



Stream Processing. Kafka Streams

Apache Kafka

Machine Learning + Big Data in Real Time +
Cloud Technologies

=> The Future of Intelligent Systems

Where to Find The Code and Materials?

<https://github.com/iproduct/course-apache-kafka>

Data Streams Programming



Problem with OOP: Mutable State

- The object methods are supposed to mutate the object's internal state
- When there is state sharing:



- Bottlenecks (Contention), Deadlocks, Complexity in State Access Management (mutual exclusion between threads)

OOP vs. Functional Composition

- **OOP** – imperative, hard to achieve concurrency, less-reusable abstractions (how many times you have created User class in your career?)
- **FP** – declarative, always safe concurrency (pure functions), coarse grained abstractions, code reuse via functional composition, Composable abstractions: Stream, Optional, etc.

Functional Programming

FP is a type of programming paradigm which has several features:

- **Purity:**
 - Function reads all inputs from its input arguments.
 - Function exports all outputs to its return values.
 - The function always evaluates the same result value given the same argument value(s).
 - Evaluation of the result does not cause any semantically observable side effect or output, such as mutation of mutable objects or output to I/O devices.
- **Immutability** – state of objects cannot be modified after it is created, but wait, how can we program without modifying state ?
- **First-Class & High-Order Function**
- **TCO, Closure, Curry...**

First Class Functions

Capability of programming language to:

- pass functions as **arguments to other functions**
- **return functions as the values** from other functions
- **assign functions** to variables
- **store functions** in data structures

To be concise, **function is just like all other values** like integer, float, double, etc..

Higher Order Functions

Function that does at least one of the following:

- takes one or more functions as arguments
- returns a function as its result
- Examples:

```
var lines = Files.lines(path).map(line -> line.toUpperCase());
```

```
var numbers = IntStream.iterate(1, x -> x + 1).boxed();
```

```
var results = zip(numbers, lines, (Integer n, String line) -> n + ":" + line);
```

```
results.forEach(System.out::println);
```

What can FP offer to distributed computing ?

- No side-effects and immutable – variables FP facilitates code distribution over several CPU and eases concurrent programming
- Functions are better building components than objects:
 - Functions can be combined, [sent remotely](#)
 - Functions can be [applied locally on distributed data sets](#) (e.g. parallel stream, using [Fork-Join pool](#) underneath).
- In order to do the splitting of the work between multiple threads (forking) the [Java Streams](#) use:
 - [spliterator = split iterator](#)
- The results can be joined after that in a single result (e.g. [reduce](#))
- Example: [Map – Reduce](#) big data architecture ([Google](#), [Hadoop](#))



Documentation FAQ Download Mailing List Code Commercial Support

akka.io

Build powerful concurrent & distributed applications **more easily.**

Akka is a toolkit and runtime for building highly concurrent, distributed, and resilient message-driven applications on the JVM.

Simple Concurrency & Distribution

Asynchronous and Distributed by design. High-level abstractions like Actors, Futures and STM.

Resilient by Design

Write systems that self-heal. Remote and/or local supervisor hierarchies.



High Performance

50 million msg/sec on a single machine. Small memory footprint; ~2.5 million actors per GB of heap.

Elastic & Decentralized

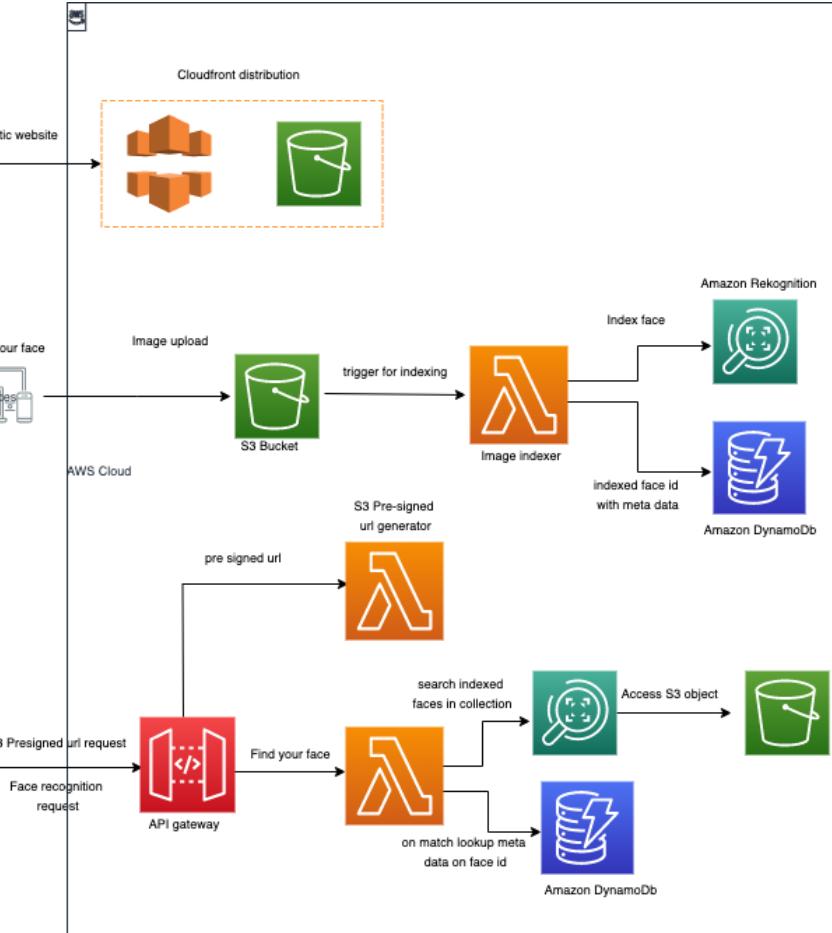
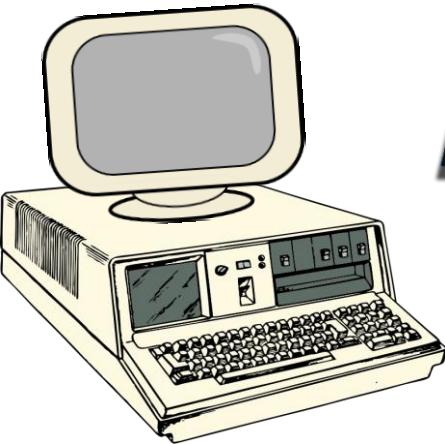
Adaptive load balancing, routing, partitioning and configuration-driven remoting.

Extensible

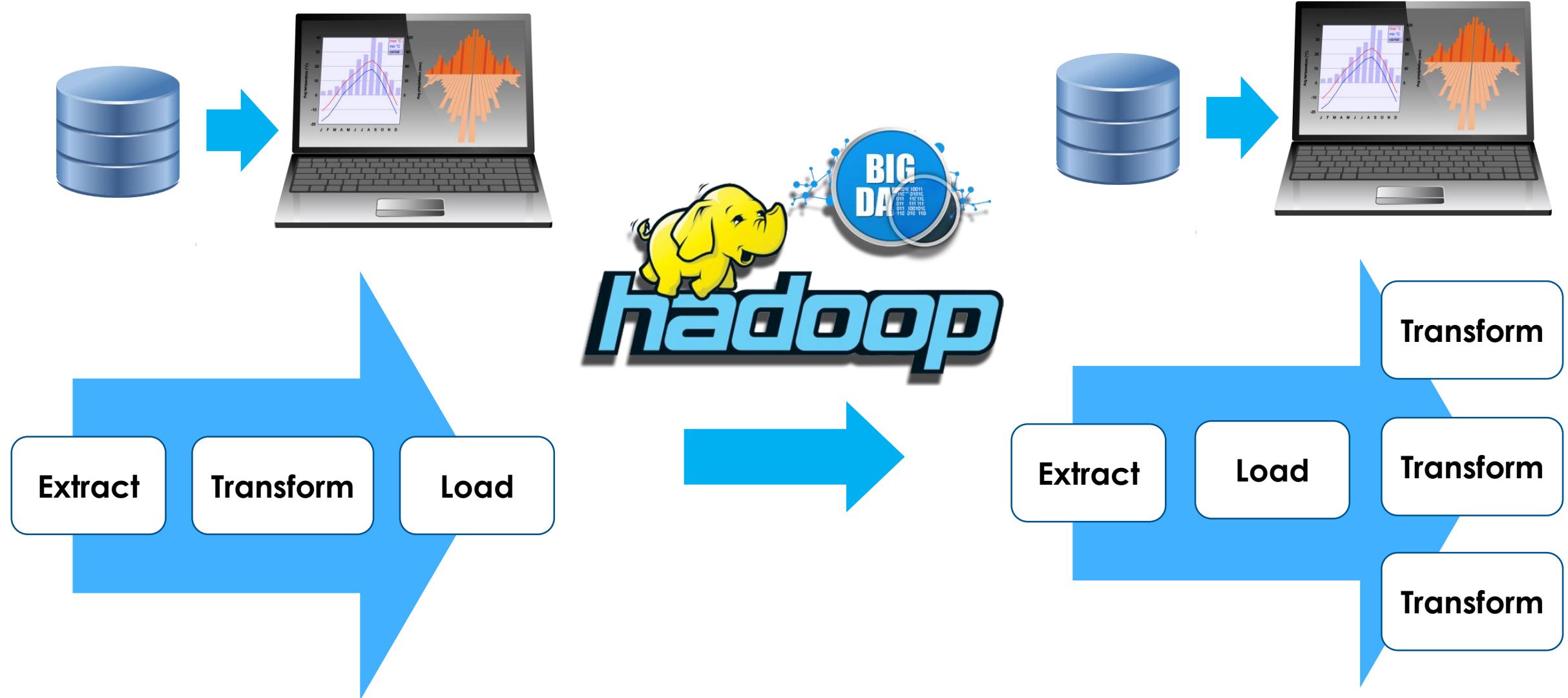
Use Akka Extensions to adapt Akka to fit your needs.



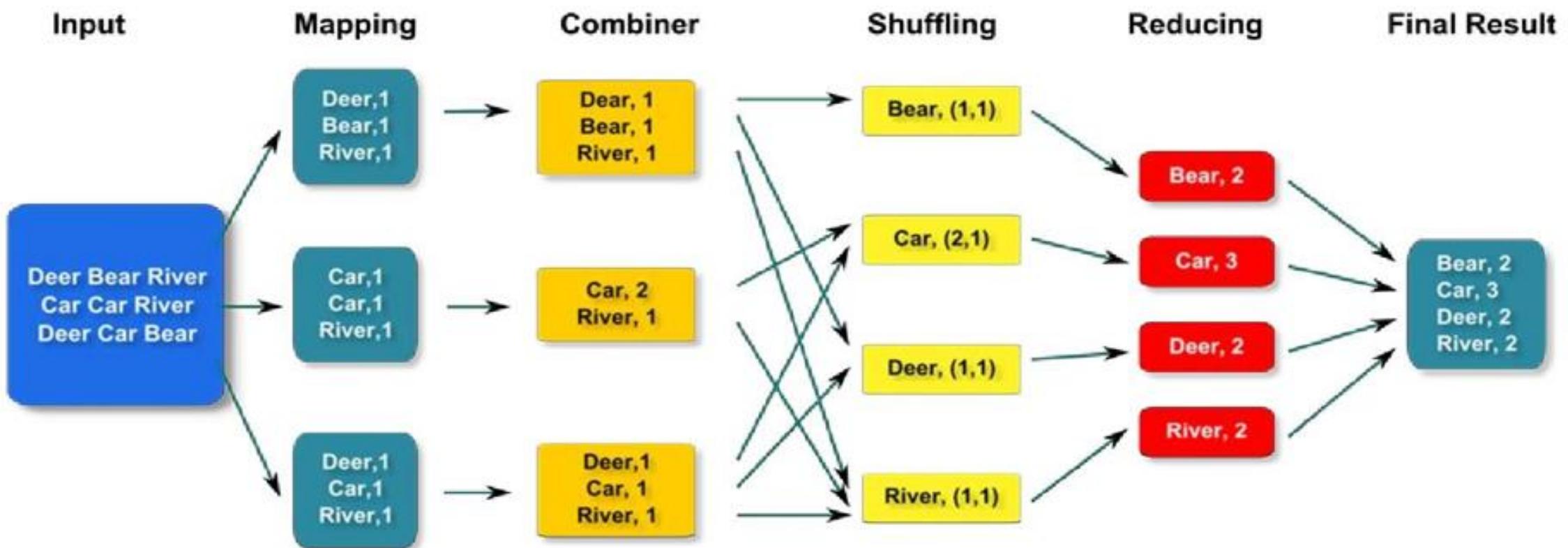
Need for Speed (and Scalability:)



