It’s About Time: An Introduction to Timely Dataflow

Data Council, October ‘19

clockworks

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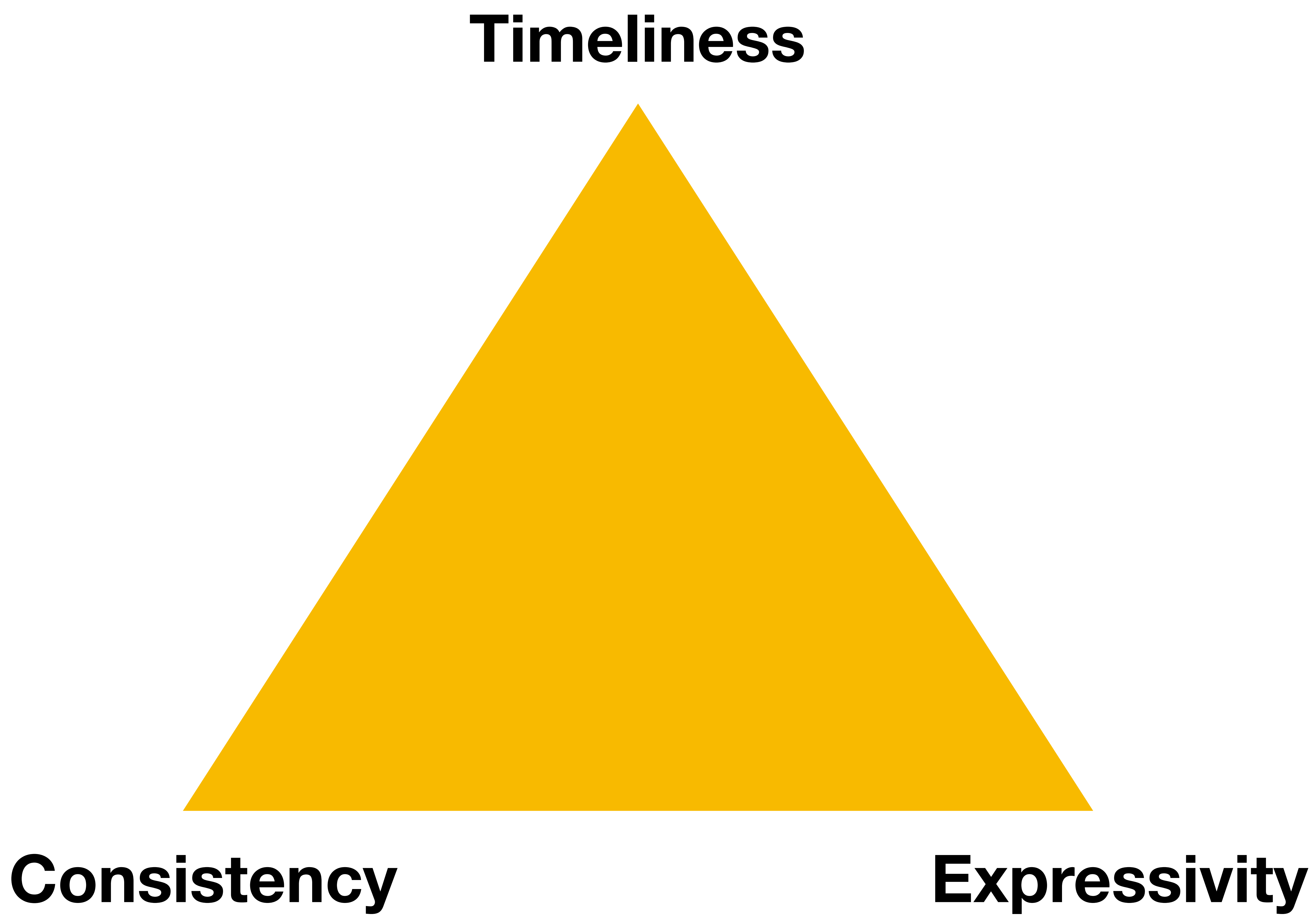
Systems Group

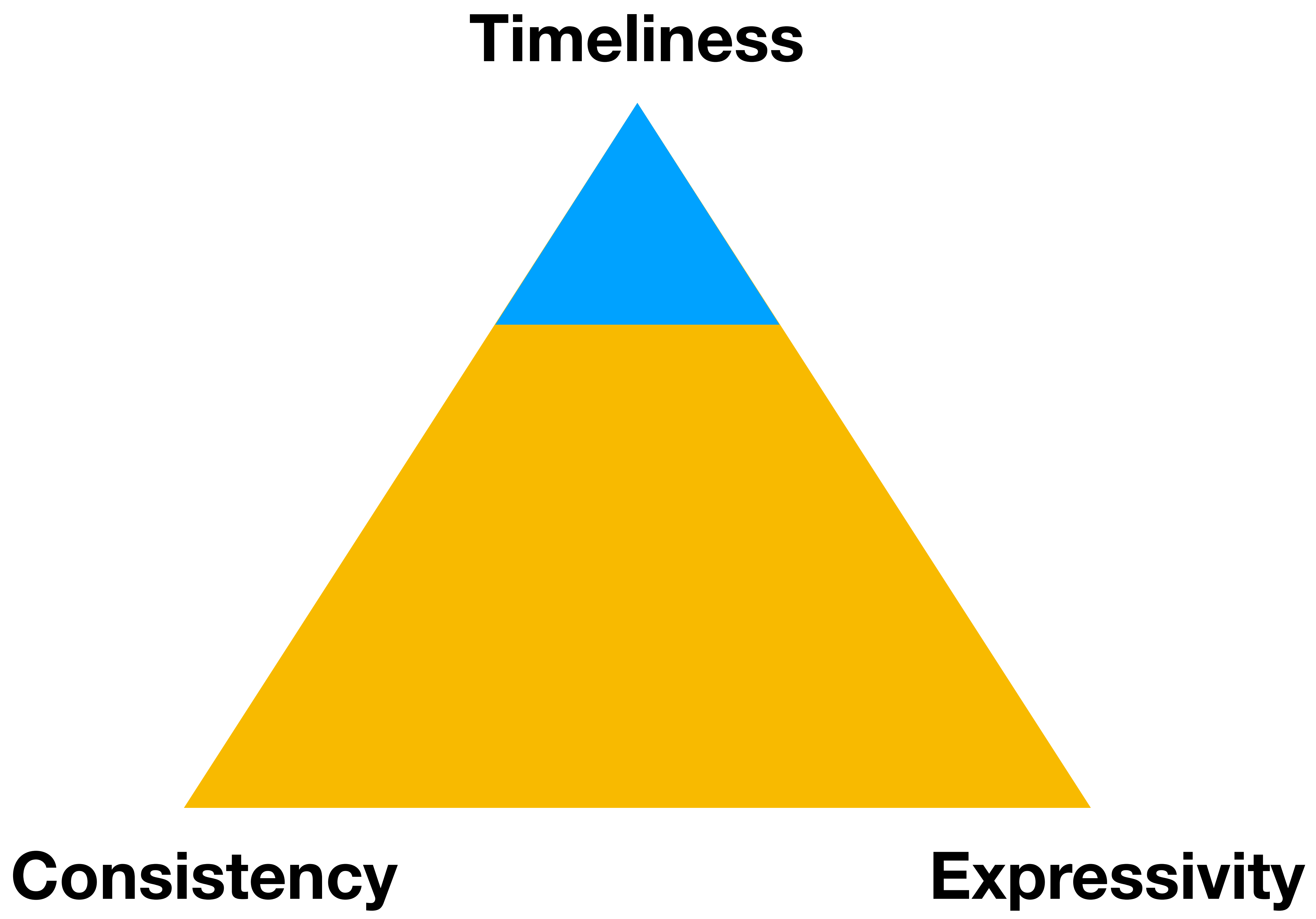
Stream Processing's Trifecta



Stream Processing's Trifecta

Naive Stateless Processing

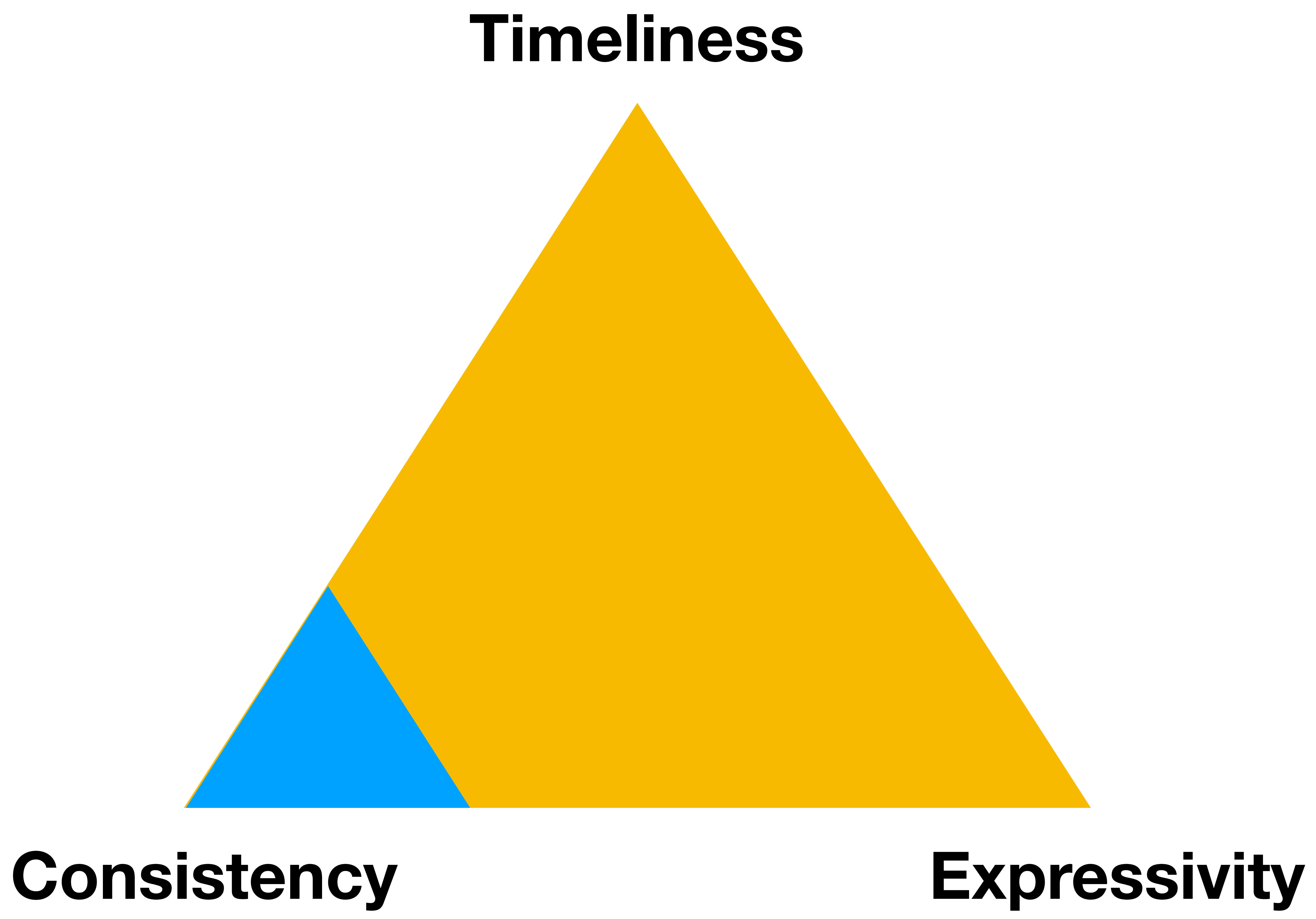
- Low latency
- Issue: Late arrivals
- Issue: Complex computations



Stream Processing's Trifecta

MapReduce

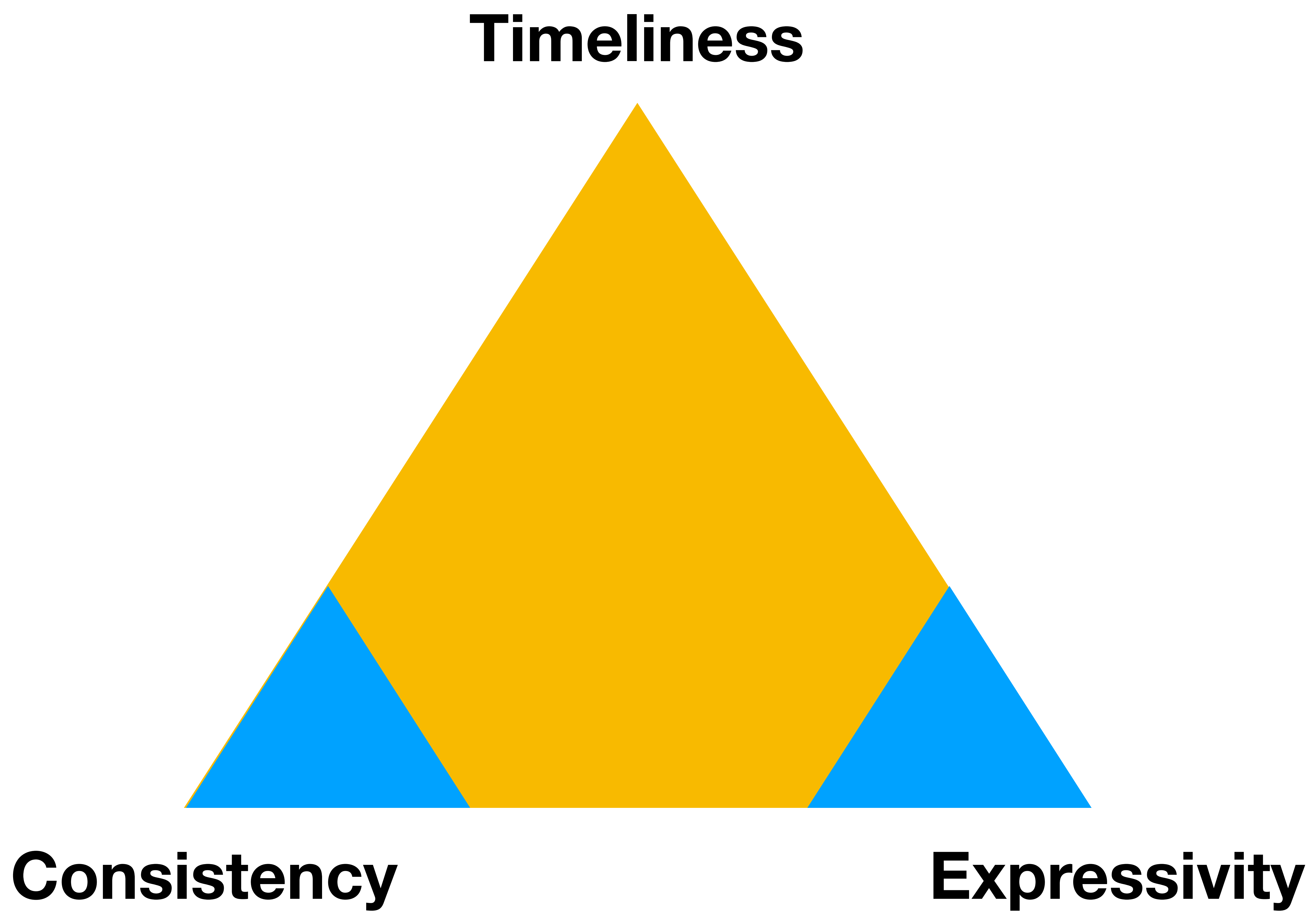
- No late arrivals (by definition)
- Easy to scale
- Issue: Complex computations
- Issue: High latency



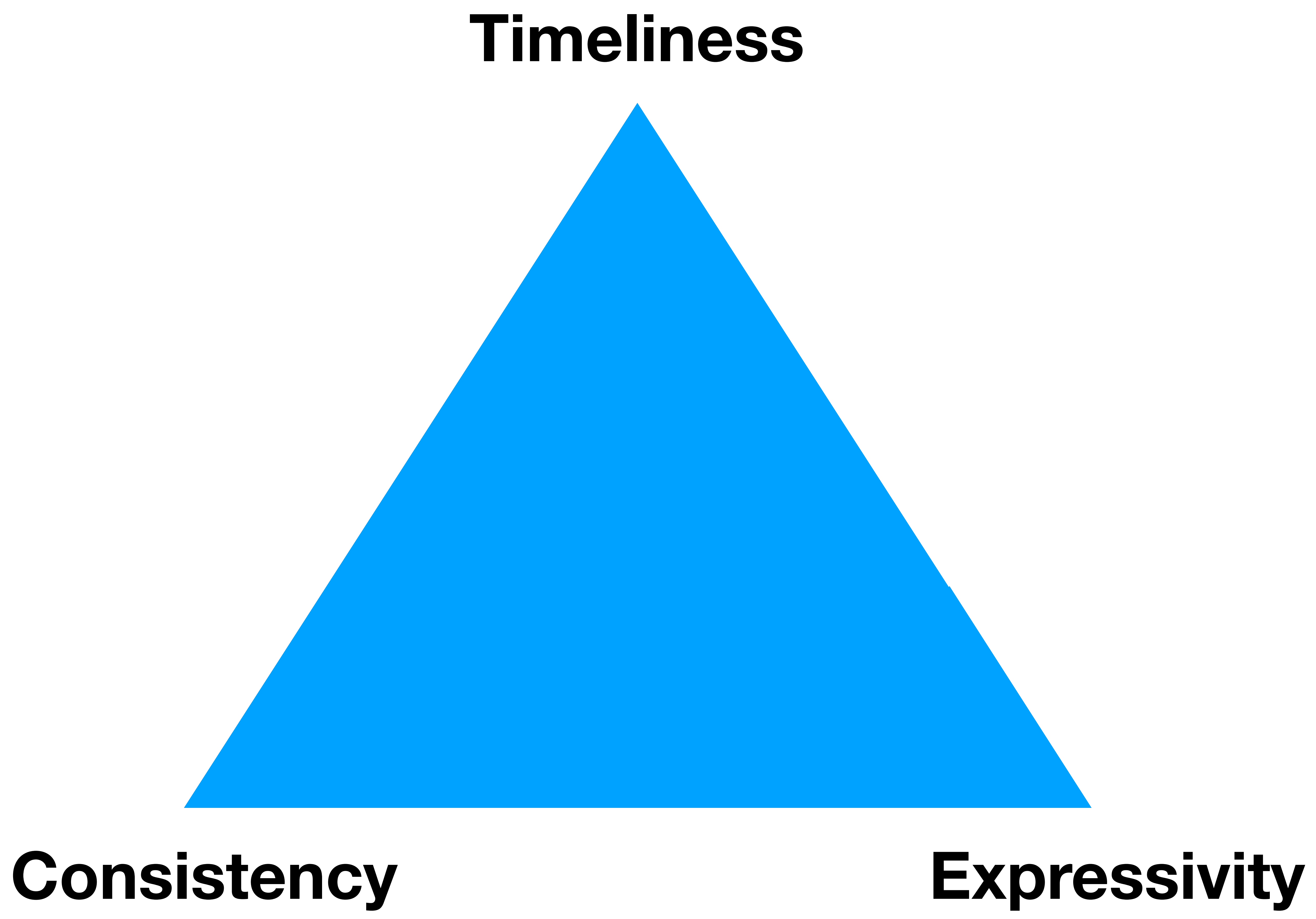
Stream Processing's Trifecta

Database

- No late arrivals
- High expressivity
- ACID
- Issue: Not realtime!

