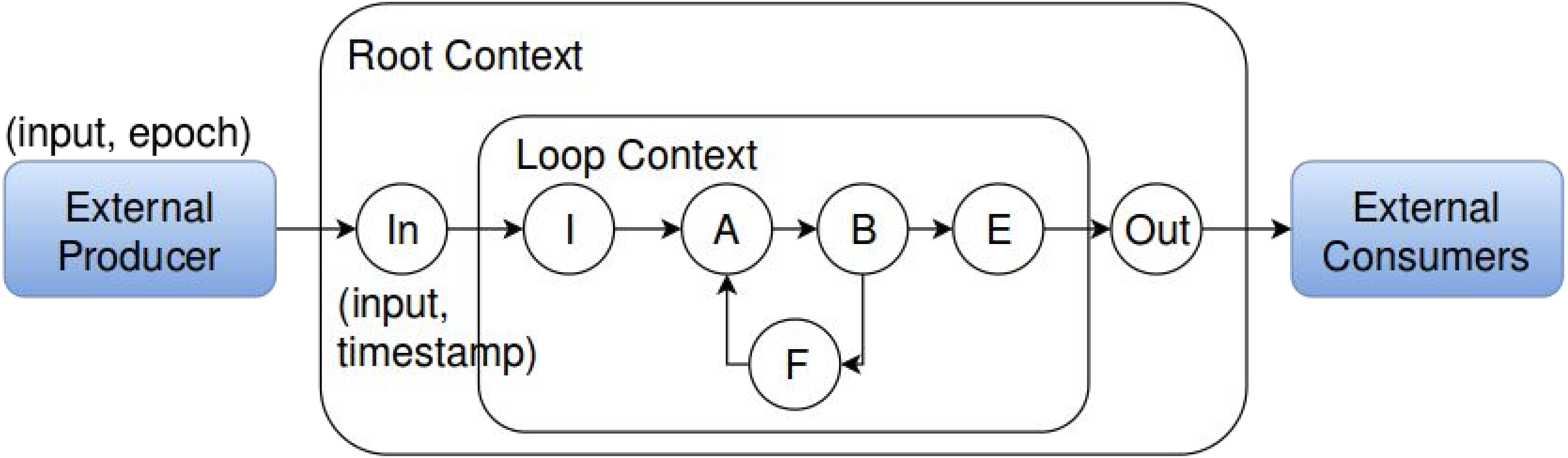
Graph Structure

(input, integer epoch)

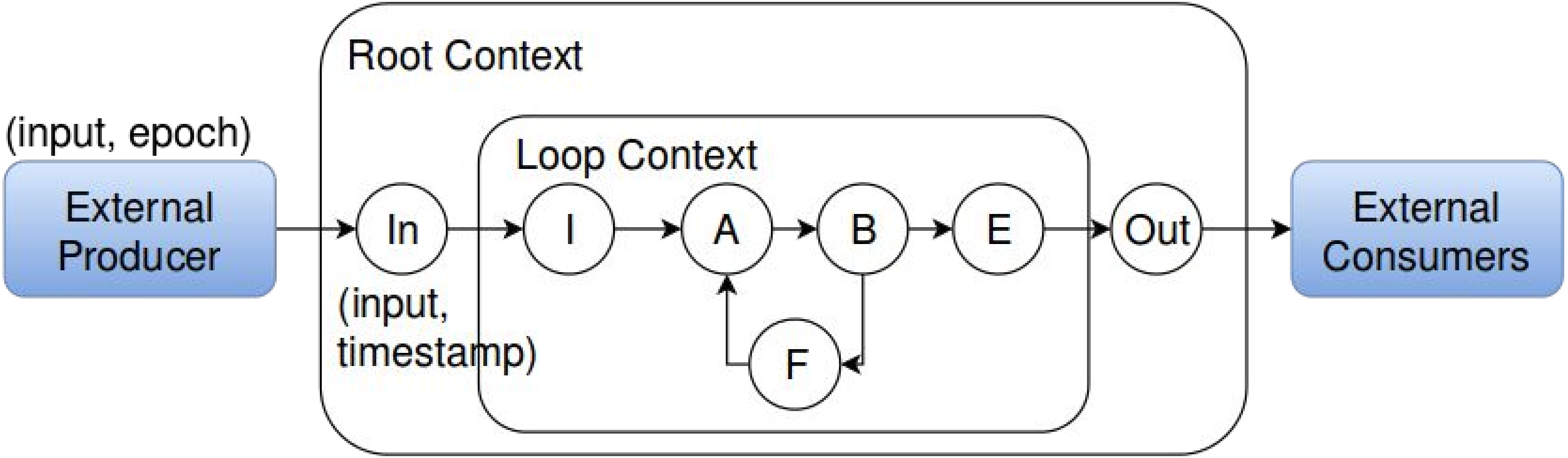


Graph Structure

Graph Structure



Graph Structure



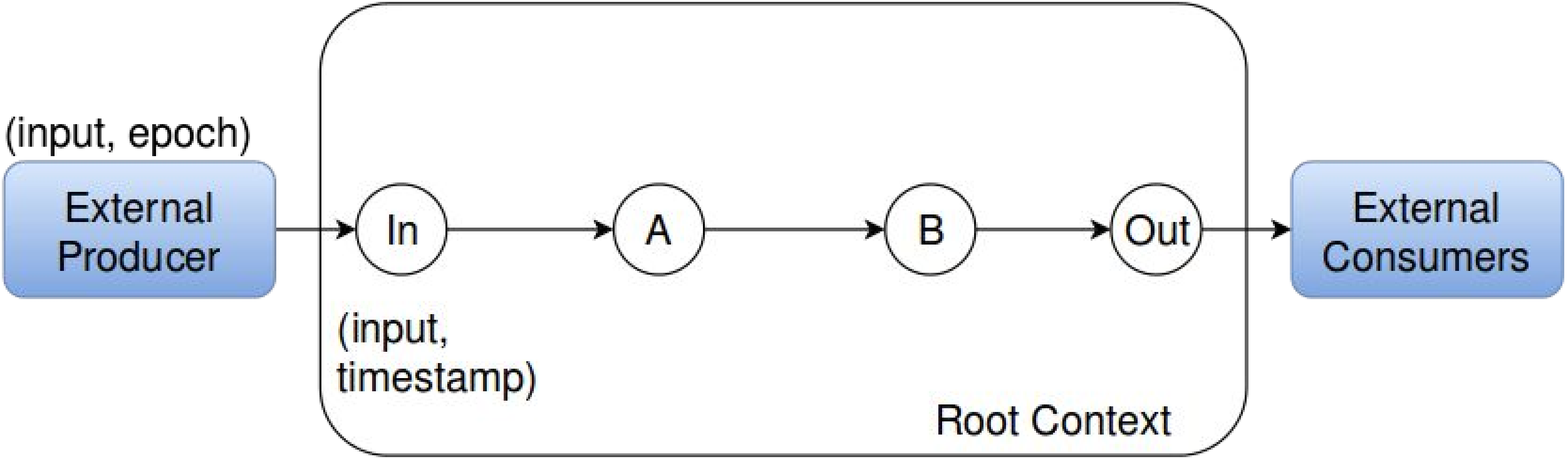
- input comes in as (data, 0), (data, 1), (data, 2)
  - Within a loop, I adds a loop counter so it is (data, epoch, 0)

