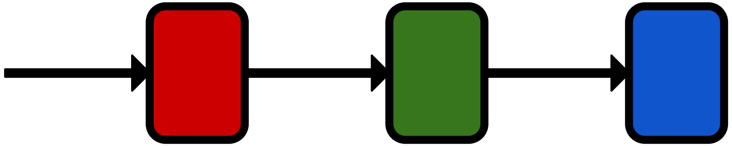
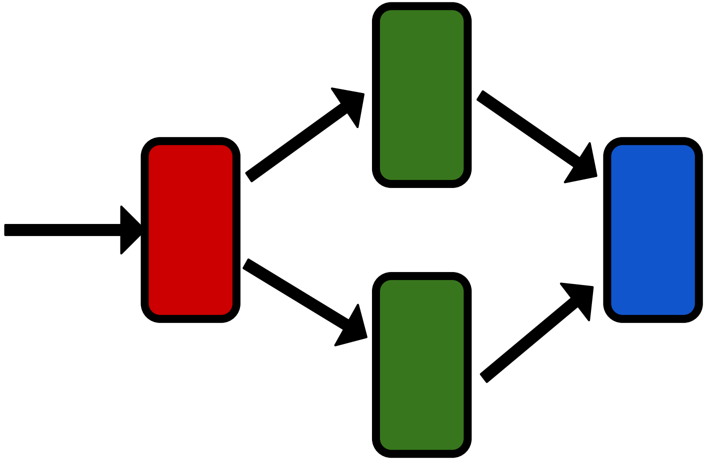
Naiad: A Timely Dataflow System

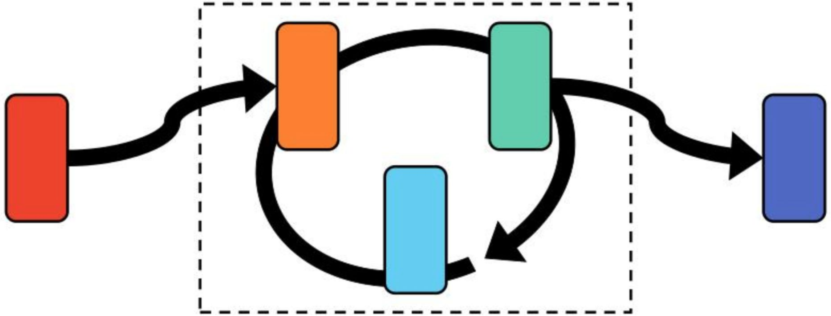
Derek G. Murray Frank McSherry
Rebecca Isaacs Michael Isard
Paul Barham Martín Abadi
MSR Silicon Valley

Presented by Jesse Mu (jlm95)

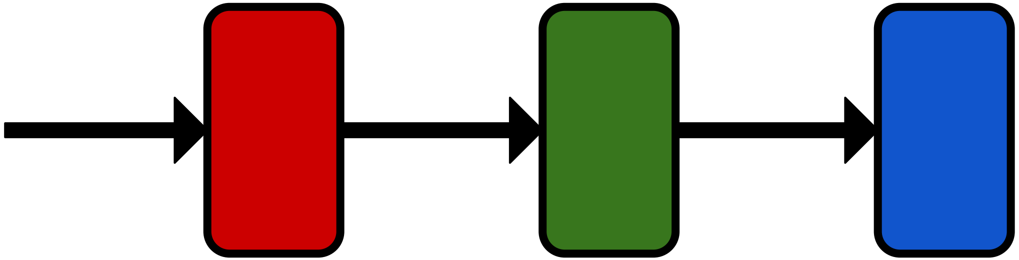
Background: dataflow programming







Batch processing



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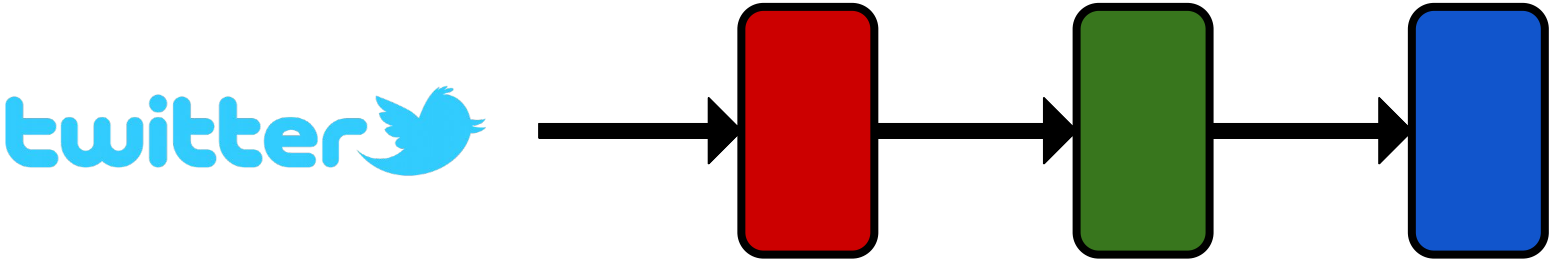
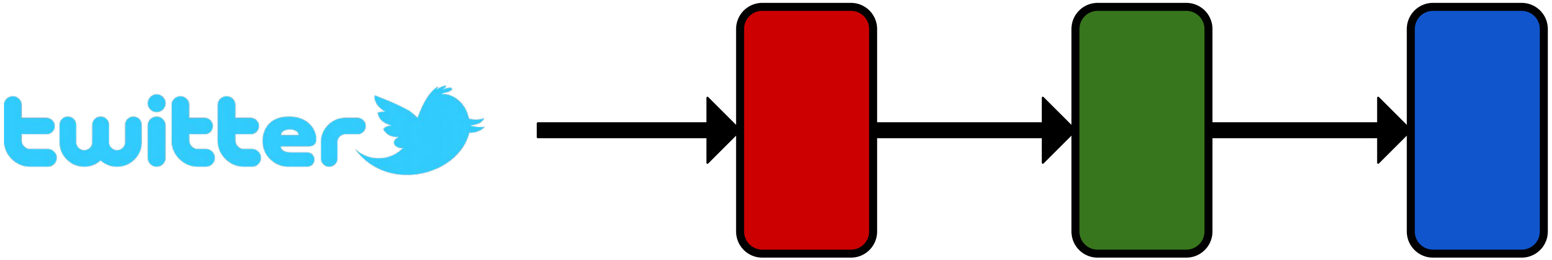


Batch processing

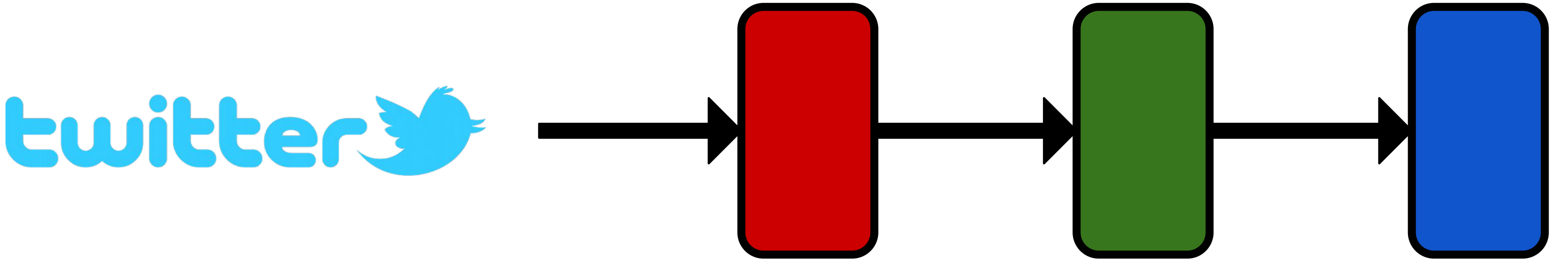
Count most popular
hashtags at a given time



Batch processing

Count most popular hashtags at a given time

...



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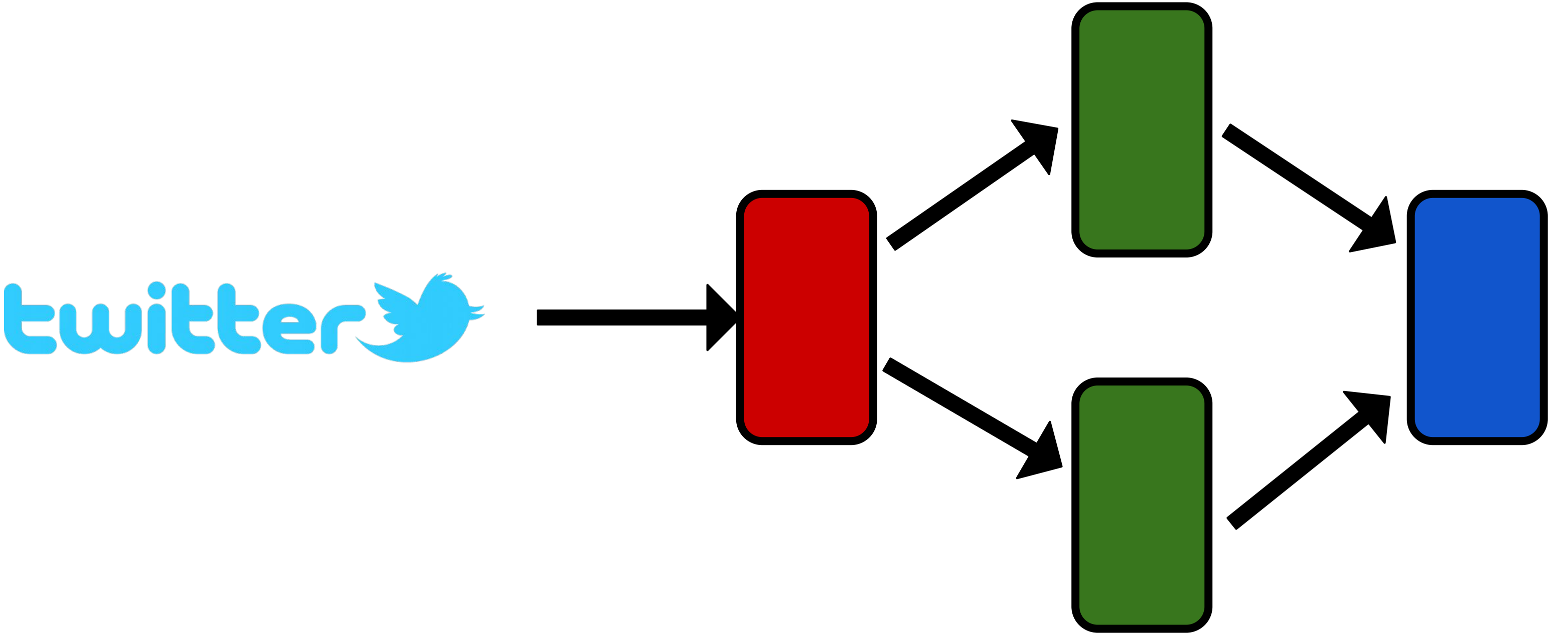

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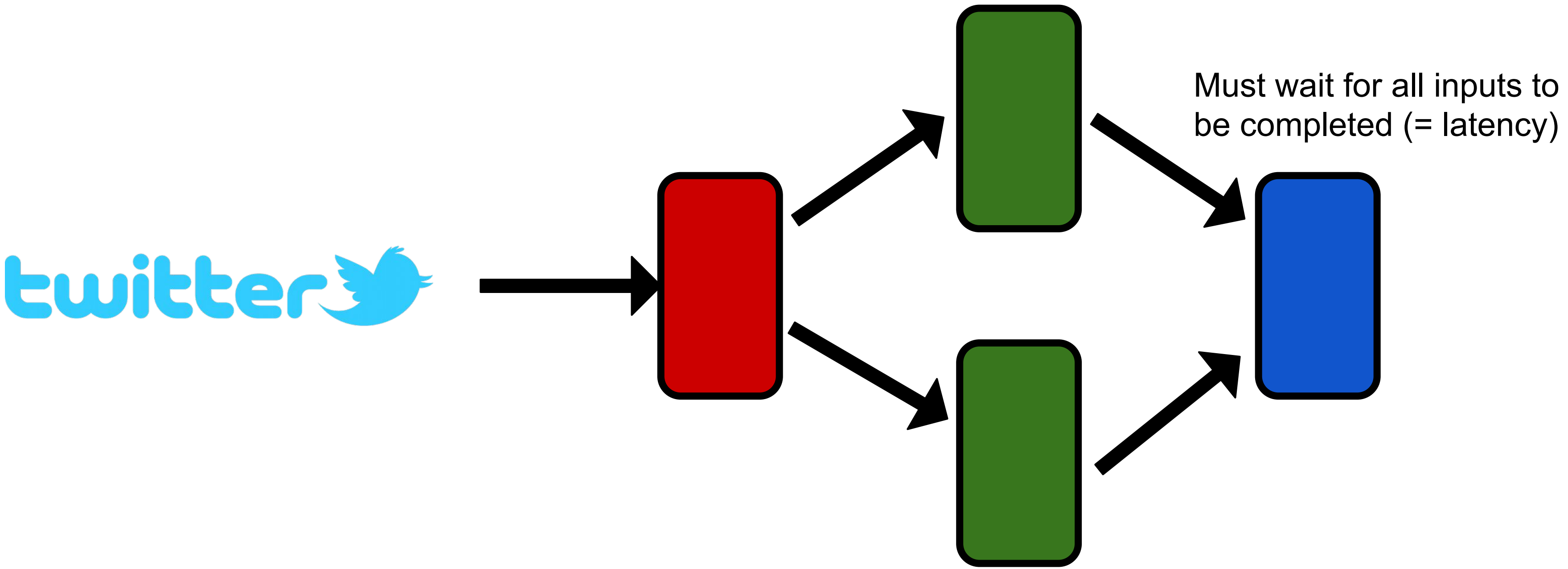
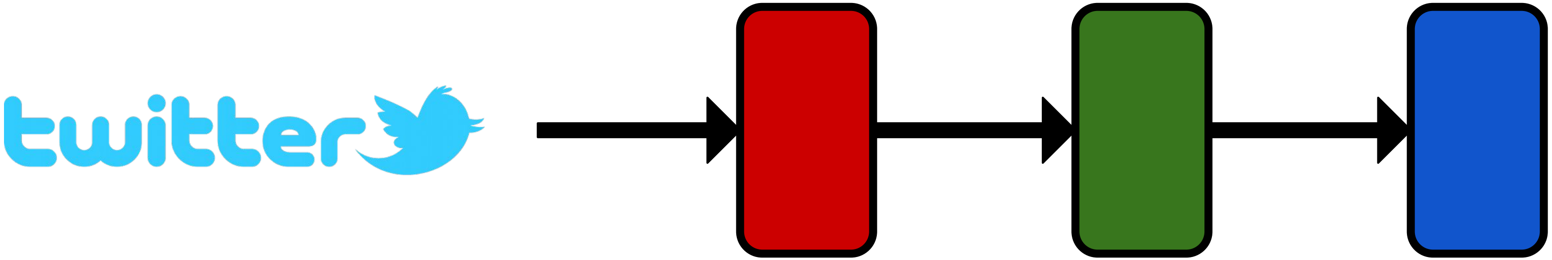
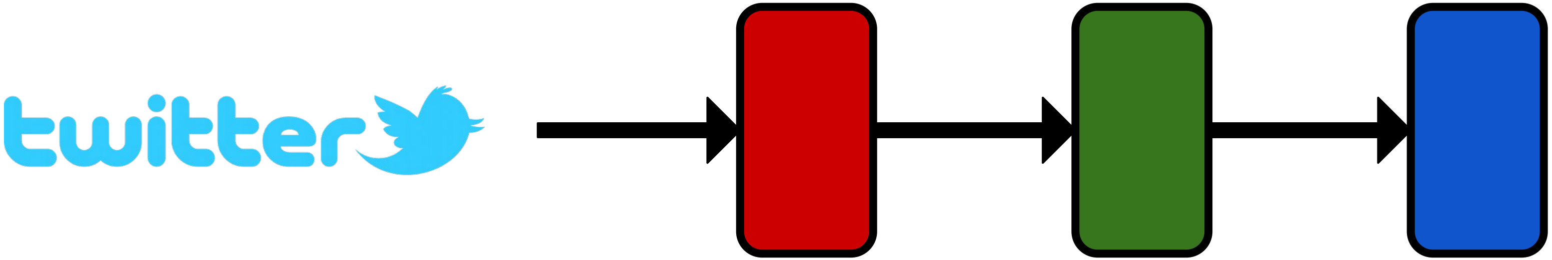