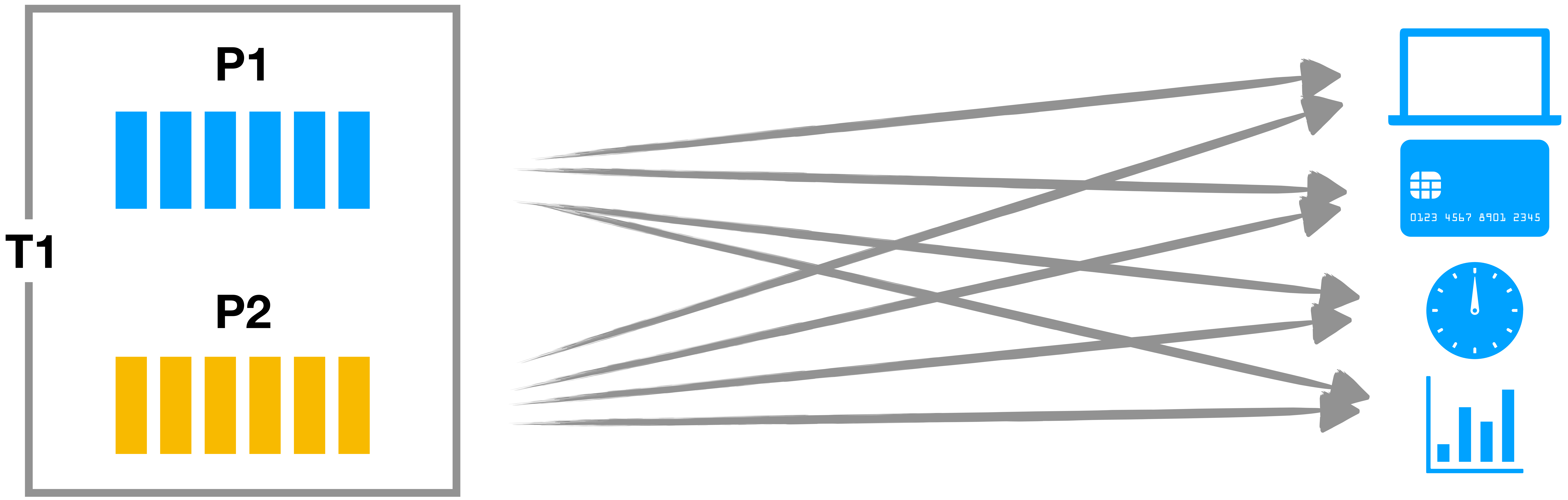


Stream Processing’s Trifecta

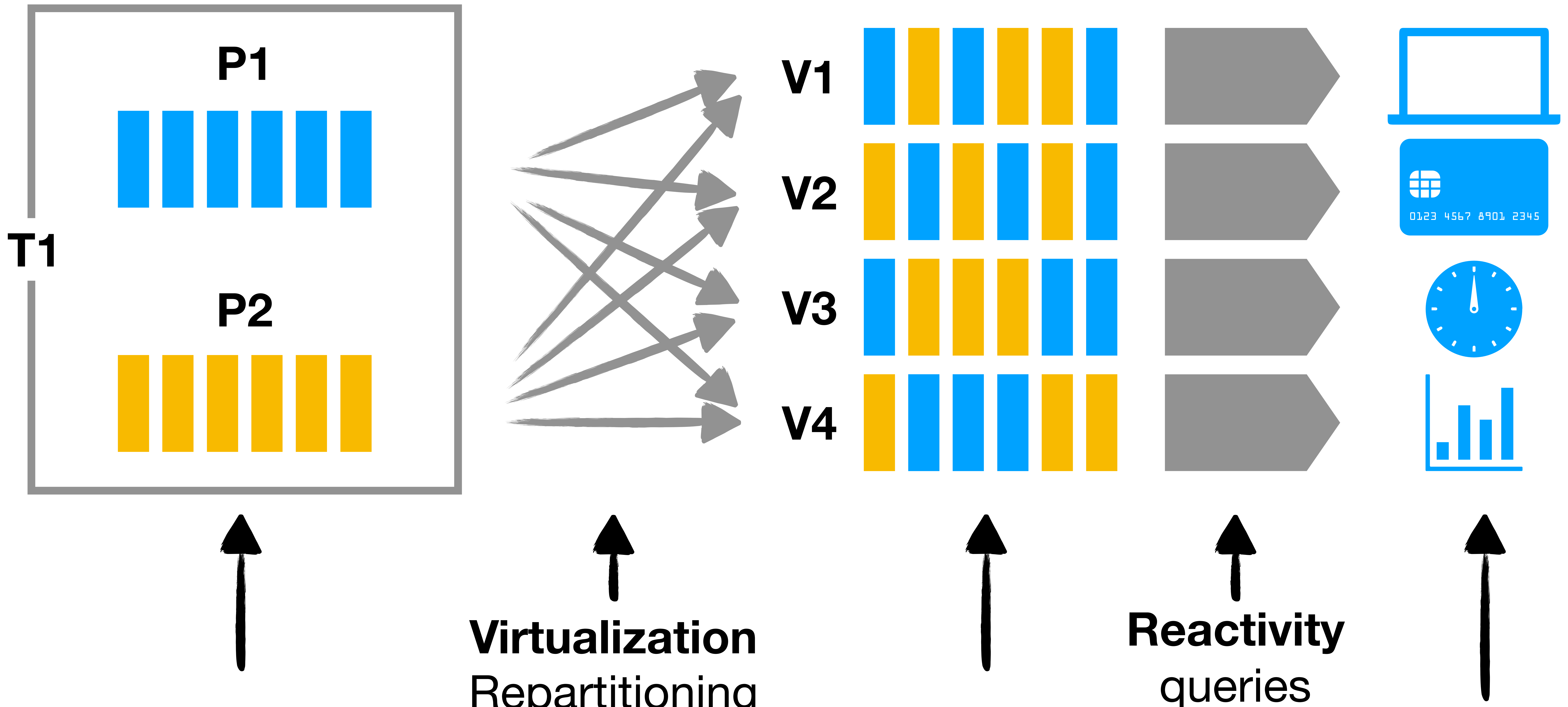


Use Case: Kafka Superpowers

(Partitions complect physical representation & use case)



Use Case: Kafka Superpowers



Physical Representation

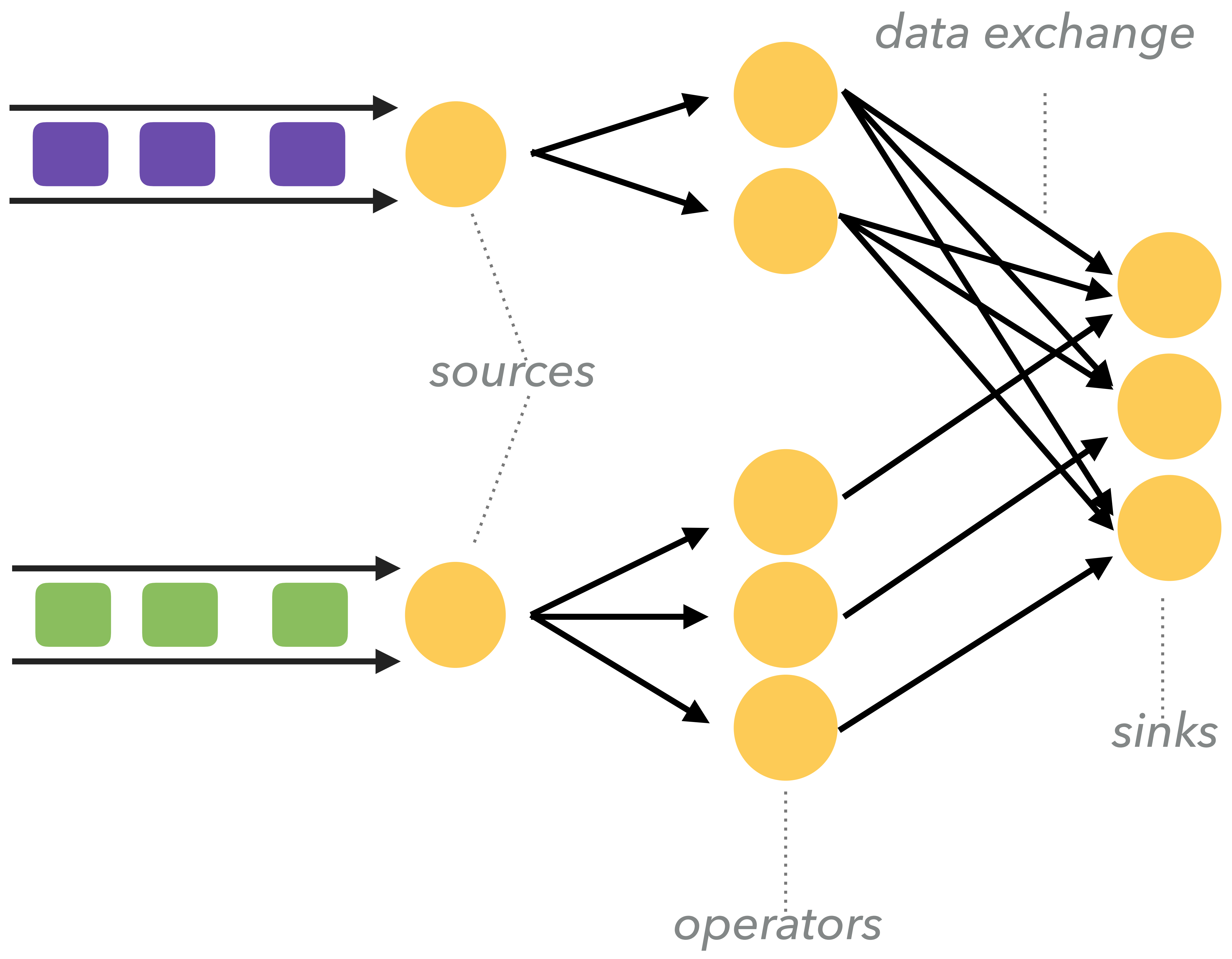
Virtualization
Repartitioning
Joins

Virtual Partitions
time order

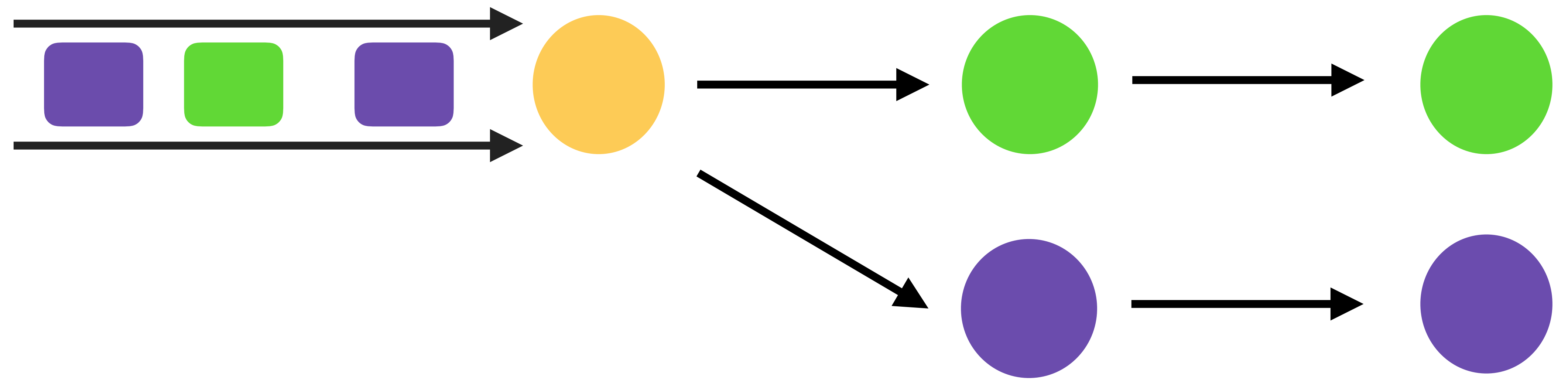
Reactivity
queries

Business Logic

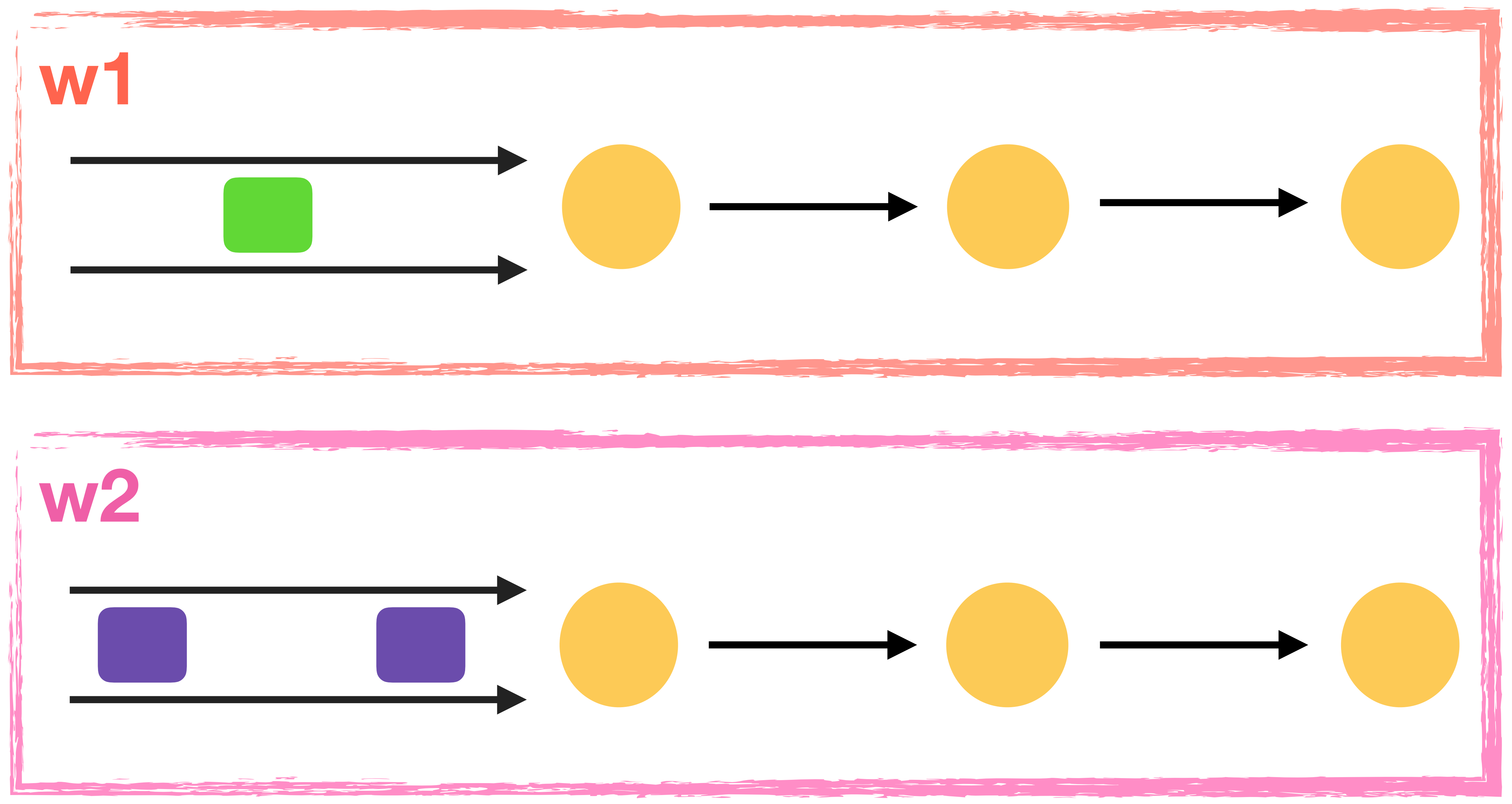
Stream Processing as Dataflow



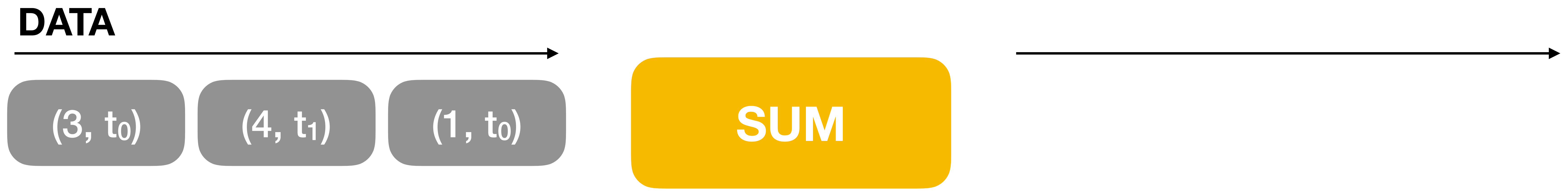
Dataflow Parallelism



Dataflow Distribution



Correctness Troubles



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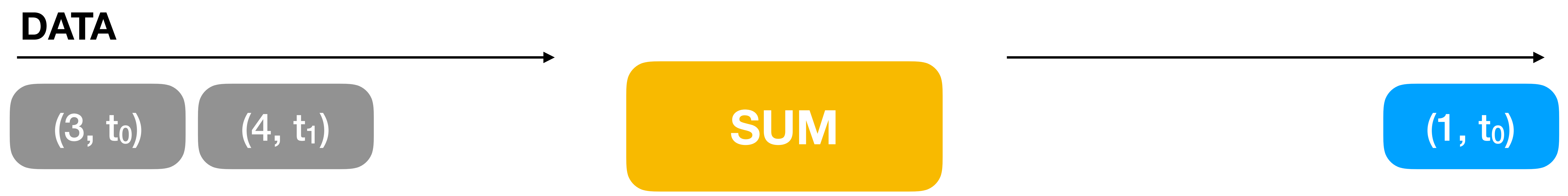

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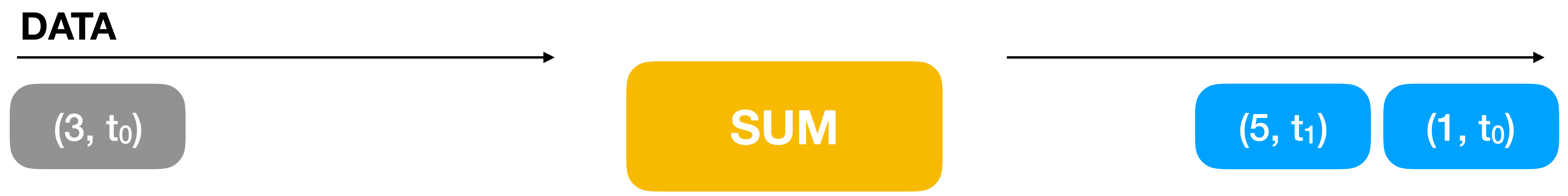