    F in each iteration increments the loop counter (data, epoch, 1) etc.

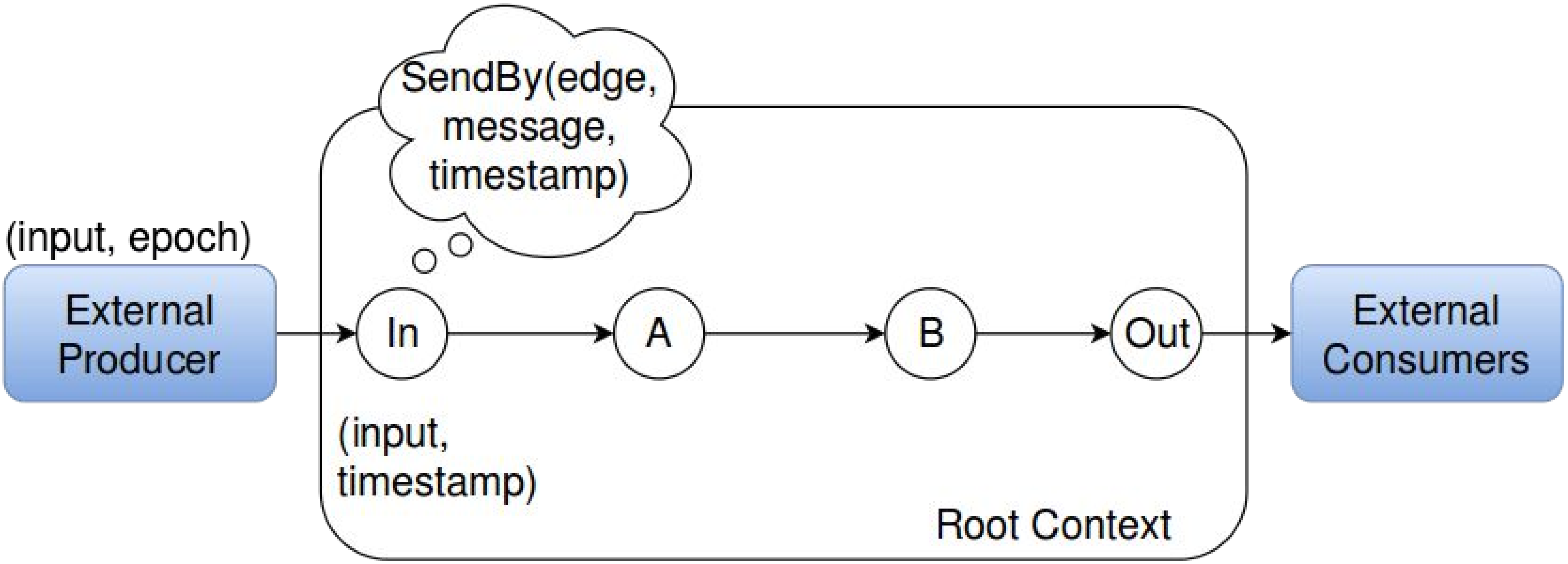
    E removes the loop counter and it is back to (data, epoch)