Stream processing (asynchronous)

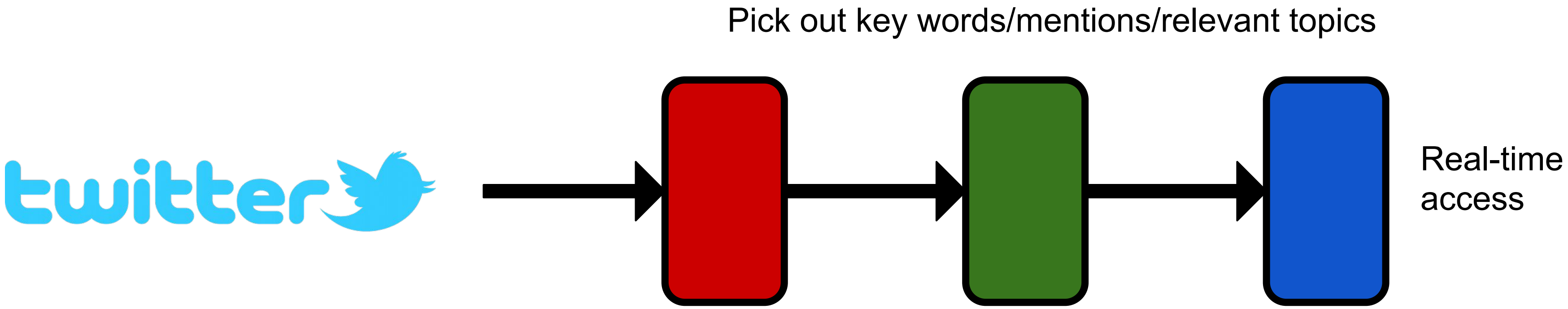


Stream processing (asynchronous)

Pick out key words/mentions/relevant topics



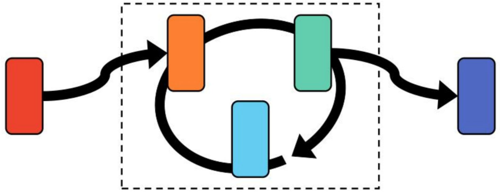
Stream processing (asynchronous)



Background: types of data processing systems

- Batch processing (e.g. Pregel, CIEL)
  - High throughput, aggregate summaries of data
  - Waiting for batches introduces latency
- Stream processing (e.g. Storm, MillWheel)
  - Low-latency, near-realtime access to results
  - No synchronization/aggregate computation

- Iterative (graph-centric) computation
  - e.g. network data, ML



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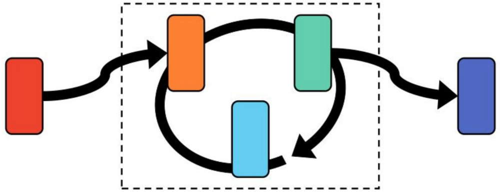
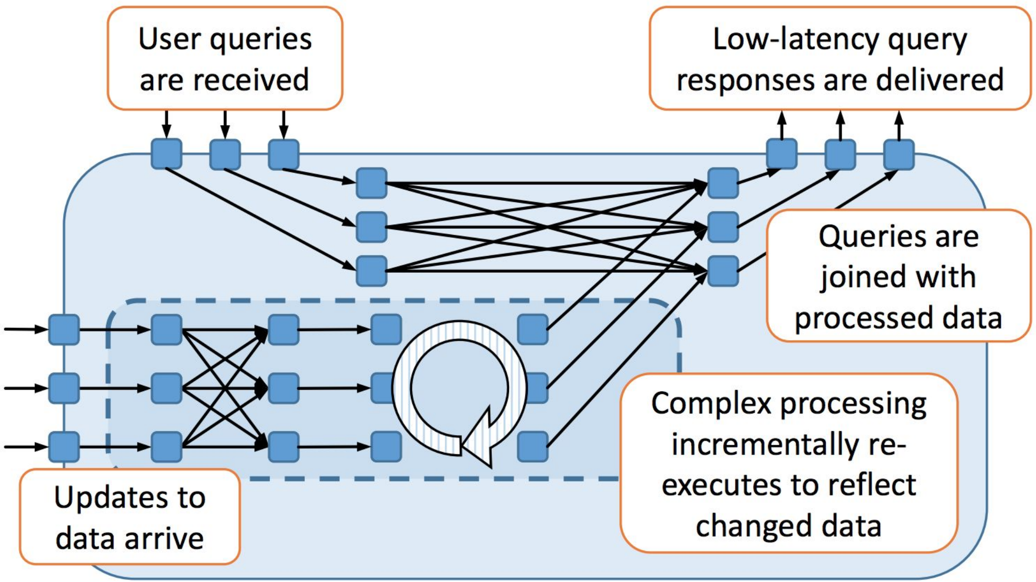


Timely Dataflow

One-size-fits-all

Background: types of data processing systems



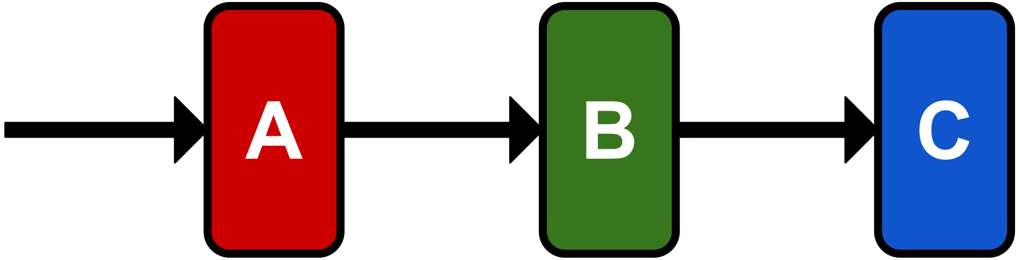
Timely Dataflow

One-size-fits-all

Contributions

1. **Timely dataflow**, a dataflow computing model which supports batch, stream, and graph-centric iterative processing
   a. Supports common high-level programming interfaces (e.g. LINQ)
2. **Naiad**, a high-performance distributed implementation of the model
   a. Faster than SOTA batch/streaming frameworks

Timely Dataflow supports Batch and Stream



Async event-based model

Nodes are always active.
Send and receive messages via

A.**SendBy**(edge, message, time)

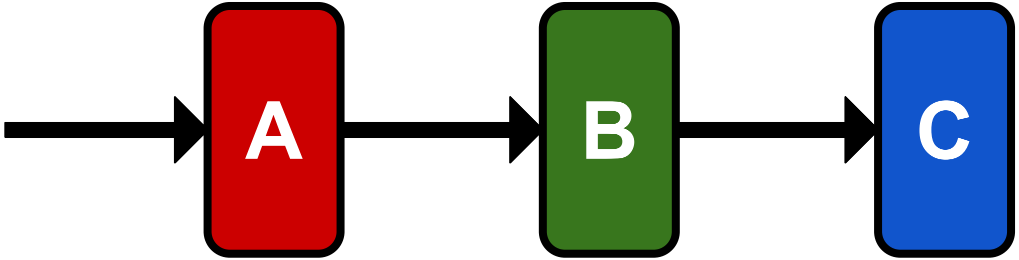
B.**OnRecv**(edge, message, time)

Request and operate on **notifications** for batches

C.**NotifyAt**(time)

C.**OnNotify**(time)

Timely Dataflow supports Batch and Stream



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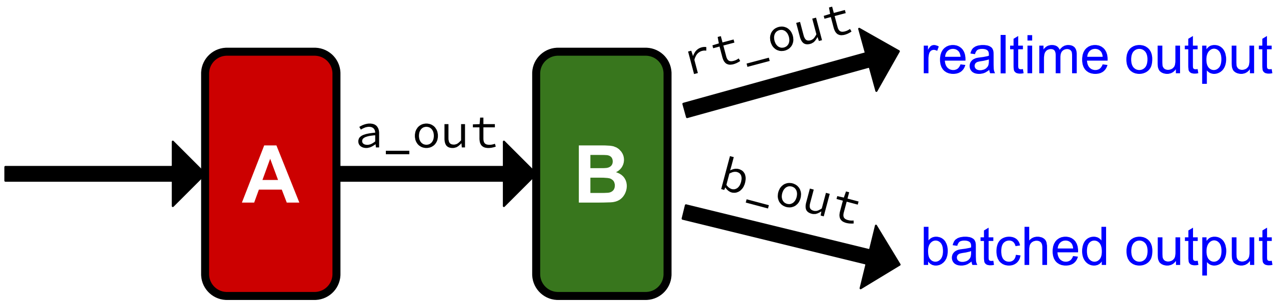
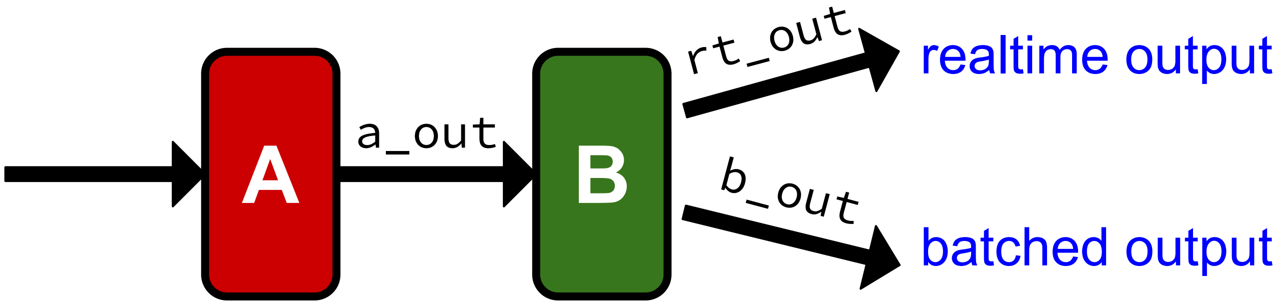
Batch processing



A
a_out
B
rt_out
b_out
realtime output
batched output

Input

time	numbers
1	9, 3, 2, 5, ...
2	3, 2, 7, 12, ...
...	



Pass through even numbers only

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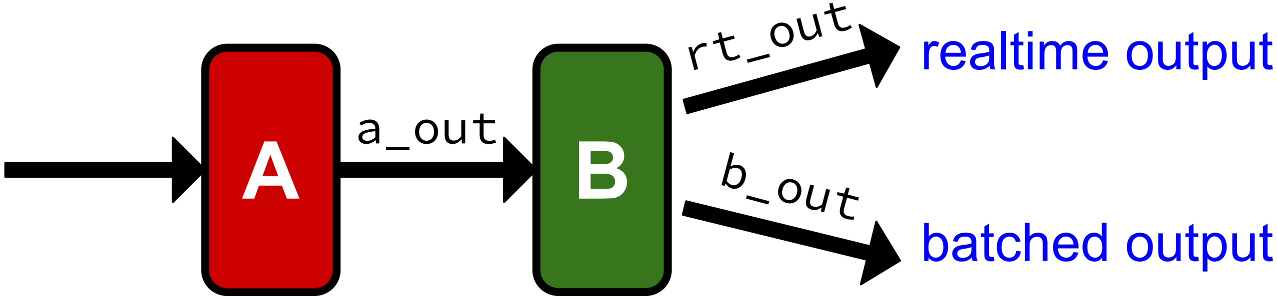

A

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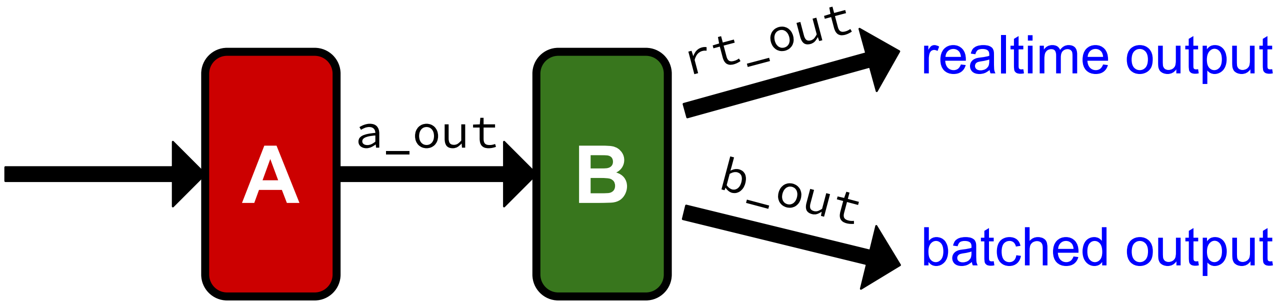

B

Pass through all numbers; compute min of each time

A

```
function OnRecv(input_edge, msg, time) {
    if (msg % 2 == 0)
        this.SendBy(a_out, msg, time)}
```