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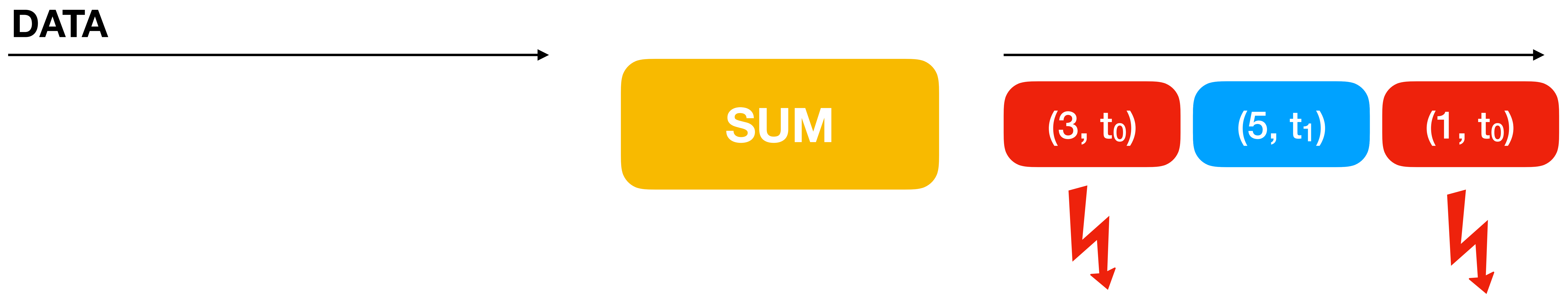
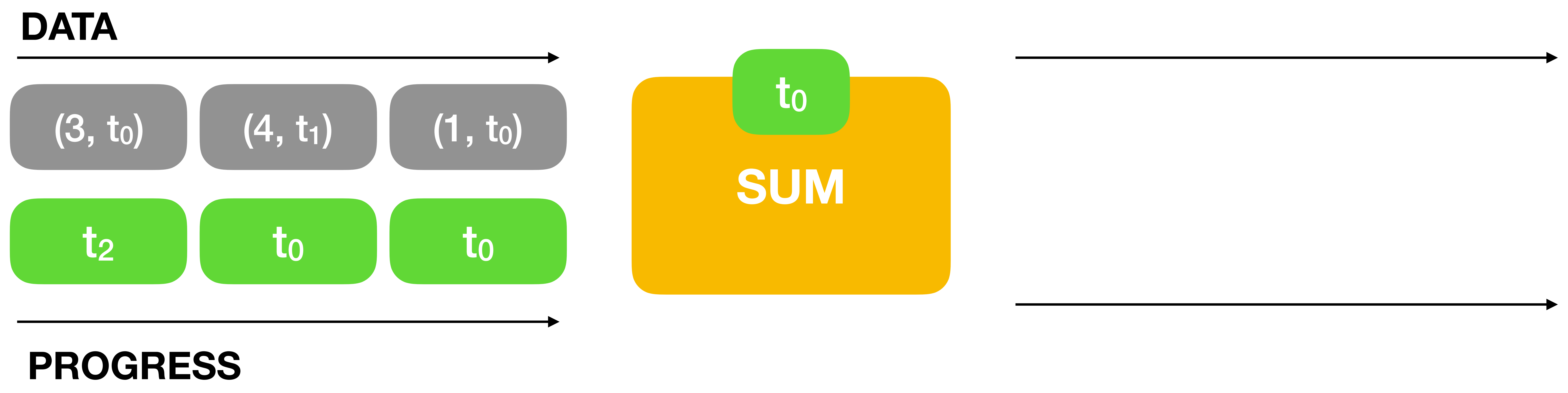


Timely Dataflow

A low-latency runtime for
distributed cyclic dataflows

github.com/**TimelyDataflow**

Correctness with Progress Tracking



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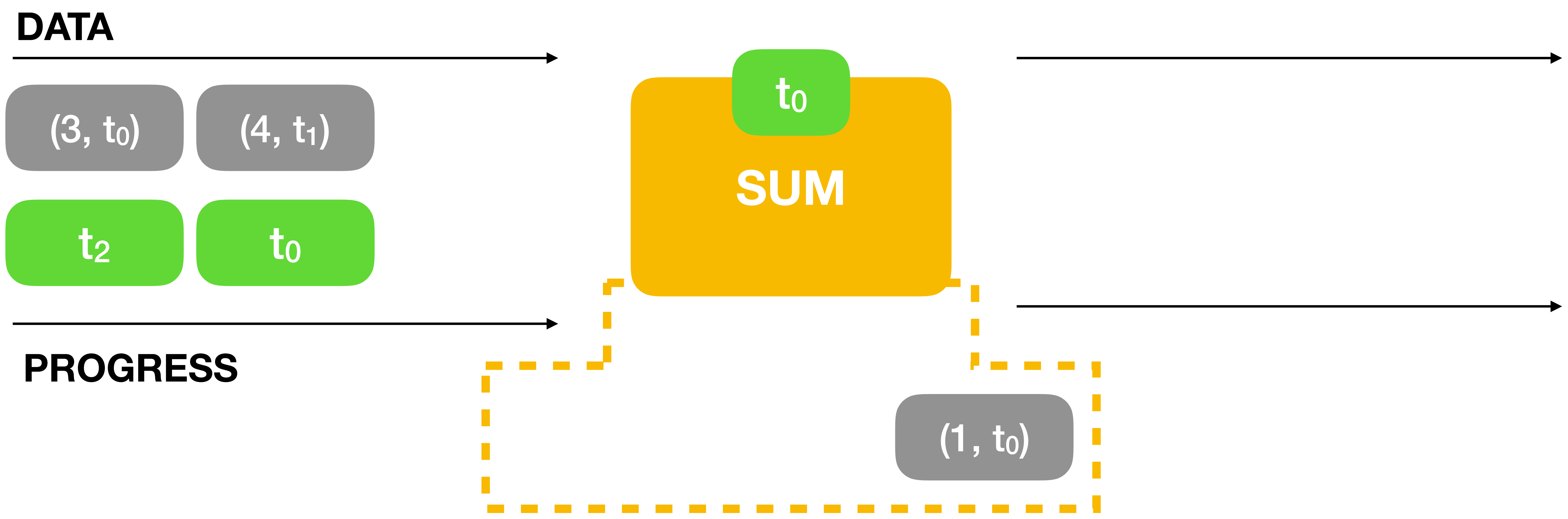

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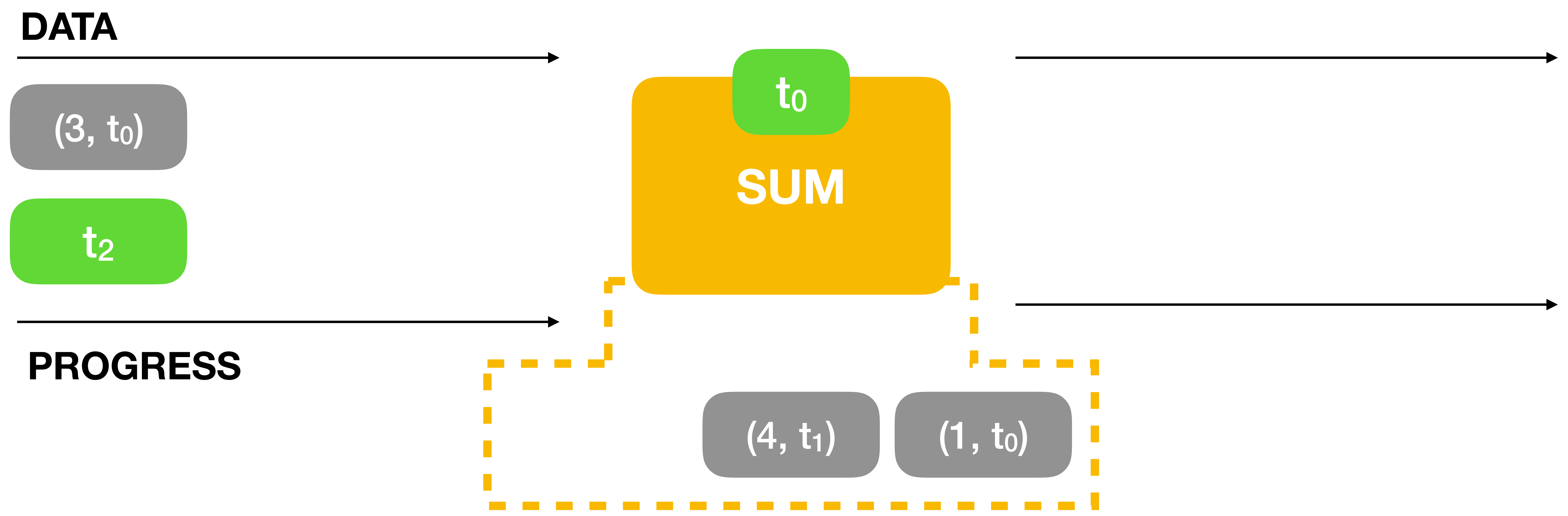

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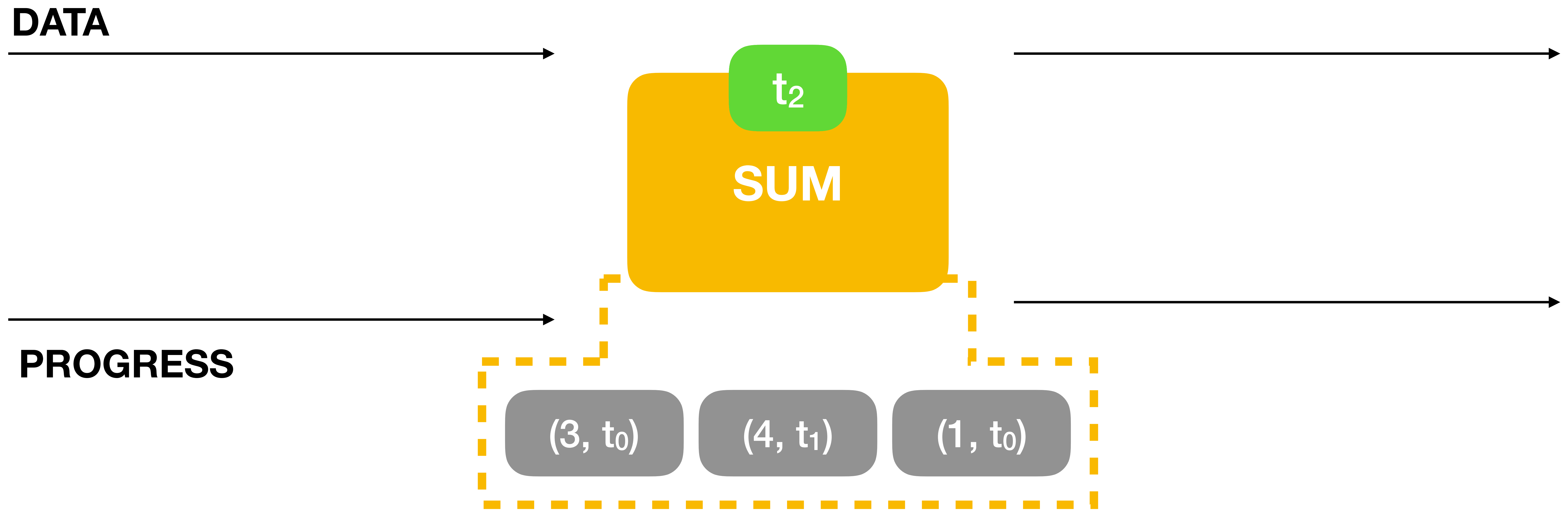

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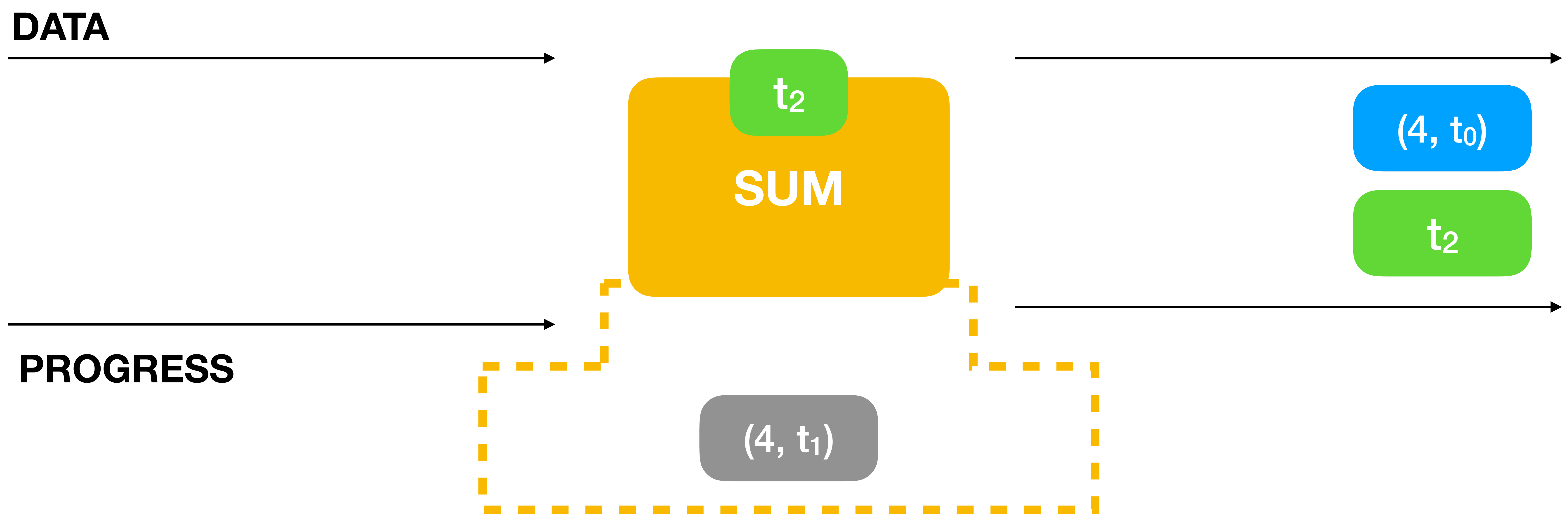