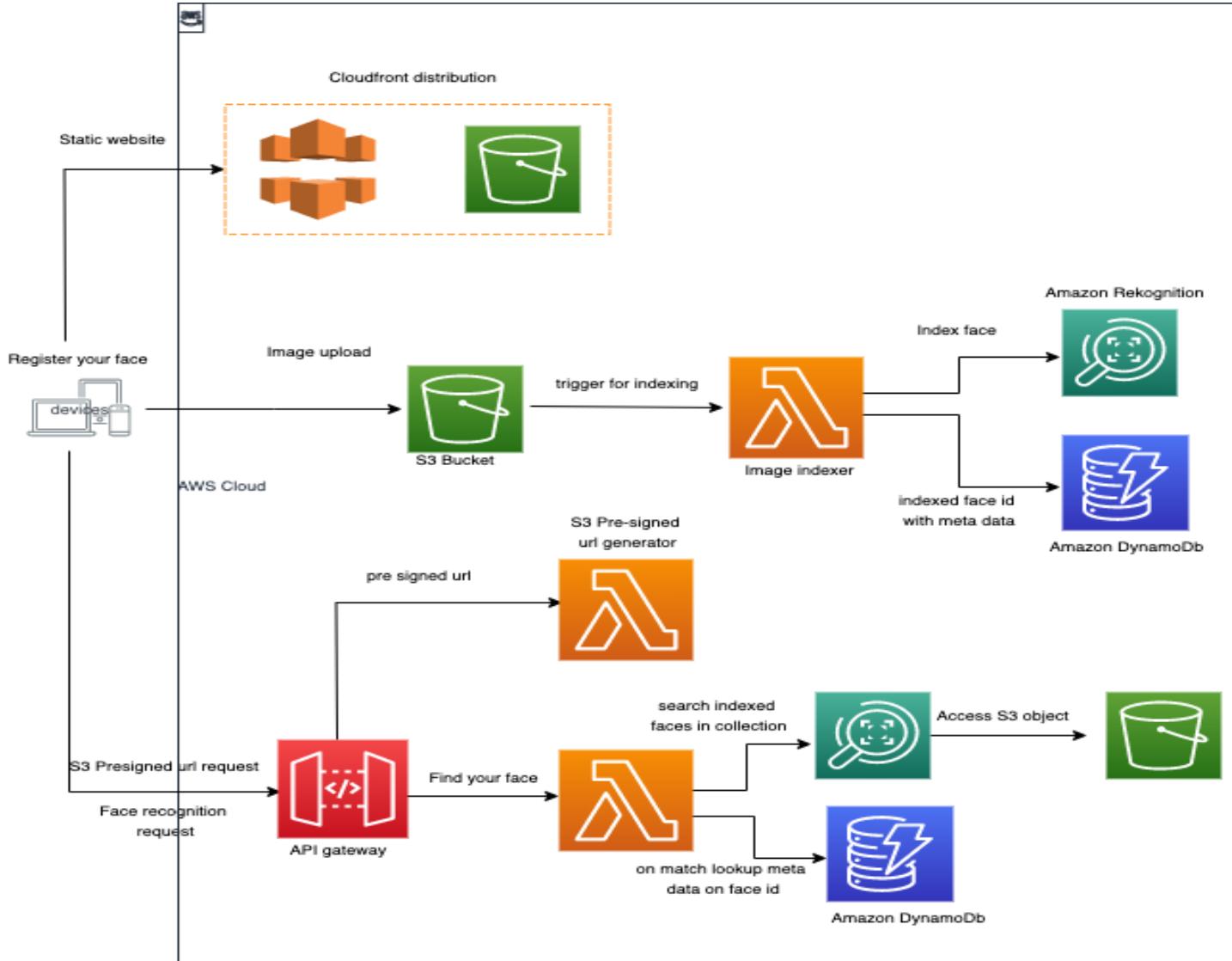
Batch Processing



Map-Reduce Architecture

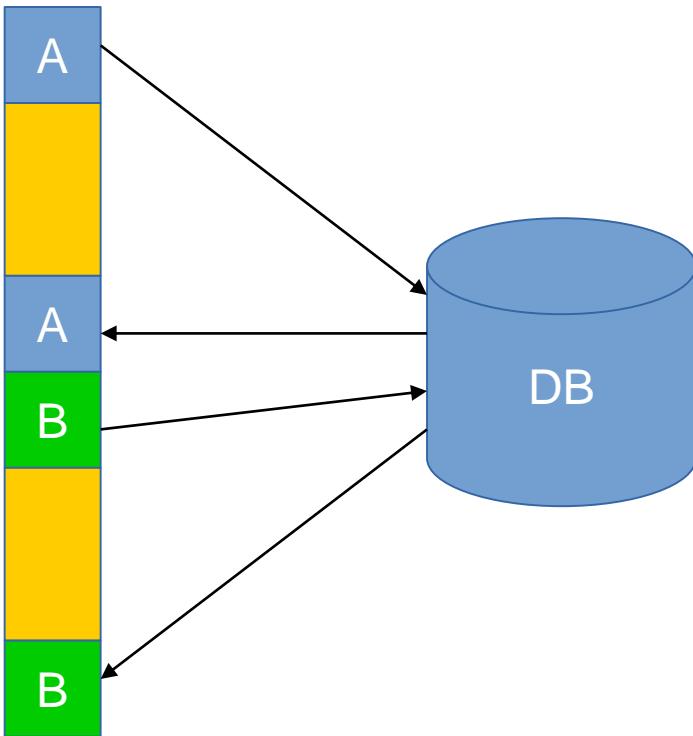


Amazon Lambda

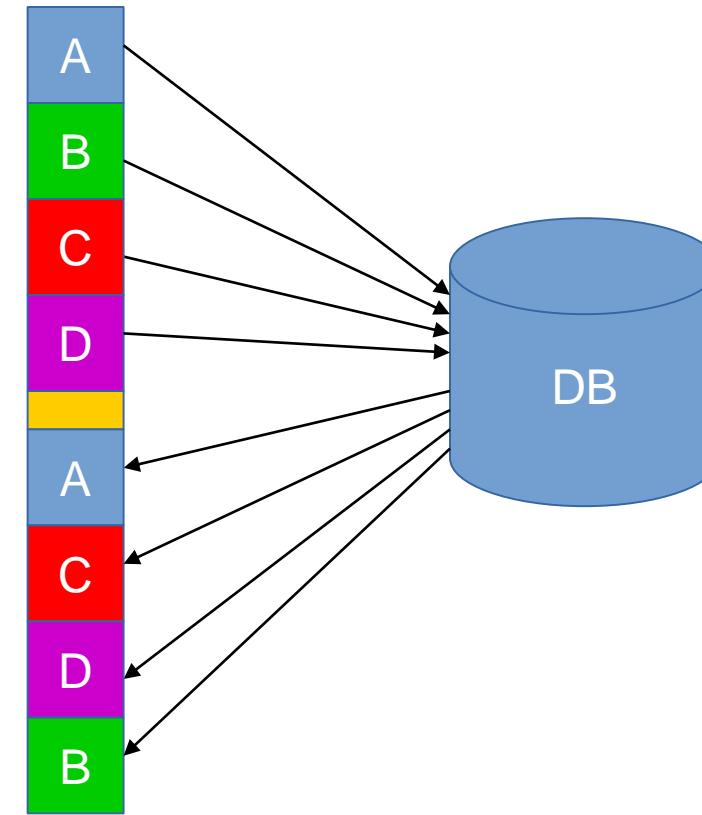


Synchronous vs. Asynchronous IO

Synchronous



Asynchronous



Difference between Local vs. Non-local, and Iterative vs. Non-iterative Processing

<https://core.ac.uk/download/pdf/16270417.pdf>

	1	2	3	4	5	6
1	X	X	X			
2	X	X	X			
3	X	X	X			
4						
5						
6						
7						

	1	2	3	4	5	6
1	X	X	X	X	X	X
2	X	X	X	X	X	X
3	X	X	X	X	X	X
4	X	X	X	X	X	X
5	X	X	X	X	X	X
6	X	X	X	X	X	X
7	X	X	X	X	X	X

The distinction between **iterative** and non-iterative algorithms is simpler: a **non-iterative algorithm** only processes the image a small, constant number of times to achieve the desired effect, whereas an iterative algorithm requires multiple passes, and often the output **image of a previous pass becomes the input of the next pass**.

ReactiveX: Observable vs. Iterable

Example code showing how similar high-order functions can be applied to an Iterable and an Observable

Iterable

```
getDataFromLocalMemory()  
    .skip(10)  
    .take(5)  
    .map({ s -> return s + " transformed" })  
    .forEach({ println "next => " + it })
```

Observable

```
getDataFromNetwork()  
    .skip(10)  
    .take(5)  
    .map({ s -> return s + " transformed" })  
    .subscribe({ println "onNext => " + it })
```

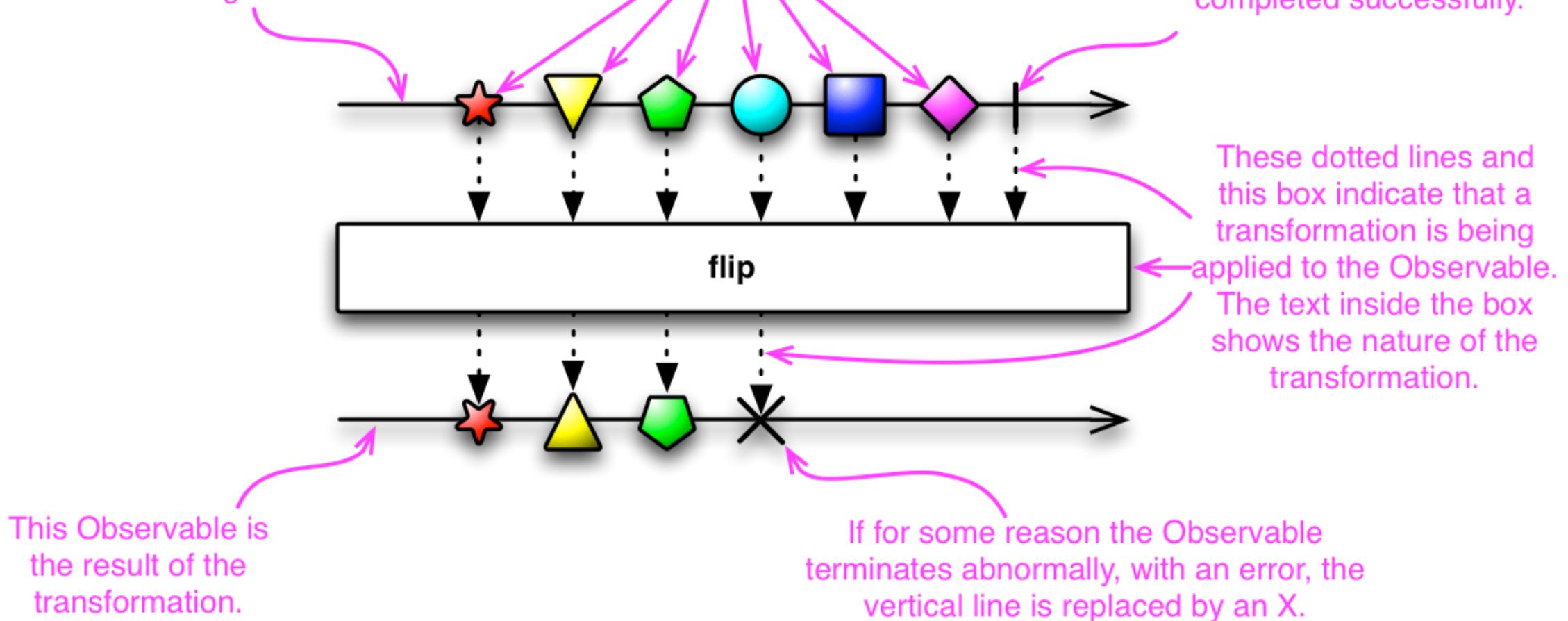
You can think of the Observable class as a “**push**” equivalent to [Iterable](#), which is a “**pull**. With an [Iterable](#), the consumer **pulls** values from the producer and the **thread blocks** until those values arrive. By contrast, with an [Observable](#) the producer **pushes** values to the consumer whenever values are available. This approach is more flexible, because **values can arrive synchronously or asynchronously**.

ReactiveX Observable – Marble Diagrams

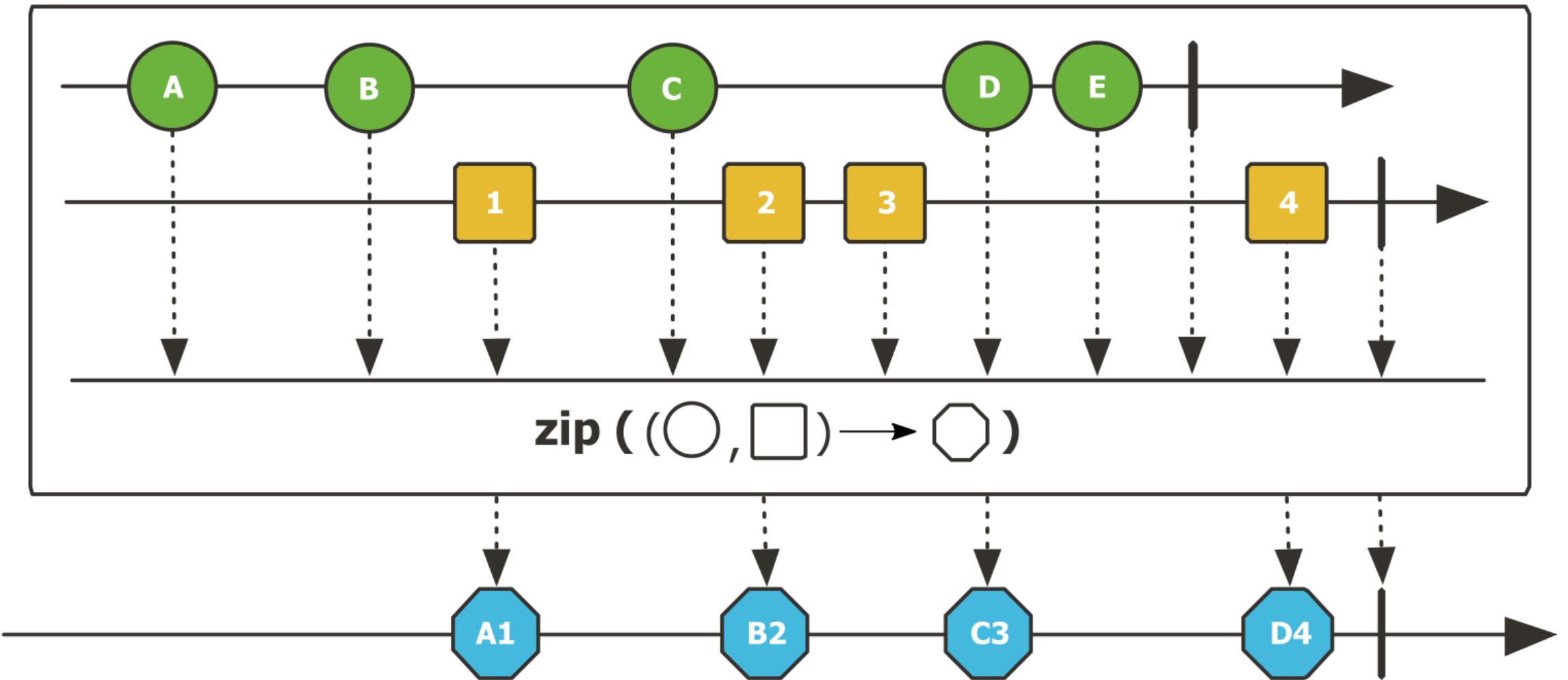
This is the timeline of the Observable. Time flows from left to right.

These are items emitted by the Observable.

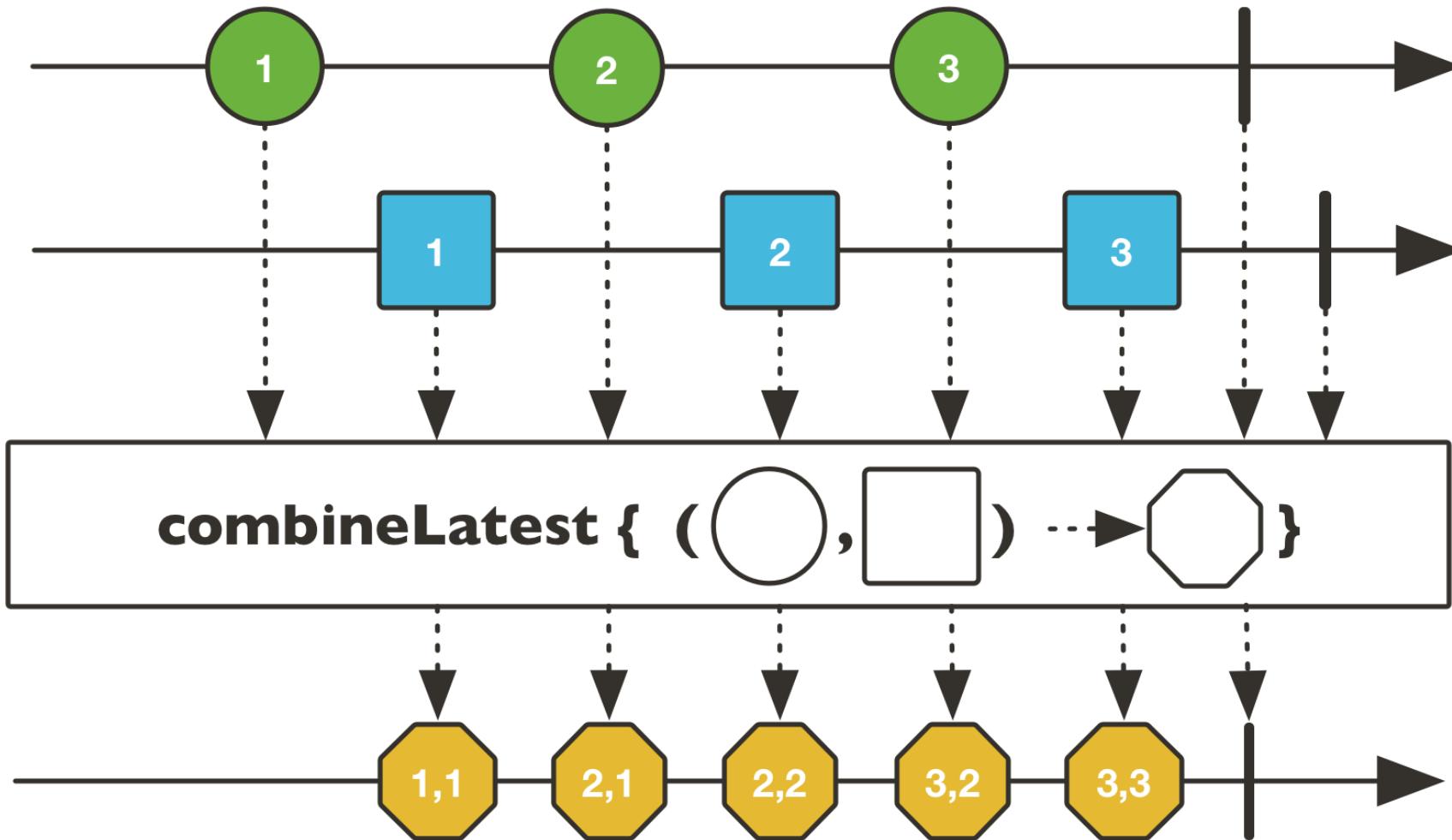
This vertical line indicates that the Observable has completed successfully.