Pass through even numbers only

Input

time	numbers
1	9, 3, 2, 5, ...
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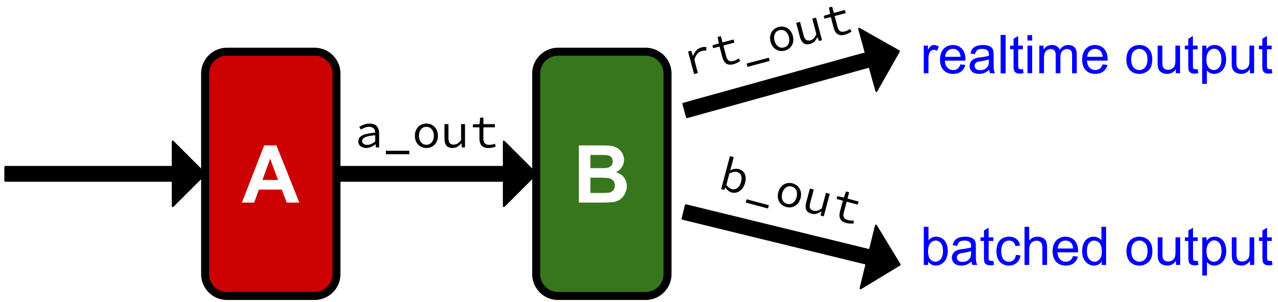

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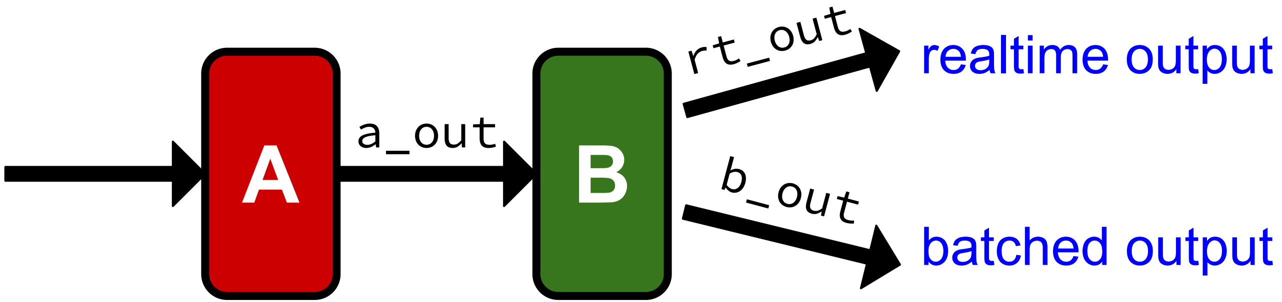

B

```
state = {}  // times -> running mins
```

Pass through all numbers; compute min of each time

```
function OnRecv(input_edge, msg, time) {
    if (msg % 2 == 0)
        this.SendBy(a_out, msg, time)}
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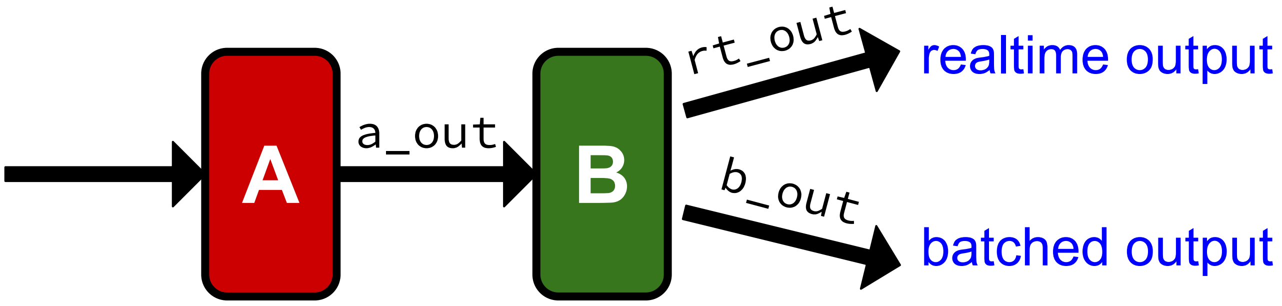


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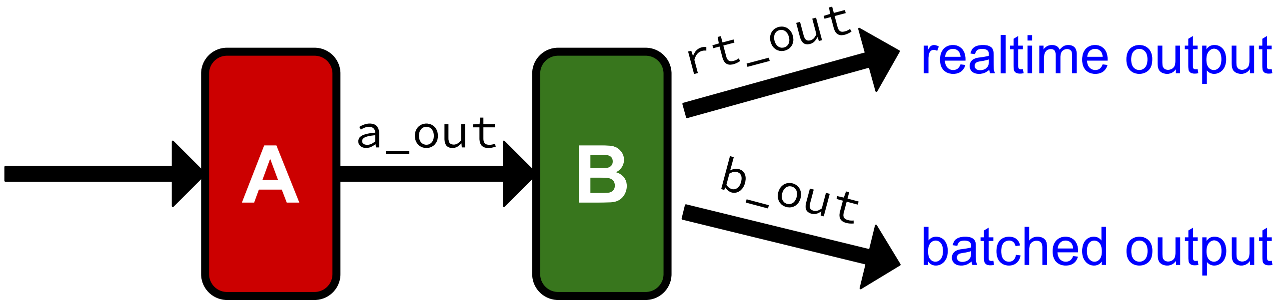

B

```
state = {}  // times -> running mins
function OnRecv(input_edge, msg, time) {
    this.SendBy(rt_out, msg, time)
```

Pass through all numbers; compute min of each time

A

```
function OnRecv(input_edge, msg, time) {
    if (msg % 2 == 0)
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Pass through even numbers only

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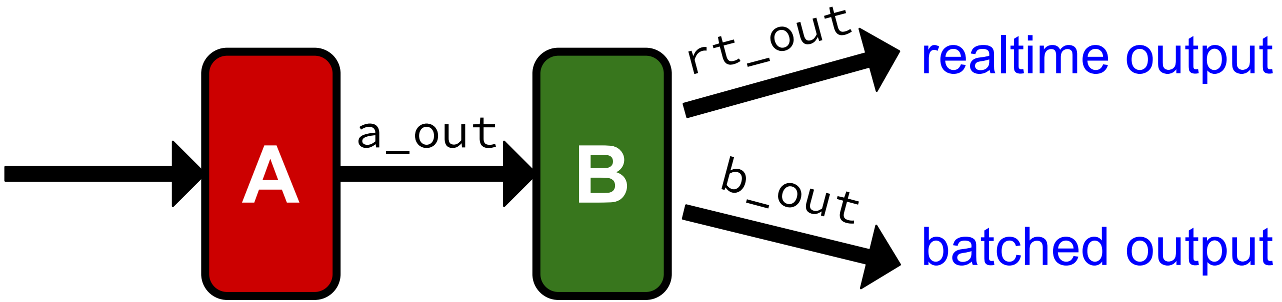

B

```
state = {}  // times -> running mins
function OnRecv(input_edge, msg, time) {
    this.SendBy(rt_out, msg, time)  // Streaming

    if (time not in state)  // New time
        state[time] = msg
        this.NotifyAt(time)
```

Pass through all numbers; compute min of each time

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```
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        this.SendBy(a_out, msg, time)}
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Pass through even numbers only

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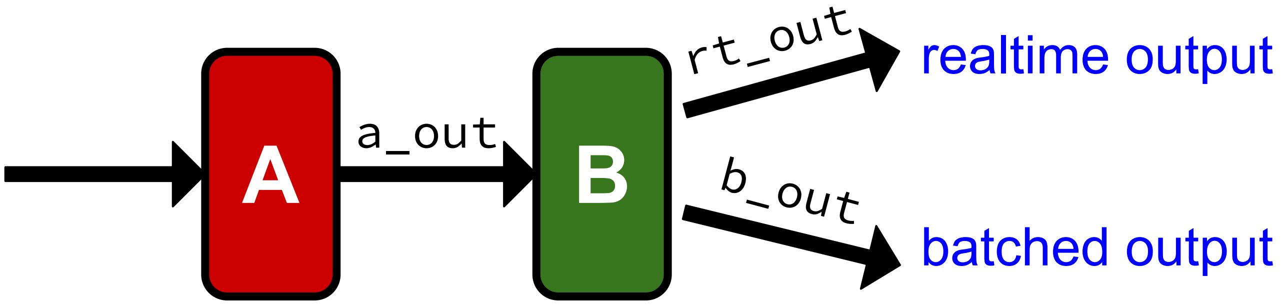

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    if (time not in state)  // New time
        state[time] = msg
        this.NotifyAt(time)

    if (msg < state[time])  // New min
        state[time] = msg
```

Pass through all numbers; compute min of each time

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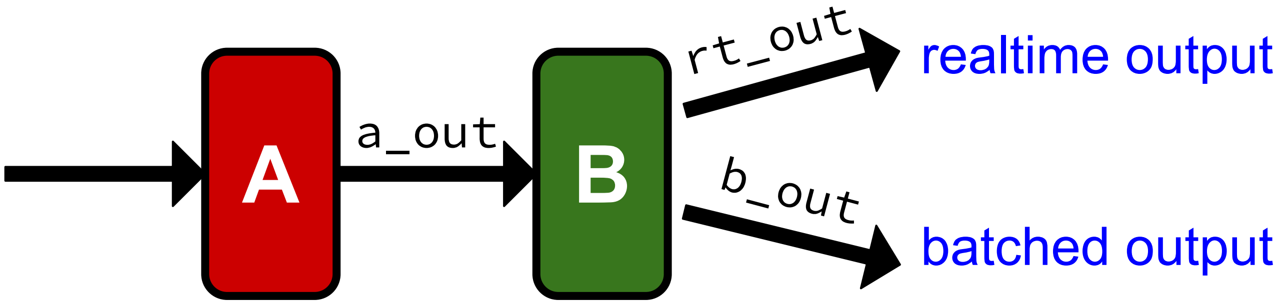


B

```
state = {}  // times -> running mins
function OnRecv(input_edge, msg, time) {
    this.SendBy(rt_out, msg, time)  // Streaming

    if (time not in state)  // New time
        state[time] = msg
        this.NotifyAt(time)

    if (msg < state[time])  // New min
        state[time] = msg
```

```
function OnNotify(time) {
    this.SendBy(batch_out,
                state[time],
                time)}
```

Pass through all numbers; compute min of each time

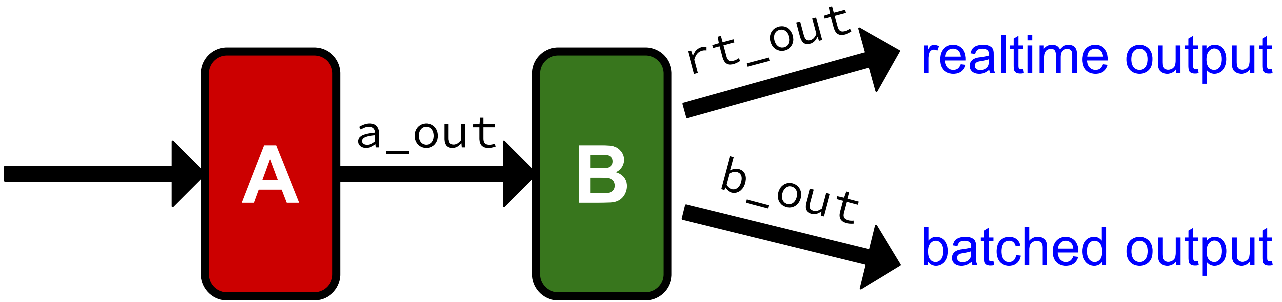
A

```
function OnRecv(input_edge, msg, time) {
    if (msg % 2 == 0)
        this.SendBy(a_out, msg, time)}
```

Pass through even numbers only

Input

time	numbers
1	9, 3, 2, 5, ...
2	3, 2, 7, 12, ...
...	



B

```
state = {}   // times -> running mins
...ut_edge, msg, time) {
...ut, msg, time)   // Streaming
...state)   // New time
... = msg
this.NotifyAt(time)