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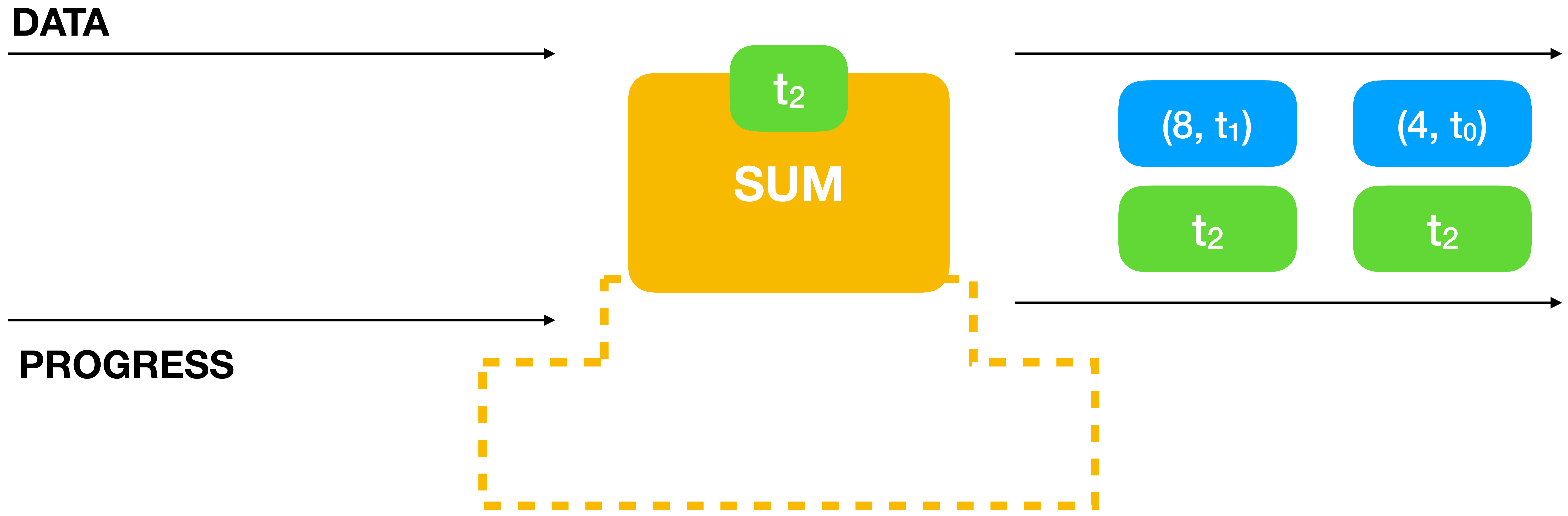
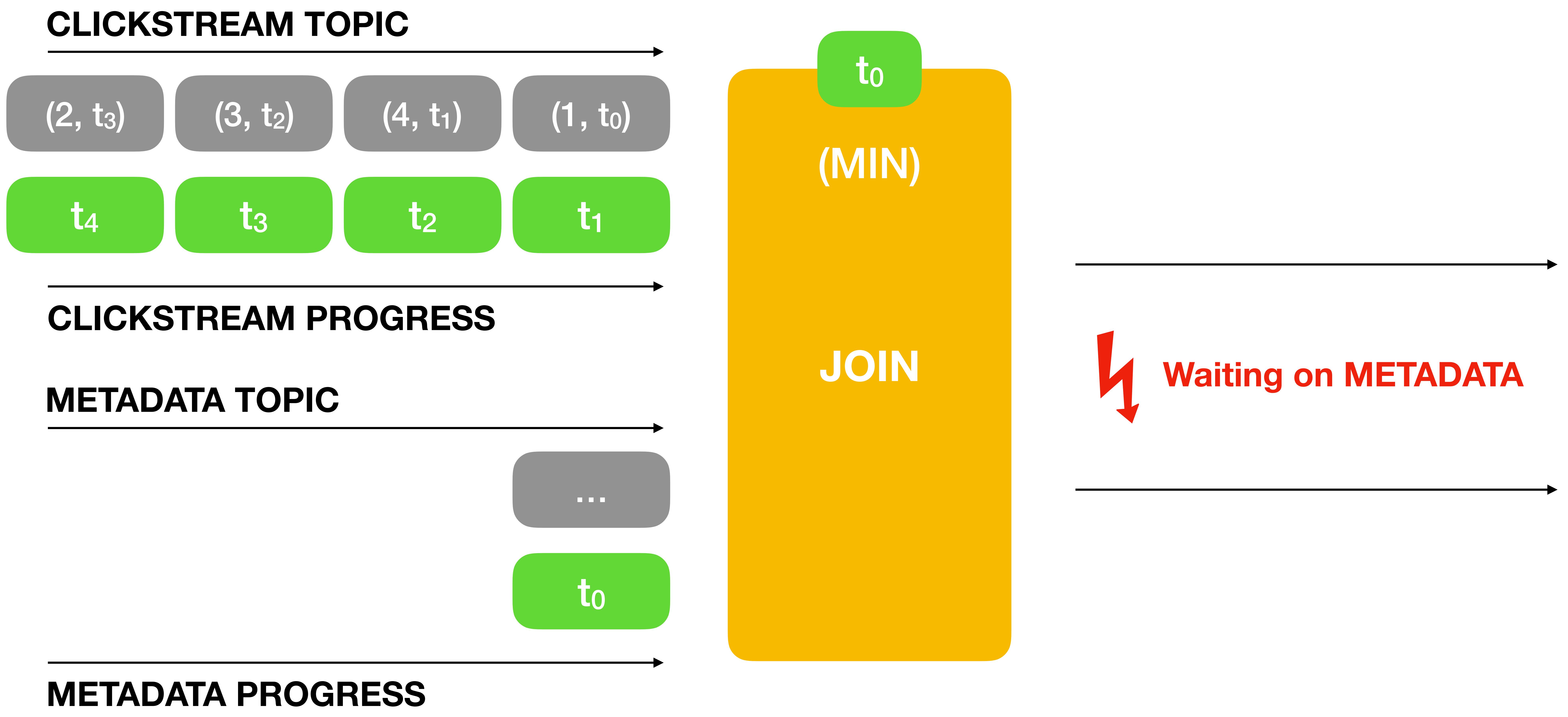
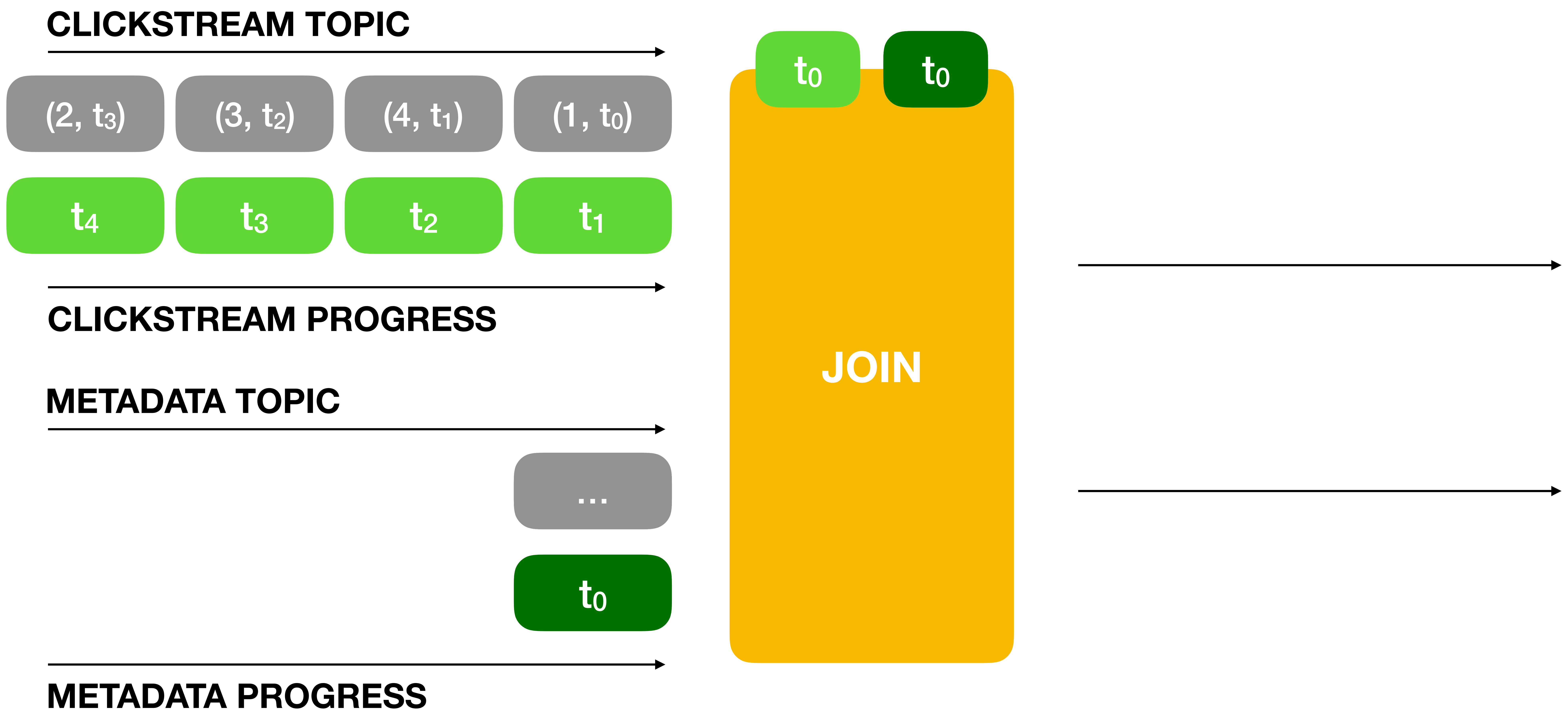


Progress Tracking… without Progress?
(data sources with different event frequencies)



Multidimensional Progress Tracking

(track sources along independent timelines)



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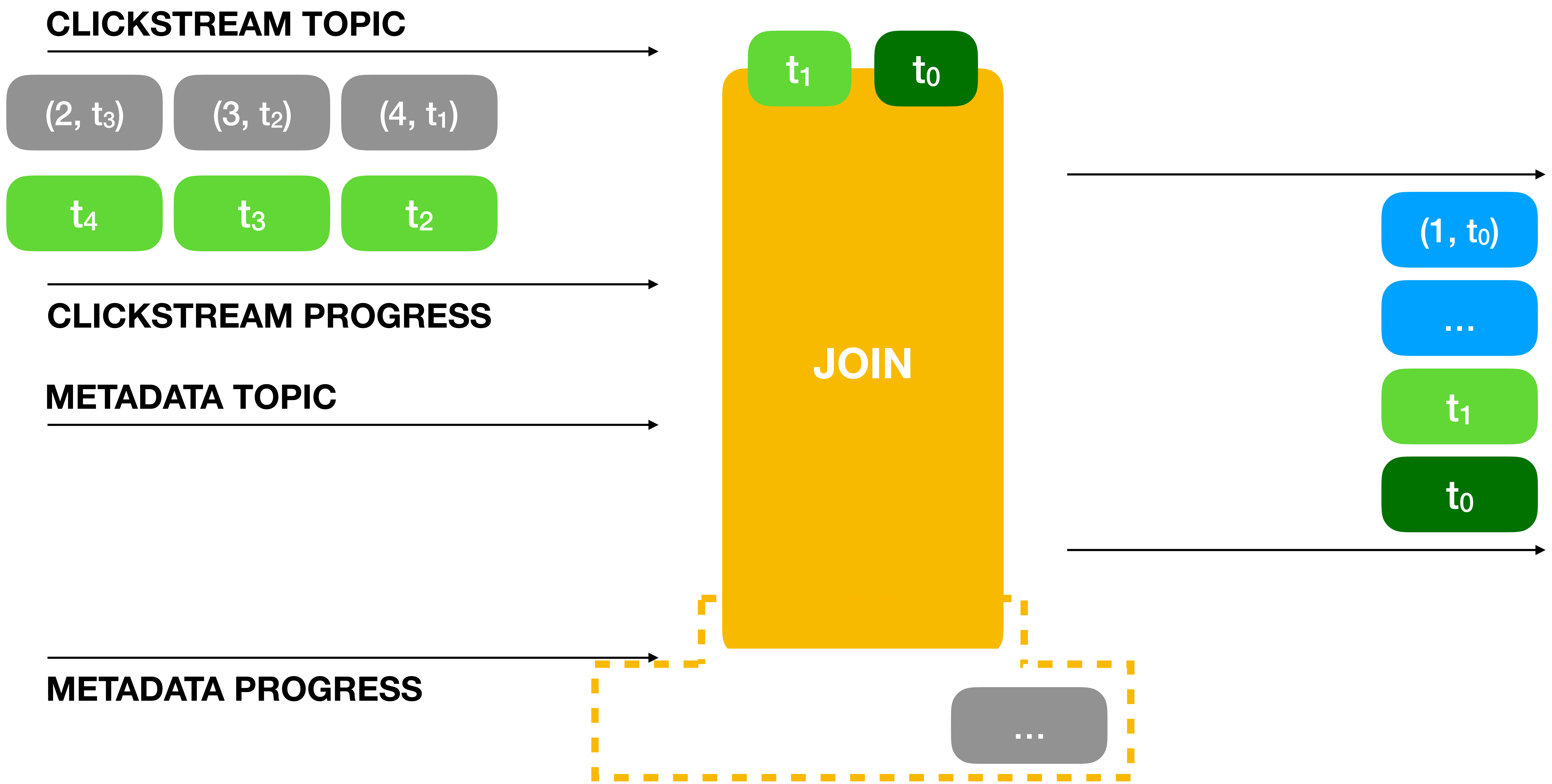

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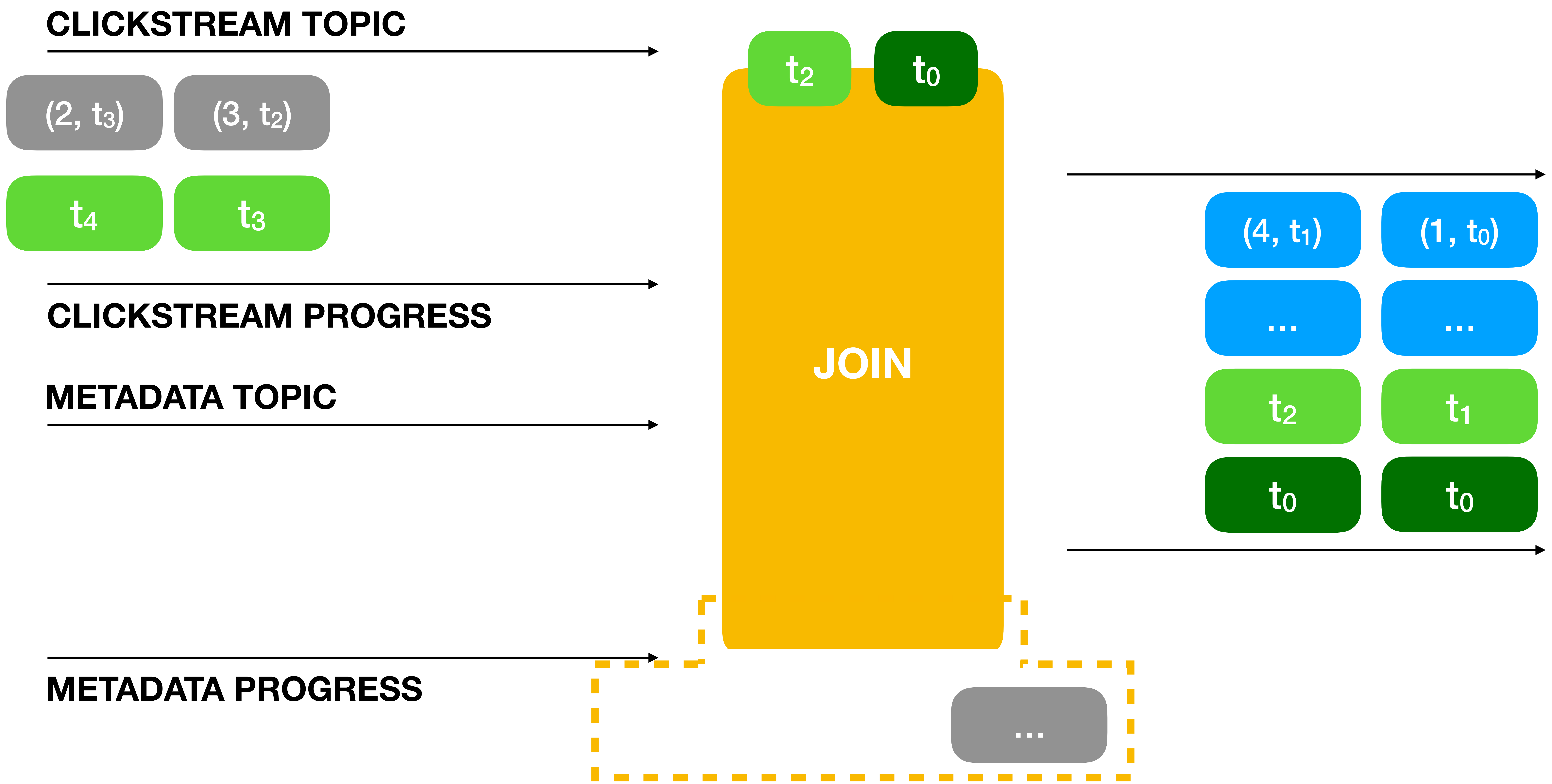

Creating Dataflows with Timely

```
fn main() {
    timely::execute_from_args(std::env::args(), |worker| {


        // Some computation
        let mut input = InputHandle::new();
        let probe = worker.dataflow(|scope|
            scope.input_from(&mut input)
                 .exchange(|x| *x as u64 + 1)
                 .inspect(move |x| println!("record {}", x))
                 .probe()
        );

        for round in 0..100 {
            if worker.index() == 0 { (0..20).for_each(|i| input.send(i) ) }
            input.advance_to(round + 1);
            while probe.less_than(input.time()) { worker.step(); }



        }
    }).unwrap();
}
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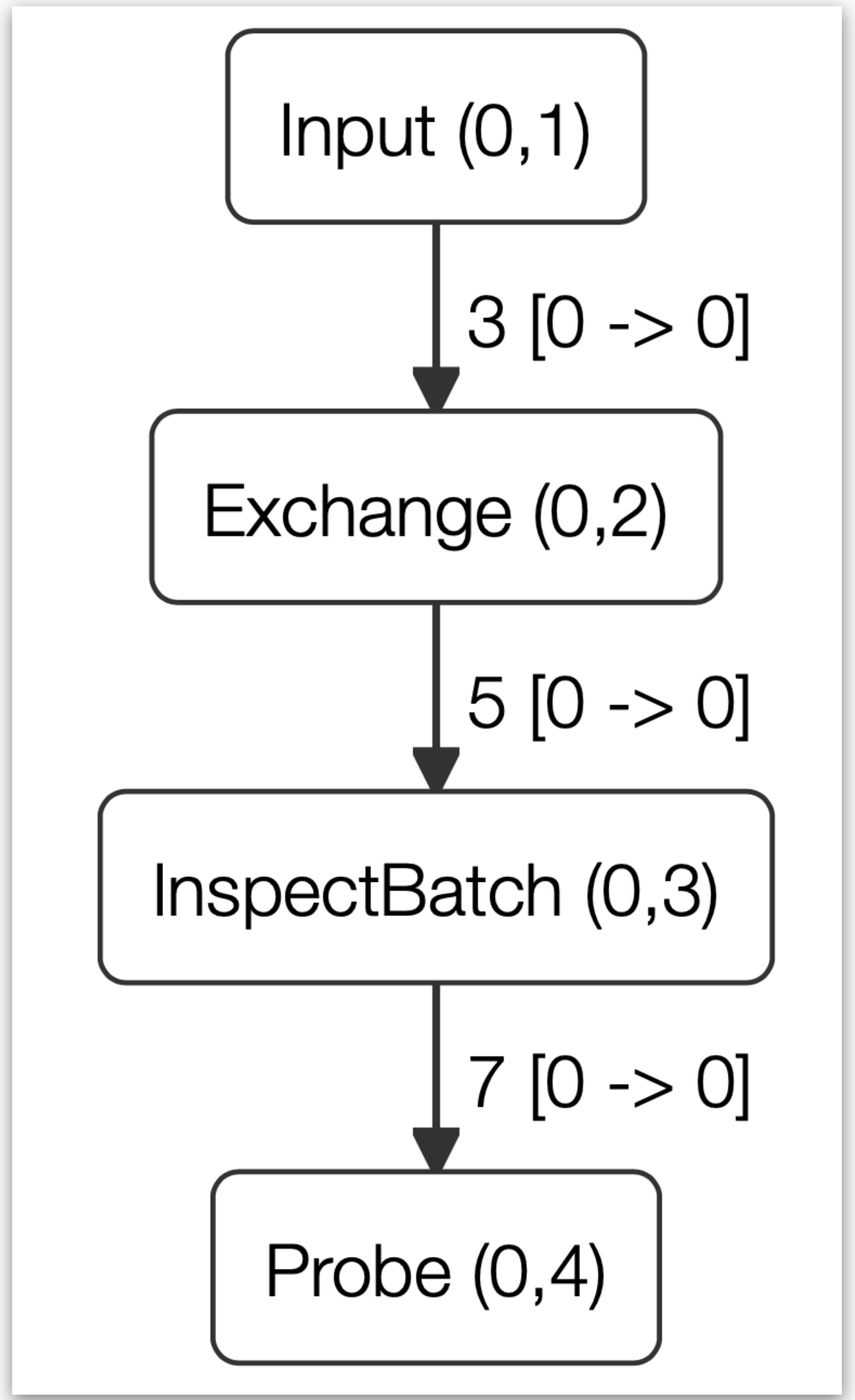
$$\begin{tikzcd}
\boxed{\text{Input (0,1)}} \arrow[d, "{3\ [0 \to 0]}"] \\
\boxed{\text{Exchange (0,2)}} \arrow[d, "{5\ [0 \to 0]}"] \\
\boxed{\text{InspectBatch (0,3)}} \arrow[d, "{7\ [0 \to 0]}"] \\
\boxed{\text{Probe (0,4)}}
\end{tikzcd}$$

Running Dataflows with Timely