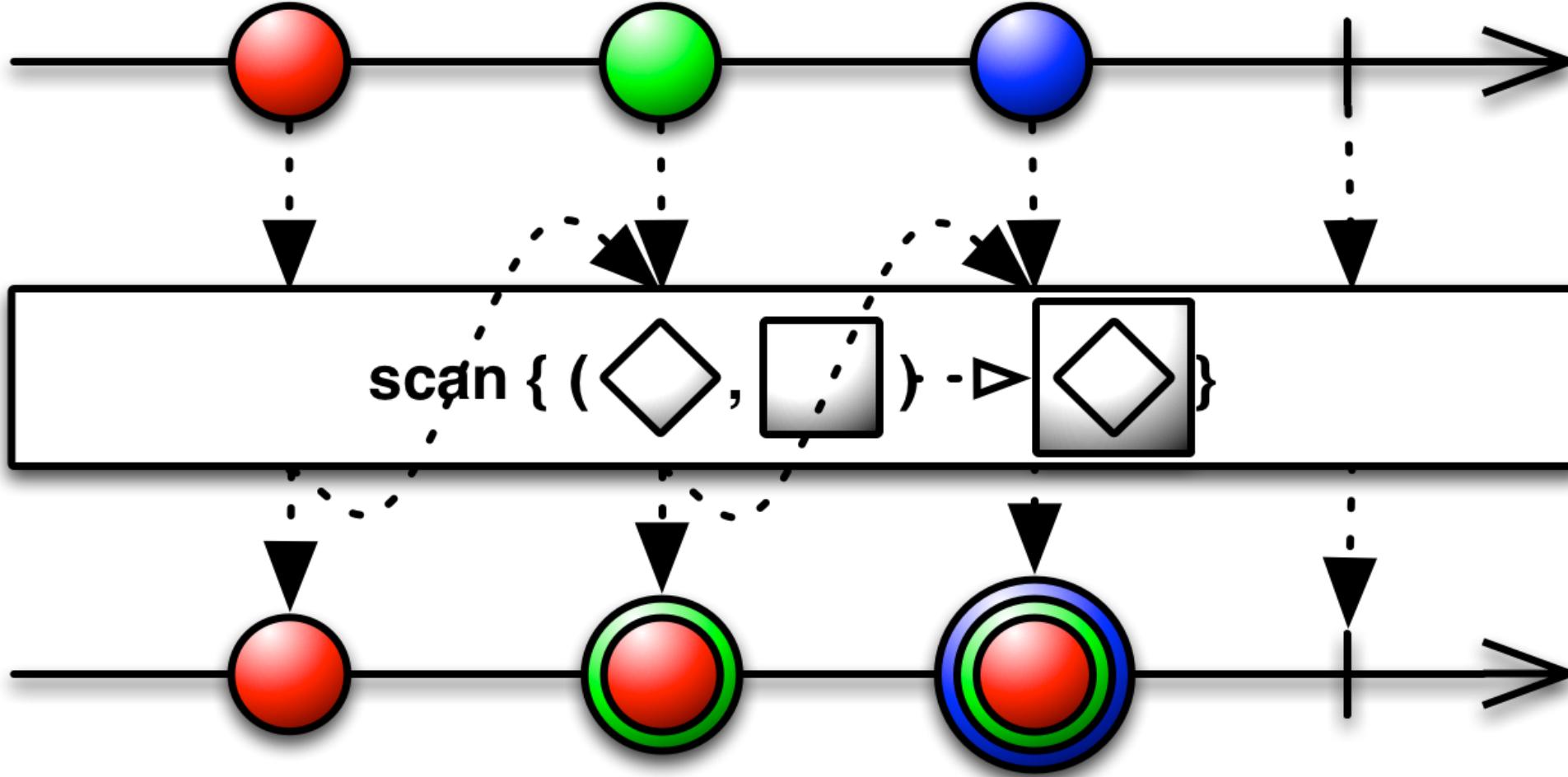
Example: Zip



Example: CombineLatest



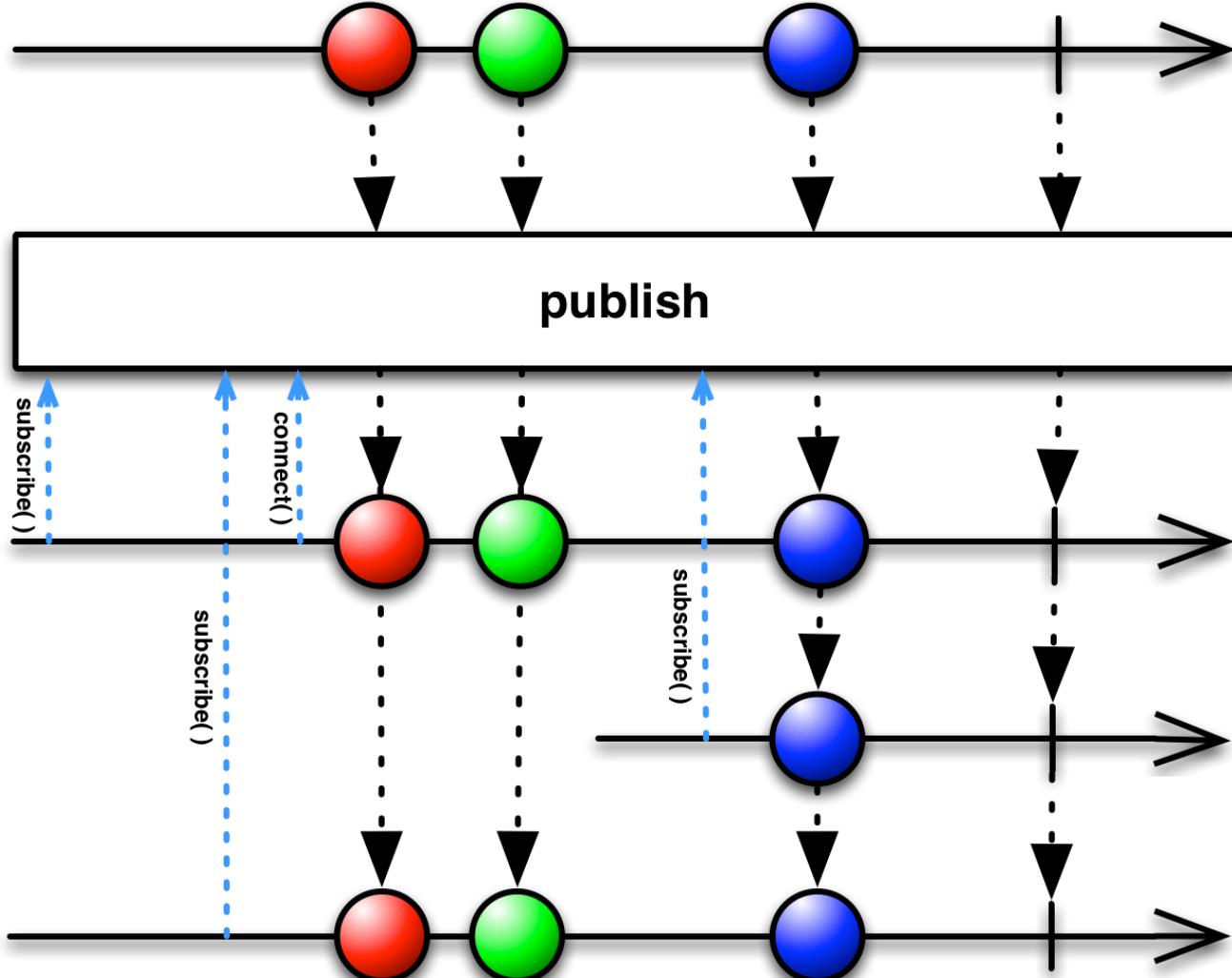
Redux == Rx Scan Operator



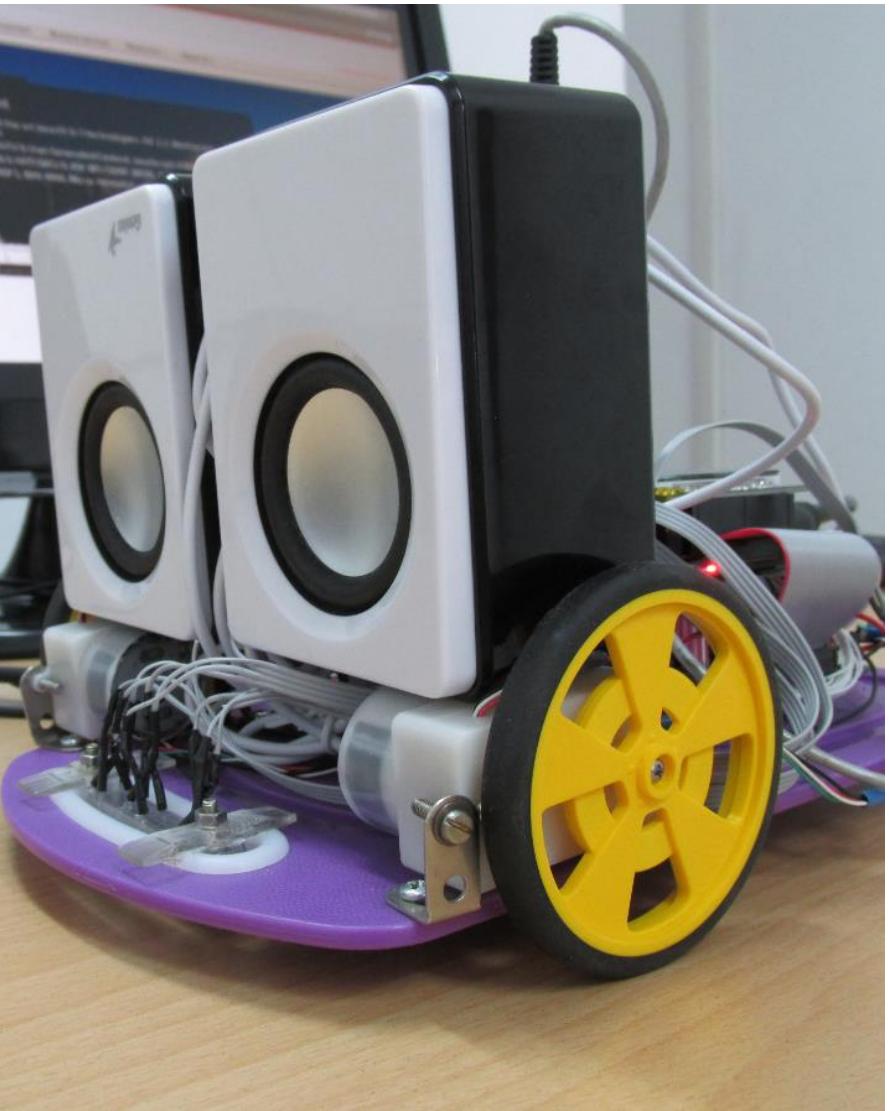
Hot and Cold Event Streams

- **PULL-based (Cold Event Streams)** – Cold streams (e.g. RxJava Observable / Flowable or Reactor Flow / Mono) are streams that run their sequence when and if they are subscribed to. They present the sequence from the start to each subscriber.
- **PUSH-based (Hot Event Streams)** – emit values independent of individual subscriptions. They have their own timeline and events occur whether someone is listening or not. When subscription is made observer receives current events as they happen.
- Example: mouse events

Converting Cold to Hot Stream



IPTPI: Raspberry Pi + Arduino Robot

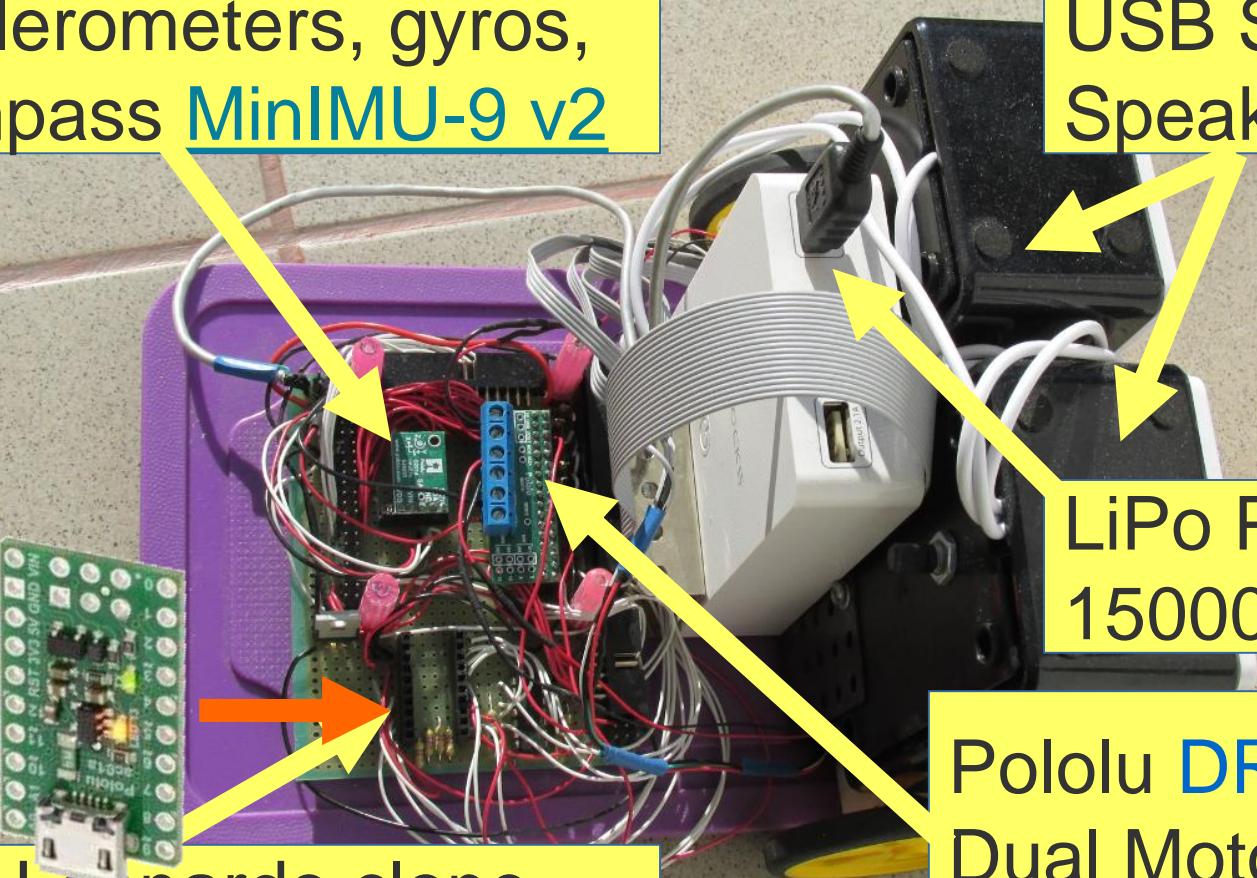


- Raspberry Pi 2 (quad-core ARMv7 @ 900MHz) + Arduino Leonardo clone [A-Star 32U4 Micro](#)
- *Optical encoders* (custom), IR optical array, 3D accelerometers, gyros, and compass [MinIMU-9 v2](#)
- **IPTPI** is programmed in Python, Java and Go using: [Wiring Pi](#), [Numpy](#), [Pandas](#), [Scikit-learn](#), [Pi4J](#), [Reactor](#), [RxJava](#), [GPIO\(Go\)](#)

IPTPI: Raspberry Pi + Arduunio Robot

3D accelerometers, gyros,
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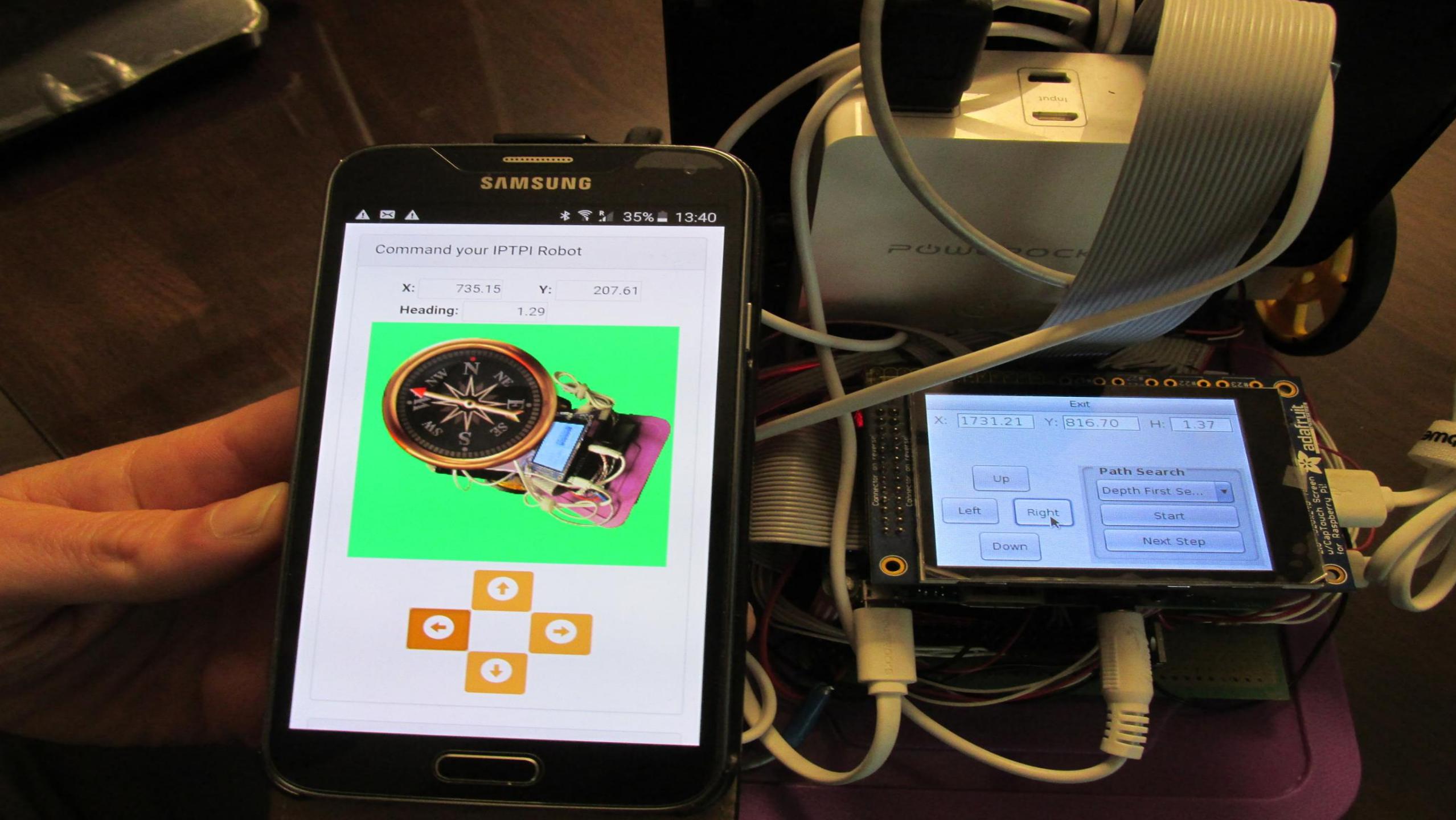
USB Stereo
Speakers - 5V