    if (msg < state[time])   // New min
        state[time] = msg
```

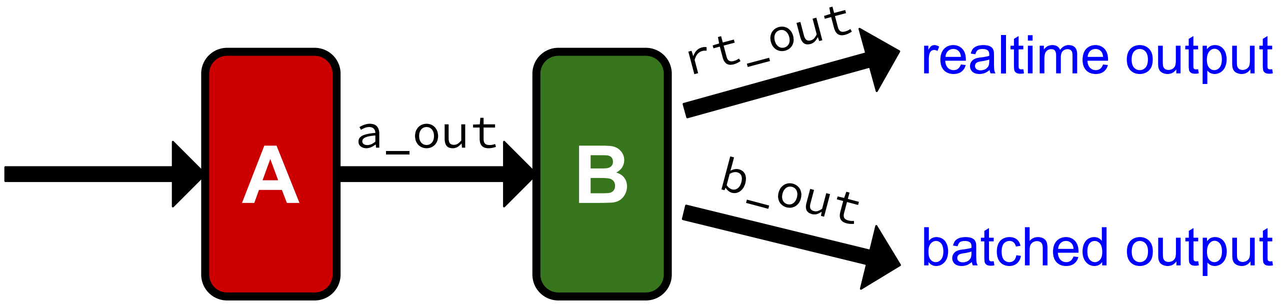
```
function OnNotify(time) {
    this.SendBy(batch_out,
                state[time],
                time)}
```

Node B, you've seen all messages for time 1

Pass through all numbers; compute min of each time

Input

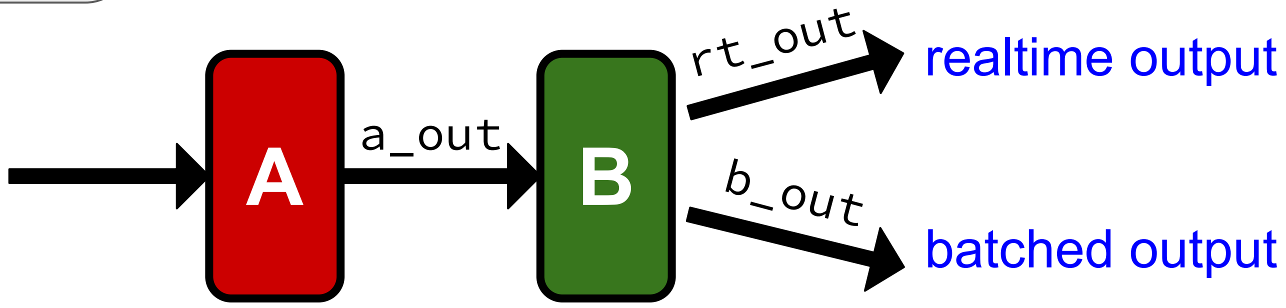
time	numbers
1	9, 3, 2, 5, ...
2	3, 2, 7, 12, ...
...	

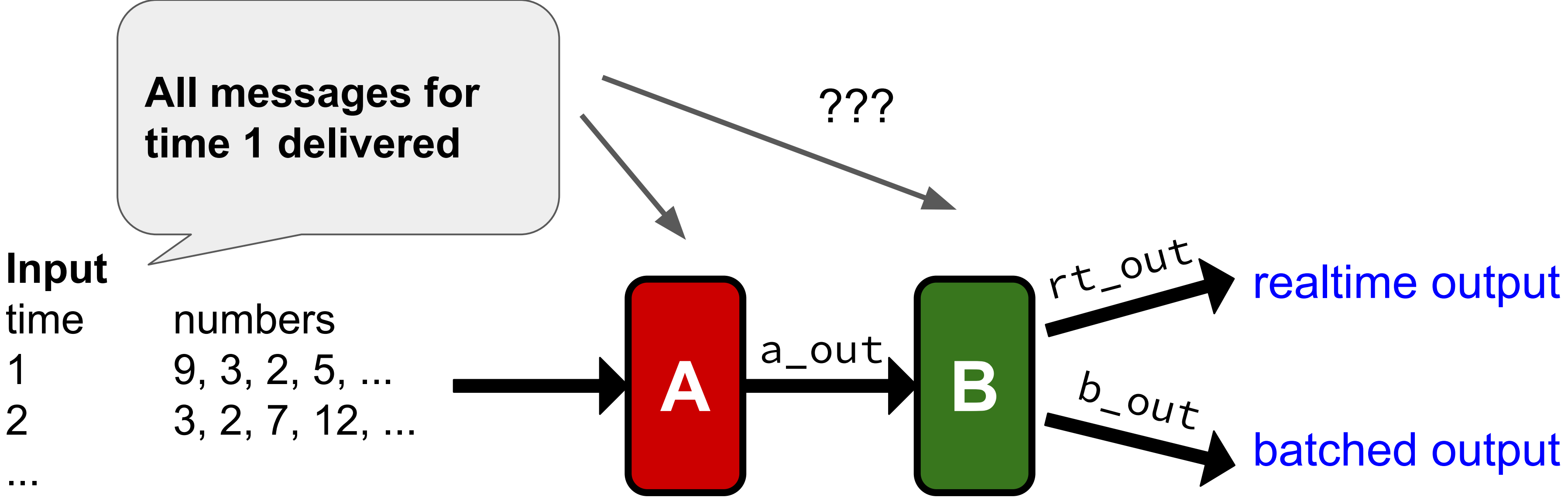


All messages for time 1 delivered

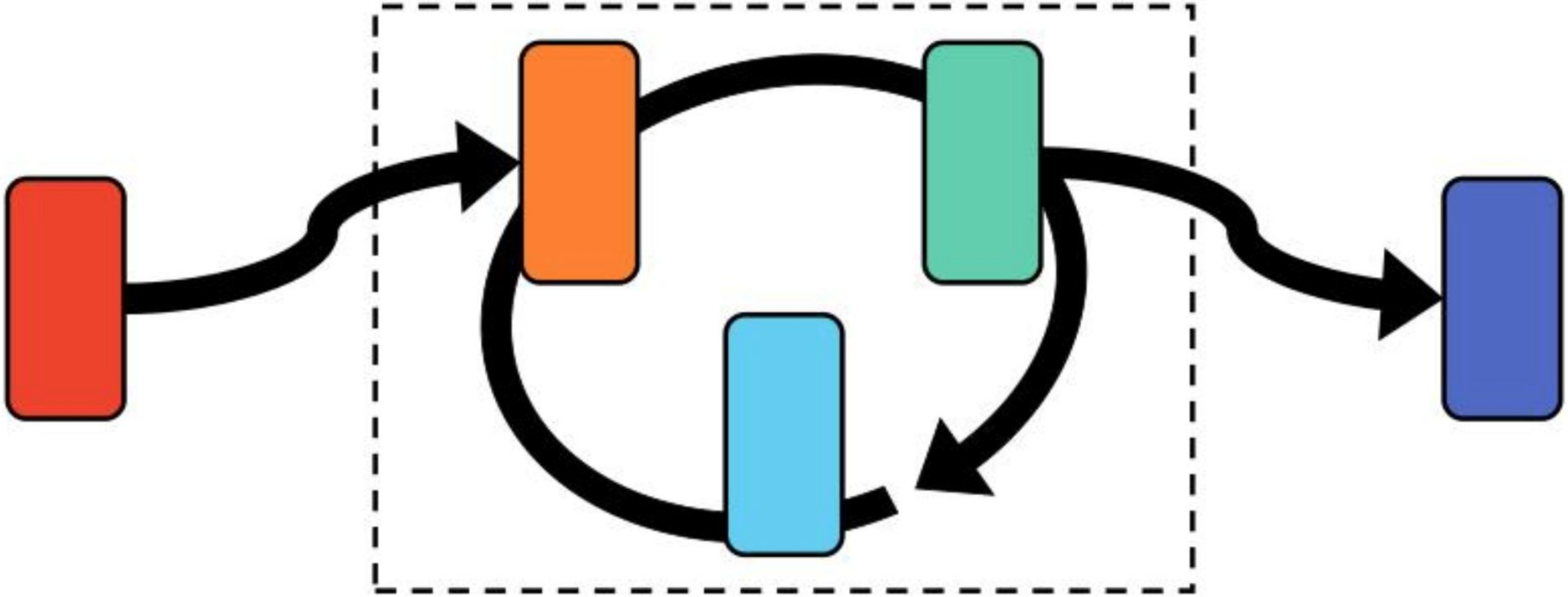
Input

time numbers
1 9, 3, 2, 5, ...
2 3, 2, 7, 12, ...
...



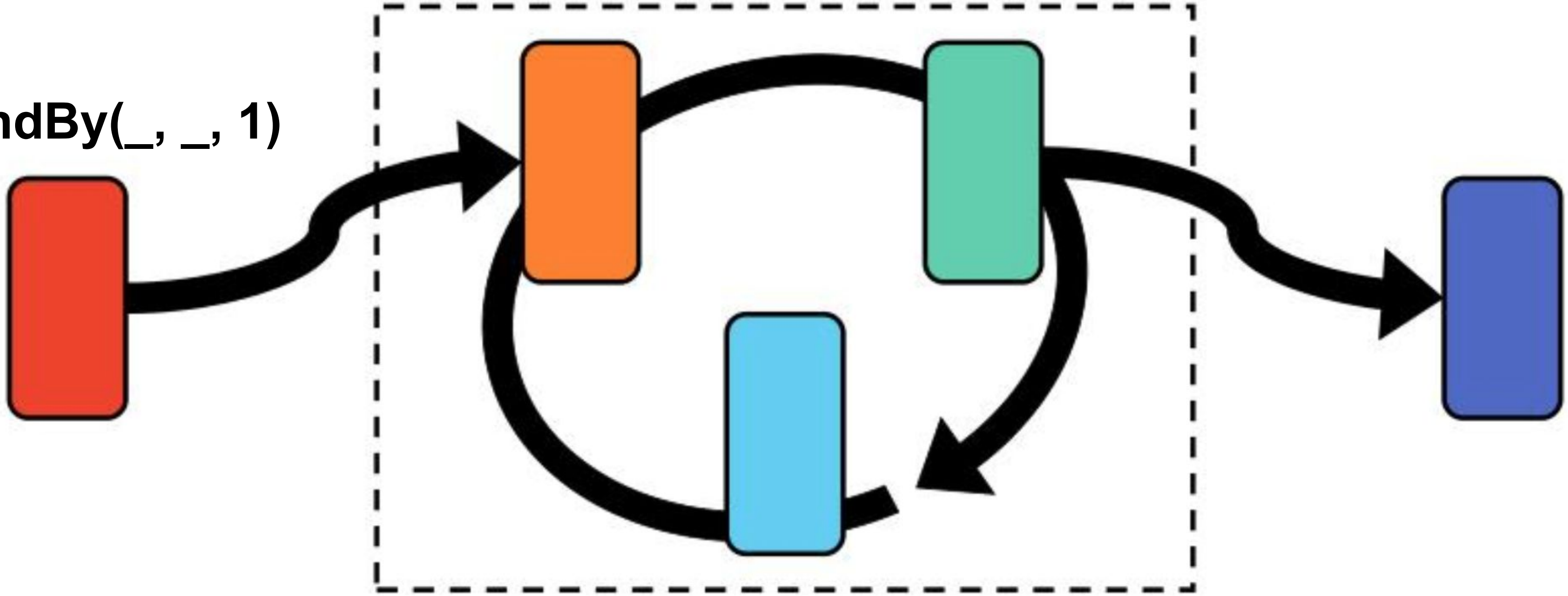

All messages for time 1 delivered
???
Input
time
numbers
1
9, 3, 2, 5, ...
2
3, 2, 7, 12, ...
...
A
a_out
B
rt_out
realtime output
b_out
batched output

Progress tracking



Progress tracking