```
fn main() {
    timely::execute_from_args(std::env::args(), |worker| {


        // Some computation
        let mut input = InputHandle::new();
        let probe = worker.dataflow(|scope|
            scope.input_from(&mut input)
                 .exchange(|x| *x as u64 + 1)
                 .inspect(move |x| println!("record {}", x))
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        );

        for round in 0..100 {
            if worker.index() == 0 { (0..20).for_each(|i| input.send(i) ) }
            input.advance_to(round + 1);
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        }
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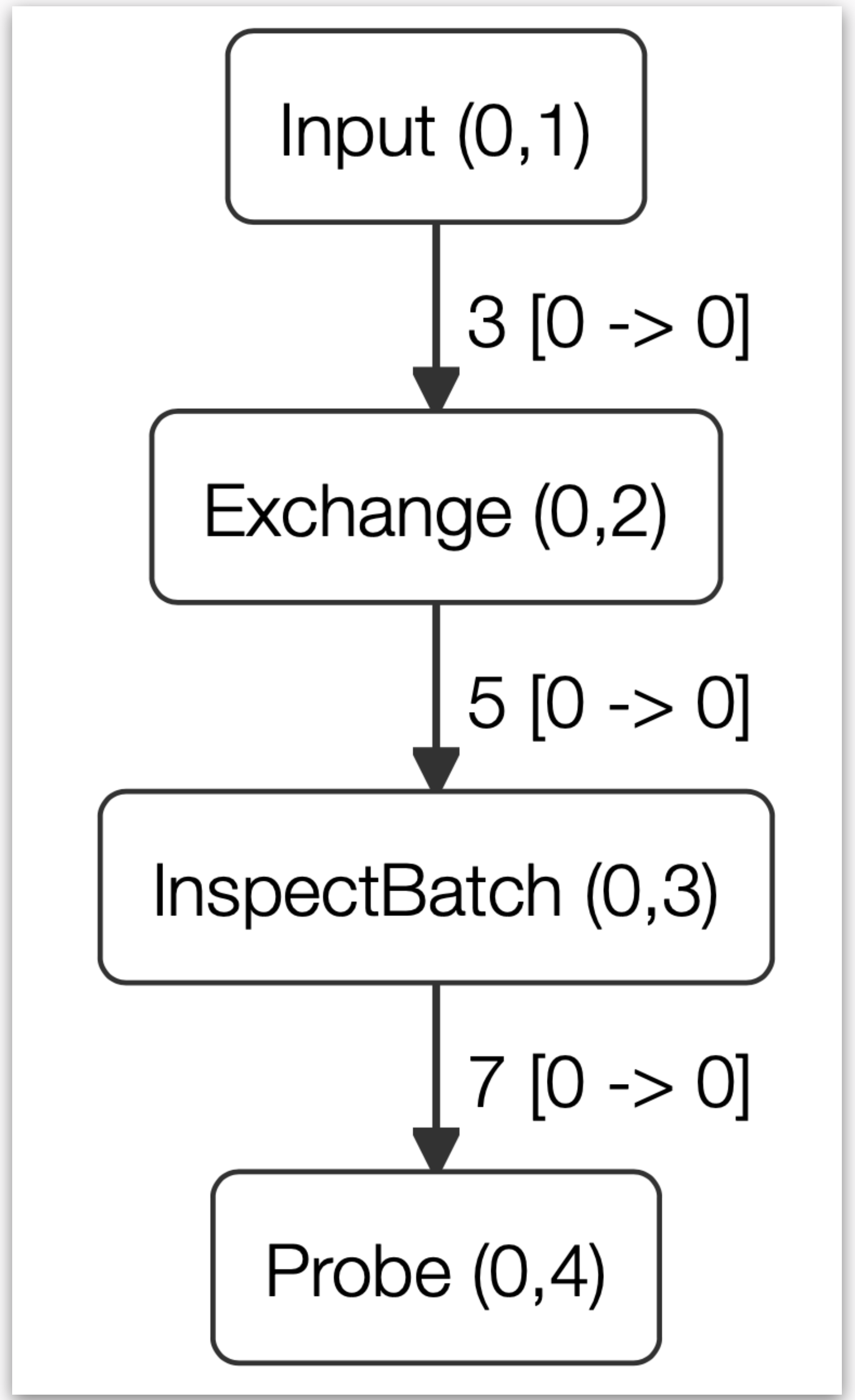
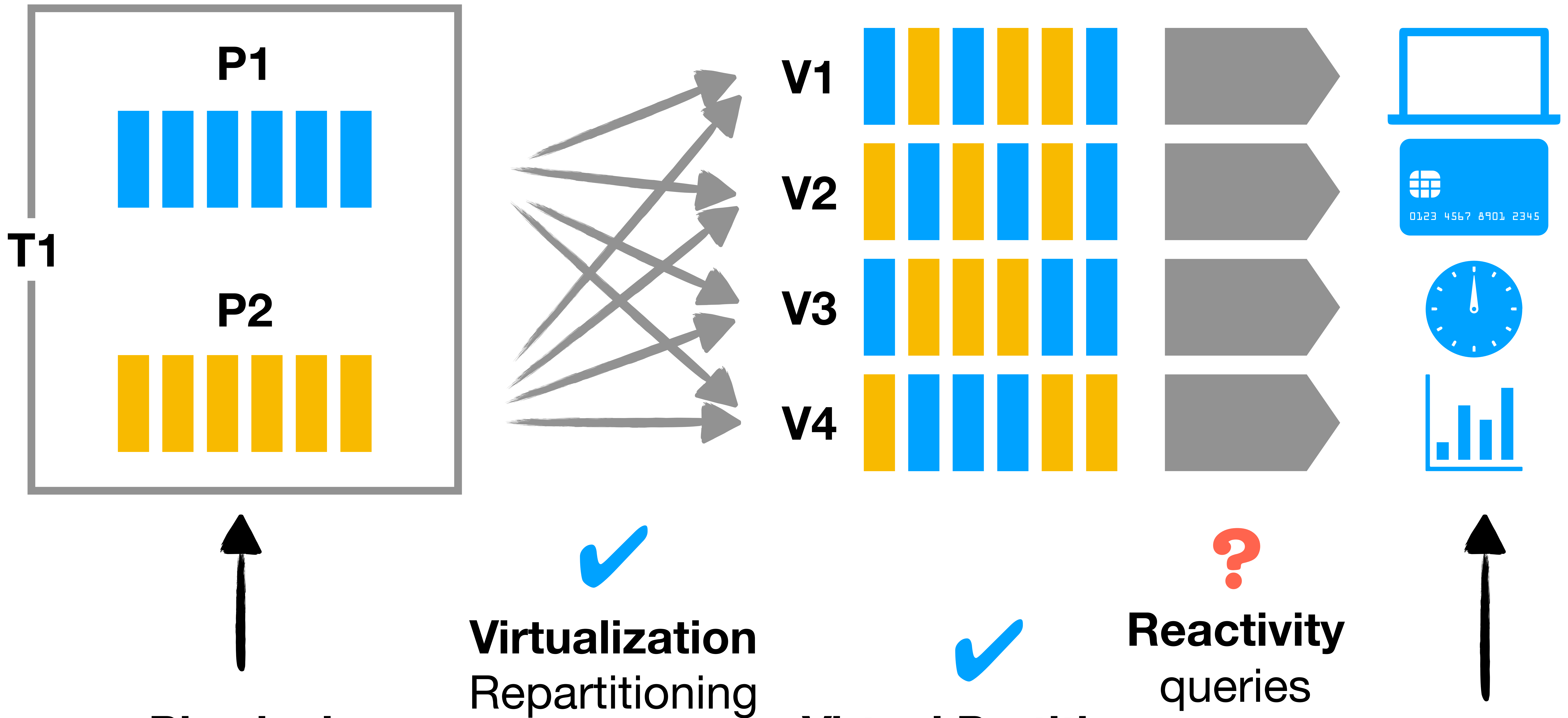
}
```


$$\begin{tikzcd}[row sep=large] \text{Input (0,1)} \arrow[d, "3\ [0 \to 0]"] \\ \text{Exchange (0,2)} \arrow[d, "5\ [0 \to 0]"] \\ \text{InspectBatch (0,3)} \arrow[d, "7\ [0 \to 0]"] \\ \text{Probe (0,4)} \end{tikzcd}$$

ArrangedSource (0,3,56)
149 [0 -> 0]
120 [0 -> 1]
ArrangedSource (0,3,58)
Map (0,3,71)
ArrangedSource (0,3,72)
124 [0 -> 1]
152 [0 -> 0]
153 [0 -> 1]
LookupMap (0,3,59)
LookupMap (0,3,73)
ArrangedSource (0,3,74)
126 [0 -> 0]
156 [0 -> 0]
157 [0 -> 1]
,49)
Partition (0,3,60)
ArrangedSource (0,3,61)
ArrangedSource (0,3,65)
LookupMap (0,3,75)
> 1]
129 [0 -> 0]
137 [1 -> 0]
130 [0 -> 1]
138 [0 -> 1]
159 [0 -> 0]
dSource (0,3,51)
LookupMap (0,3,62)