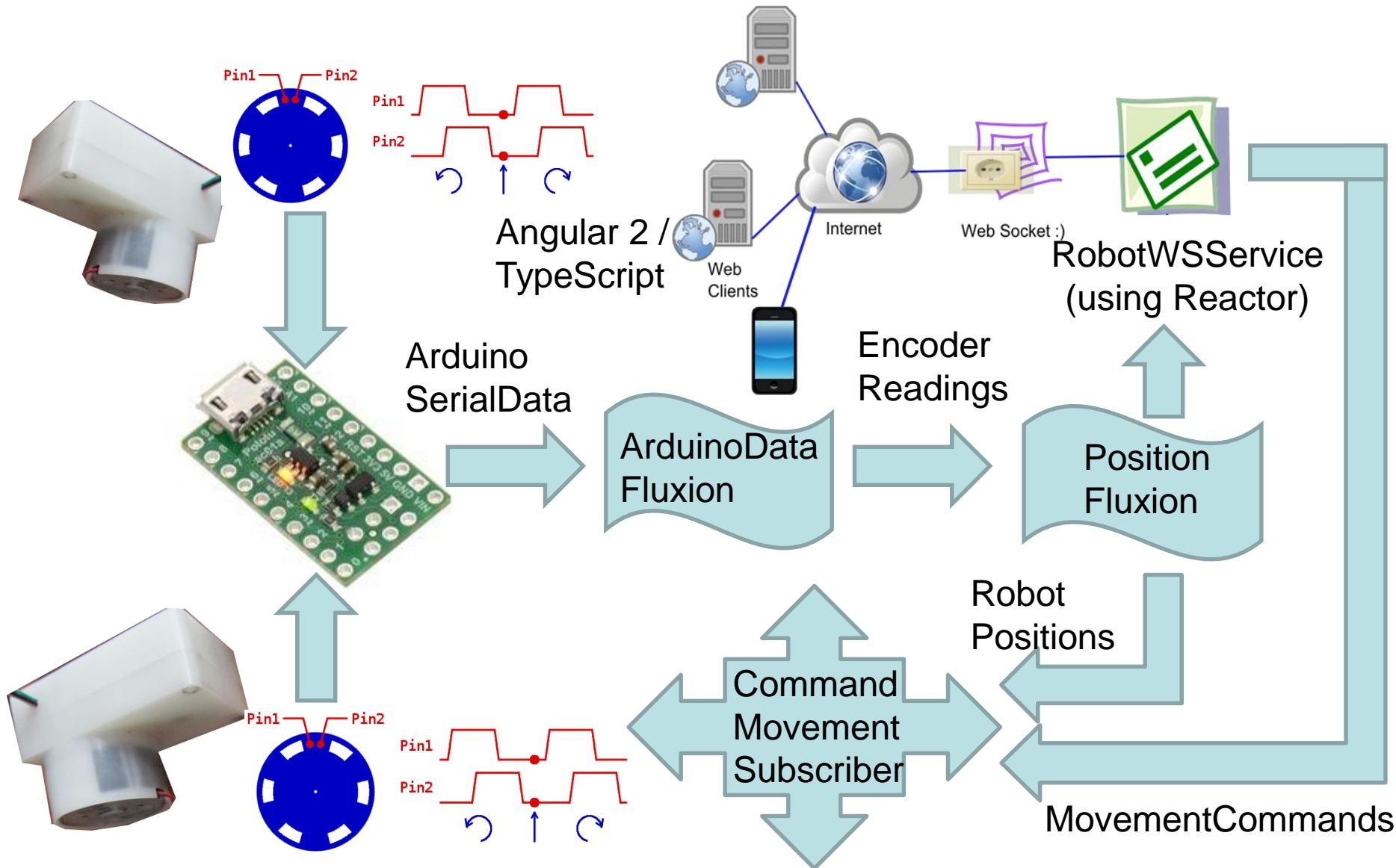
Arduino Leonardo clone
[A-Star 32U4 Micro](#)

LiPo Powebank
15000 mAh

Pololu [DRV8835](#)
Dual Motor Driver
for Raspberry Pi

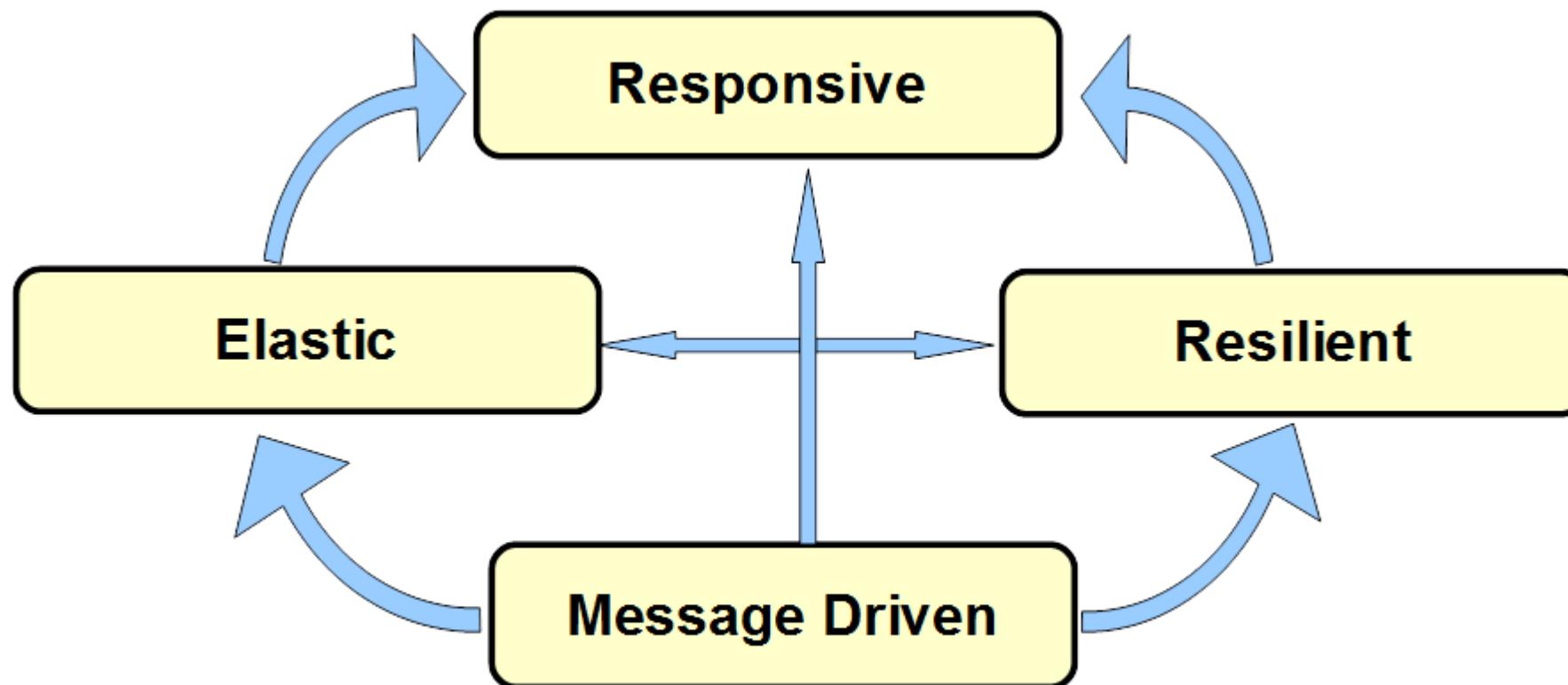


IPTPI Reactive Streams



Reactive Manifesto

[<http://www.reactivemanifesto.org>]



Scalable, Massively Concurrent

- **Message Driven** – asynchronous message-passing allows to establish a boundary between components that ensures loose coupling, isolation, location transparency, and provides the means to delegate errors as messages [Reactive Manifesto].
- The main idea is to separate concurrent producer and consumer workers by using **message queues**.
- **Message queues** can be **unbounded** or **bounded** (limited max number of messages)
- **Unbounded** message queues can present memory allocation problem in case the producers outrun the consumers for a long period → **OutOfMemoryError**

Data / Event / Message Streams

“Conceptually, a stream is a (potentially never-ending) **flow of data records**, and a transformation is an operation that takes one or more streams as input, and produces one or more output streams as a result.”

Apache Flink: Dataflow Programming Model

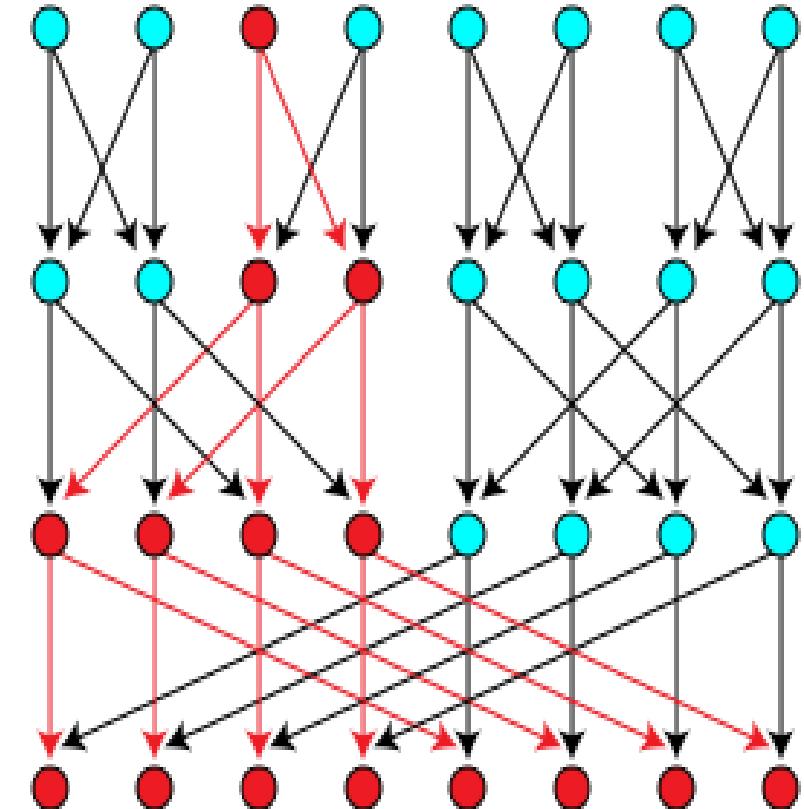
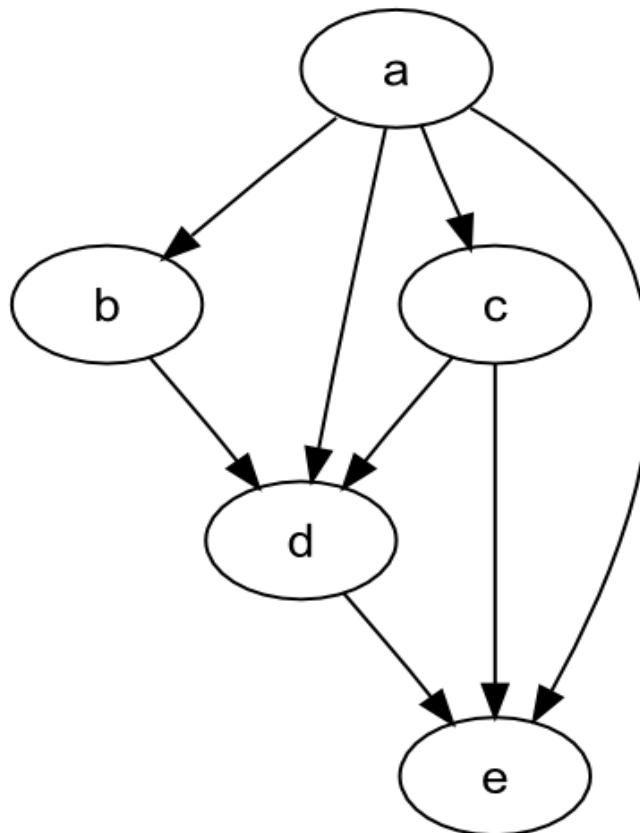
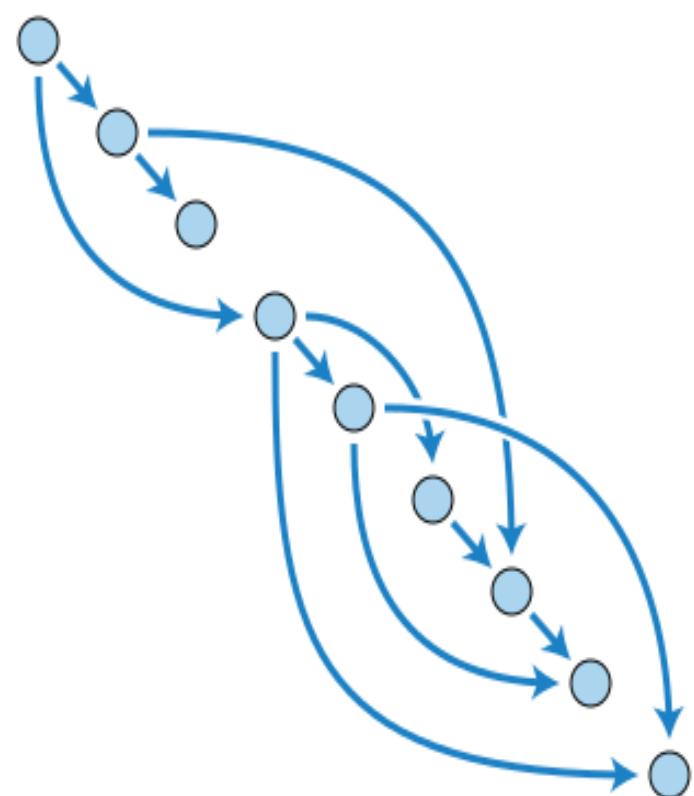
Data Stream Programming

The idea of **abstracting logic from execution** is hardly new -- it was the dream of **SOA**. And the recent emergence of **microservices** and **containers** shows that the dream still lives on.