SendBy(_, _, 1)



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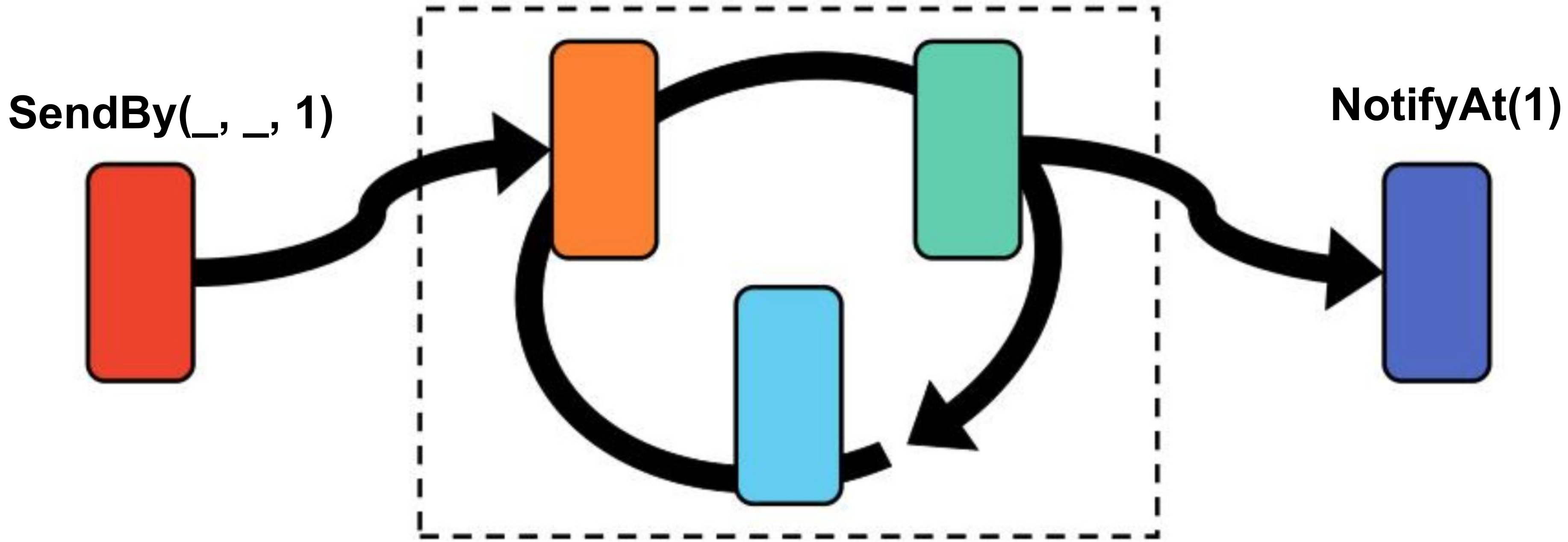

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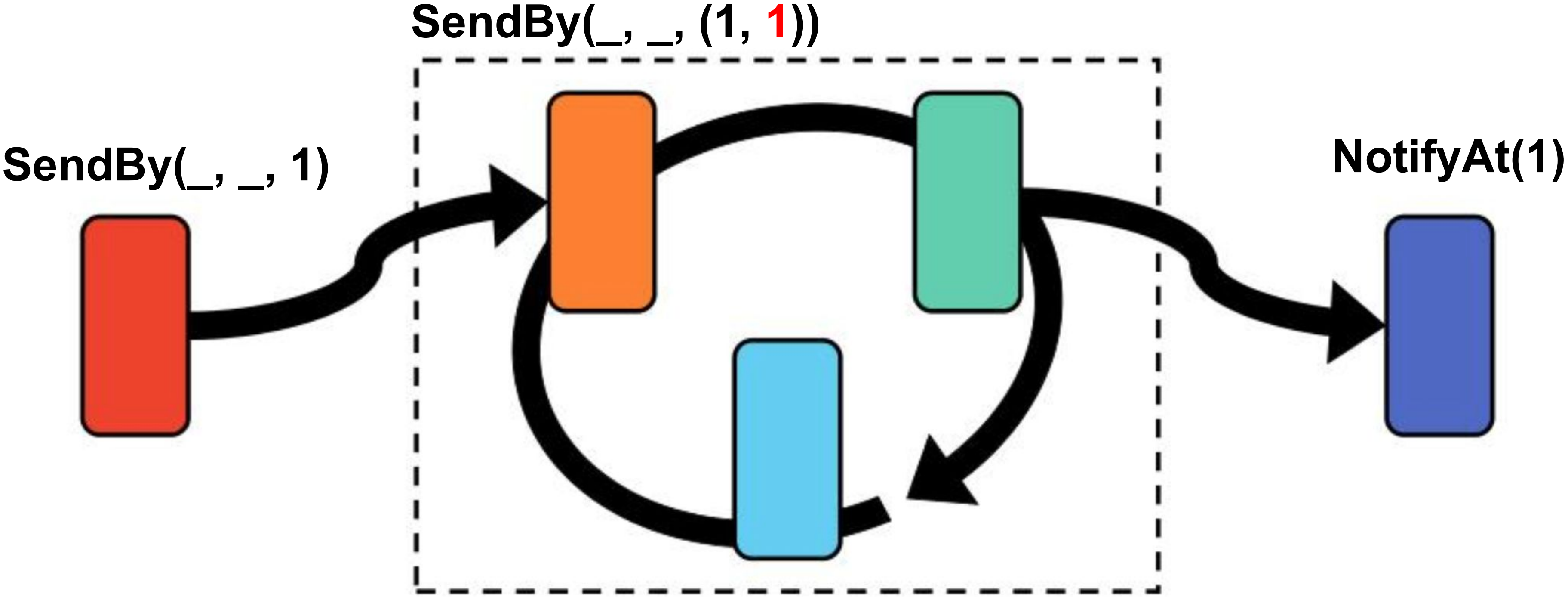

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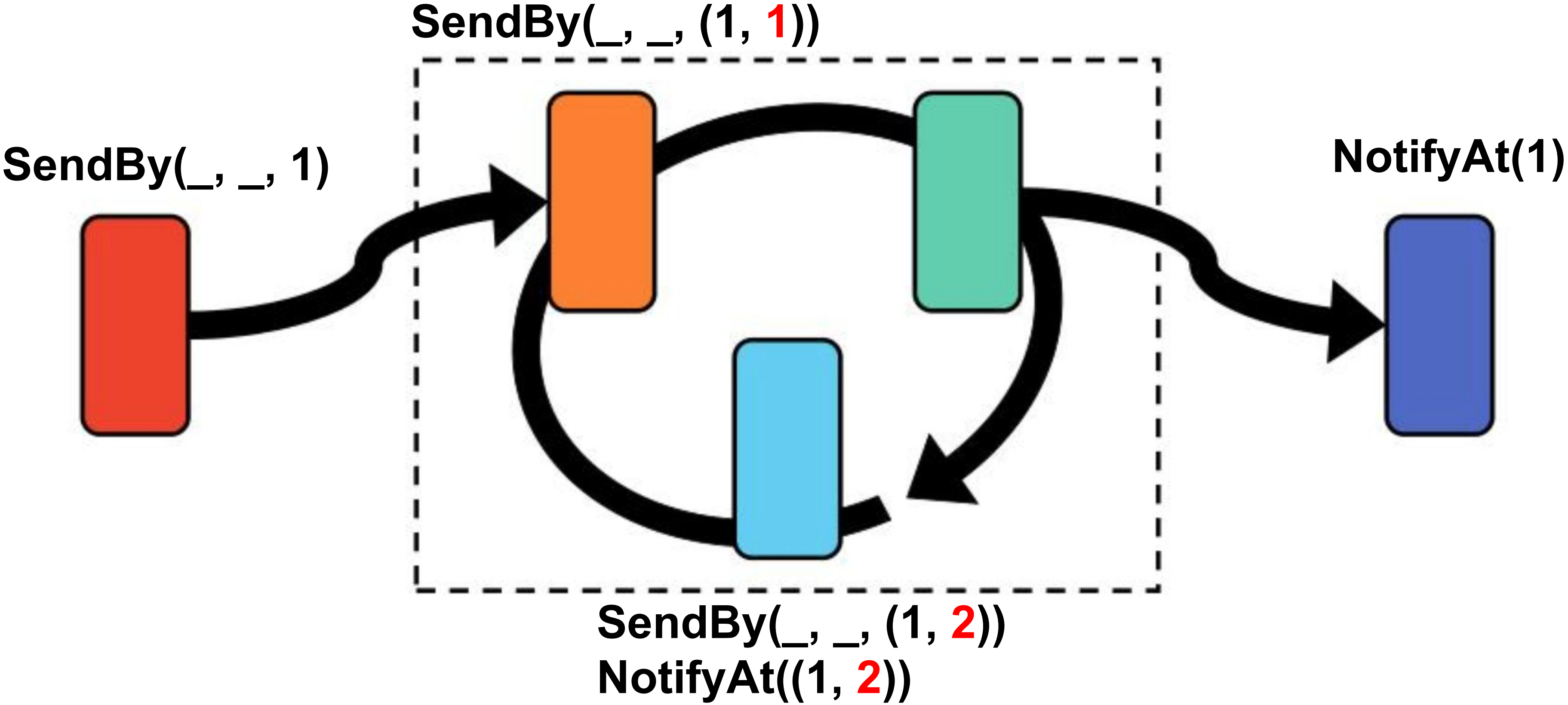


Progress tracking

SendBy(_, _, (1, 1))

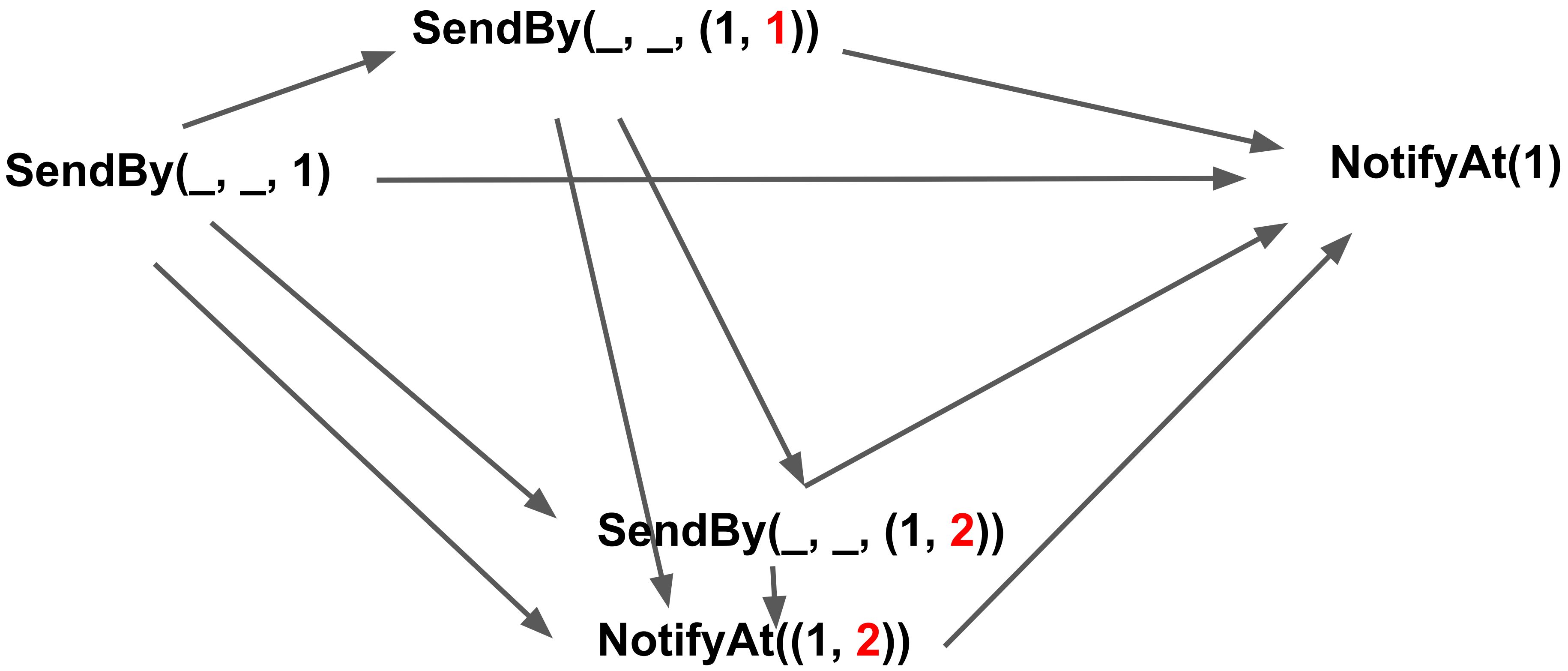
SendBy(_, _, 1)

NotifyAt(1)

SendBy(_, _, (1, 2))

NotifyAt((1, 2))

Sort by *could-result-in* order



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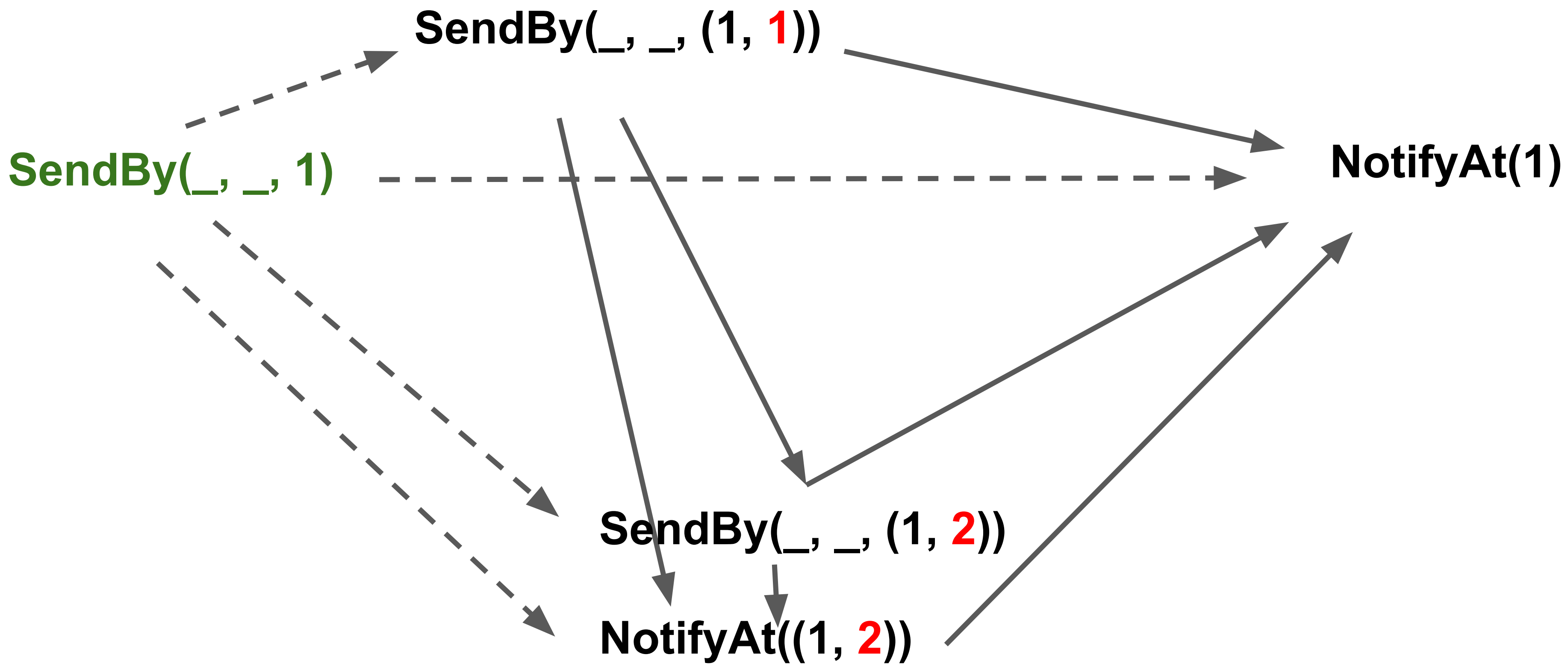

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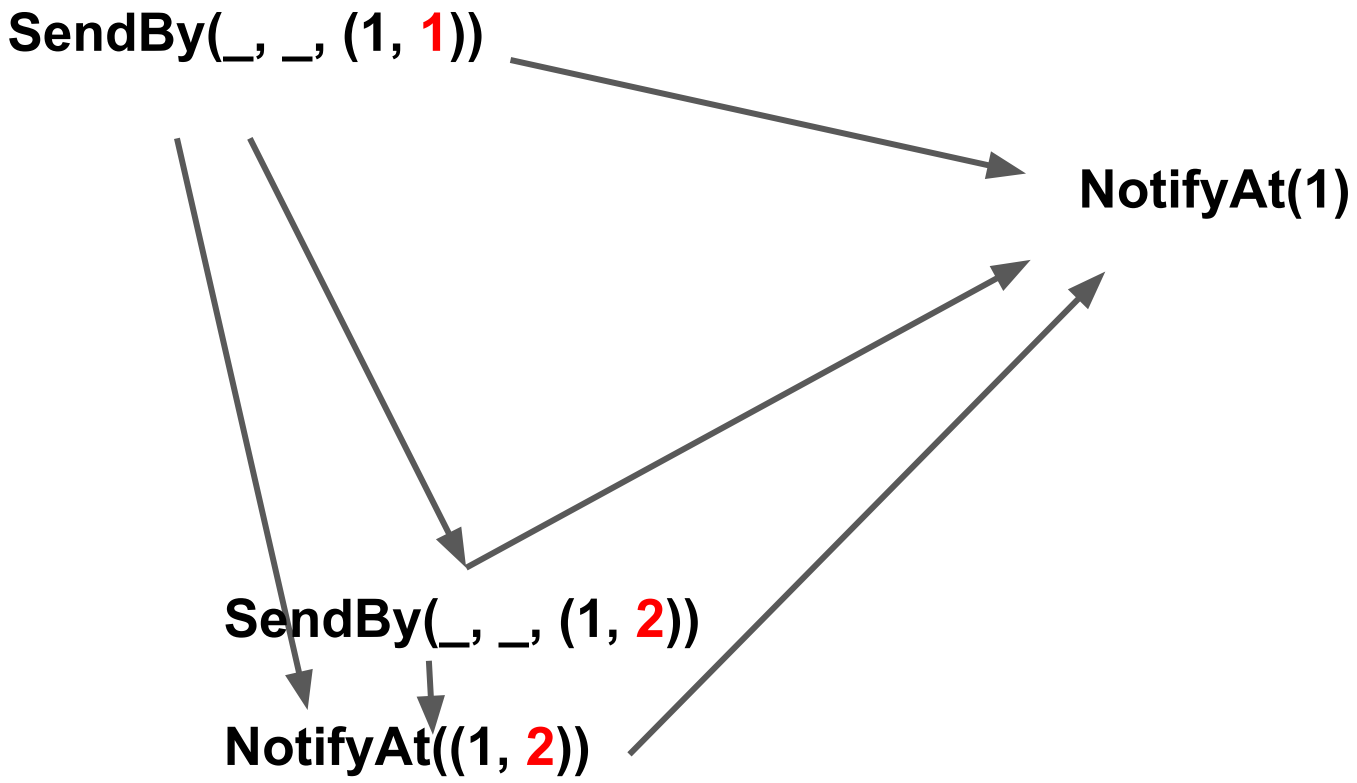

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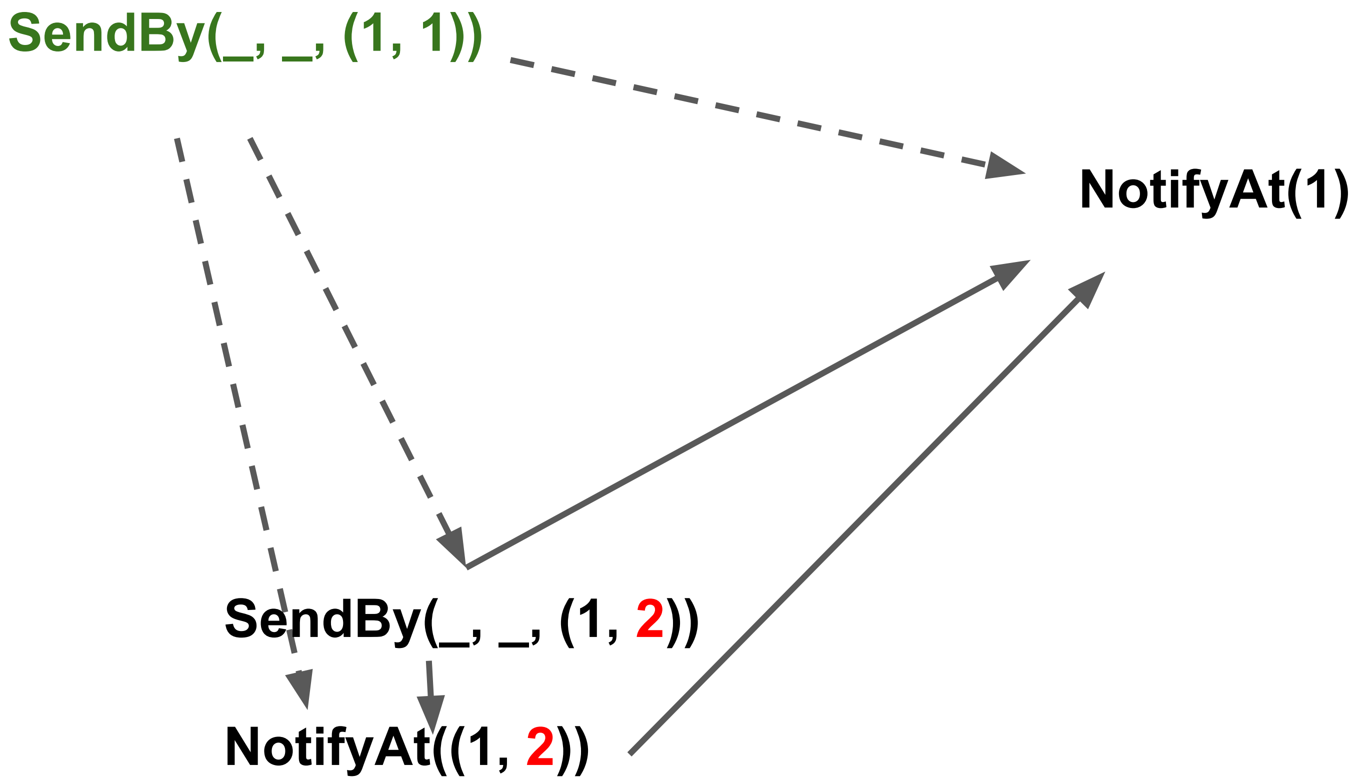

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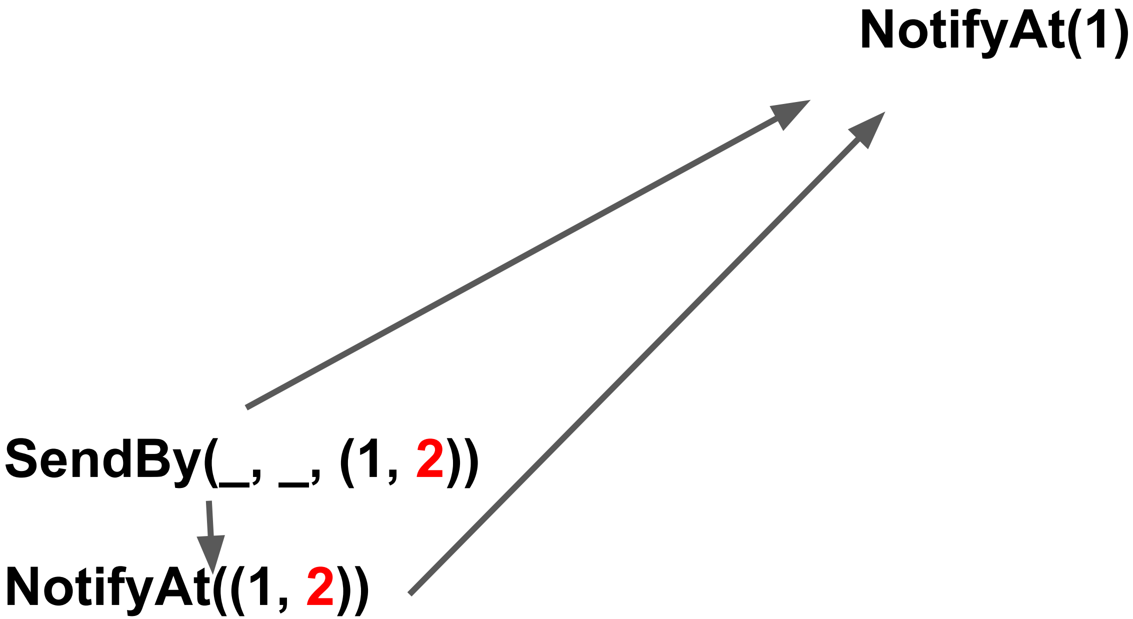