ArrangedSource (0,3,63)
LookupMap (0,3,66)
ArrangedSource (0,3,67)
Partition (0,3,76)
ArrangedSource (0,3,77)
ArrangedSource (0,3,81)
109 [0 -> 1]
133 [0 -> 0]
134 [0 -> 1]
141 [0 -> 0]
142 [0 -> 1]
162 [0 -> 0]
170 [1 -> 0]
163 [0 -> 1]
171 [0 -> 1]
LookupMap (0,3,64)
LookupMap (0,3,68)
LookupMap (0,3,78)
ArrangedSource (0,3,79)
LookupMap (0,3,82)
ArrangedSource (0,3,83)
144 [0 -> 0]
145 [0 -> 1]
166 [0 -> 0]
167 [0 -> 1]
174 [0 -> 0]
175 [0 -> 1]
Concatenate (0,3,69)
LookupMap (0,3,80)
LookupMap (0,3,84)
147 [0 -> 0]
177 [0 -> 0]
178 [0 -> 1]
Map (0,3,70)
Concatenate (0,3,85)
183 [0 -> 1]
180 [0 -> 0]
Concatenate (0,3,87)
Map (0,3,86)
185 [0 -> 0]
186 [0 -> 1]
Concatenate (0,3,88)
187,189 [0 -> 0]
Map (0,4)
193 [0 -> 0]
Probe (0,5)

Kafka Superpowers



Physical Representation

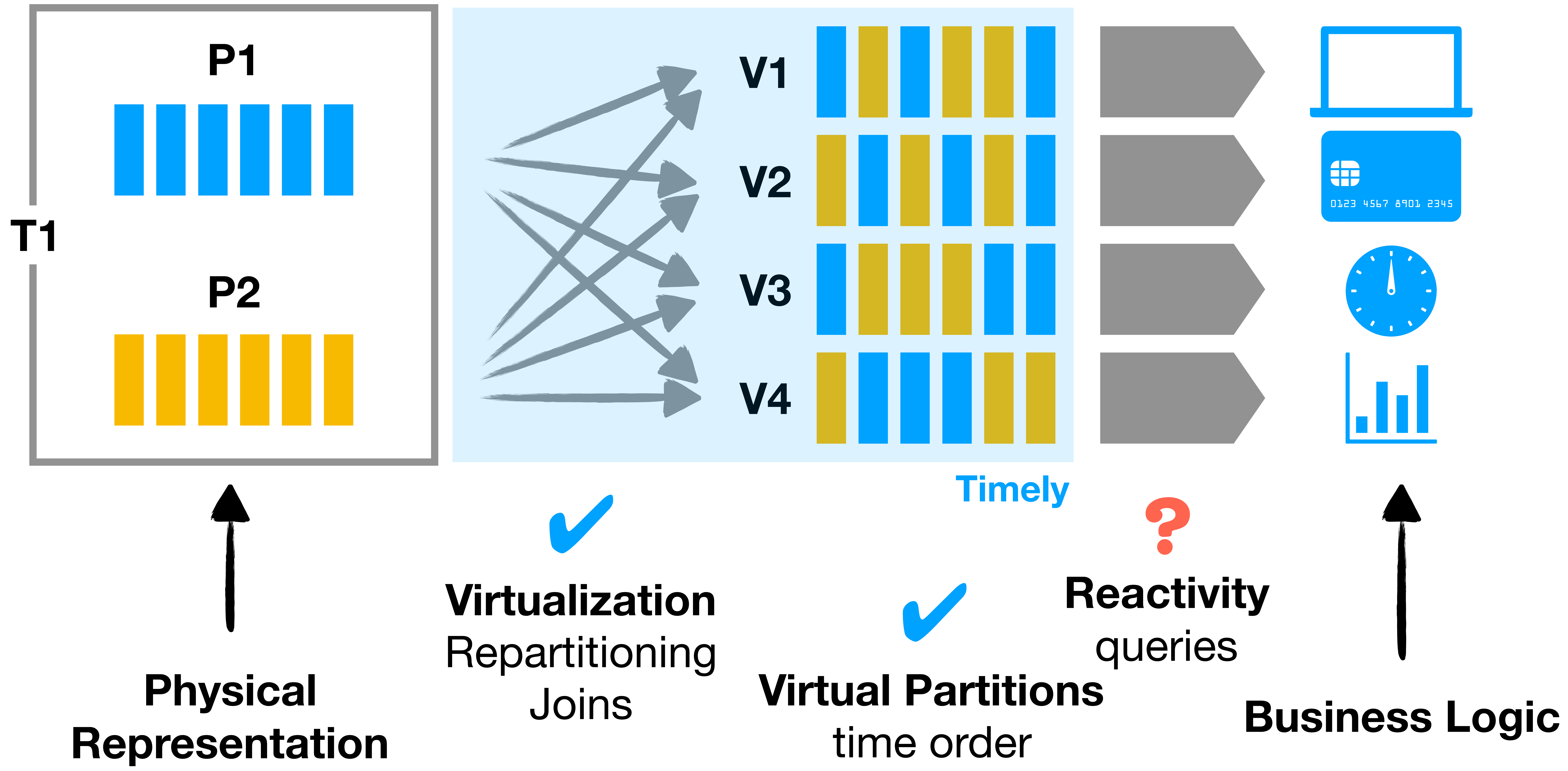
Virtualization
Repartitioning
Joins

Virtual Partitions
time order

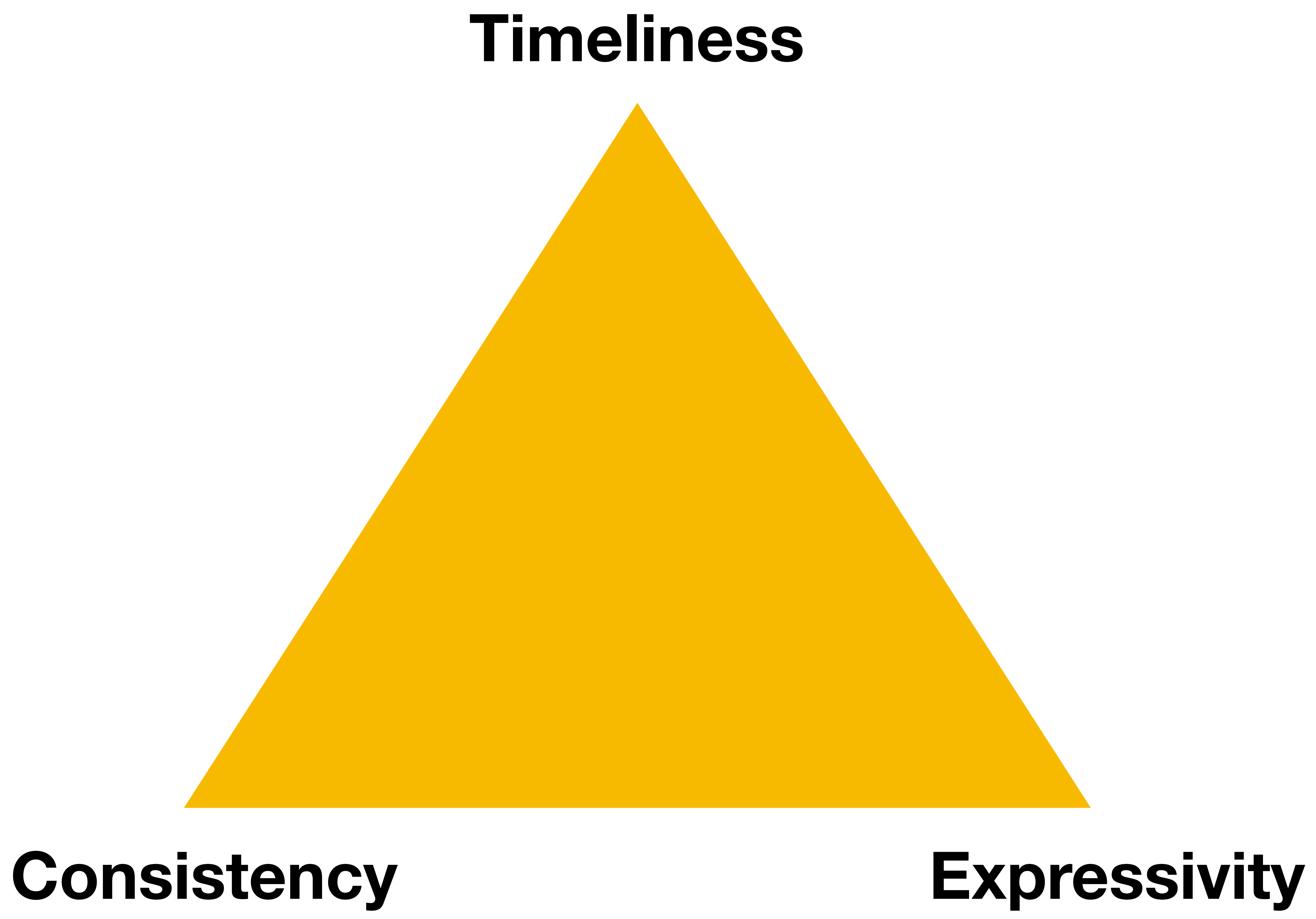
Reactivity
queries

Business Logic

Kafka Superpowers



The Trifecta?



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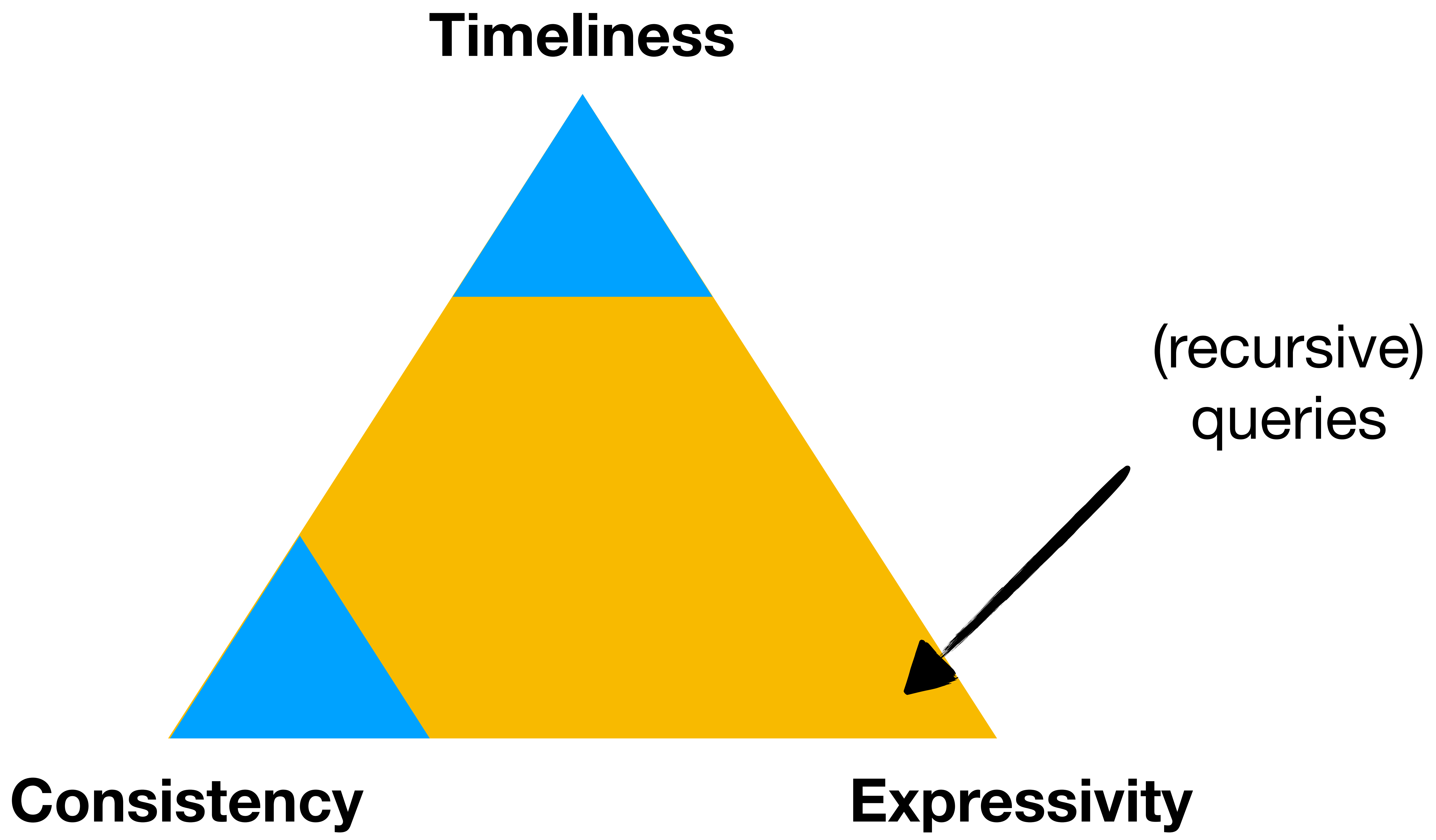
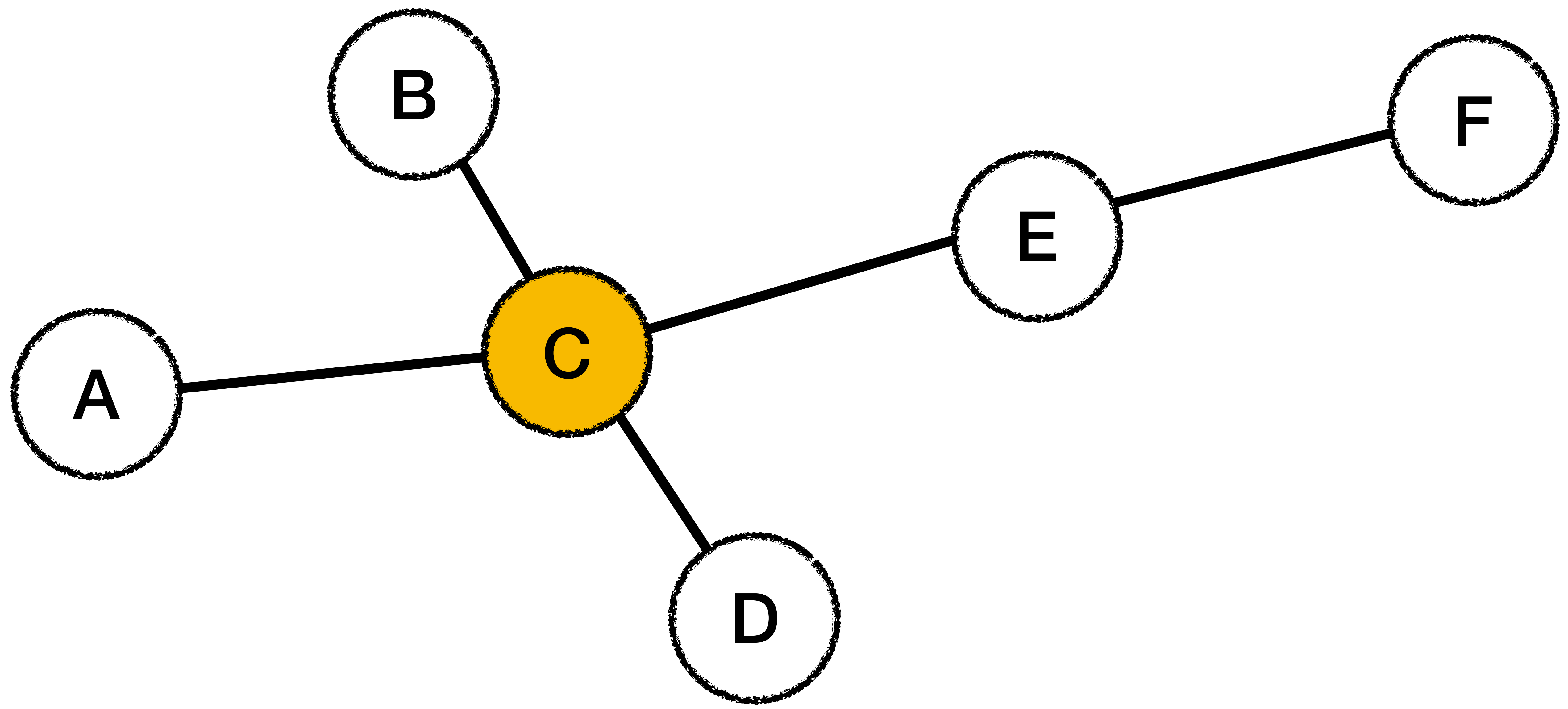


Recursive Graph Traversal



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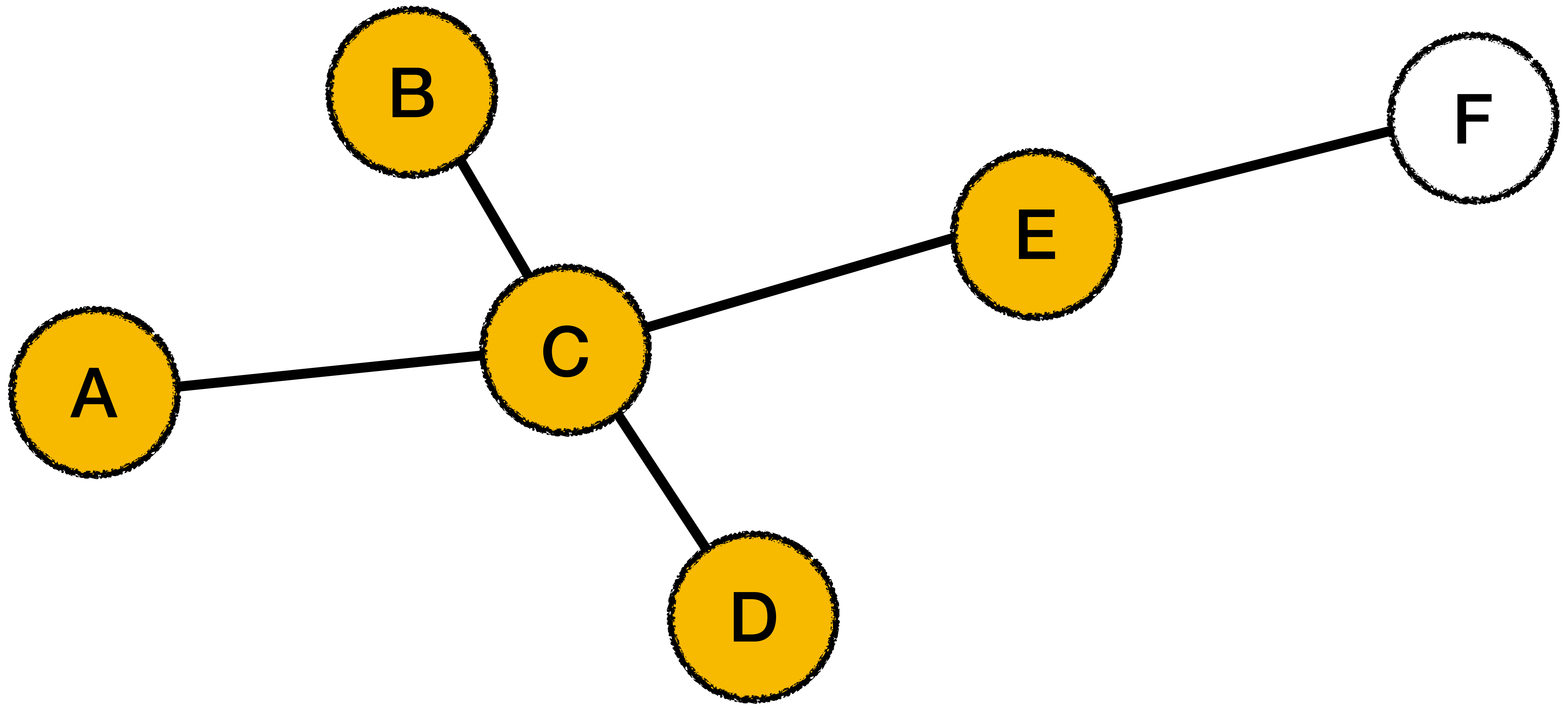
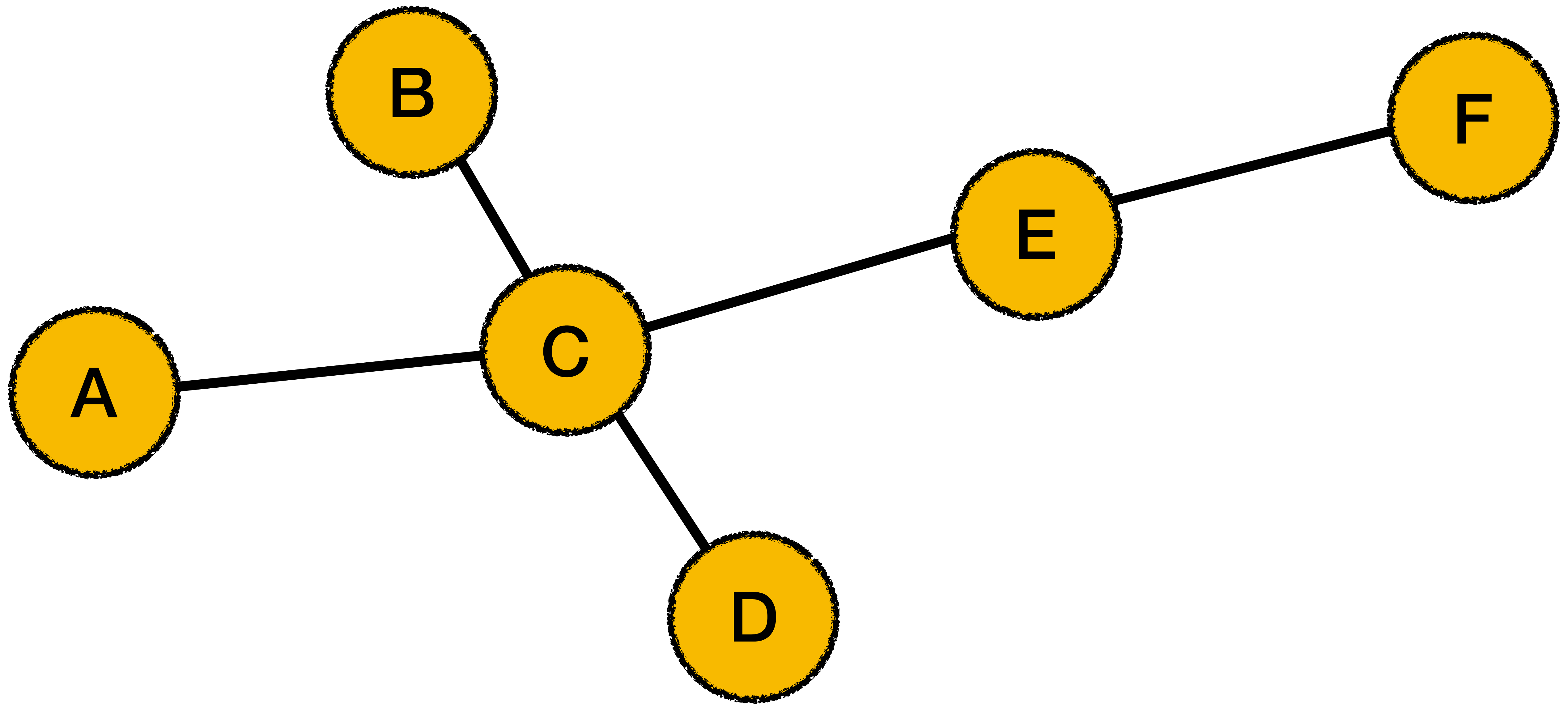


Recursive Graph Traversal



Recursive Dataflows

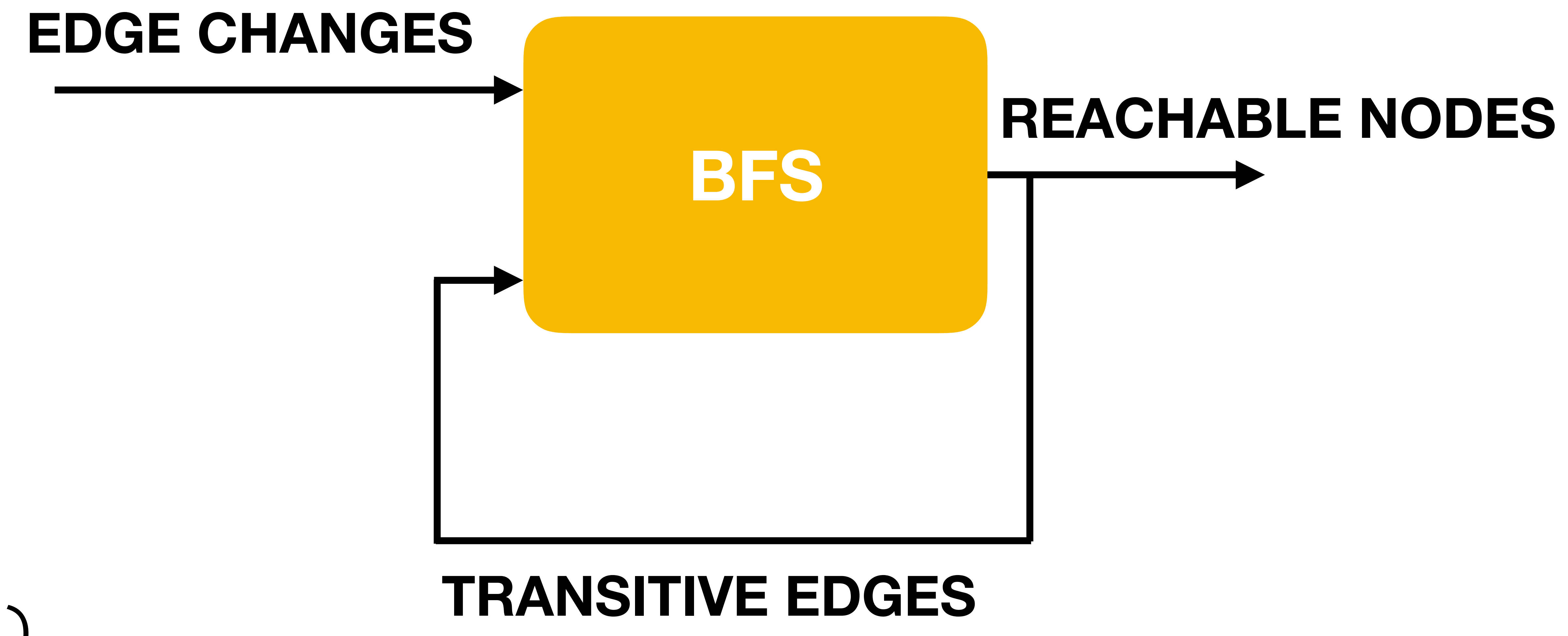
```
/// Breadth-First Search

