DataStream API

Windows & Time

Apache Flink® Training

dataArtisans

Flink v1.3 – 19.06.2017

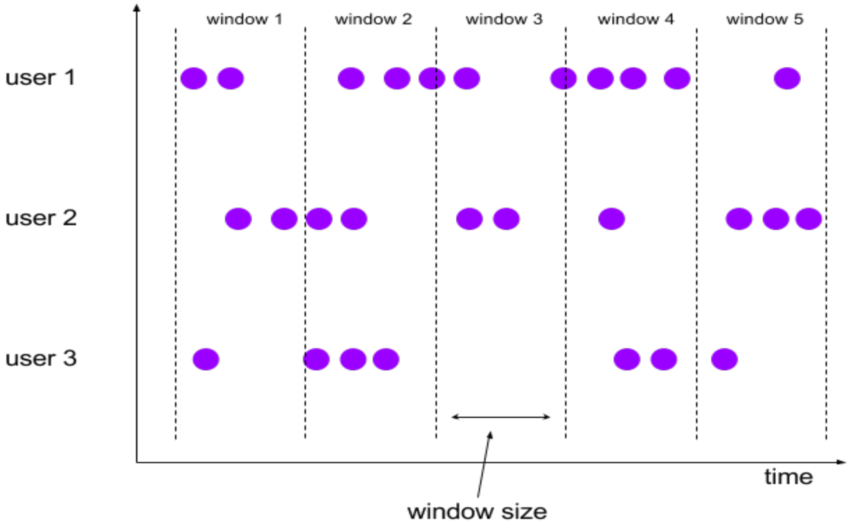
Windows and Aggregates

Windows

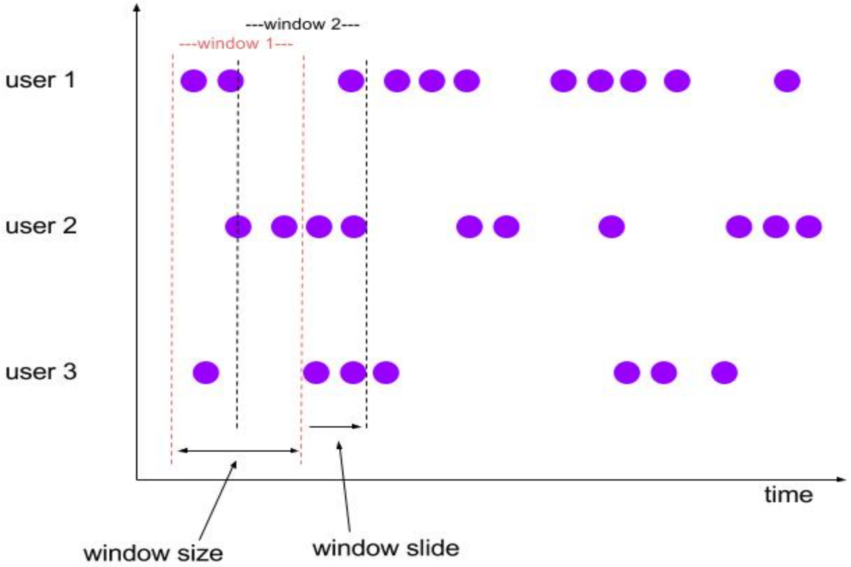
- Aggregations on streams are different from aggregations on batched data
  - You cannot count all records of an unbounded stream

- Aggregations do make sense on windowed streams, e.g.,
  - Number of transactions per minute