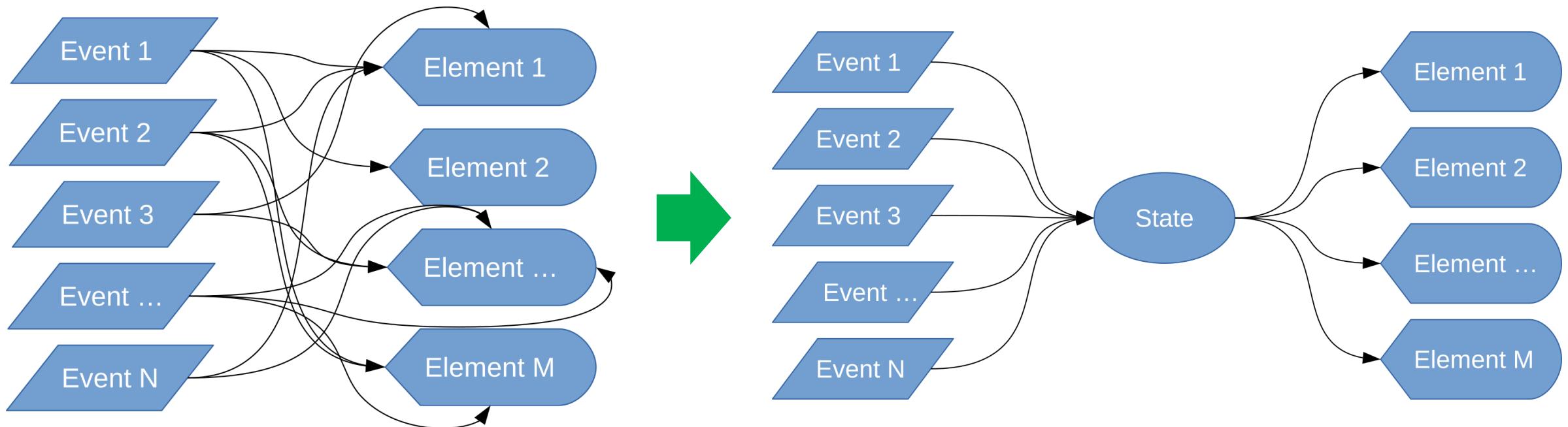
For developers, the question is whether they want to learn yet **one more layer of abstraction** to their coding. On one hand, there's the elusive promise of a **common API to streaming engines** that in theory should let you mix and match, or swap in and swap out.

*Tony Baer (Ovum) @ ZDNet - Apache Beam and Spark:
New competition for squashing the Lambda Architecture?*

Direct Acyclic Graphs - DAG



Event Sourcing – Events vs. State (Snapshots)



What can FP offer to distributed computing ?

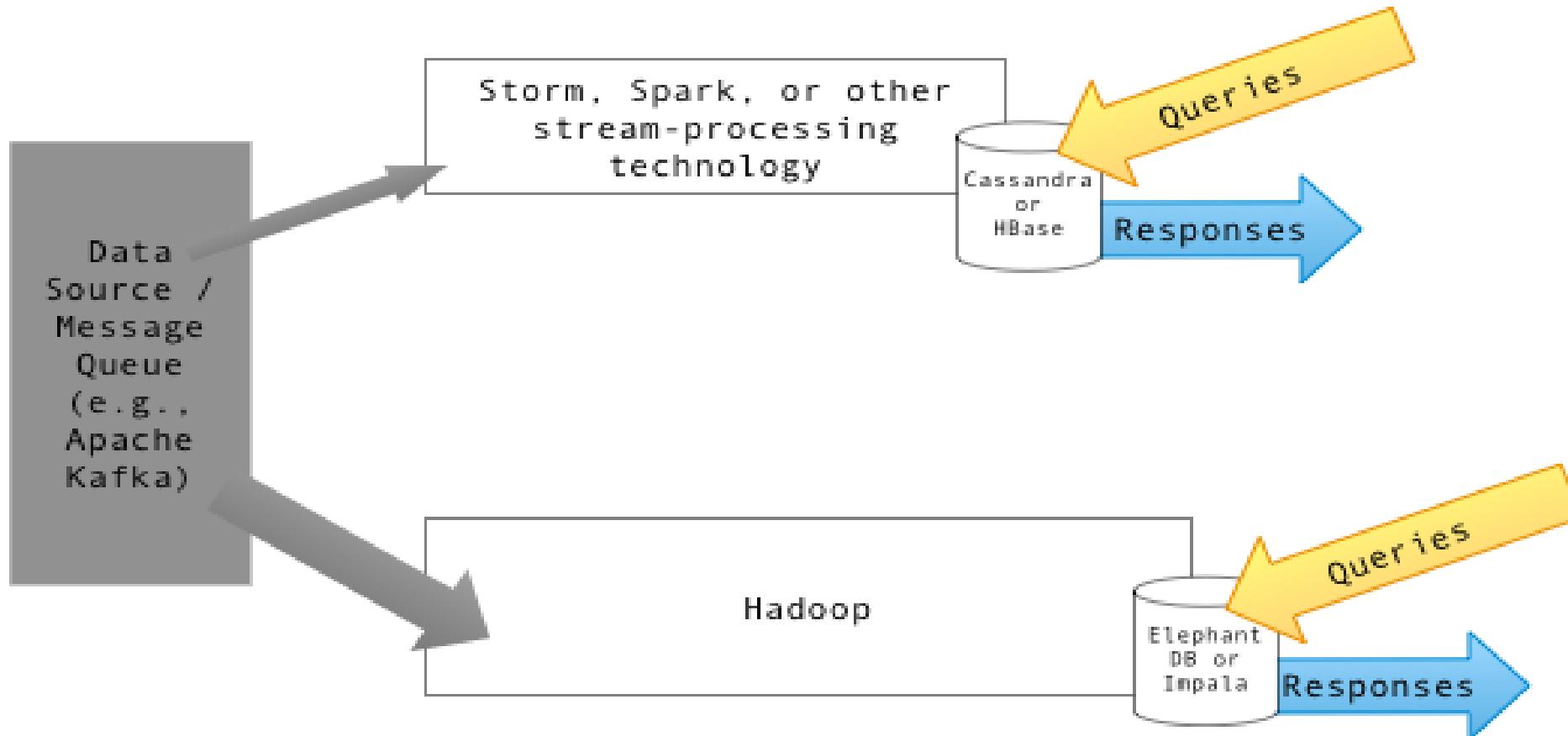
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Lambda Architecture



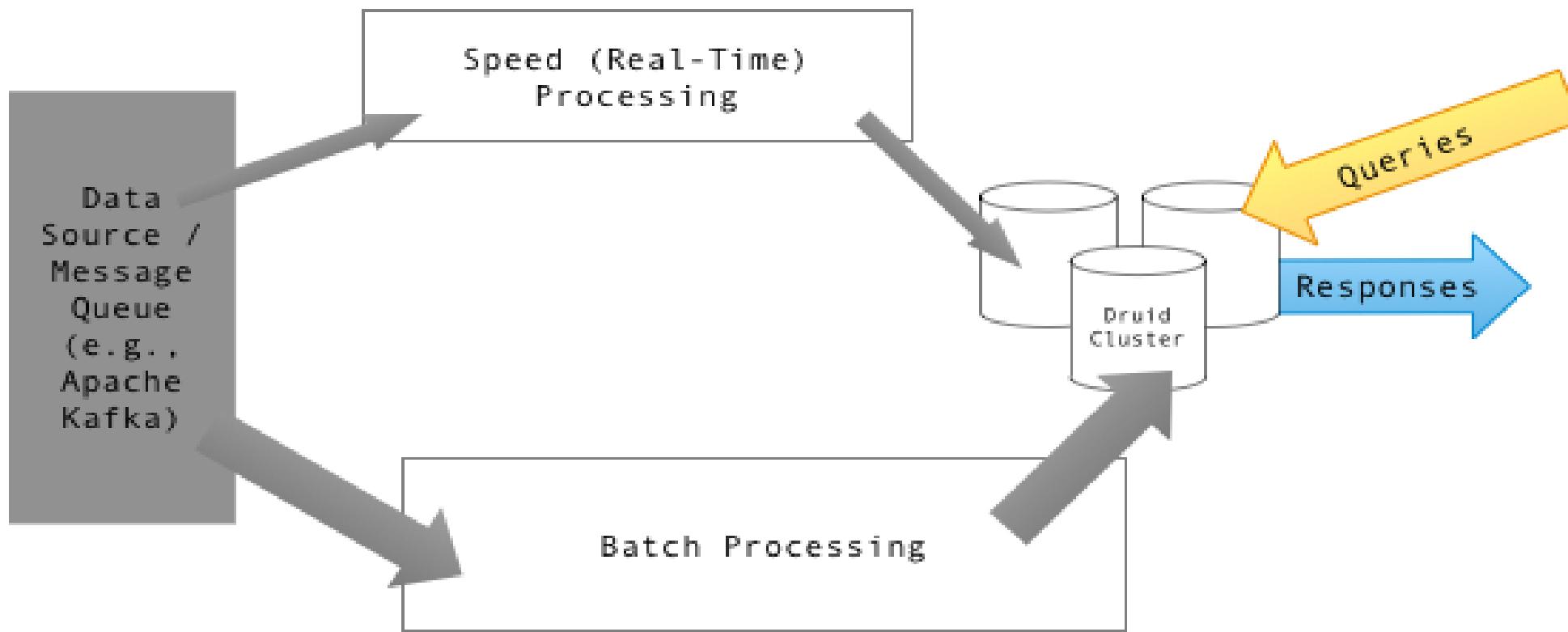
Lambda Architecture - I

Query = λ (Complete data) = λ (live streaming data) * λ (Stored data)



Lambda Architecture - II

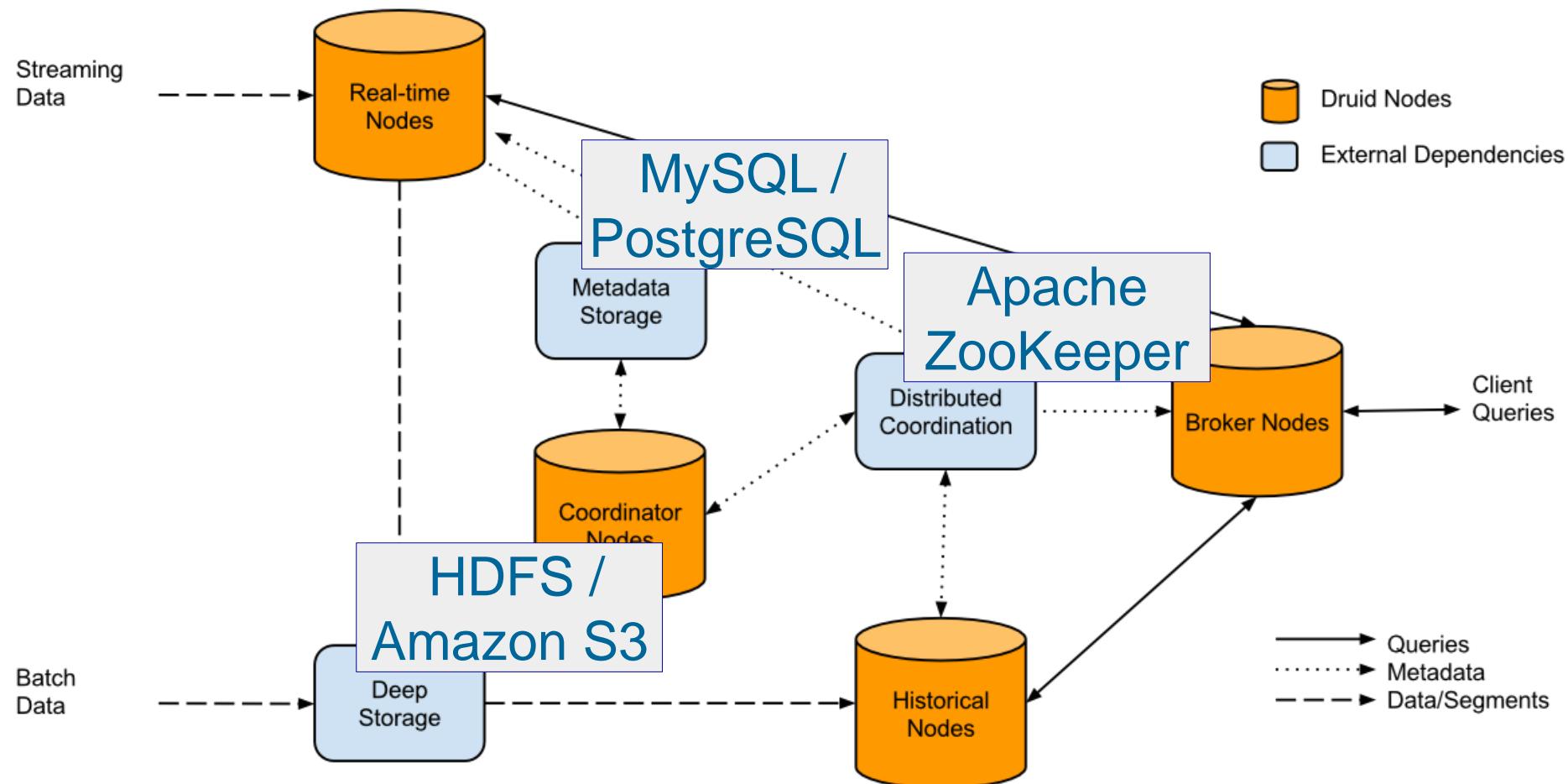
Query = λ (Complete data) = λ (live streaming data) * λ (Stored data)



Lambda Architecture - III

- Data-processing architecture designed to handle massive quantities of data by using both *batch-* and *stream-processing* methods
- Balances *latency*, *throughput*, *fault-tolerance*, *big data*, *real-time analytics*, mitigates the latencies of map-reduce
- Data model with an *append-only*, *immutable data* source that serves as a system of record
- Ingesting and processing *timestamped events* that are appended to existing events. State is determined from the *natural time-based ordering* of the data.
- Can use relational SQL DBs or a key-value store like Cassandra

Druid Distributed Data Store (Java)



<https://commons.wikimedia.org/w/index.php?curid=33899448> By Fangjin Yang - sent to me personally, GFDL

Lambda Architecture: Projects - I

- Apache Spark is an open-source cluster-computing framework. Spark Streaming, Spark Mllib
- Apache Storm is a distributed stream processing – streams DAG
- Apache Samza is a distributed real-time stream processing framework.

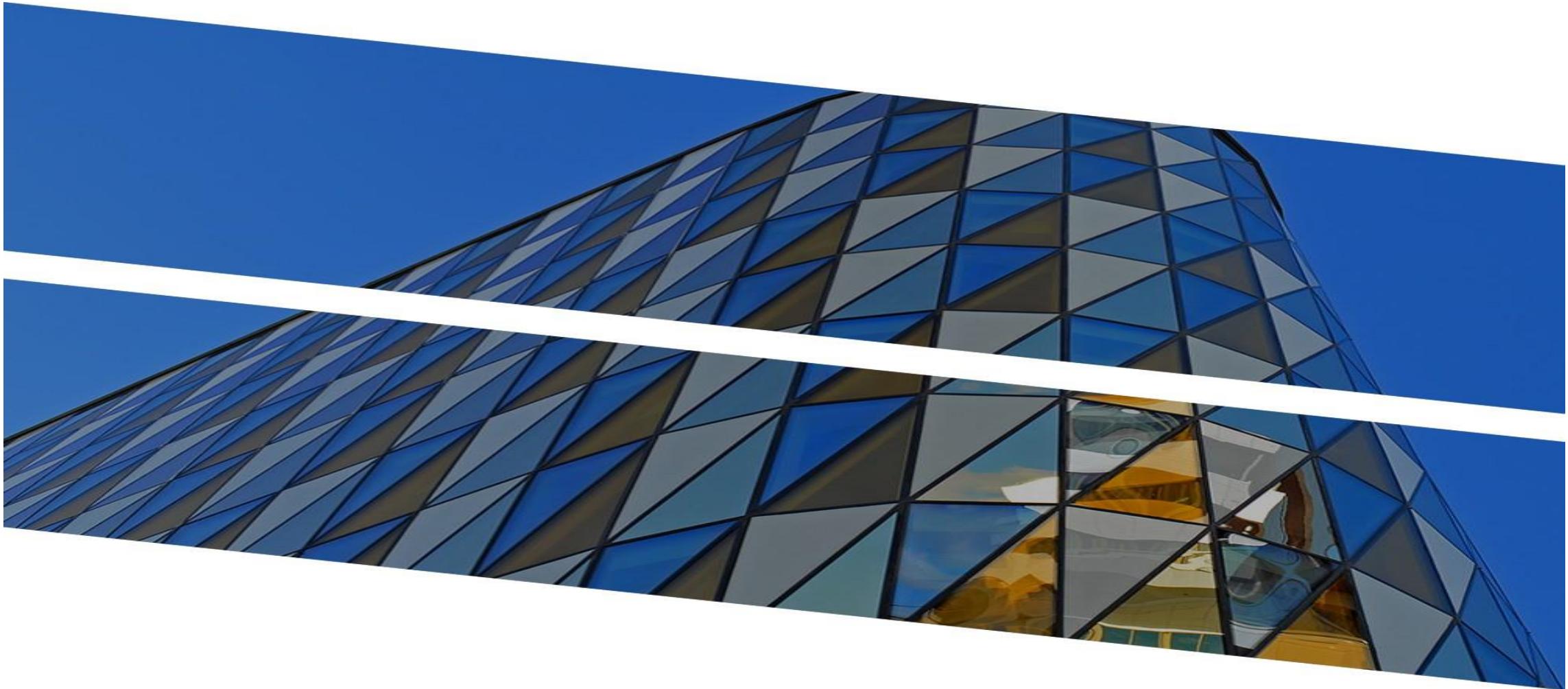


Lambda Architecture: Projects - II

- **Apache Flink** - open source stream processing framework – Java, Scala
- **Apache Kafka** - open-source stream processing (Kafka Streams), real-time, low-latency, high-throughput, massively scalable pub/sub
- **Apache Beam** – unified batch and streaming, portable, extensible