Programming Model
Using the timestamps

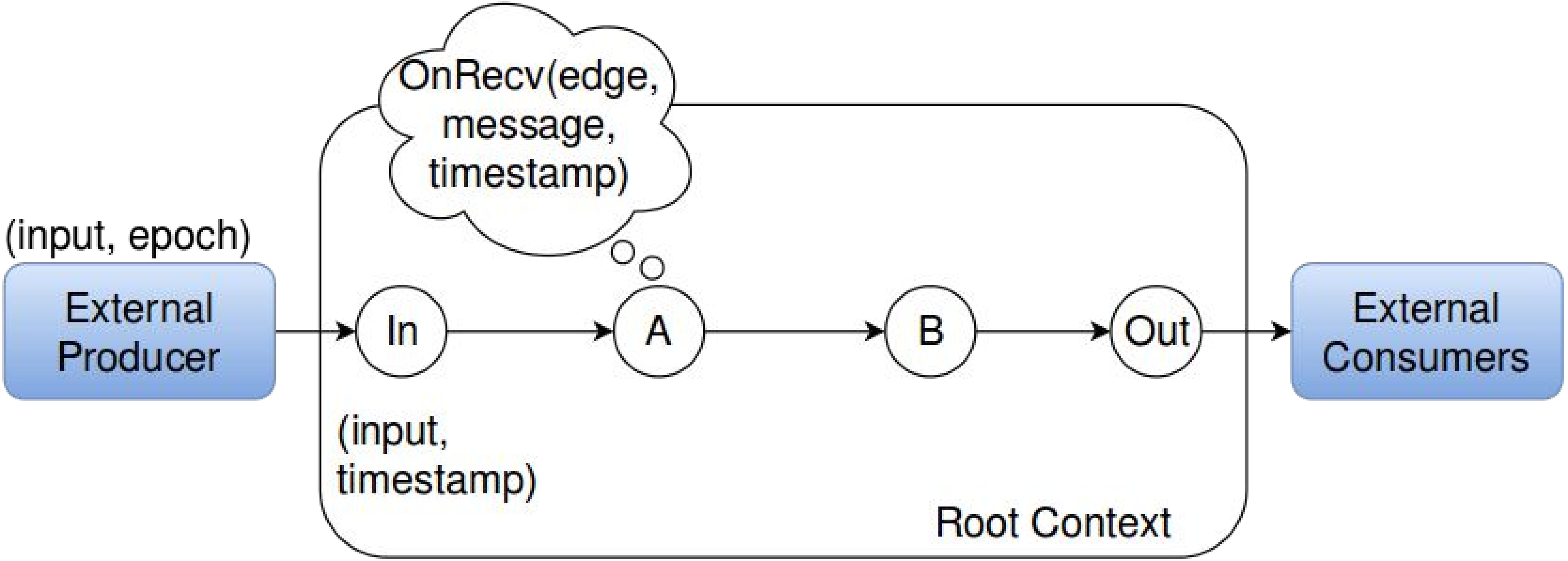
Programming Model



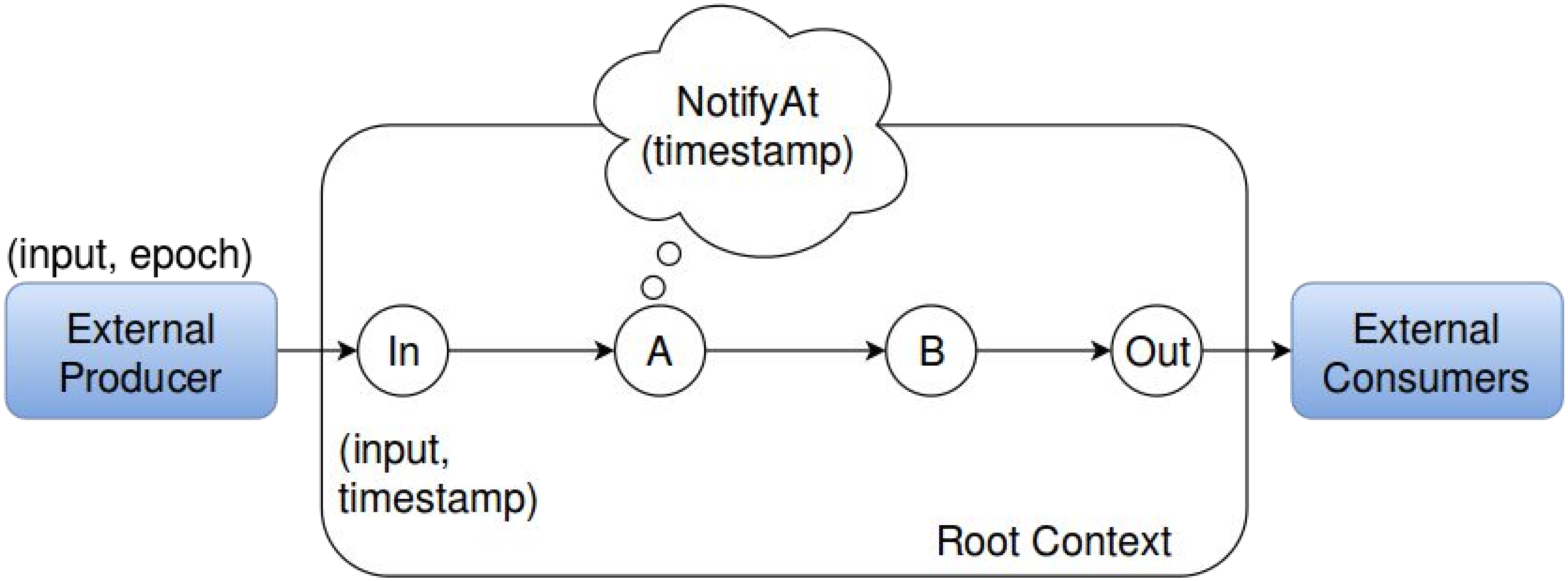
Programming Model



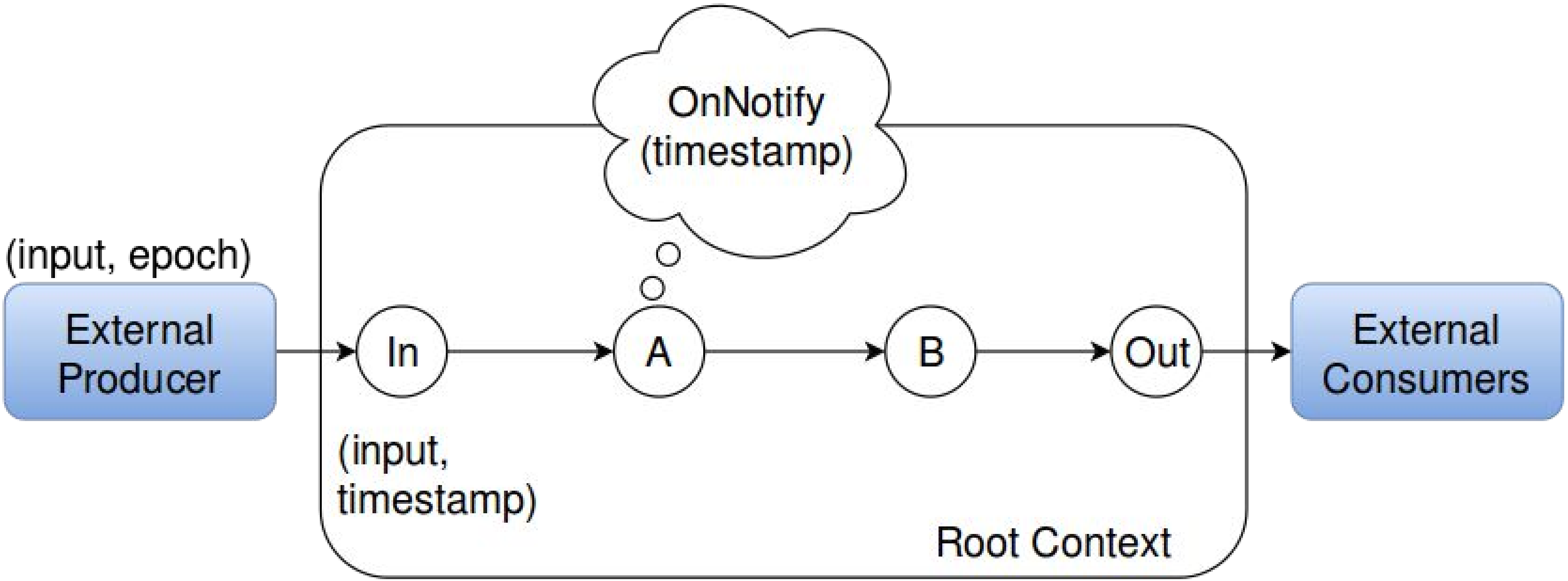
Programming Model



Programming Model



Programming Model



Programming Model Summary

- `SendBy(edge, message, timestamp)`
- `OnRecv(edge, message, timestamp)`
- `NotifyAt(timestamp)`
- `OnNotify(timestamp)`