let nodes = roots.map(|x| (x, 0));

nodes.iterate(|inner| {

 let edges = edges.enter(&inner.scope());
 let nodes = nodes.enter(&inner.scope());

 inner.join(&edges, |_k,l,d| (*d, l+1))
     .concat(&nodes)
     .reduce(|_, s, t| t.push((*s[0].0, 1)))
})
```



Recursive Dataflows

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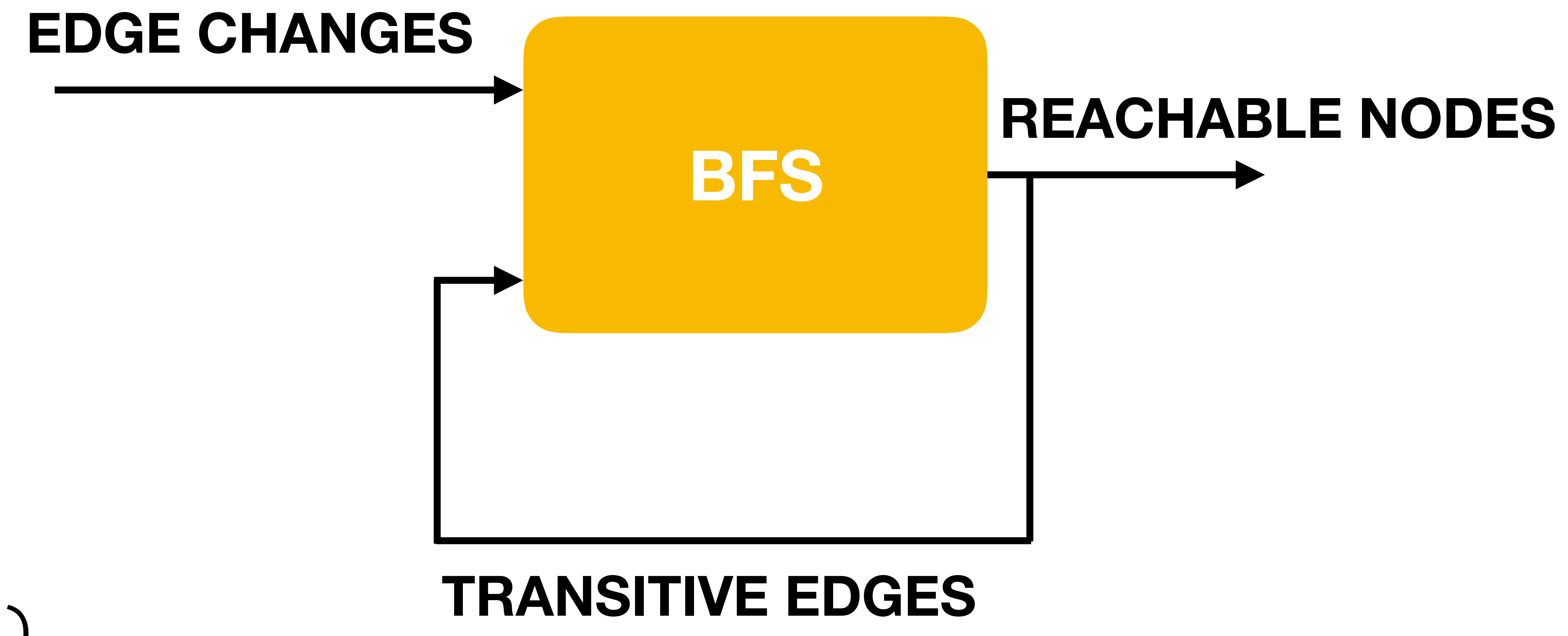
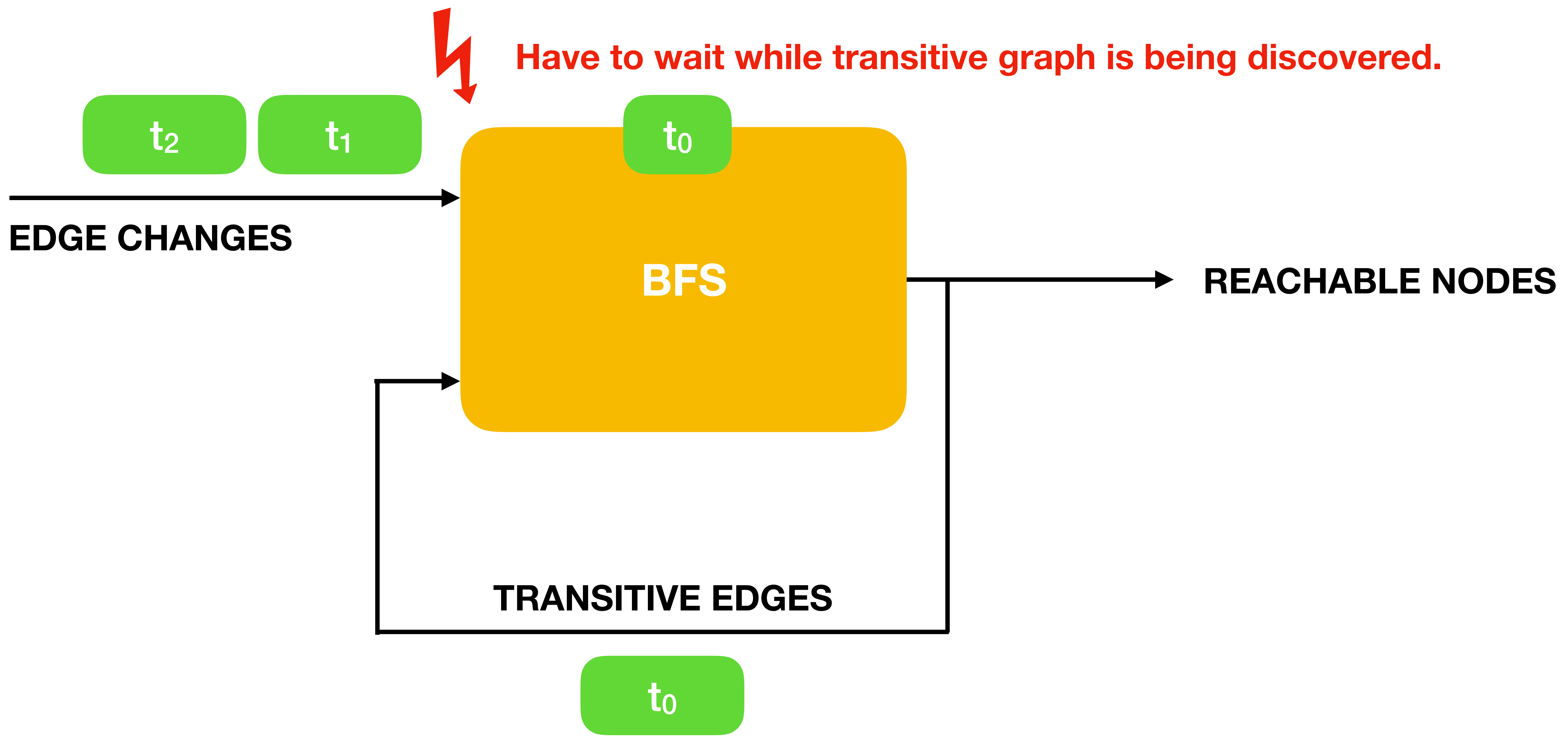


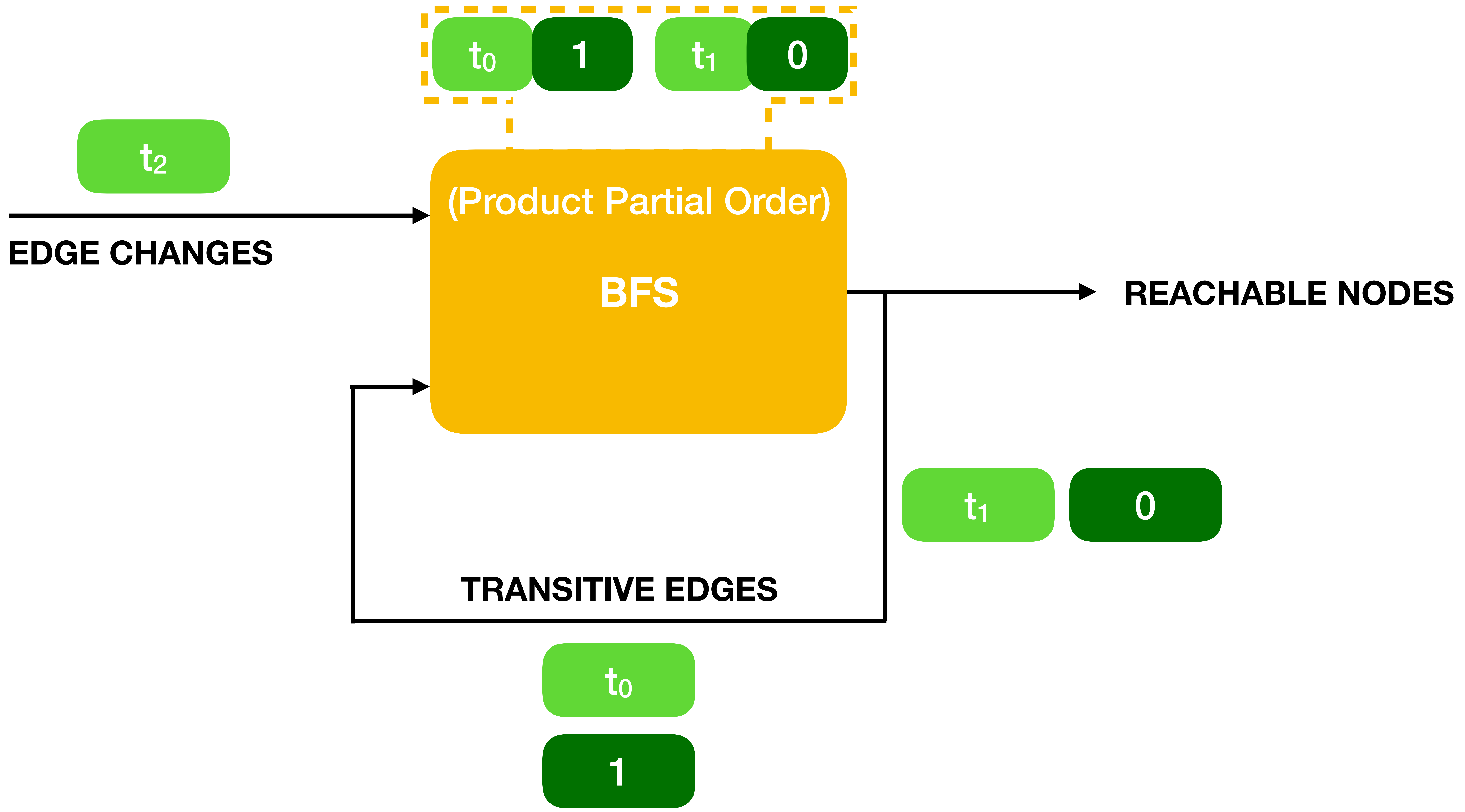
Progress Tracking… with Loops?

(have to finish iterating before we can handle next input)



Multidimensional Progress Tracking

(track iteration depth separately)



Lexicographical Order (Join)

(visibility for t_2 t_2)

	t_0	t_1	t_2	t_3
t_0	✓	✓	✓	✓
t_1	✓	✓	✓	✓
t_2	✓	✓	✓	✗
t_3	✗	✗	✗	✗

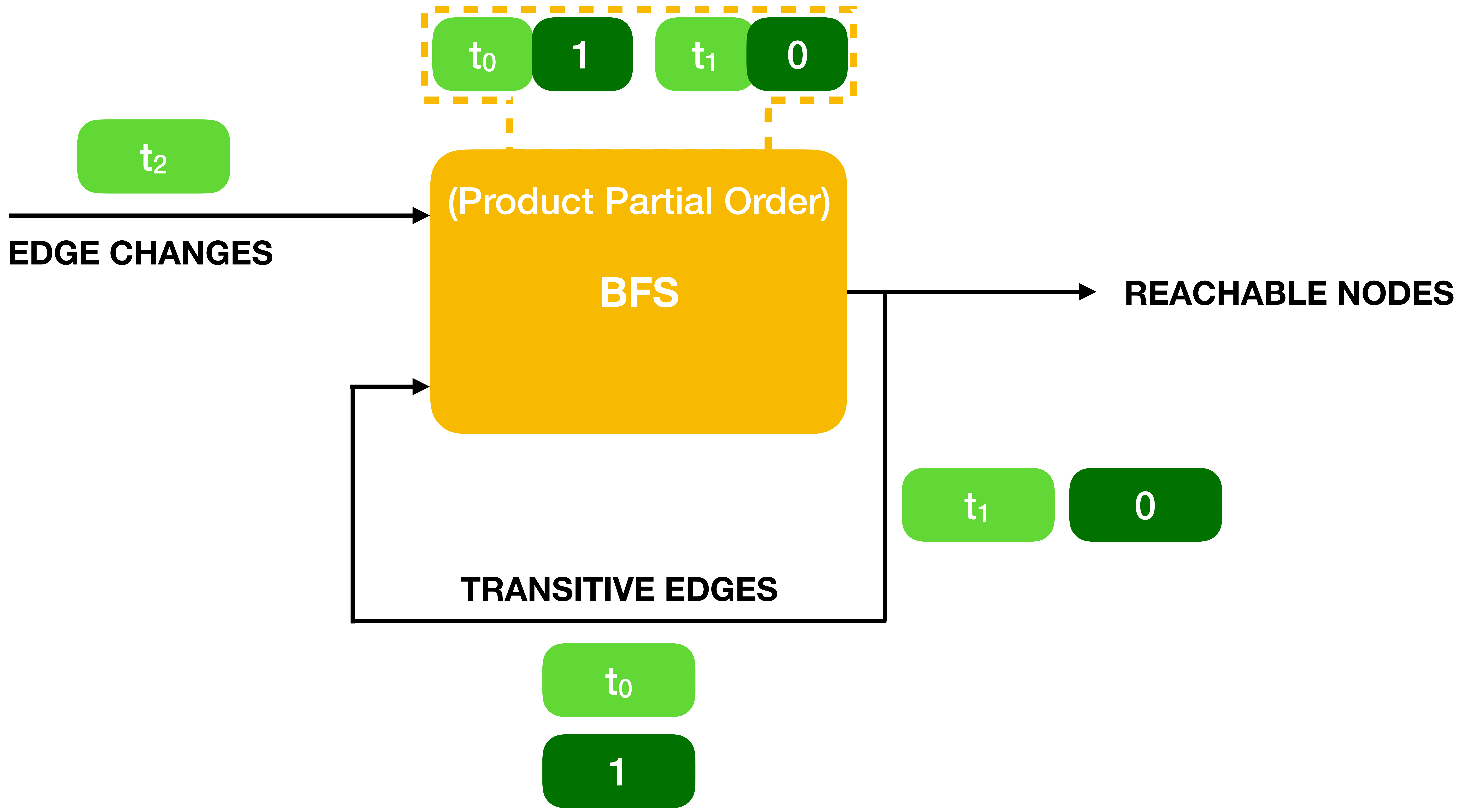
Product Partial Order (Iteration)

(visibility for t_2 2)

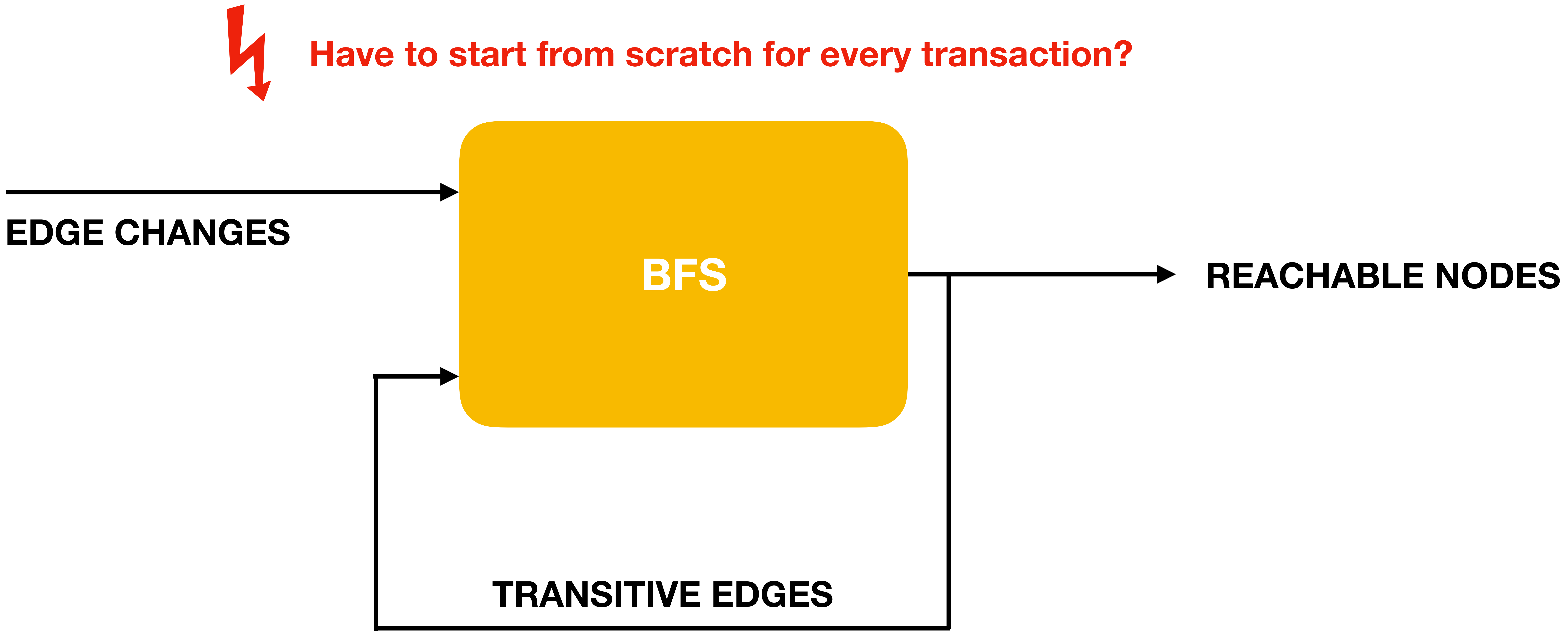
	0	1	2	3
t_0	✓	✓	✓	✗
t_1	✓	✓	✓	✗
t_2	✓	✓	✓	✗
t_3	✗	✗	✗	✗

Multidimensional Progress Tracking

(track iteration depth separately)



Incremental Execution?

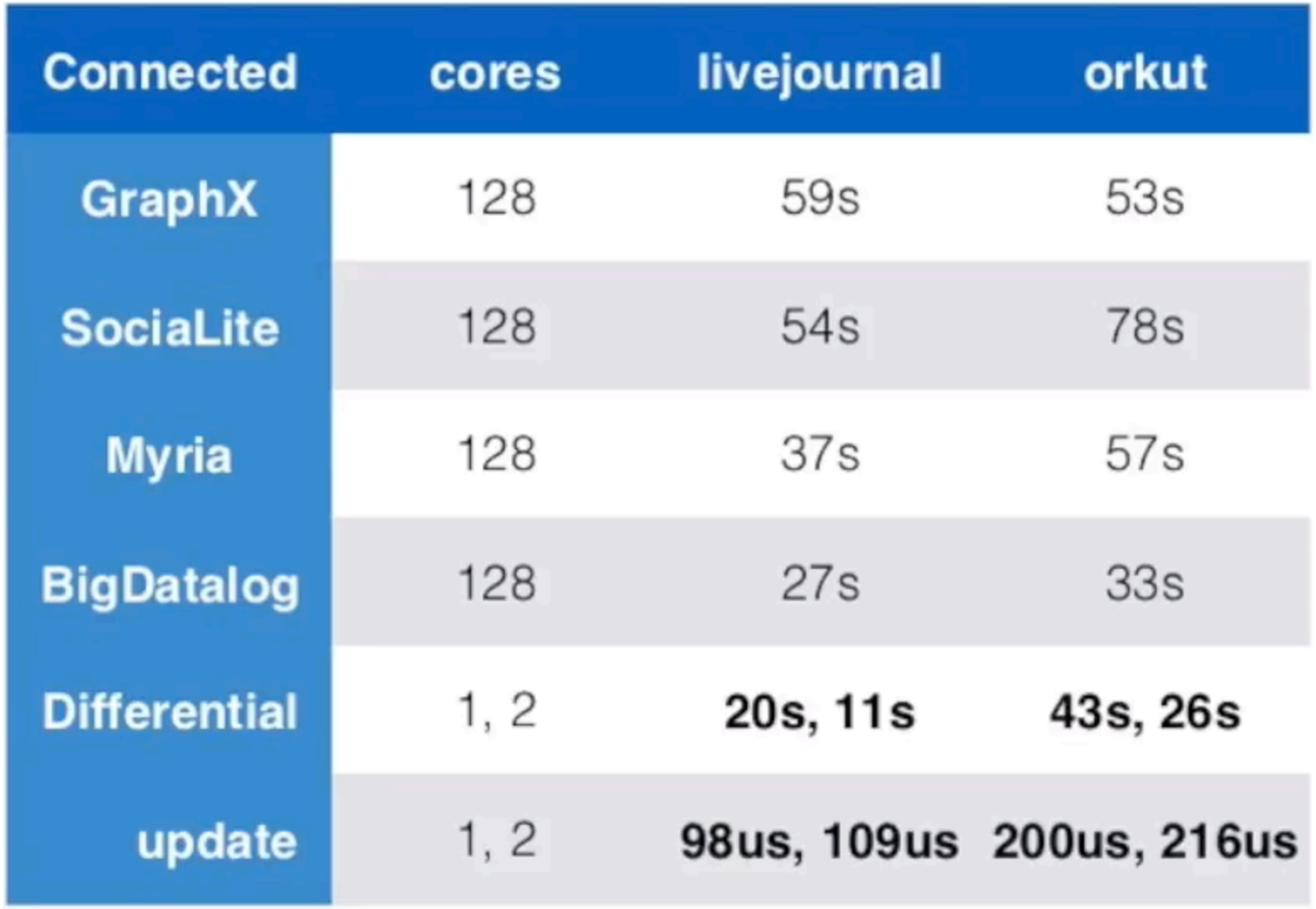


Differential Dataflow

Iterative, incrementalized operators for Timely

github.com/**TimelyDataflow**

Performance



Connected	cores	livejournal	orkut
GraphX	128	59s	53s
SociaLite	128	54s	78s
Myria	128	37s	57s
BigDatalog	128	27s	33s
Differential	1, 2	**20s, 11s**	**43s, 26s**
update	1, 2	**98us, 109us**	**200us, 216us**

Streaming & Relational Queries

Declarative Differential Dataflows (3DF)