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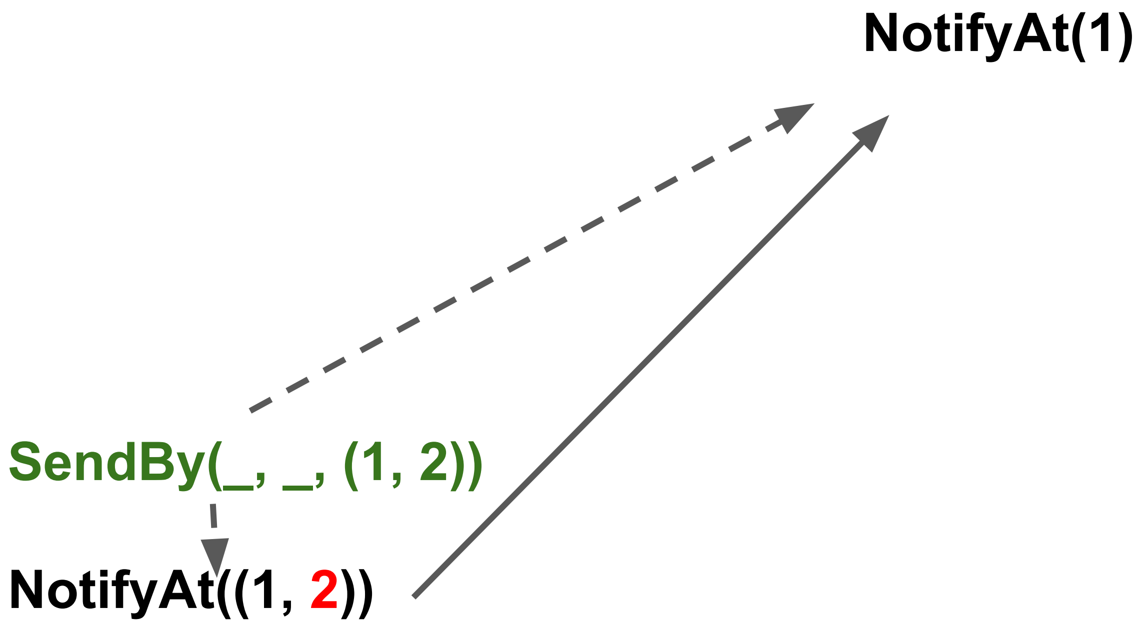
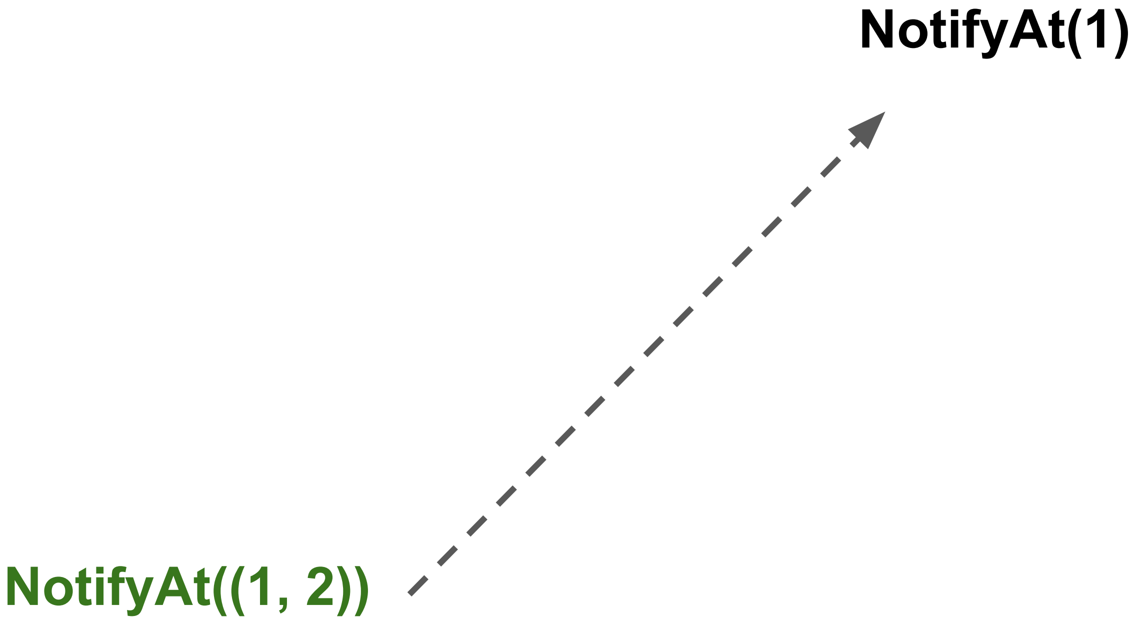


Sort by *could-result-in* order

NotifyAt(1)

NotifyAt((1, 2))

Sort by *could-result-in* order



Sort by *could-result-in* order

NotifyAt(1)

Send notification!

NotifyAt((1, 2))

Sort by *could-result-in* order

NotifyAt(1)

Sort by *could-result-in* order

Send notification!

NotifyAt(1)

Sort by *could-result-in* order

Sort by *could-result-in* order

...a notification can be delivered **only** when no possible predecessors of a timestamp exist

Sort by *could-result-in* order

...a notification can be delivered **only** when no possible predecessors of a timestamp exist

(based on timestamps + graph structure)

Low vs High Level Interfaces

Low vs High Level Interfaces

Event-based system