Programming Model
In Practice

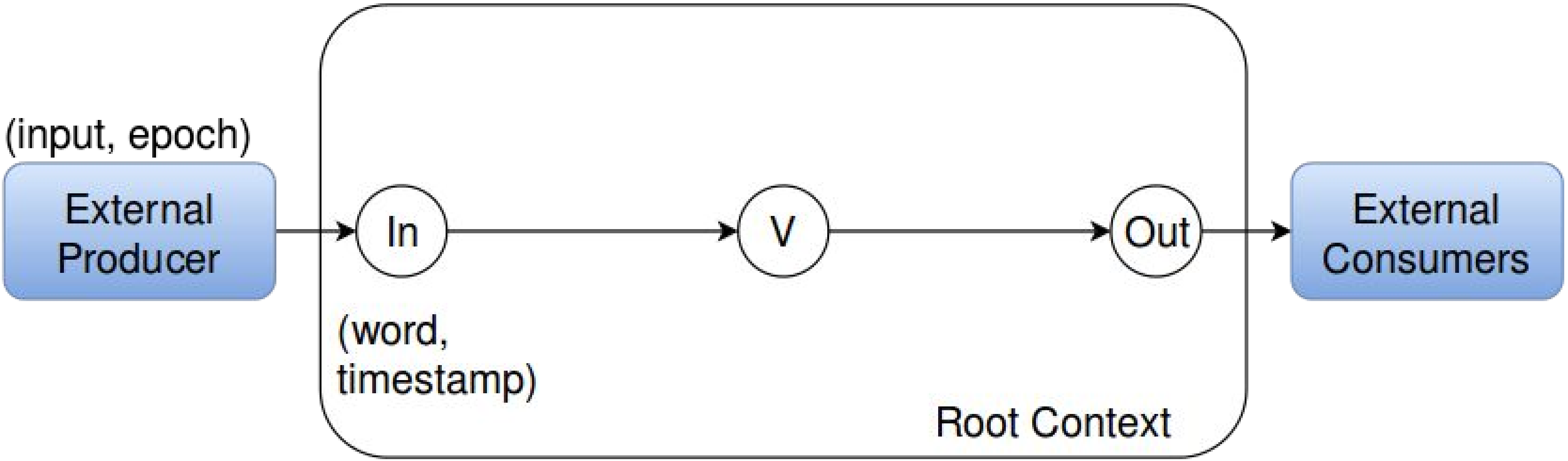
Notice

- Project was discontinued in 2014.
  Silicon Valley lab closed.

- The paper uses C#.
  The latest one is open sourced and is in Rust.

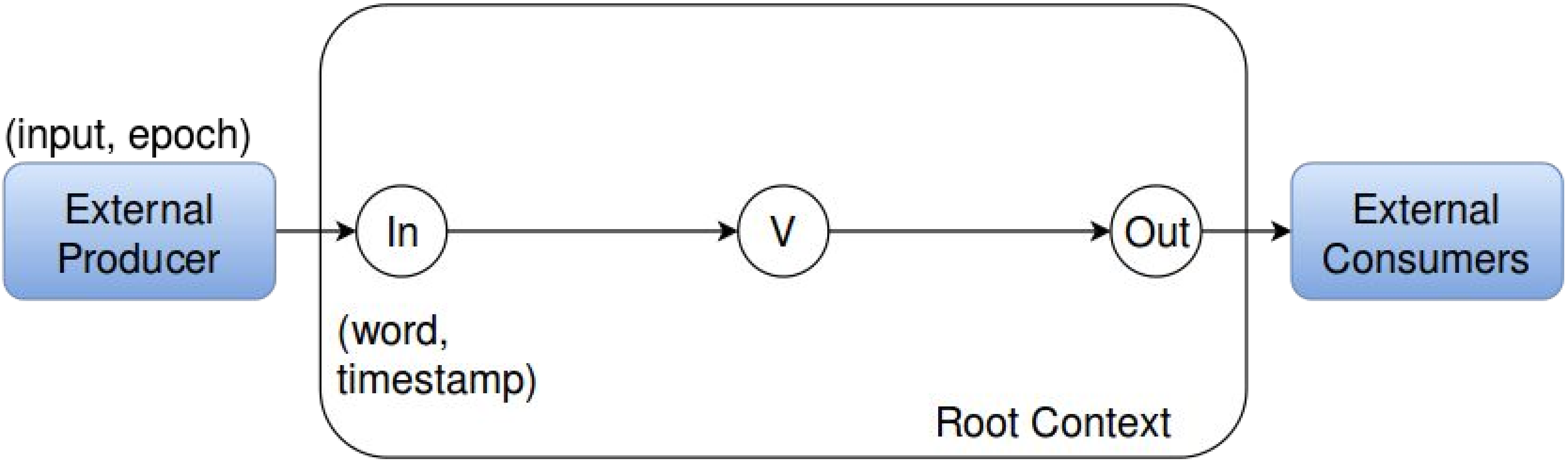
Word Count Example

```
Class V<Msg, Time>: Vertex<Time> { ... }
```



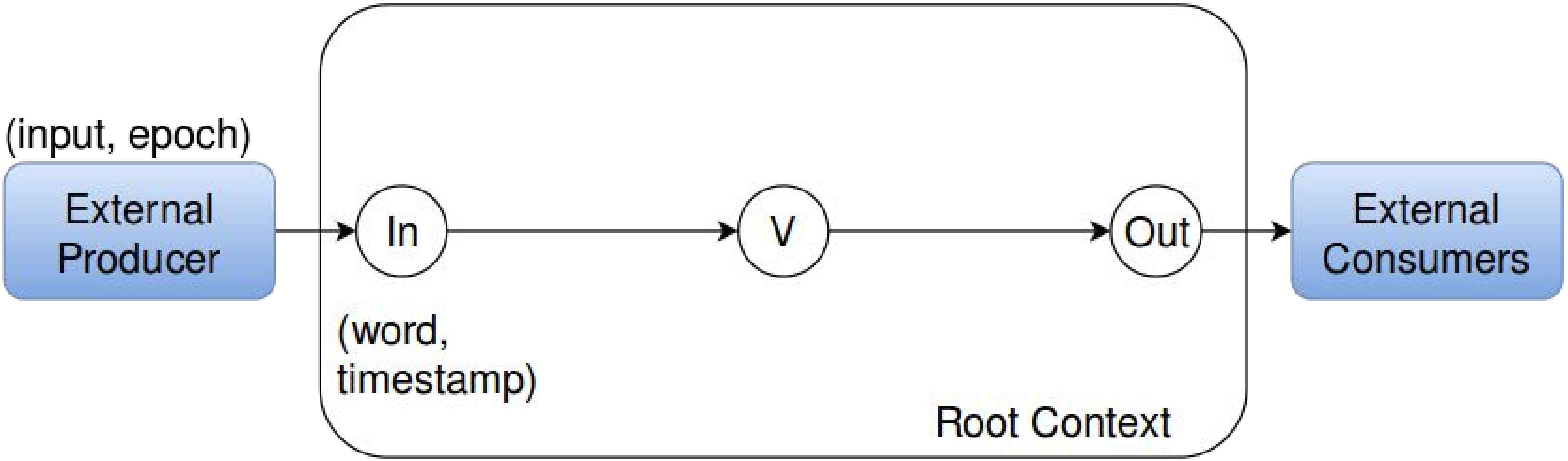
Word Count Example

```
{ Dict<Time, Dict<Msg, int> > counts; ... }
```