```
/// BFS

let nodes = roots.map(|x| (x, 0));

nodes.iterate(|inner| {

 let edges = edges.enter(&inner.scope());
 let nodes = nodes.enter(&inner.scope());

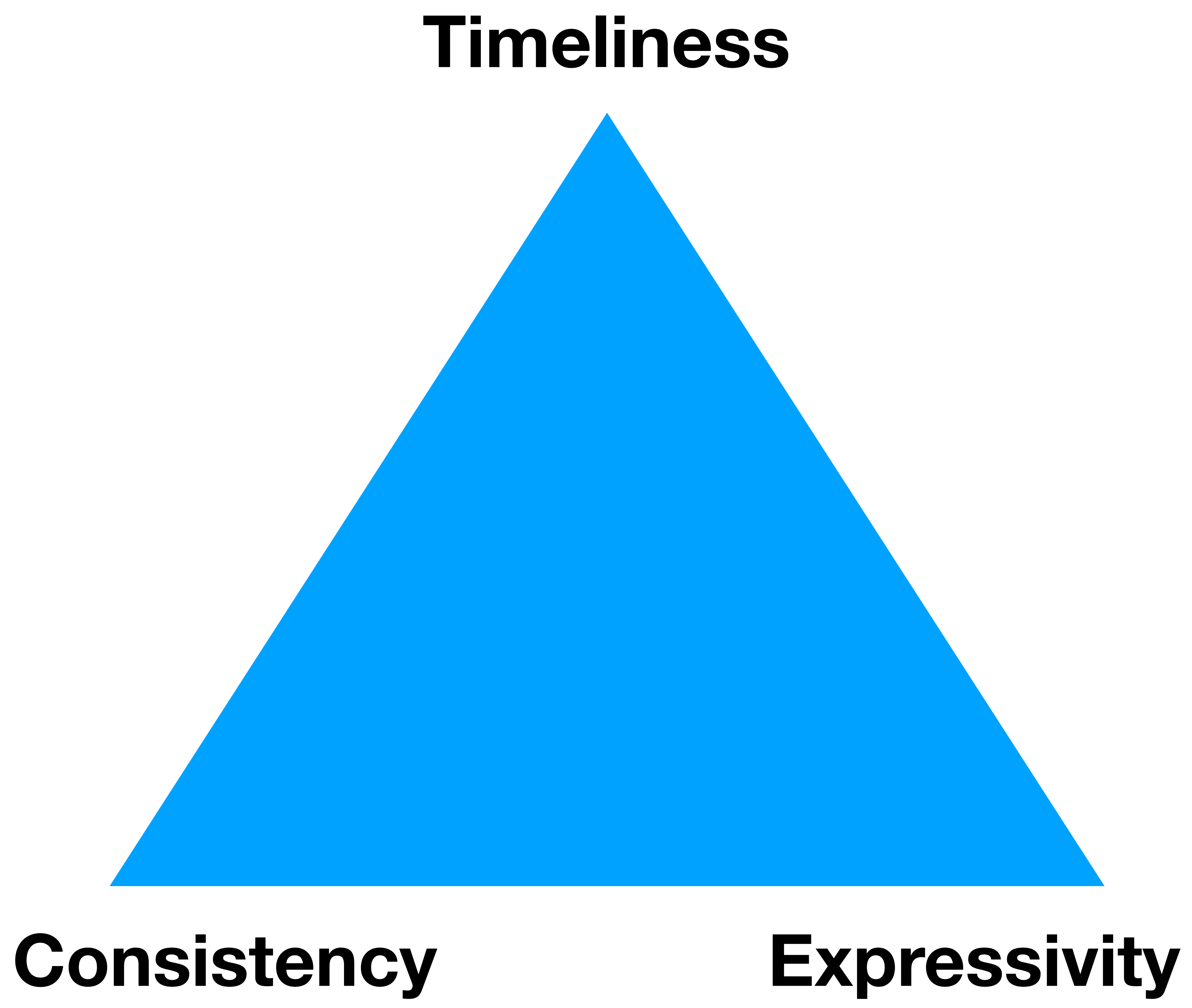
 inner.join_map(&edges, |_k,l,d| (*d, l+1))
     .concat(&nodes)
     .reduce(|_, s, t| t.push((*s[0].0, 1)))
})
```

```
[[(bfs ?from ?to)
  [?from :edge ?to]]

 [(bfs ?from ?to)
  [?from :edge ?hop]
  (bfs ?hop ?to)]]
```

github.com/comnik/**declarative-dataflow**

The Trifecta!



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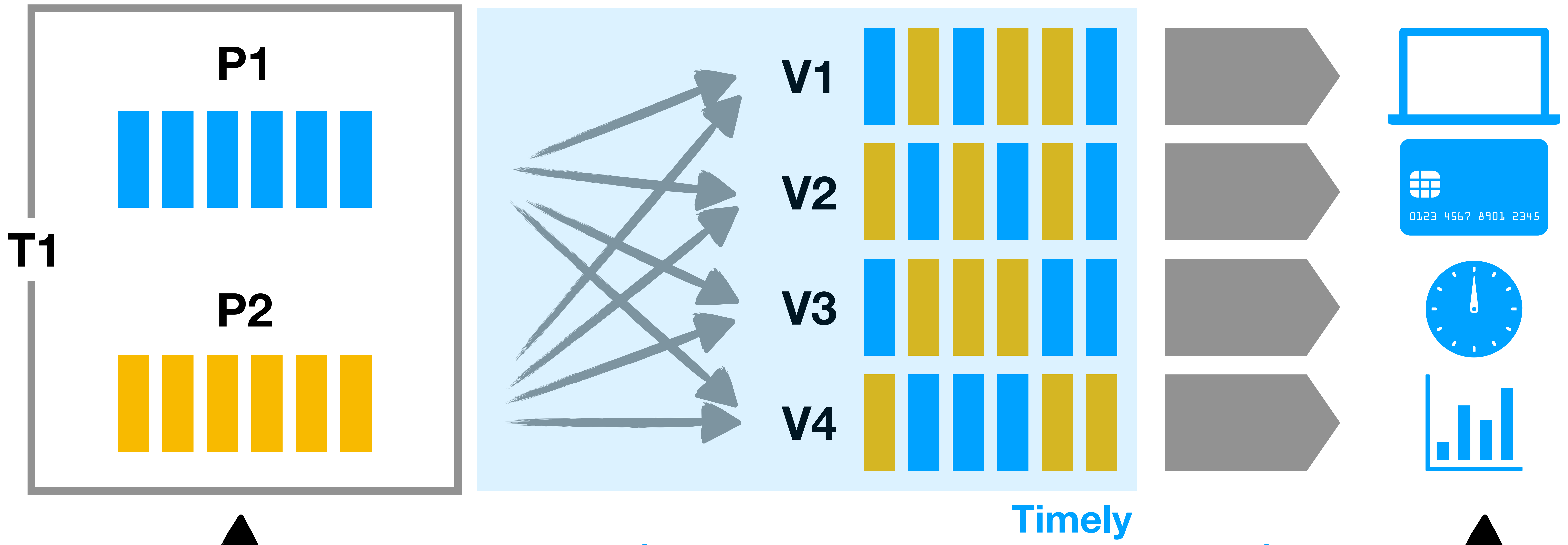

✓ **Virtualization**
Repartitioning
Joins

✓ **Virtual Partitions**
time order

✓ **Reactivity**
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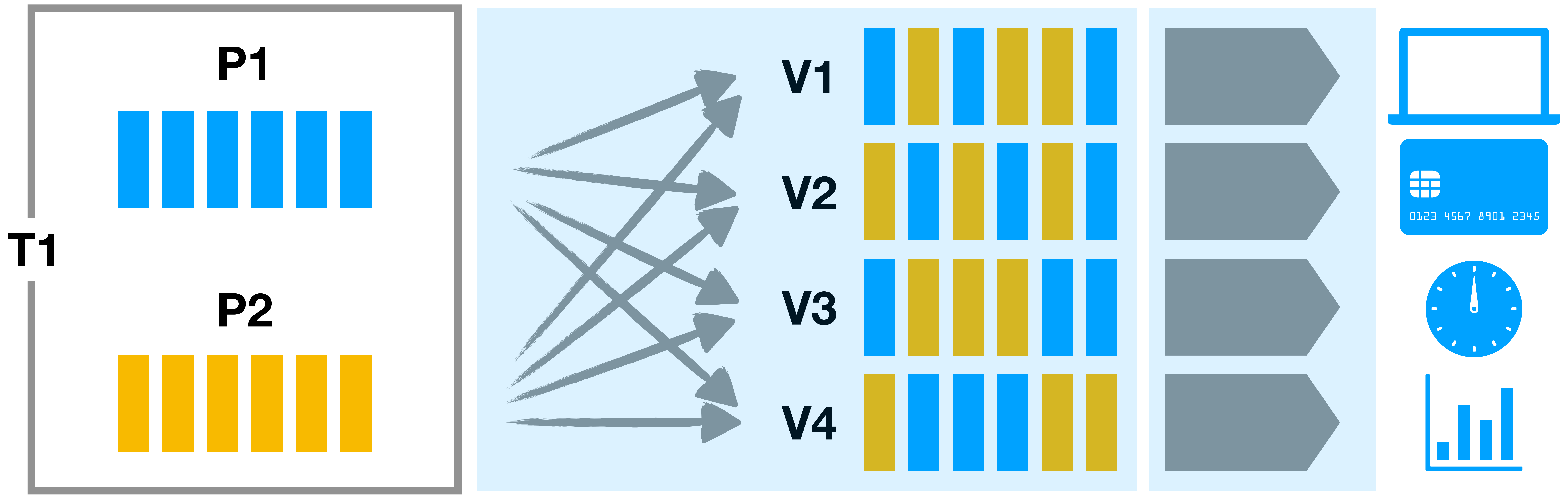

Timely

DD+3DF

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Repartitioning
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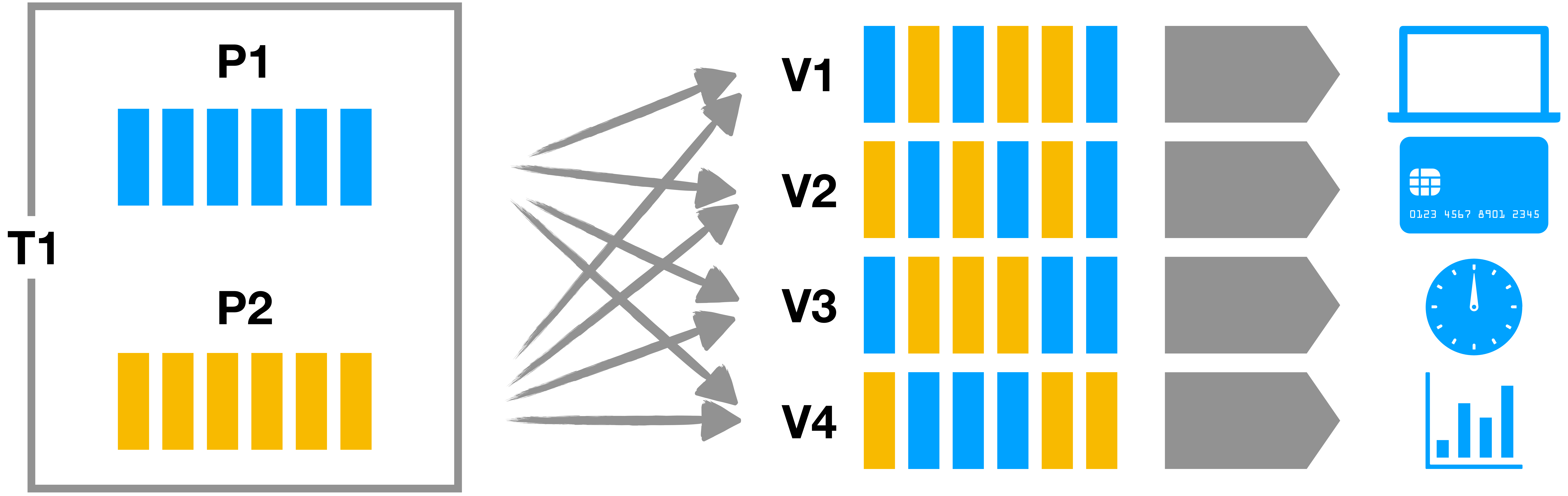
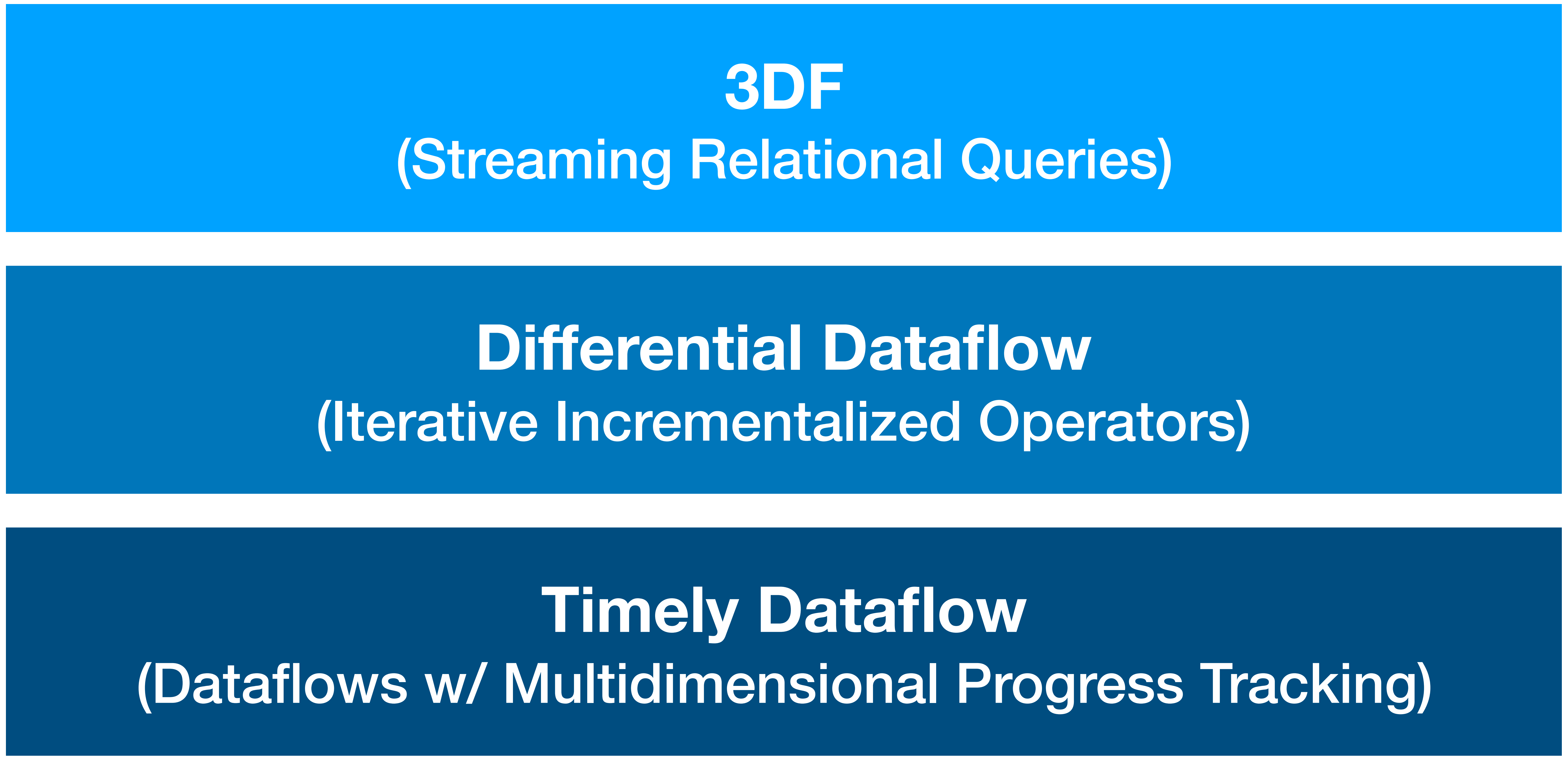
Business Logic

Kafka Superpowers



clockworks.io/kplex

Timely as a Programming Model


3DF
(Streaming Relational Queries)
Differential Dataflow
(Iterative Incrementalized Operators)
Timely Dataflow
(Dataflows w/ Multidimensional Progress Tracking)

github.com/TimelyDataflow

github.com/comnik/declarative-dataflow

Sources

clockworks

www.clockworks.io

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Repositories

- Timely: github.com/TimelyDataflow
- ST2: github.com/li1/snailtrail
- 3DF: github.com/comnik/declarative-dataflow
- Differential FAQ: github.com/eoxxs/differential-aggregate-query

Papers

- Naiad (Timely Dataflow): http://dl.acm.org/citation.cfm?doid=2517349.2522738
- Differential Dataflow: http://michaelisard.com/pubs/differentialdataflow.pdf, arxiv.org/abs/1812.02639
- SnailTrail: hdl.handle.net/20.500.11850/228581

Talks

- Reactive Datalog for Datomic (clojure/conj 2018): clockworks.io/2018/12/01/conj-talk.html
- Across Time and Space (BobKonf 2019): clockworks.io/2019/03/22/across-time-space.html

Blog Posts

- frankmcsherry.org
- Incremental Functional Aggregate Queries: clockworks.io/2019/07/06/Incremental-Functional-Aggregate-Queries.html
- Dataflows you can't refuse: clockworks.io/2019/02/10/dataflows-you-cant-refuse.html
- Reactive Datalog with Vega: clockworks.io/2018/11/25/reactive-datalog-with-vega.html
- Incremental Datalog with Differential Dataflows: clockworks.io/2018/09/13/incremental-datalaog.html