Kappa Architecture



Kappa Architecture

Query = K (New Data) = K (Live streaming data)

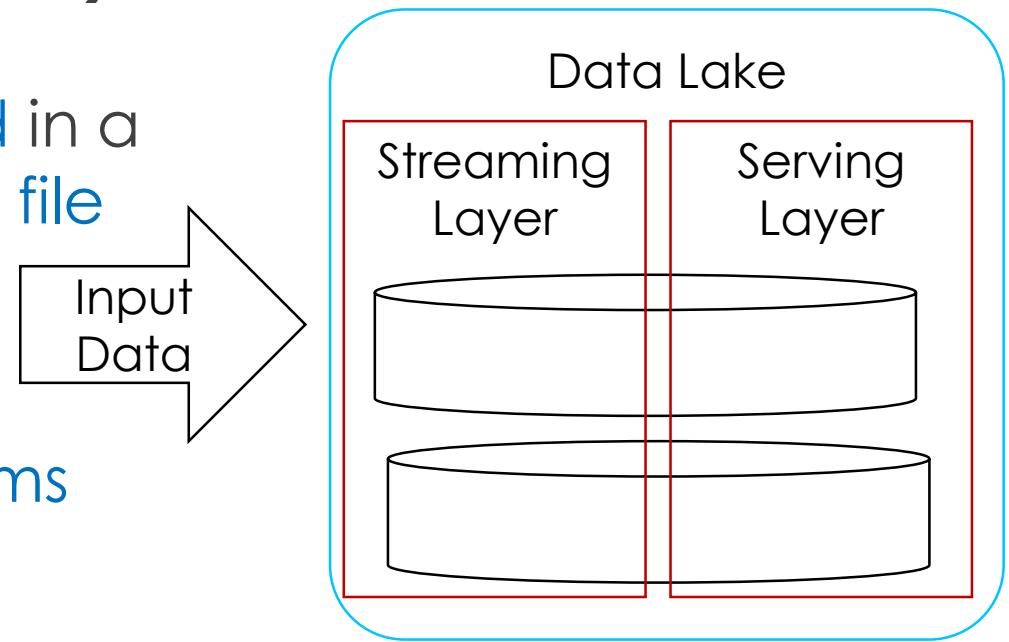
- Proposed by Jay Kreps in 2014
- Real-time processing of distinct events
- Drawbacks of Lambda architecture:
 - It can result in coding overhead due to comprehensive processing
 - Re-processes every batch cycle which may not be always beneficial
 - Lambda architecture modeled data can be difficult to migrate
- Canonical data store in a Kappa Architecture system is an append-only immutable log (like Kafka, Pulsar)



Kappa Architecture II

Query = K (New Data) = K (Live streaming data)

- Multiple **data events or queries** are logged in a queue to be catered against a **distributed file system storage** or **history**.
- The order of the events and queries is not predetermined. **Stream processing platforms** can interact with **database** at any time.
- It is **resilient** and **highly available** as handling **terabytes of storage** is required for each node of the system to **support replication**.
- Machine learning is done on the **real time basis**



Pros and Cons of Kappa architecture

- Pros
 - Kappa architecture can be used to develop data systems that are online learners and therefore don't need the batch layer.
 - Re-processing is required only when the code changes.
 - It can be deployed with fixed memory.
 - It can be used for horizontally scalable systems.
 - Fewer resources are required as the machine learning is being done on the real time basis.
- Cons
 - Absence of batch layer might result in errors during data processing or while updating the database that requires having an exception manager to reprocess the data or reconciliation.

Zeta Architecture

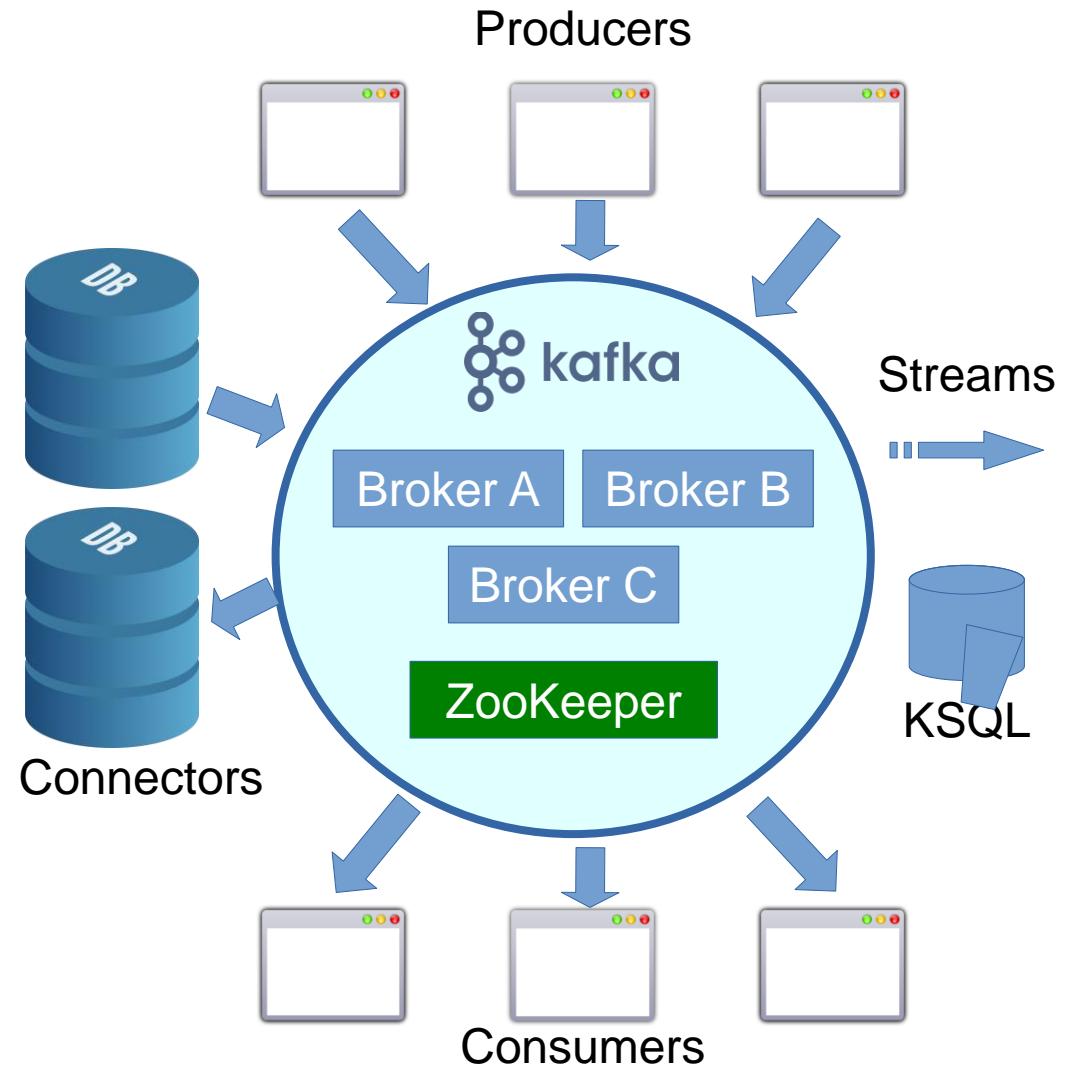
- Main characteristics of Zeta architecture:
 - file system ([HDFS](#), [S3](#), [GoogleFS](#)),
 - realtime data storage ([HBase](#), [Spanner](#), [BigTable](#)),
 - modular processing model and platform ([MapReduce](#), [Spark](#), [Drill](#), [BigQuery](#)),
 - containerization and deployment ([cgroups](#), [Docker](#), [Kubernetes](#)),
 - Software solution architecture ([serverless computing](#) – e.g. [Amazon Lambda](#))
- Recommender systems and [machine learning](#)
- Business applications and dynamic global resource management ([Mesos + Myriad](#), [YARN](#), [Diego](#), [Borg](#)).

Apache Kafka



Kafka Core APIs

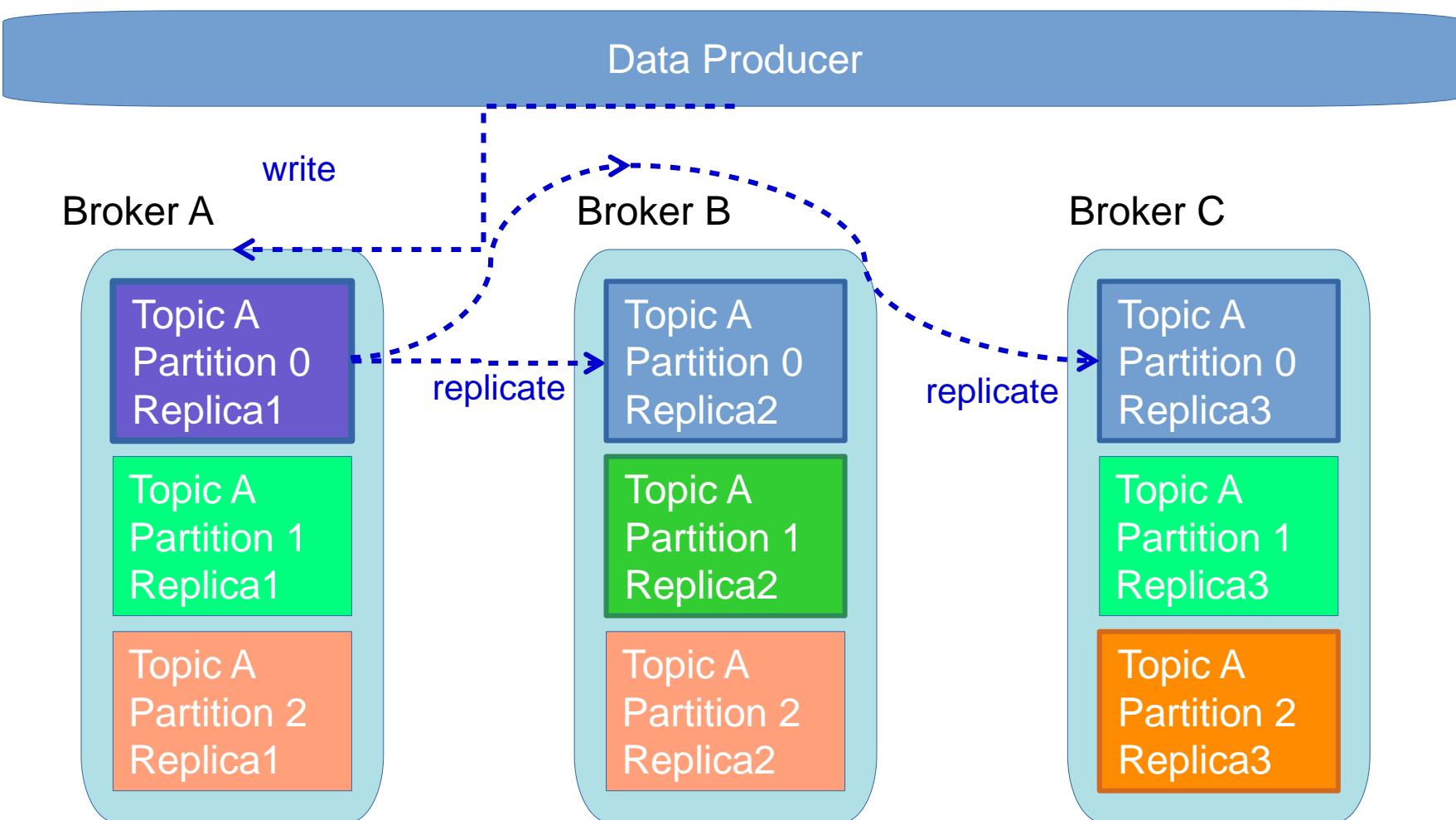
- The **Producer API** - publish a stream of records to one or more Kafka topics.
- The **Consumer API** - subscribe to one or more topics and process the stream of records produced to them.
- The **Streams API** - a stream processor, consuming an input stream from one or more topics and producing an output stream to one or more output topics, effectively transforming the input streams to output streams.
- The **Connector API** allows building and running reusable producers or consumers that connect Kafka topics to existing applications or data systems – e.g. connector to a DB might capture every change in a table



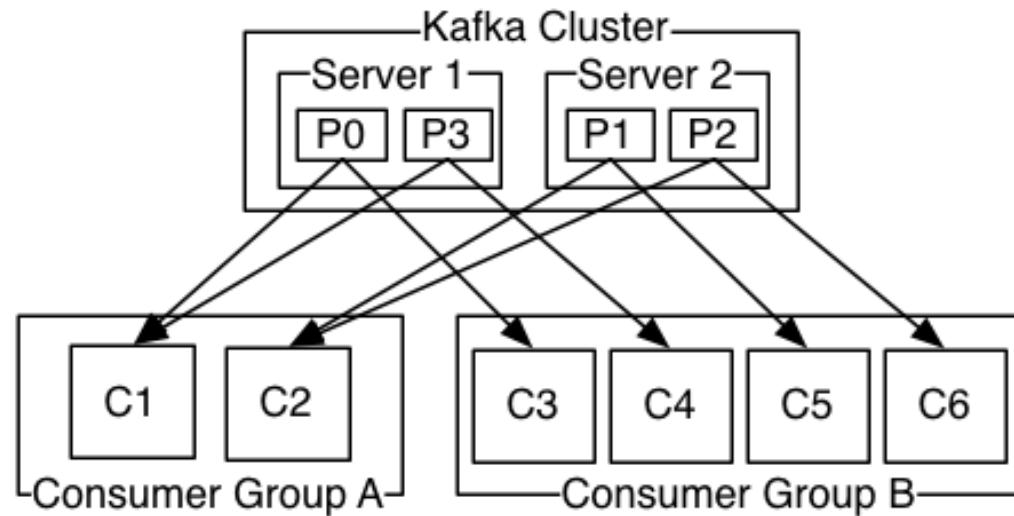
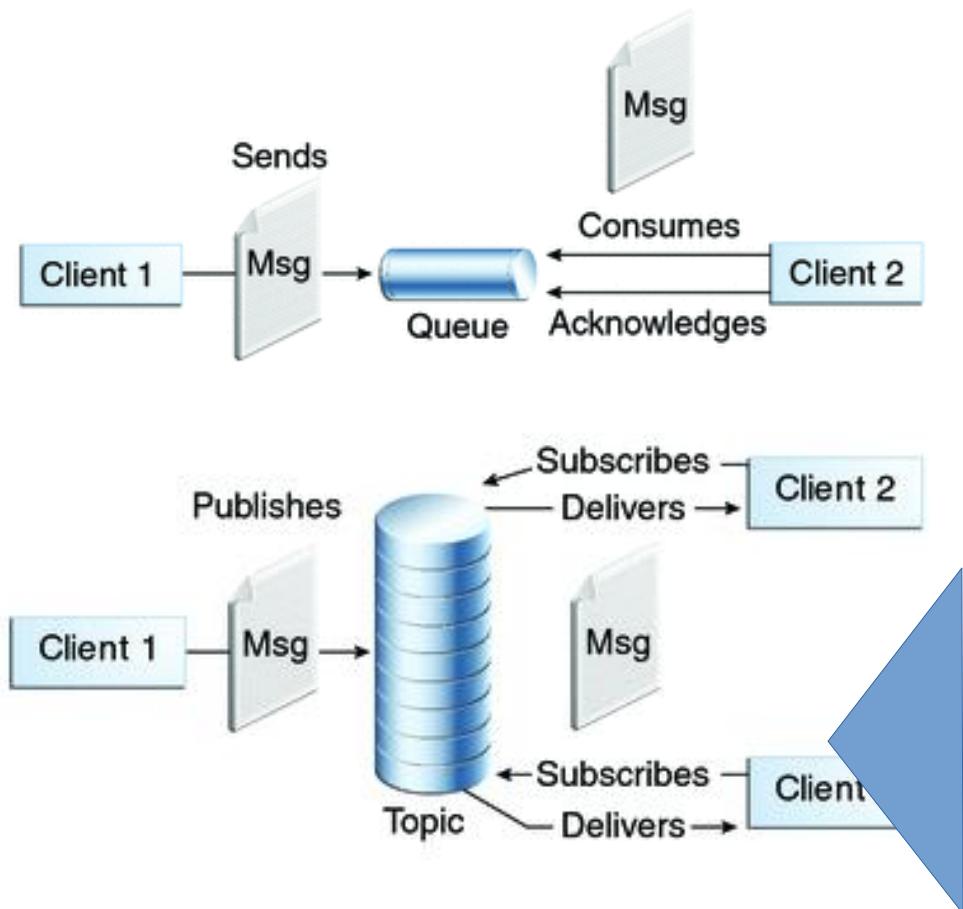
Kafka Stream Processing

- Kafka streams **read** data from a topic, running some form of analysis or **data transformation**, and finally **writing** the data back to another topic or shipping it to an **external source**.
- Streams we can achieve **real-time stream processing** rather than batch processing. For the majority of cases, it's recommended to use **Kafka Streams Domain Specific Language (DSL)** to perform data transformations (e.g. map, filter, join, aggregations).
- Stream processors are independent of Kafka Producers, Consumers, and Connectors.
- Kafka offers a streaming SQL engine called **KSQL** for working with Kafka Streams in a SQL-like manner without having to write code like Java. **KSQL** allows you to transform data within Kafka streams such as preparing the data for **processing**, **running analytics** and **monitoring**, and **detecting anomalies** in real-time.