Word Count Example (2 Different Implementations)

```
{ void OnRecv (Edge e, Msg m, Time t) { ... }
  void OnNotify (Time t) { ... }  }
```



Writing Programs in General

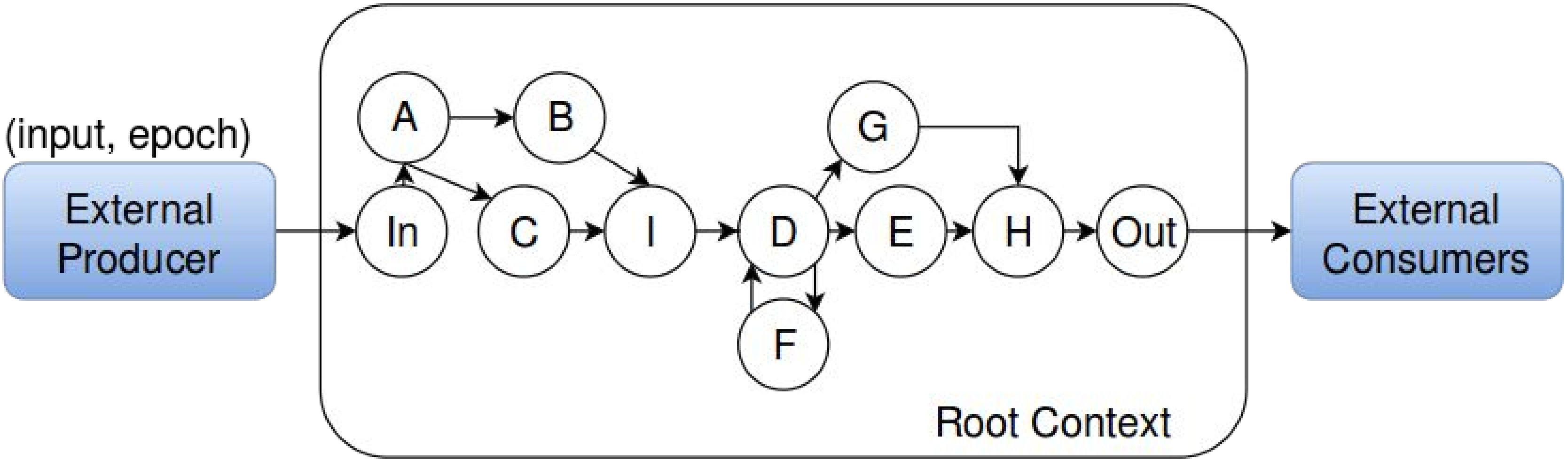
- It is possible to write programs against the Timely Dataflow abstraction.

- It is possible to use libraries (MapReduce, Pregel, PowerGraph, LINQ etc.)

- In General:
    - Define Input, computational & Output vertices.
    - Create a timely dataflow graph using the appropriate interface.
    - Supply labeled data to input stages.
    - Stages follow a push-based model.