```
SendBy(edge, message, time)

OnRecv(edge, message, time)

NotifyAt(time)

OnNotify(time)
```

Low vs High Level Interfaces

Event-based system

SendBy(edge, message, time)

OnRecv(edge, message, time)

NotifyAt(time)

OnNotify(time)

Common dataflow interfaces (LINQ, Pregel)

```
// 1a. Define input stages for the dataflow.
var input = controller.NewInput<string>();

// 1b. Define the timely dataflow graph.
// Here, we use LINQ to implement MapReduce.
var result = input.SelectMany(y => map(y))
                  .GroupBy(y => key(y),
                    (k, vs) => reduce(k, vs));

// 1c. Define output callbacks for each epoch
result.Subscribe(result => { ... });

// 2. Supply input data to the query.
input.OnNext(/* 1st epoch data */);
input.OnNext(/* 2nd epoch data */);
input.OnCompleted();
```

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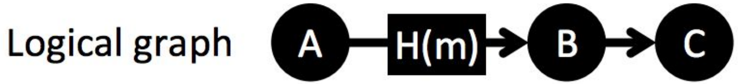
Implementation: Naiad



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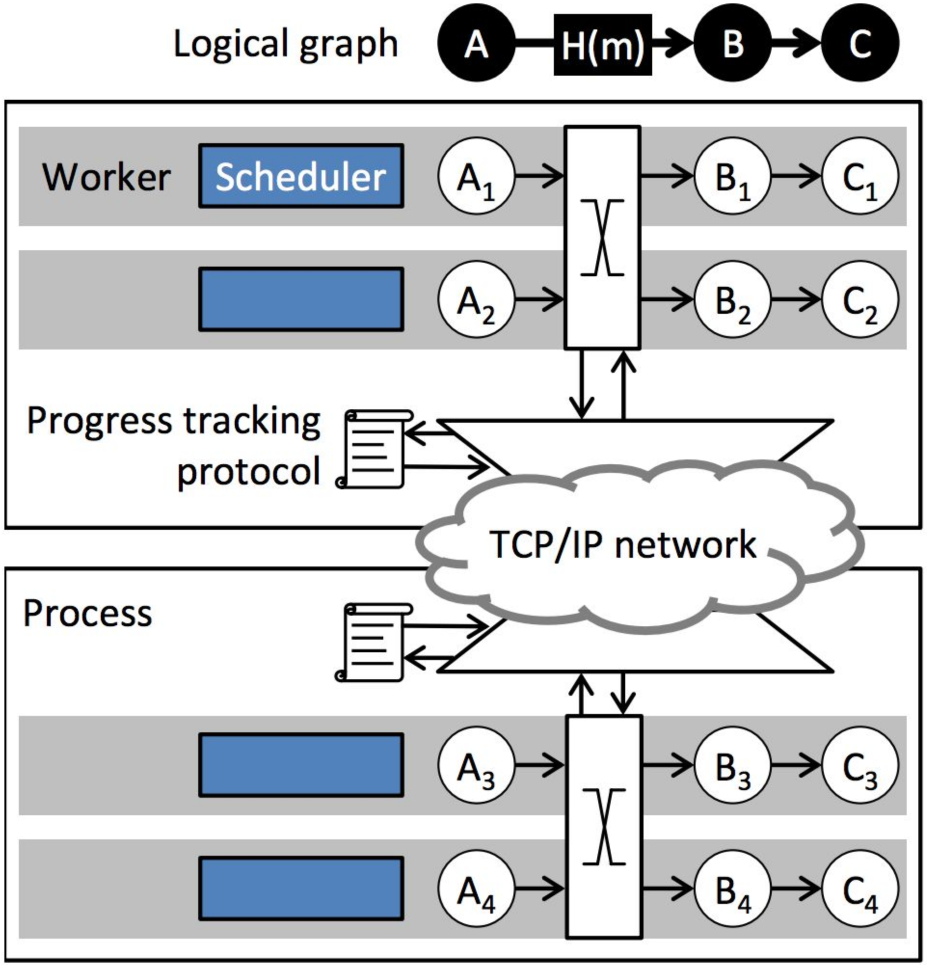
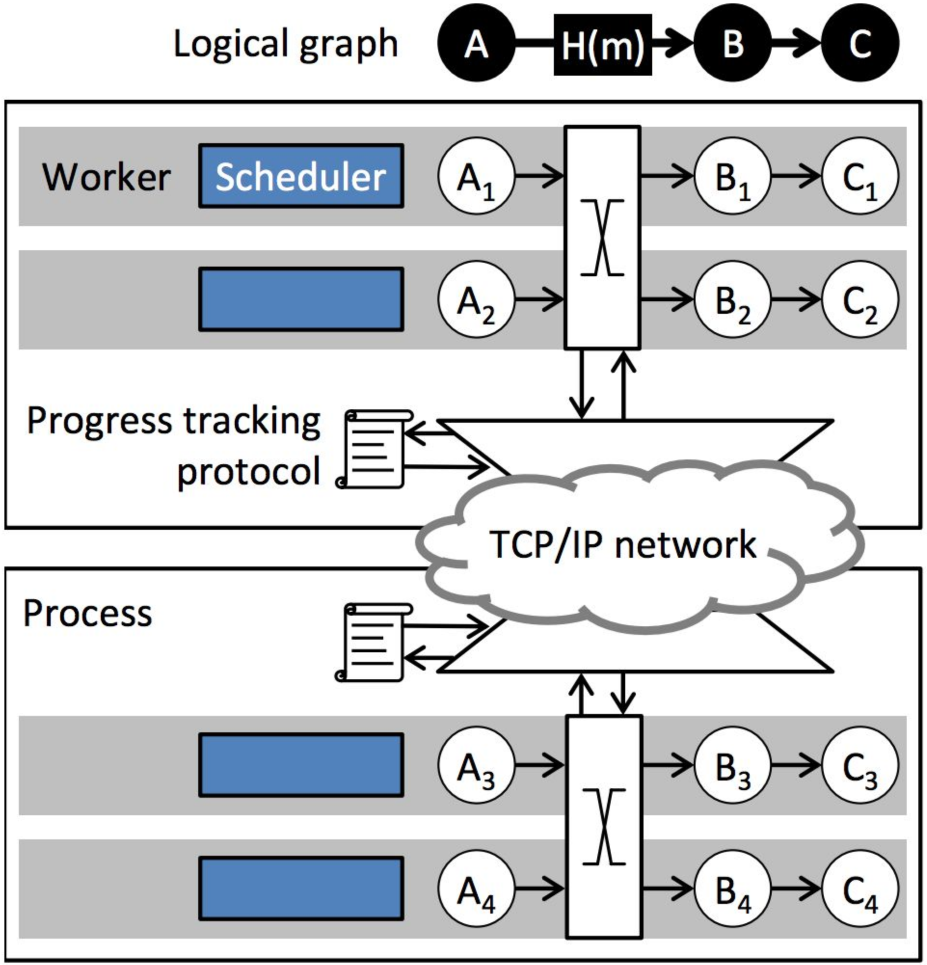


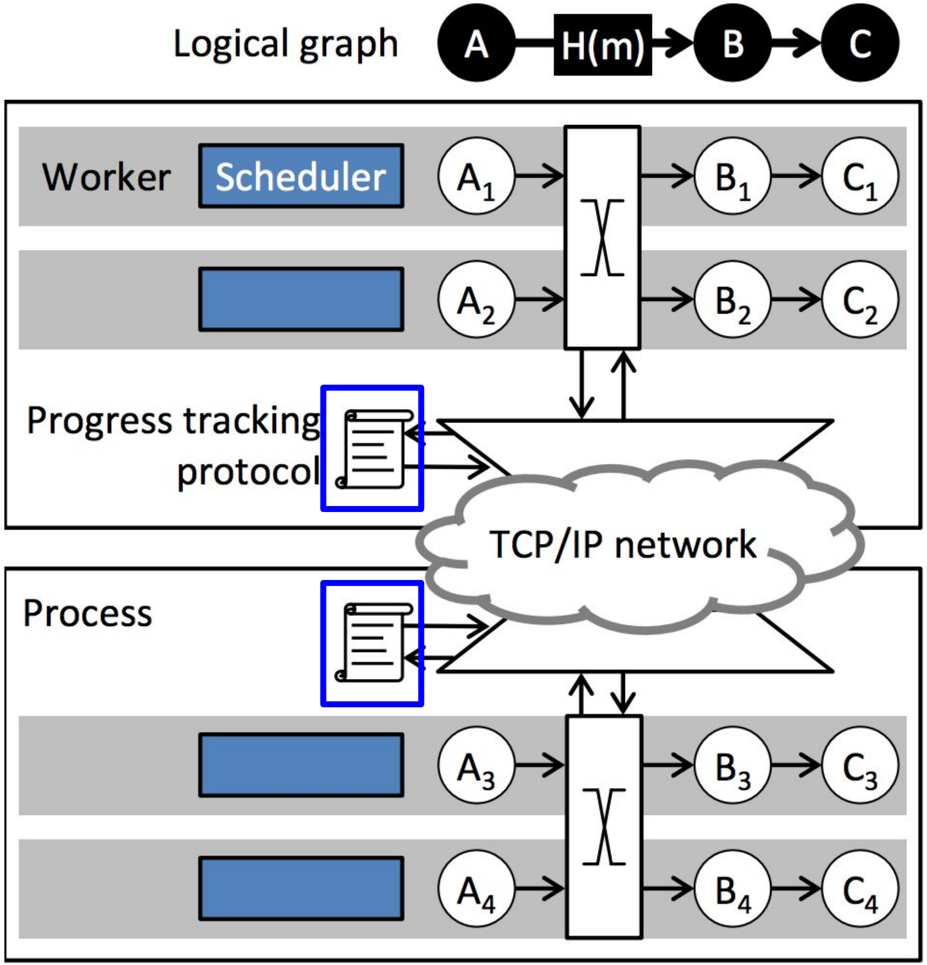
Distributed Progress Tracking



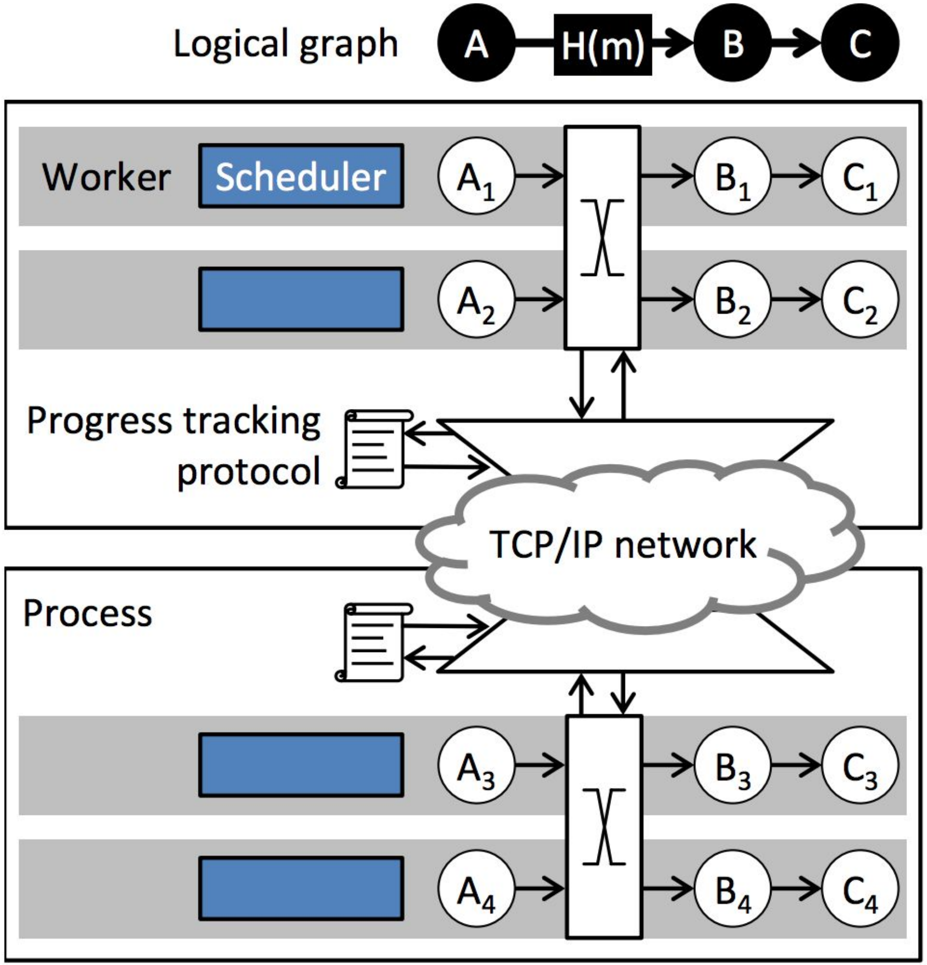
Distributed Progress Tracking

Each node has its own local progress tracker, must be *conservative*

Updates other nodes over network as events finish



Optimizations



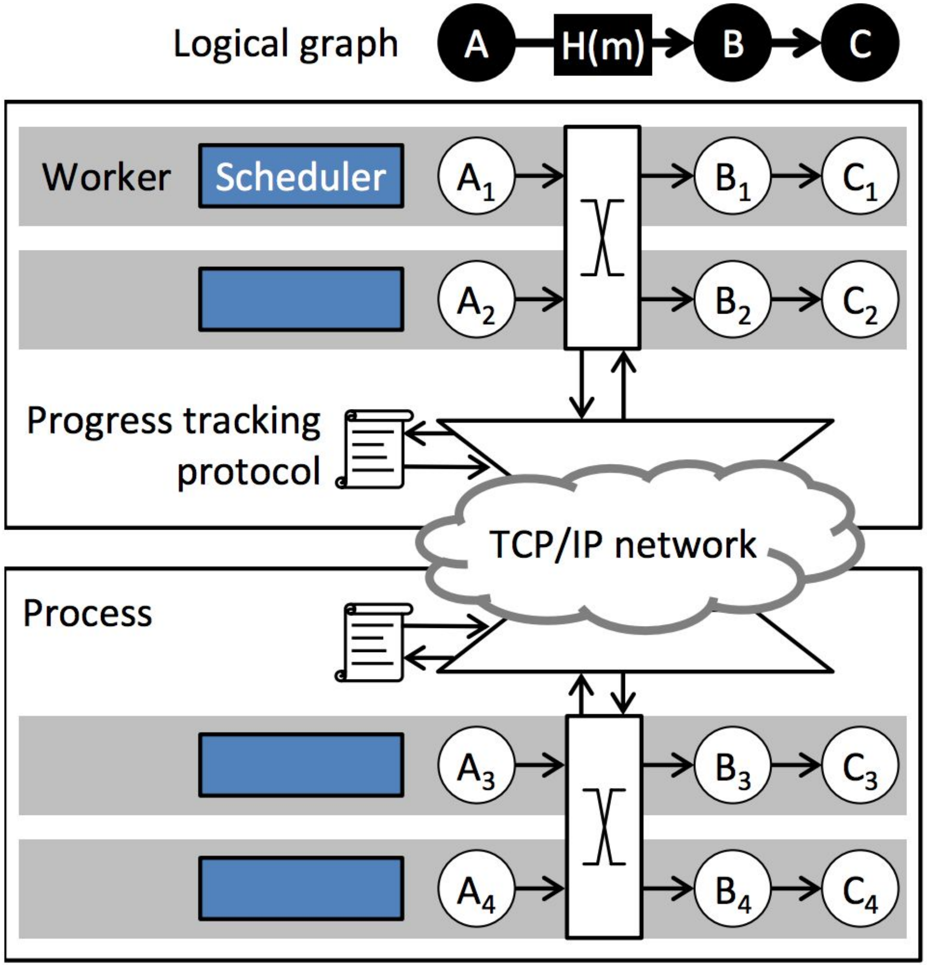
Optimizations

Reduce small delays
micro-stragglers

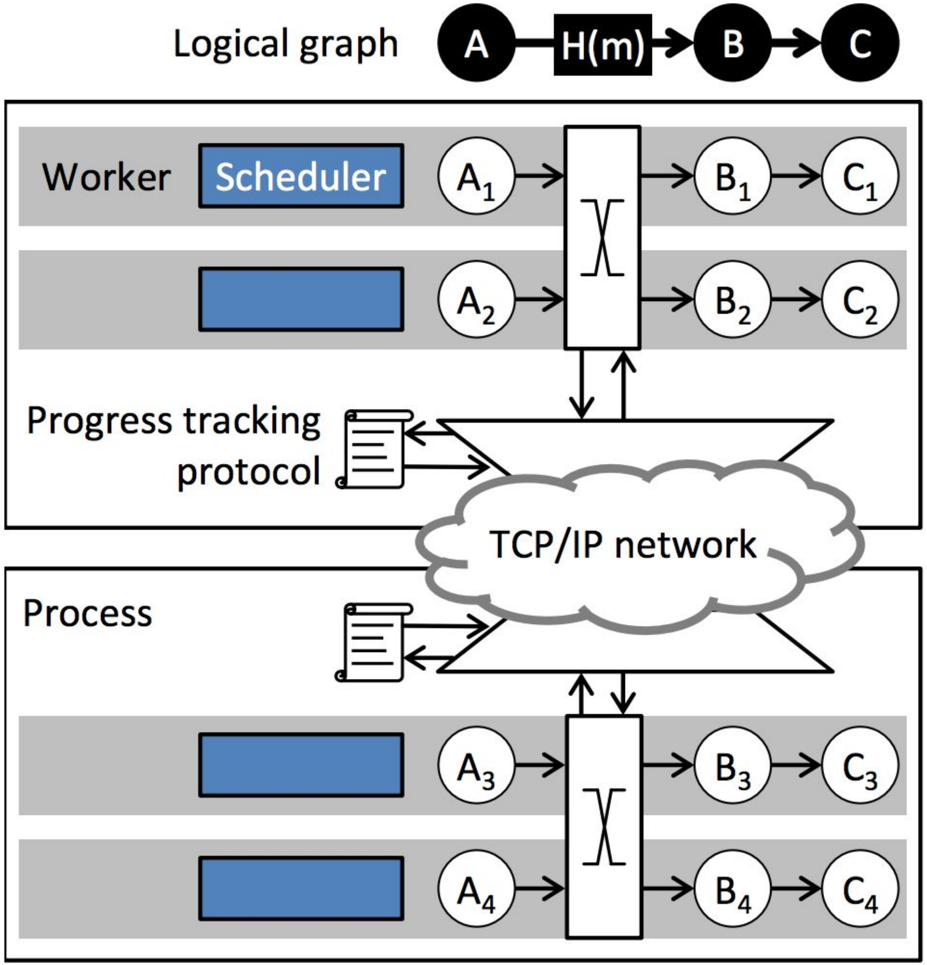
Tweak TCP configuration

GC less often

Reduce backoff time to 1ms after concurrent access to shared memory



Fault Tolerance

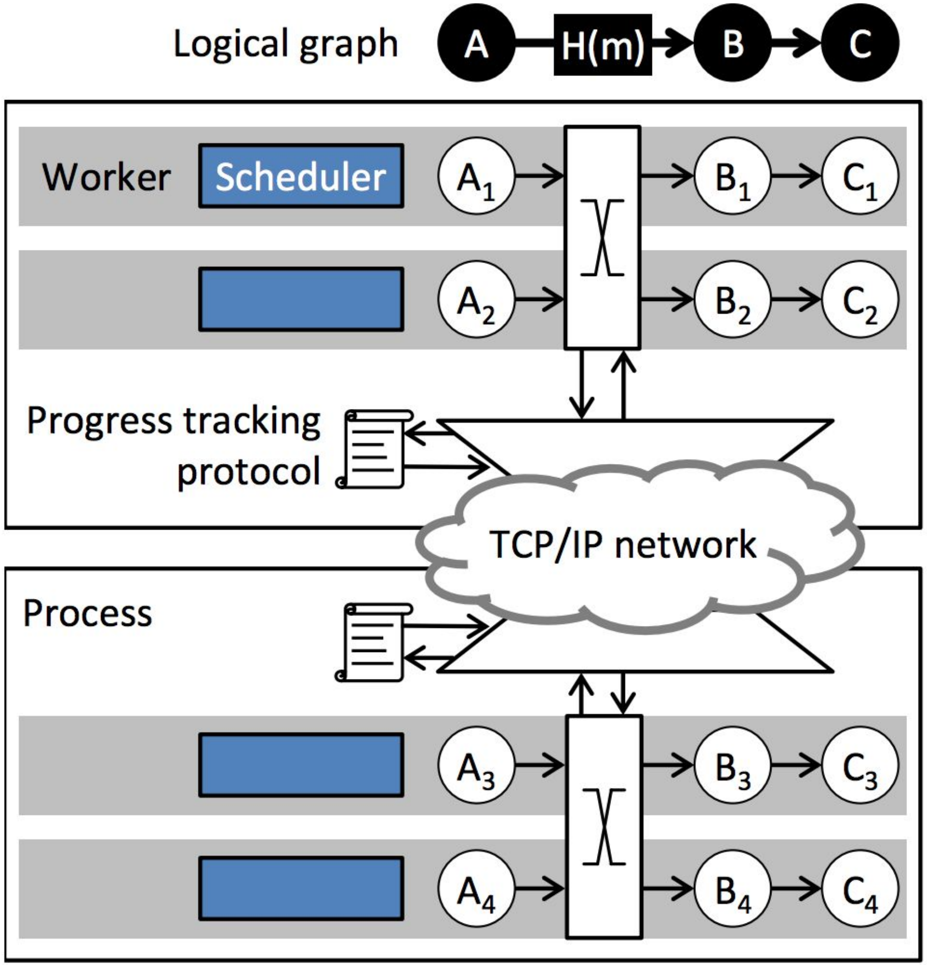


Fault Tolerance

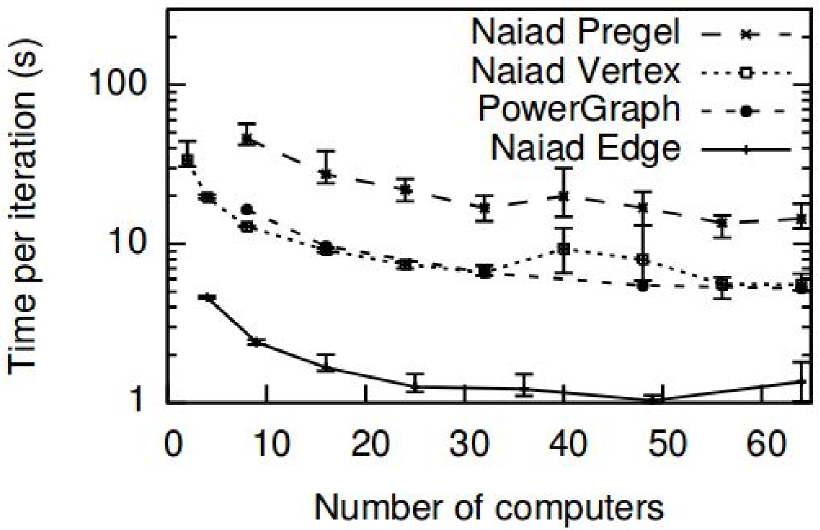
Since vertices have dynamic state, one failure -> all nodes have to reset from checkpoint

System-wide synchronized checkpoints

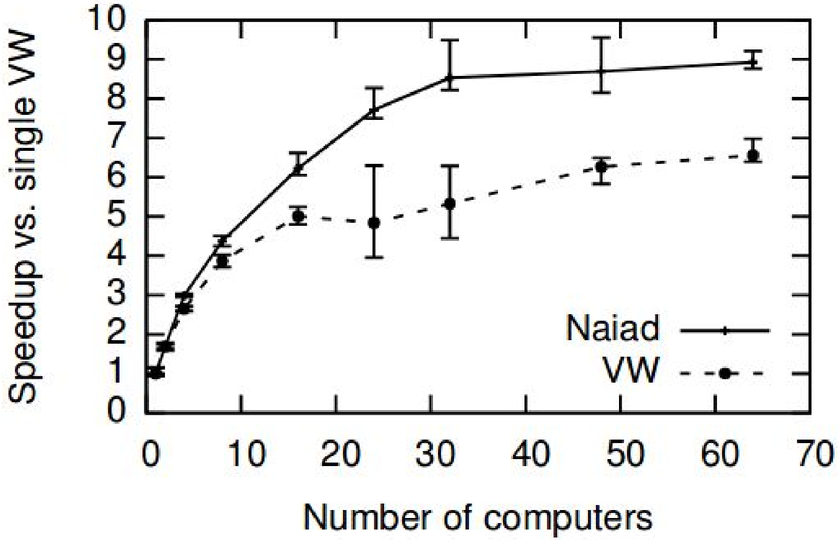
Tradeoff between how often to log checkpoints and performance



Evaluation

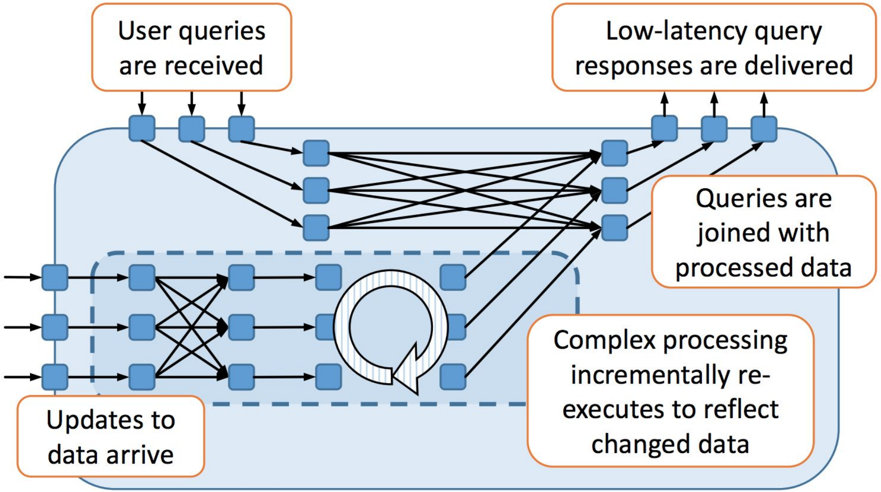


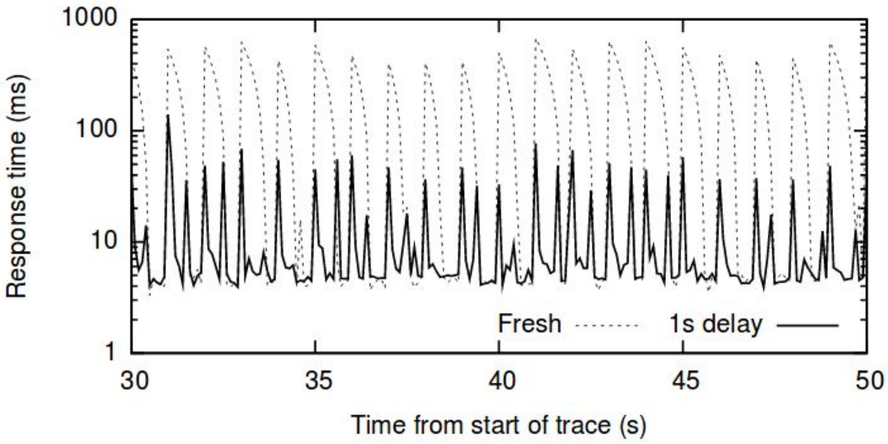
(a) PageRank on Twitter follower graph (§6.1)



(b) Logistic regression speedup (§6.2)

Evaluation


User queries are received
Low-latency query responses are delivered