Data Replication



Kafka as a Messaging System



Kafka Streams

- By combining **storage** and **low-latency subscriptions**, **streaming applications can treat both past and future data the same way**. That is a single application can process historical, stored data but rather than ending when it reaches the last record it can keep processing as future data arrives. This is a generalized notion of stream processing that subsumes batch processing as well as message-driven applications ==> **Kappa architecture**
- Likewise for streaming data pipelines the combination of subscription to real-time events make it possible to use Kafka for very low-latency pipelines; but the **ability to store data reliably make it possible to use it for critical data** where the delivery of data must be guaranteed or for **integration with offline systems** that load data only periodically or may go down for extended periods of time for maintenance. The stream processing facilities make it possible to **transform data as it arrives**.

Why you'll love using Kafka Streams?

- Elastic, highly scalable, fault-tolerant
- Deploy to containers, VMs, bare metal, cloud
- Equally viable for small, medium, & large use cases
- Fully integrated with Kafka security
- Write standard Java and Scala applications
- Exactly-once processing semantics
- No separate processing cluster required
- Develop on Mac, Linux, Windows

Kafka Streams Advantages

- Designed as a **simple and lightweight client library**, which can be easily embedded in any Java application and integrated with any existing packaging, deployment and operational tools that users have for their streaming applications.
- Has **no external dependencies on systems other than Apache Kafka itself** as the internal messaging layer; notably, it uses Kafka's partitioning model to horizontally scale processing while maintaining strong ordering guarantees.
- Supports **fault-tolerant local state**, which enables very fast and efficient stateful operations like windowed joins and aggregations.

Kafka Streams Advantages - II

- Supports **exactly-once** processing semantics to guarantee that each record will be processed once and only once even when there is a failure on either Streams clients or Kafka brokers in the middle of processing.
- Employs **one-record-at-a-time** processing to achieve millisecond processing latency, and supports **event-time based windowing operations** with **out-of-order arrival** of records.
- Offers necessary stream processing primitives, along with a **high-level Streams DSL** and a **low-level Processor API**.

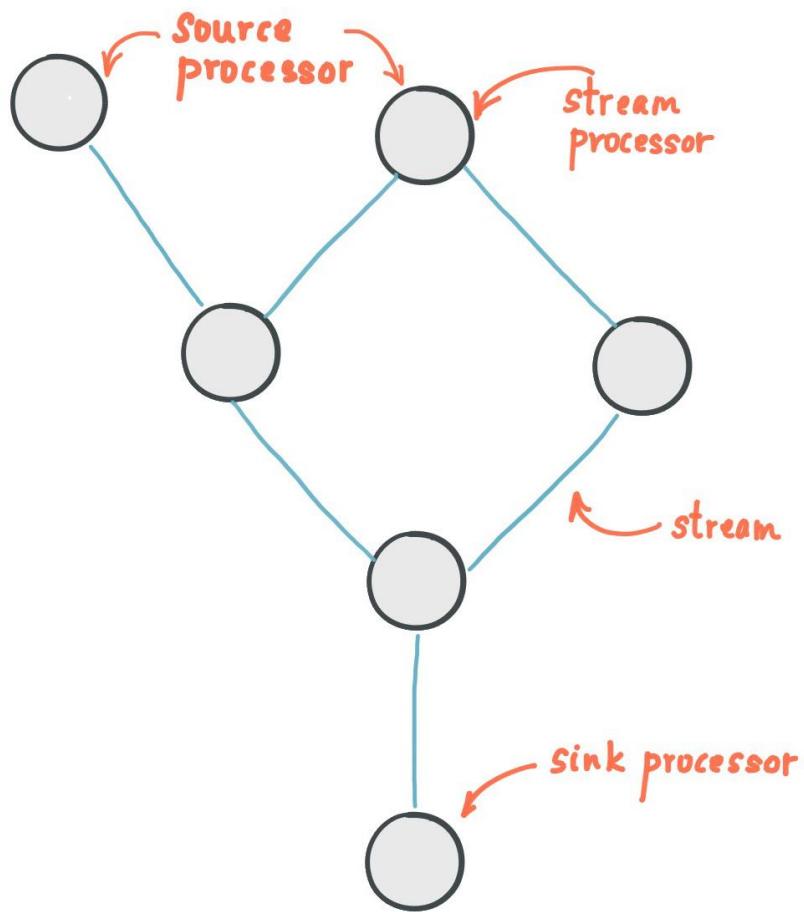
Stream Processing Topology - I

- A **stream** is the most important abstraction provided by Kafka Streams: it represents an unbounded, continuously updating data set. A stream is an ordered, replayable, and fault-tolerant sequence of **immutable data records**, where a **data record** is defined as a **key-value pair**.
- A **stream processing application** is any program that makes use of the **Kafka Streams** library. It defines its computational logic through one or more processor topologies, where a **processor topology** is a **graph of stream processors (nodes)** that are connected by streams (edges).
- A **stream processor** is a **node in the processor topology**; it represents a **processing step** to transform data in streams by receiving **one input record** at a time from its **upstream processors** in the topology, **applying its operation** to it, and may subsequently produce one or more output records to its **downstream processors**.

Stream Processing Topology - II

- There are two special processors in the topology:
- **Source Processor**: A source processor is a special type of stream processor that **does not have any upstream processors**. It produces an input stream to its topology from one or multiple Kafka topics by consuming records from these topics and forwarding them to its **down-stream processors**.
- **Sink Processor**: A sink processor is a special type of stream processor that **does not have down-stream processors**. It sends any received records from its up-stream processors to a specified **Kafka topic**.
- Note that in normal processor nodes other remote systems can also be accessed while processing the current record. Therefore the **processed results** can either be **streamed back into Kafka** or **written to an external system**.

Kafka Stream Processing - DAG



PROCESSOR TOPOLOGY

Time in Kafka Streams - I

- A critical aspect in stream processing is the **notion of time**, and how it is modeled and integrated. For example, some operations such as **windowing** are defined based on **time boundaries**. Common notions of time in streams are:
- **Event time** - the point in time when an event or data record occurred, i.e. was originally created "at the source".
- **Processing time** - the point in time when the event or data record happens to be processed by the stream processing application, i.e. when the record is being consumed.
- **Example:** Imagine an analytics application that reads and processes the geo-location data reported from car sensors to present it to a fleet management dashboard. Here, processing-time in the analytics application might be milliseconds or seconds (e.g. for real-time pipelines based on Apache Kafka and Kafka Streams) or hours (e.g. for batch pipelines based on Apache Hadoop or Apache Spark) after event-time.

Time in Kafka Streams - II

- **Ingestion time** - The point in time when an event or data record is stored in a topic partition by a Kafka broker. The difference to **event time** is that this **ingestion timestamp** is generated **when the record is appended to the target topic by the Kafka broker**, not when the record is created "at the source". The difference to **processing time** is that processing time is when the stream processing application processes the record. For example, if a record is never processed, there is no notion of processing time for it, but it still has an ingestion time.
- The choice between event-time and ingestion-time is actually done through the configuration of Kafka (not Kafka Streams) – timestamps are automatically embedded into Kafka messages. Depending on Kafka's configuration these timestamps represent **event-time** or **ingestion-time**. The respective Kafka configuration setting can be specified on the broker level or per topic. The default timestamp extractor in Kafka Streams will **retrieve these embedded timestamps as-is**. Hence, the effective time semantics of your application depend on the effective Kafka configuration for these embedded timestamps.

Time in Kafka Streams - III

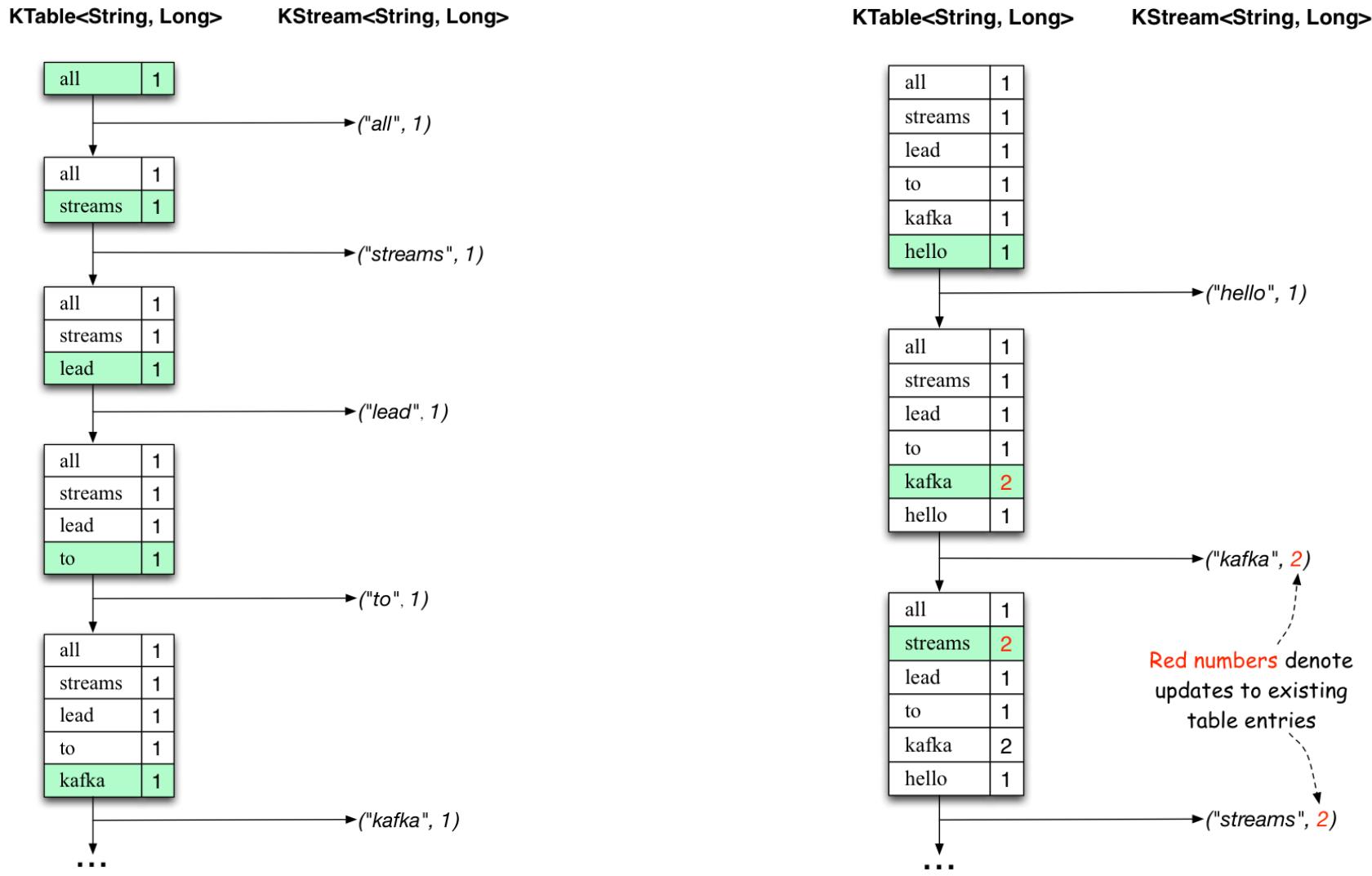
- **log.message.timestamp.type** – define whether the timestamp in the message is message create time or log append time. The value should be either `CreateTime` or `LogAppendTime`
- **log.message.timestamp.difference.max.ms** – The maximum difference allowed between the timestamp when a broker receives a message and the timestamp specified in the message. If `log.message.timestamp.type=CreateTime`, a message will be rejected if the difference in timestamp exceeds this threshold. This configuration is ignored if `log.message.timestamp.type=LogAppendTime`. The maximum timestamp difference allowed should be no greater than `log.retention.ms` to avoid unnecessarily frequent log rolling.

Custom TimestampExtractor

@Slf4j

```
public class CustomTimeExtractor implements TimestampExtractor {  
    @Override  
    public long extract(ConsumerRecord<Object, Object> record, long partitionTime) {  
        final long timestamp = record.timestamp();  
  
        // `TemperatureReading` is your own custom class, which we assume has a method that returns  
        // the embedded timestamp (in milliseconds).  
        var myReading = (TemperatureReading) record.value();  
        if (myReading != null) {  
            return java.sql.Timestamp.valueOf(myReading.getTimestamp()).getTime();  
        }  
        else {  
            // Kafka allows `null` as message value. How to handle such message values  
            // depends on your use case. In this example, we decide to fallback to  
            // wall-clock time (= processing-time).  
            return System.currentTimeMillis();  
        }  
    }  
}
```

Kafka Stream Processing Example



Kafka Streams Dependencies

```
dependencies {  
    implementation 'org.apache.kafka:kafka-clients:3.2.0'  
    implementation 'org.apache.kafka:kafka-streams:3.2.0'  
    ...  
}
```

Kafka Streams Code Skeleton

```
public static void main(String[] args) {
    // Use the builders to define the actual processing topology, e.g. to specify from which input topics to read,
    // which stream operations (filter, map, etc.) should be called, and so on.

    StreamsBuilder builder = ...; // when using the DSL
    Topology topology = builder.build();
    //
    // OR
    //
    Topology topology = ...; // when using the Processor API

    // Use the configuration to tell your application where the Kafka cluster is,
    // which Serializers/Deserializers to use by default, to specify security settings, and so on.
    Properties props = ...;
    KafkaStreams streams = new KafkaStreams(topology, props);

    // Add shutdown hook to stop the Kafka Streams threads. You can optionally provide a timeout to `close`.
    Runtime.getRuntime().addShutdownHook(new Thread(streams::close));
}
```

Stream Partitions and Tasks

- Kafka messaging layer partitions data for storing and transporting it.
- Kafka Streams partitions data for processing it.
- In both cases, this partitioning is what enables data locality, elasticity, scalability, high performance, and fault tolerance. Kafka Streams uses the concepts of partitions and tasks as logical units of its parallelism model based on Kafka topic partitions.
- Each stream partition is a totally ordered sequence of data records and maps to a Kafka topic partition.
- A data record in the stream maps to a Kafka message from that topic.
- The keys of data records determine the partitioning of data in both Kafka and Kafka Streams, i.e., how data is routed to specific partitions within topics.

Stream Partitions and Tasks - I

- An application's processor topology is scaled by breaking it into multiple tasks.
- Kafka Streams creates a fixed number of tasks based on the input stream partitions for the application, with each task assigned a list of partitions from the input streams (i.e., Kafka topics).
- The assignment of partitions to tasks never changes so that each task is a fixed unit of parallelism of the application.
- Tasks can then instantiate their own processor topology based on the assigned partitions; they also maintain a buffer for each of its assigned partitions and process messages one-at-a-time from these record buffers.
- As a result stream tasks can be processed independently and in parallel without manual intervention.