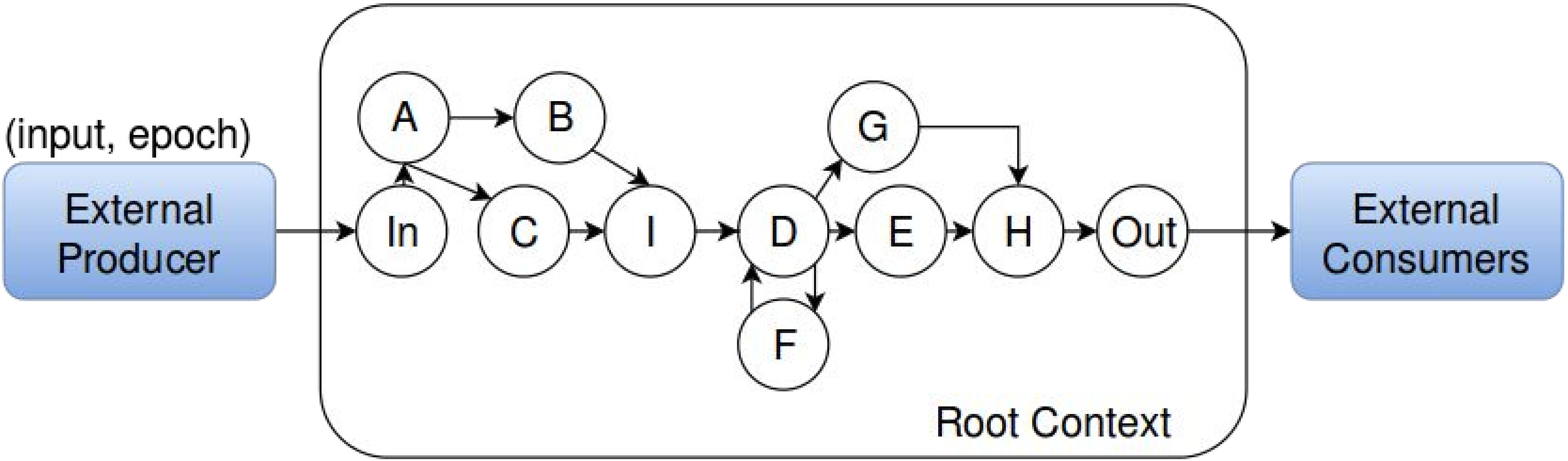
Timely Guarantees

How is timely dataflow achieved



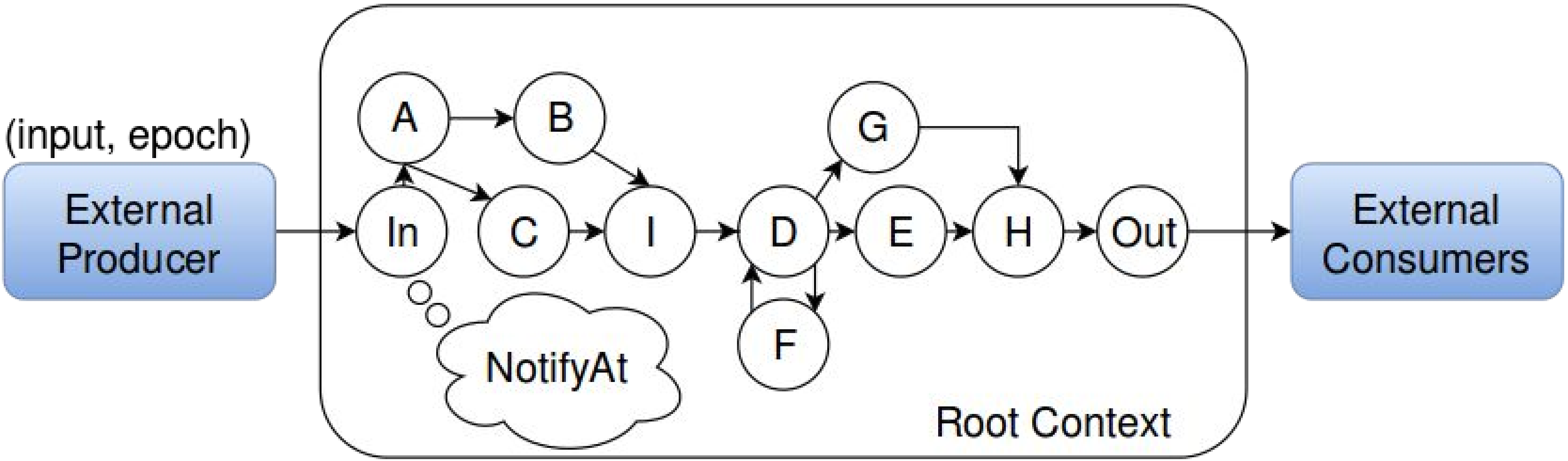
How is timely dataflow achieved

- **Key point:** timestamps at which future message can occur depends on: 1. Unprocessed events & 2. Graph Structure.



How is timely dataflow achieved

- **Pointstamp** of an event (timestamp, location: E or V)
  - SendBy -> Msg event of pointstamp (t, e)
  - NotifyAt -> Notif event of pointstamp (t, v)

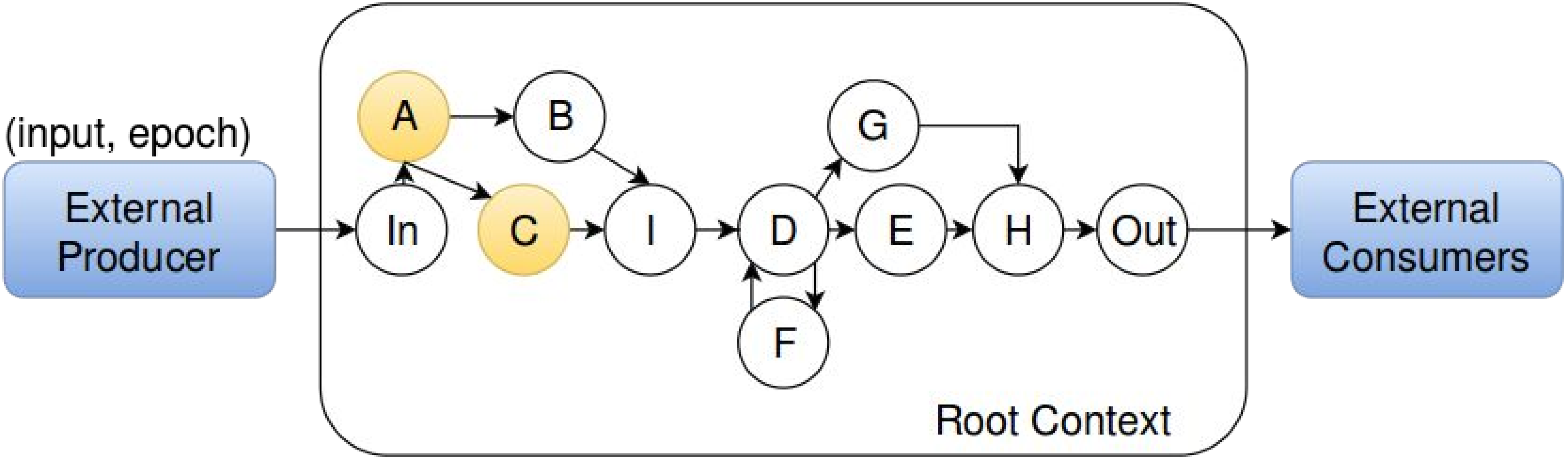


How is timely dataflow achieved

- Pointstamp(t1, l1) **could-result-in** Pointstamp(t2, l2)
  If there is a path between l1 and l2 presented by f()
  i.e. f(t1) <= t2