Queries are joined with processed data
Complex processing incrementally re-executes to reflect changed data
Updates to data arrive


1000
100
10
1
Response time (ms)
30
35
40
45
50
Time from start of trace (s)
Fresh
1s delay

Contributions

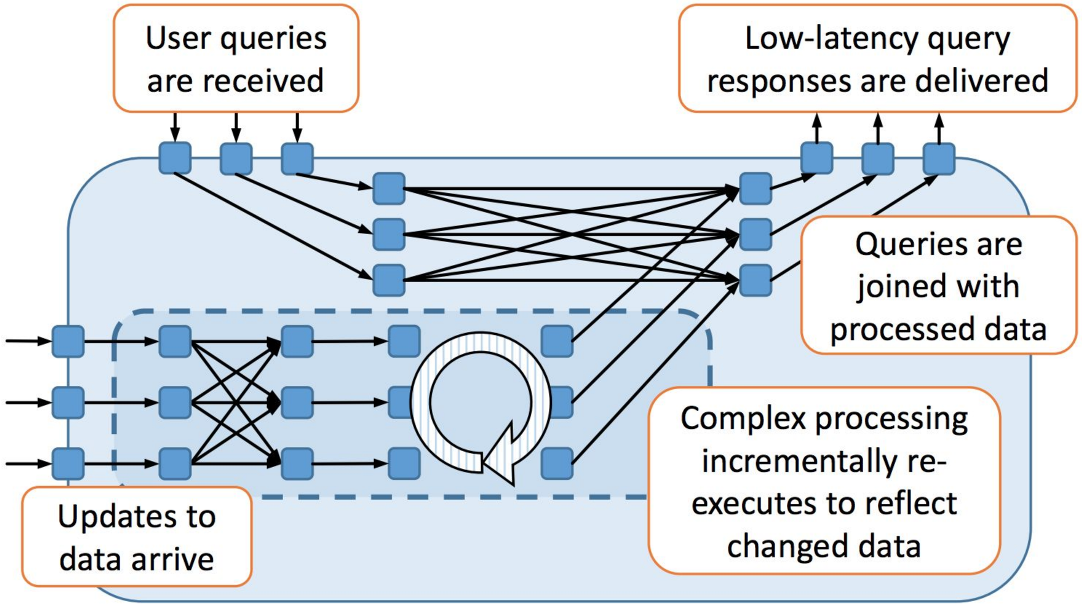
1. **Timely dataflow**, a dataflow computing model which supports batch, stream, and graph-centric iterative processing
   a. Supports common high-level programming interfaces (e.g. LINQ)
2. **Naiad**, a high-performance distributed implementation of the model
   a. Faster than SOTA batch/streaming frameworks

My opinion

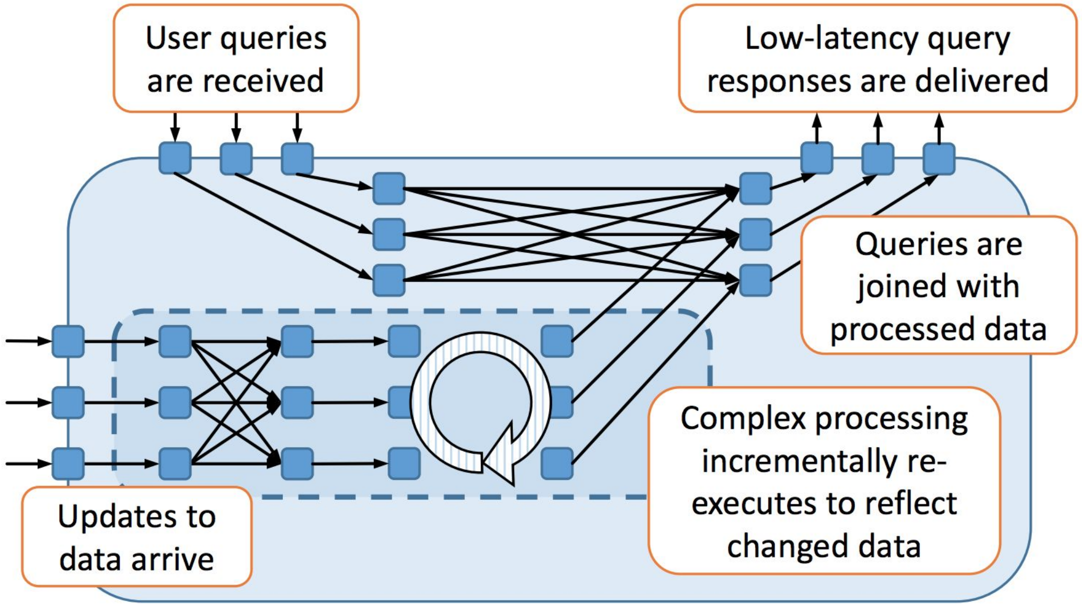
My opinion

- Computational model is theoretically sound
  - Iterative computation without modifying graph in e.g. CIEL (which has overhead)
- Evaluation good too, though dramatic speedups likely better than real-world applications
- Fine-grained control over logging for fault tolerance/throughput tradeoff seems annoying
- But…

What problem does Naiad solve?

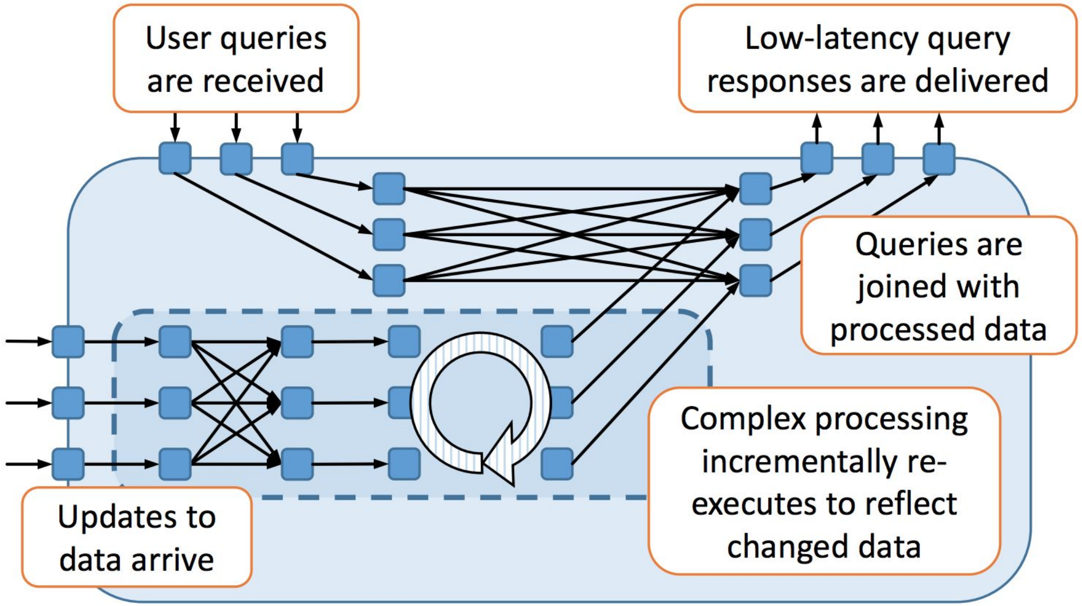


What problem does Naiad solve?



"While it might be possible to assemble the application in Figure 1 by combining multiple existing systems, applications built on a single platform are typically more efficient, succinct, and maintainable."

What problem does Naiad solve?



“While it might be possible to assemble the application in Figure 1 by combining multiple existing systems, applications built on a single platform are **typically** more efficient, succinct, and maintainable.”

My opinion

- Computational model is theoretically sound
  - Iterative computation without modifying graph in e.g. CIEL (which has overhead)
- Evaluation good too, though dramatic speedups likely better than real-world applications
- Fine-grained control over logging for fault tolerance/throughput tradeoff seems annoying
- But…
  - For all but especially complex systems requiring graph + stream + batch, existing systems probably work just fine + have better infrastructure

Naiad: A Timely Dataflow System

Derek G. Murray Frank McSherry
Rebecca Isaacs Michael Isard
Paul Barham Martín Abadi
MSR Silicon Valley

Presented by Jesse Mu (jlm95)