Stream Partitions and Tasks – II

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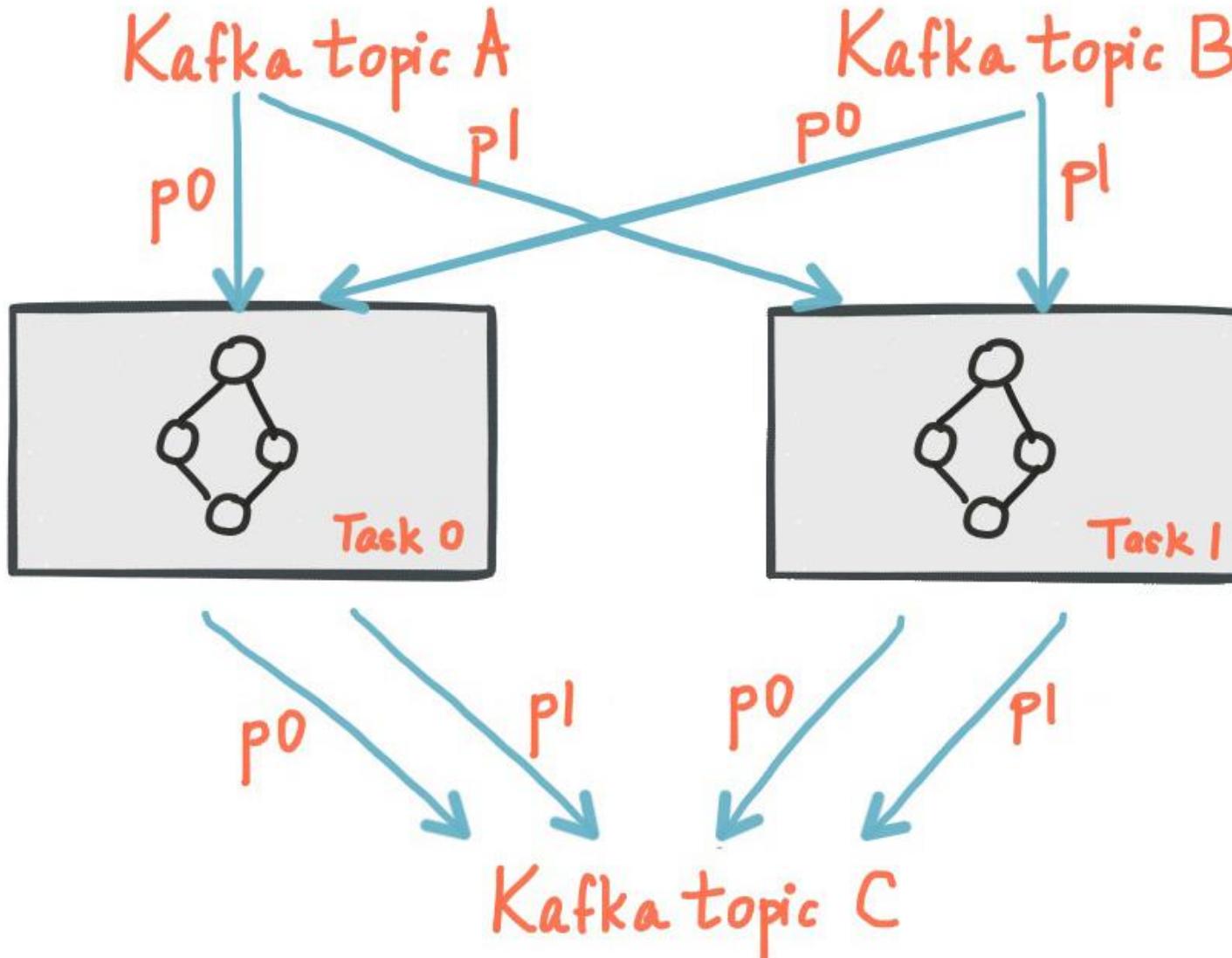
Stream Partitions and Tasks - III

- Kafka Streams is NOT a resource manager, but a library that "runs" anywhere its stream processing application runs.
- Multiple instances of the application are executed either on the same machine, or spread across multiple machines and tasks can be distributed automatically by the library to those running application instances.
- Assignment of partitions to tasks never changes - if an application instance fails, all its assigned tasks will be automatically restarted on other instances and continue to consume from the same stream partitions.
- Topic partitions are assigned to tasks, and tasks are assigned to all threads over all instances, in a best-effort attempt to trade off load-balancing and stickiness of stateful tasks. For this assignment, Kafka Streams uses the StreamsPartitionAssignor class and doesn't let you change to a different assignor. If you try to use a different assignor, Kafka Streams ignores it.

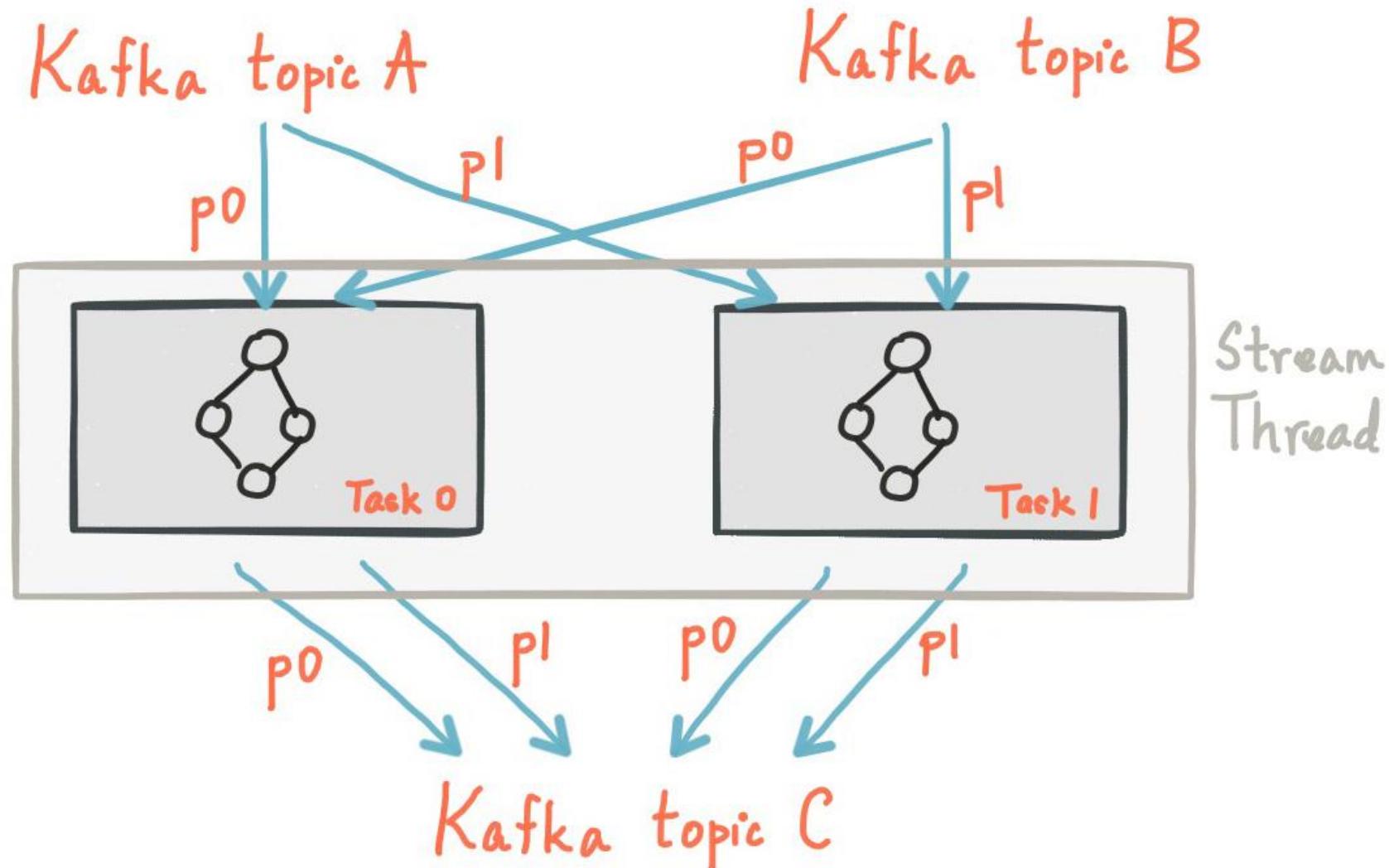
StreamsPartitionAssignor Tasks Assignment Algorithm

1. Decode the [subscriptions](#) to assemble the metadata for each [client](#) and check for version probing.
2. Check all [repartition source topics](#) and use internal topic manager to make sure they have been created with the [right number of partitions](#). Also verify and/or create any [changelog topics](#) with the [correct number of partitions](#).
3. Use the partition grouper to generate [tasks](#) along with their [assigned partitions](#), then use the configured [TaskAssignor](#) to construct the mapping of tasks to clients.
4. Construct the [global mapping](#) of [host to partitions](#) to enable [query routing](#).
5. Within each [client](#), assign [tasks](#) to [consumer clients](#).

Kafka Streams Partitions and Tasks - I



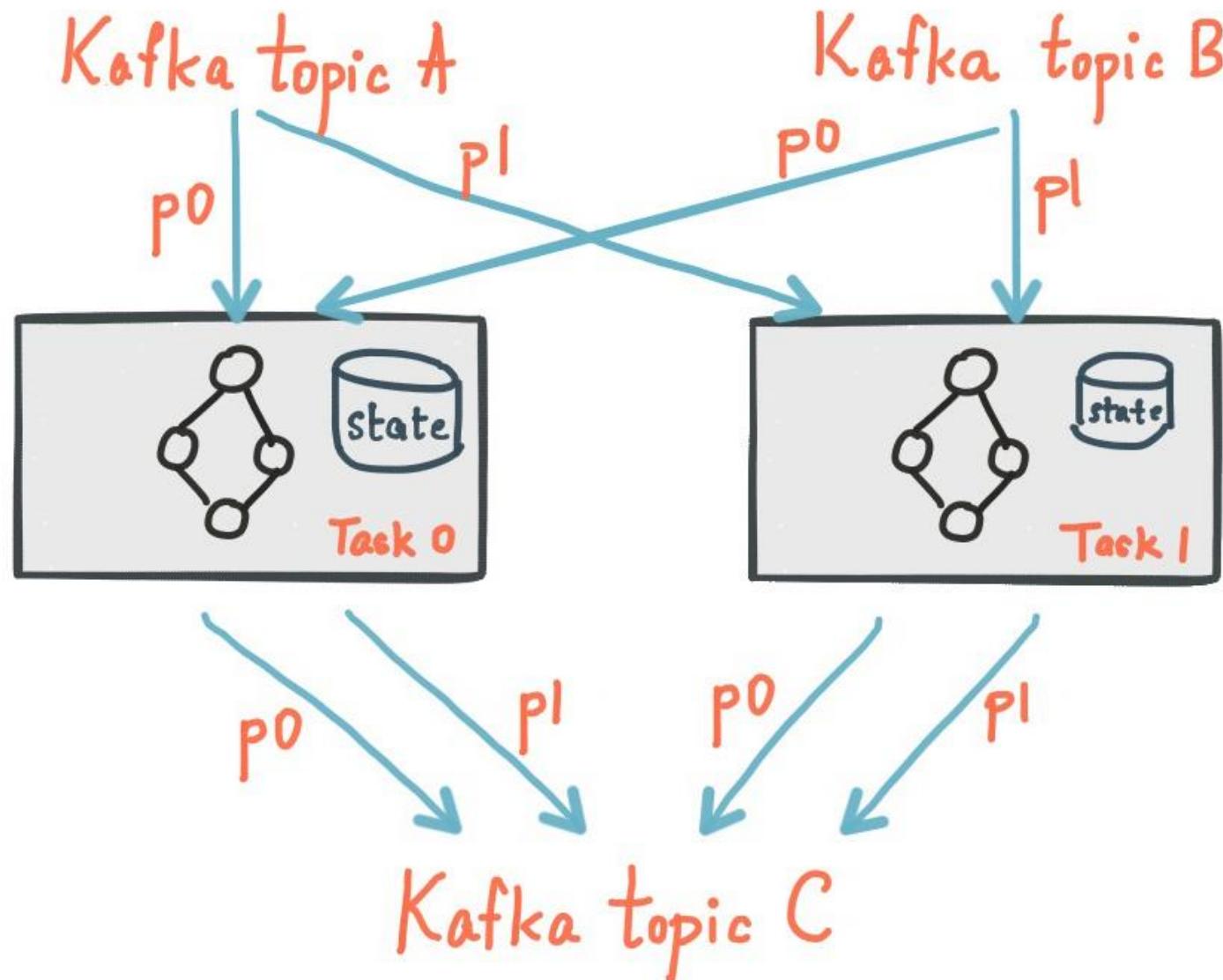
Kafka Streams Partitions and Tasks - II



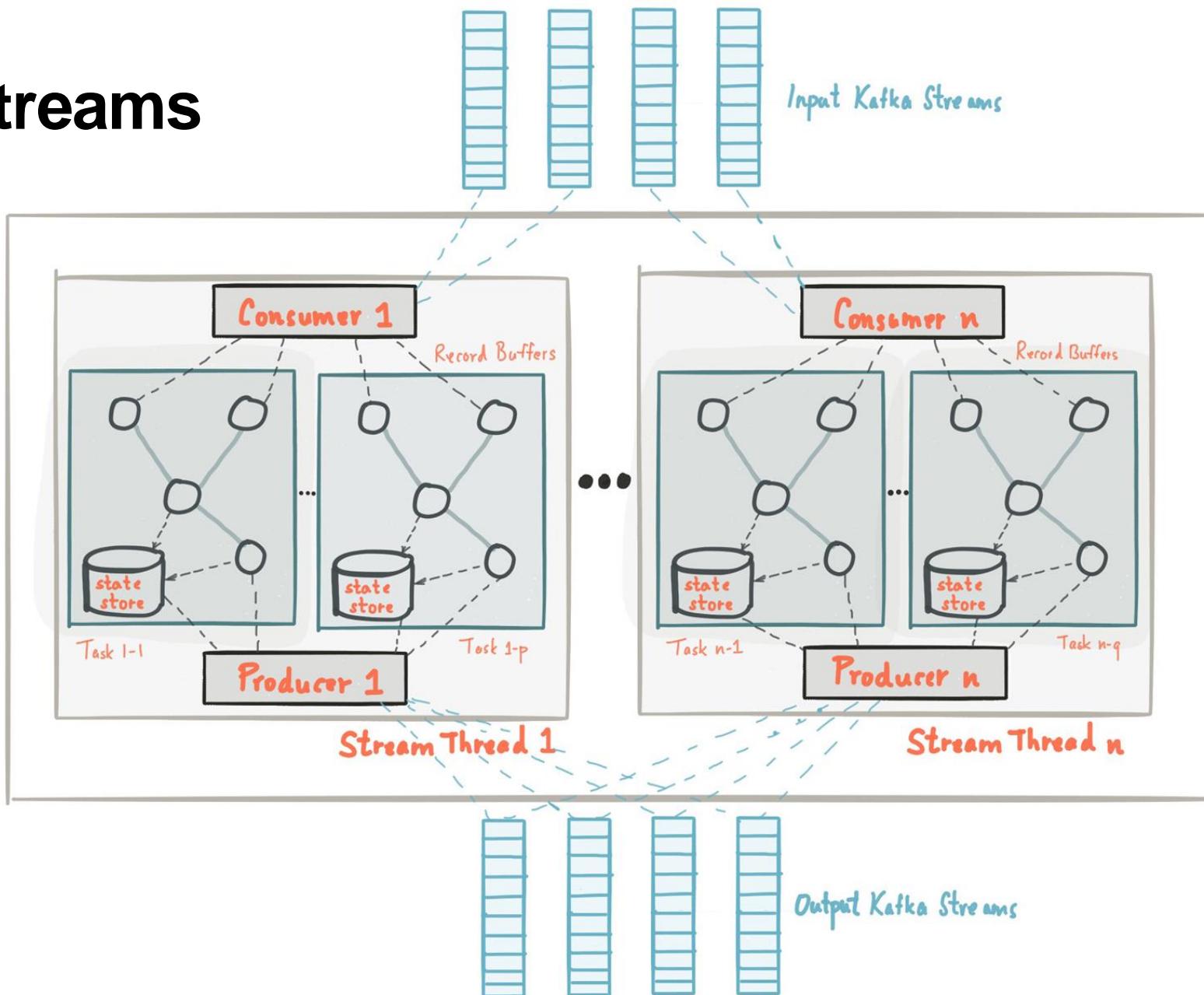
Tasks Threading Model

- Starting more stream threads or more instances of the application merely amounts to replicating the topology and having it process a different subset of Kafka partitions, effectively parallelizing processing.
- It is worth noting that there is no shared state amongst the threads, so no inter-thread coordination is necessary.
- This makes it very simple to run topologies in parallel across the application instances and threads.
- The assignment of Kafka topic partitions amongst the various stream threads is transparently handled by Kafka Streams leveraging Kafka's coordination functionality.
- You can start as many threads of the application as there are input topic partitions so that, across all running instances of an application, every thread (or rather, the tasks it runs) has at least one input partition to process.

Kafka Streams Partitions and Tasks - III



Kafka Streams



Thank's for Your Attention!



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