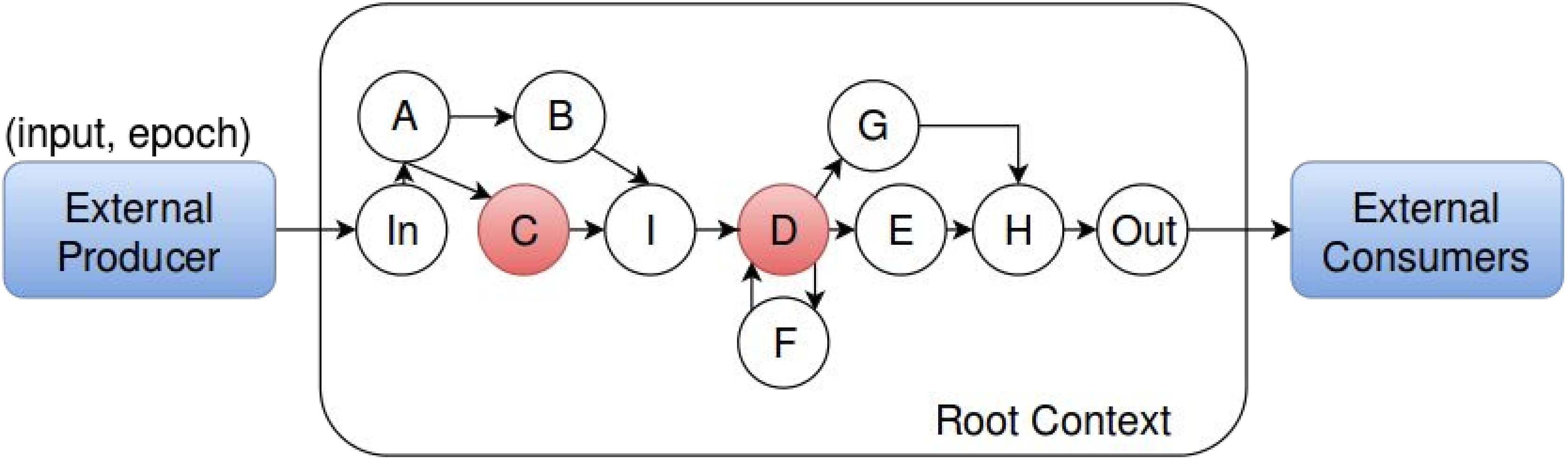
How is timely dataflow achieved (Correctness Guarantees)

- Path Summary between A and C: “”



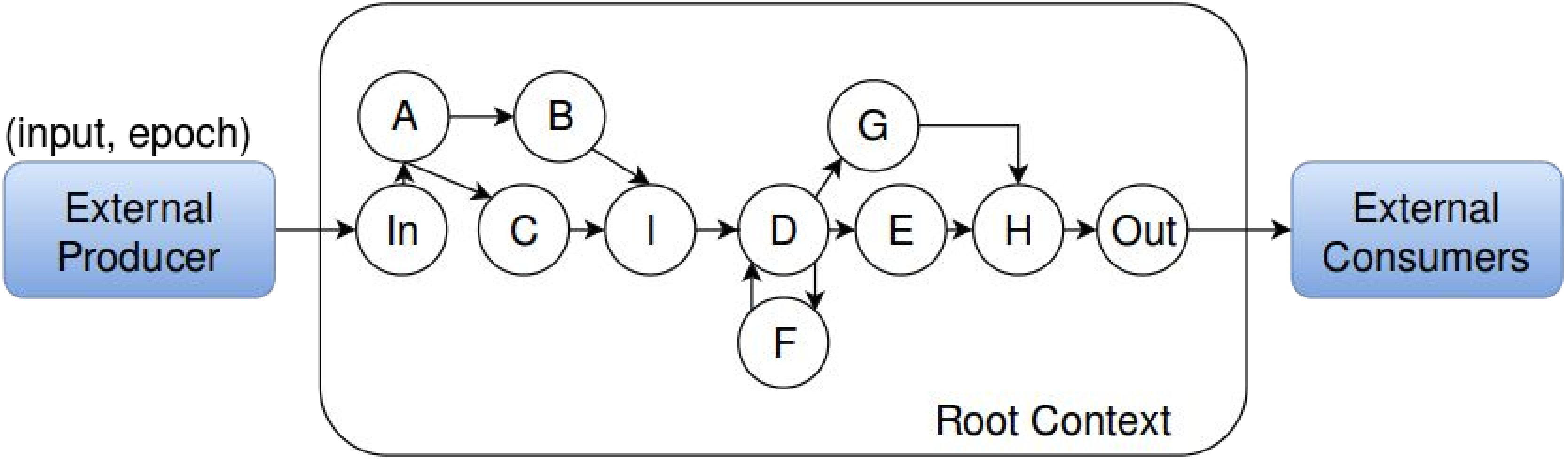
How is timely dataflow achieved (Correctness Guarantees)

- Path Summary between A and C: “add” or “add-increment(n)”



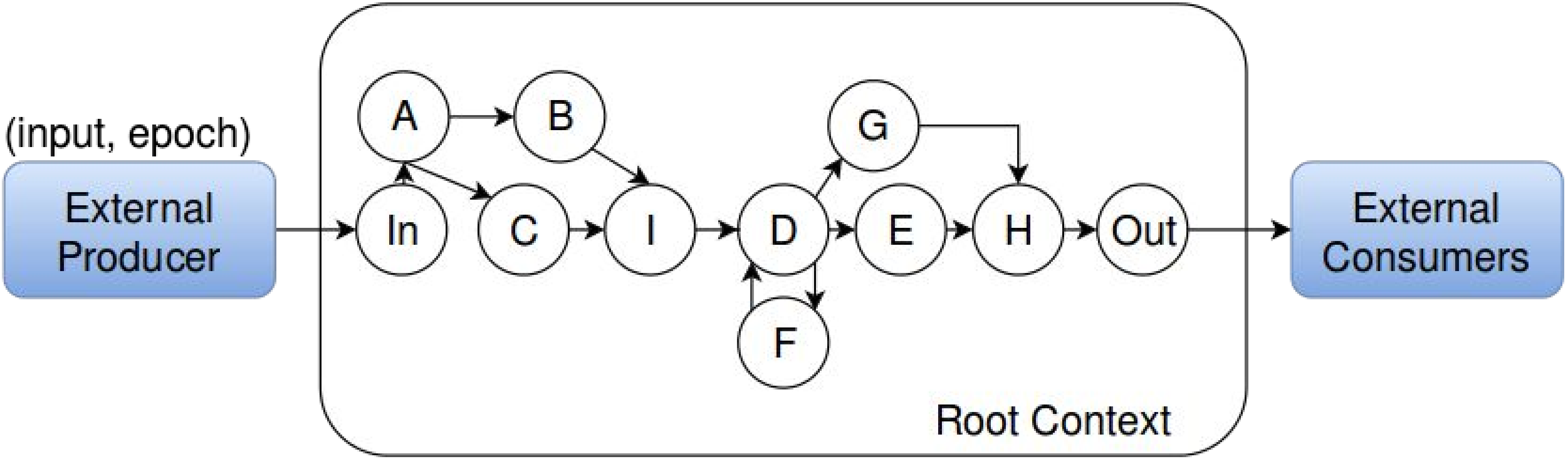
Single-Threaded Implementation

- Scheduler that needs to deliver events.



Single-Threaded Implementation

- Scheduler has active pointstamps <-> unprocessed events.



Single-Threaded Implementation

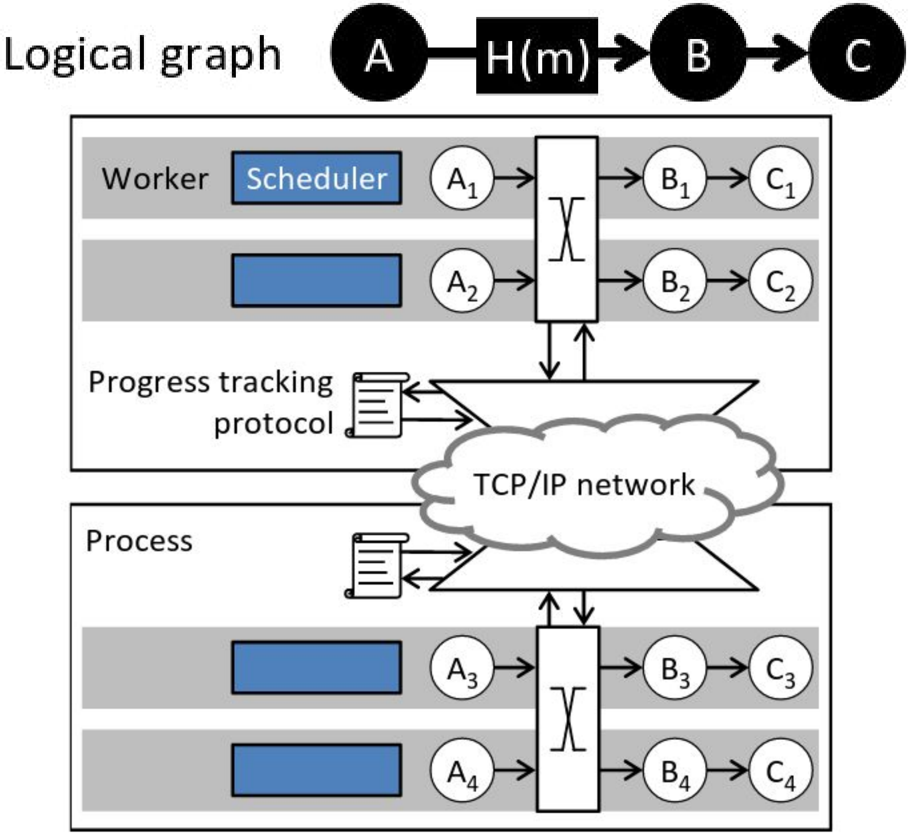
- Scheduler has active pointstamps <-> unprocessed events.
- Scheduler has two counts:
    - Occurrence count of not resolved event.
    - Precursor count of how many active pointstamps precede it in the could-result-in order.

Single-Threaded Implementation

- Pointstamp(t, l) becomes **active**.
  Precursor count to number of existing active pointstamps that could result in it.
  Increment precursor count of any pointstamp it could-result-in.
  Becomes not active when occurrence is zero.
  When not active, decrement the precursor count for any pointstamp that it could-result-in.

The Distributed Environment

Distributed Implementation



Distributed Progress Tracking

- Initial protocol: same as single multi-threaded.
  - Broadcast occurrence count updates.

- Do not immediately update local occurrence count.
  - Broadcast progress updates to all workers including myself.
  - Broadcast from a worker to another delivered in a FIFO manner.

- Use of a projected timestamp.
- A technique to buffer and accumulate updates.

Micro-Stragglers

- Have a big effect on overall performance.
  - Packet Loss (Networking)
  - Contention on concurrent data
  - Garbage collection

Performance Evaluation

Performance Evaluation

- I invite you to read: "Scalability! BUT at what Cost"

Performance Evaluation

- Comparison with:
  - SQL Server Parallel Data Warehouse (RDBMS)
  - Scalable HyperLink Store (distributed in-memory DB for storing large portions of the web graph)
  - DryadLINQ (data parallel computing using a declarative / high level programming language)

- Algos i.e. PageRank, SCC etc.

Conclusion: “Our prototype outperforms general-purpose batch processors and often outperforms state-of-the-art async systems which provide few semantic guarantees.”

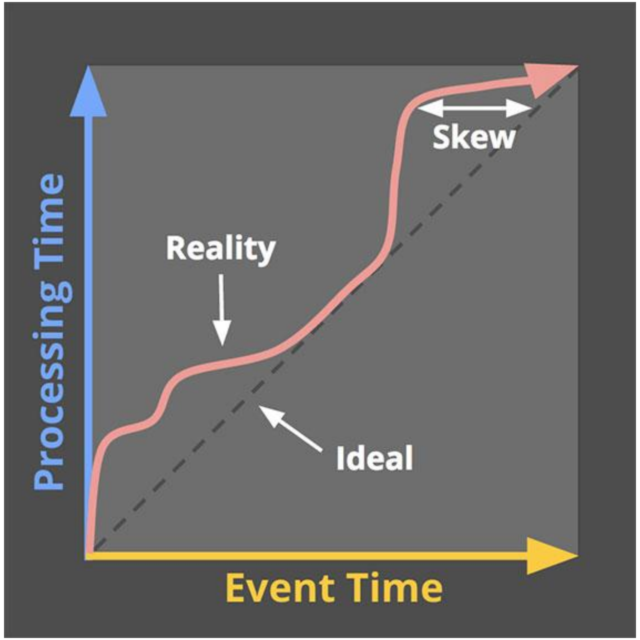
Conclusion: "Our prototype outperforms general-purpose batch processors and often outperforms state-of-the-art async systems ~~which provide few semantic guarantees.~~"

Streaming Systems as of today

Streaming Systems

- Systems that have unbounded data in mind.
- They are a superset of batch processing systems.

Streaming Systems



Reference: Fig-1: Example of time domain mapping. Streaming 101

Streaming Systems

Design Questions:

- ***What*** **results are calculated?**
  The types of *transformations* within the pipeline.
- ***Where*** **in event time are results calculated?**
  The use of *event-time windowing* within the pipeline.
- ***When*** **in processing time are results materialized?** The use of watermarks and triggers.
- ***How*** **do refinements of results relate?**
  Discard or accumulate or accumulate and retract.

FIN.

Thank you!

Resources

- Link to transcribed talk in pdf format.
- Timely Dataflow (Rust Implementation)
- Frank blog posts:
  - Timely dataflow
  - Differential dataflow
- The world beyond batch: Streaming 101
- The world beyond batch: Streaming 102