Tumbling and Sliding Windows



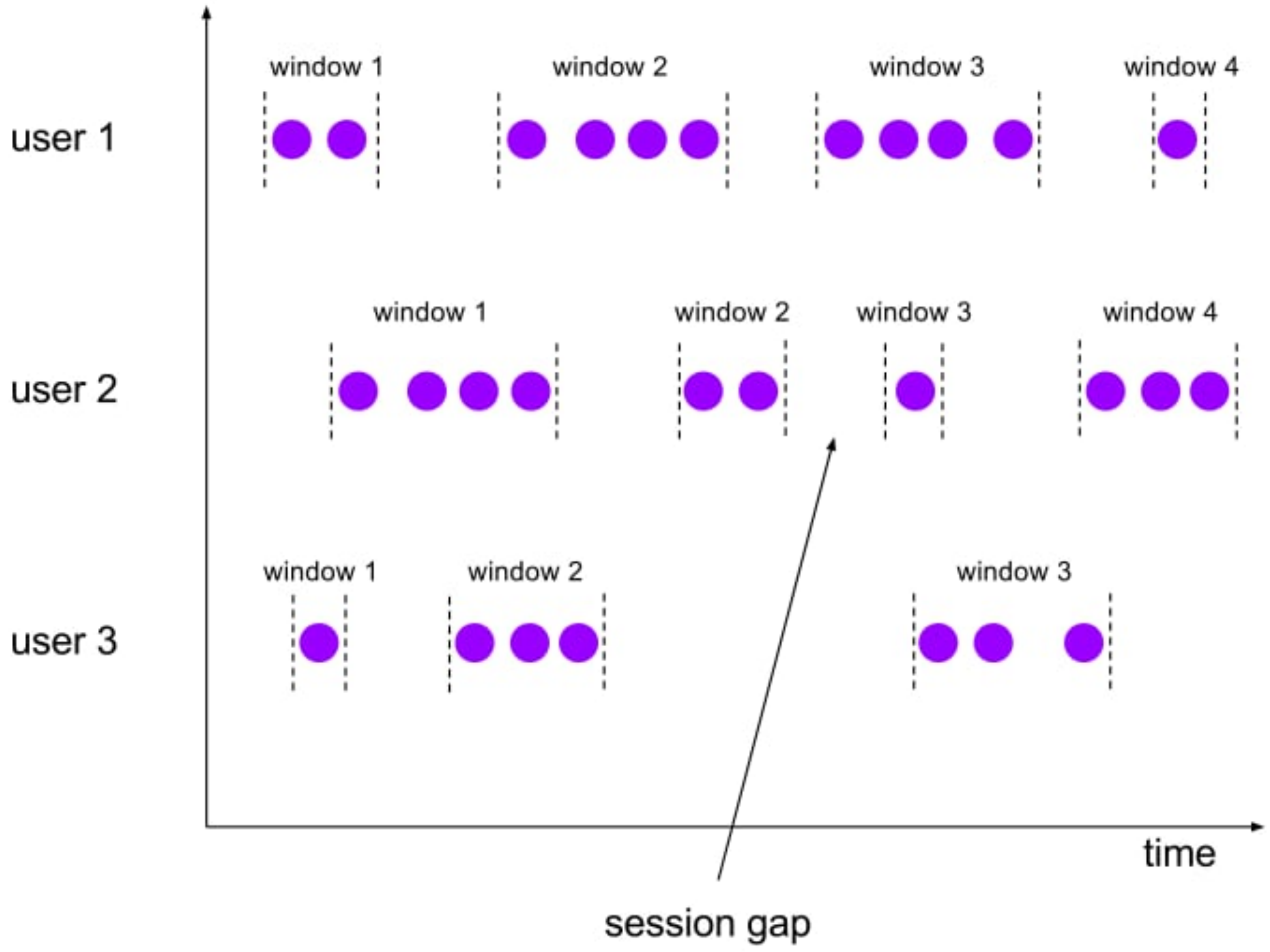
Tumbling:
aligned, fixed length,
non-overlapping windows



Sliding:
aligned, fixed length,
overlapping windows

Session Windows

Non-aligned, variable length windows.



Specifying Windowing

```
stream
    .keyBy(…)                / keyed vs non-keyed windows
    .window(…)               / “Assigner”
    .trigger(…)              / each Assigner has a default Trigger
    .evictor(…)              / default: no Evictor
    .allowedLateness()       / default: zero
    .process|apply|reduce()  / window function
```

Predefined Keyed Windows

- Tumbling time window

```
.timeWindow(Time.minutes(1))
```

- Sliding time window

```
.timeWindow(Time.minutes(1), Time.seconds(10))
```

- Tumbling count window

```
.countWindow(100)
```

- Sliding count window

```
.countWindow(100, 10)
```

- Session window

```
.window(SessionWindows.withGap(Time.minutes(30)))
```

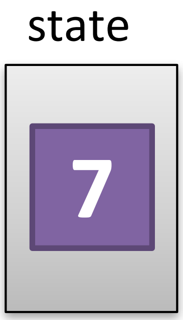
Non-keyed Windows

- Windows on non-keyed streams are not processed in parallel!
  - `stream.windowAll(…)…`
  - `stream.timeWindowAll(Time.seconds(10))…`
  - `stream.countWindowAll(20, 10)…`

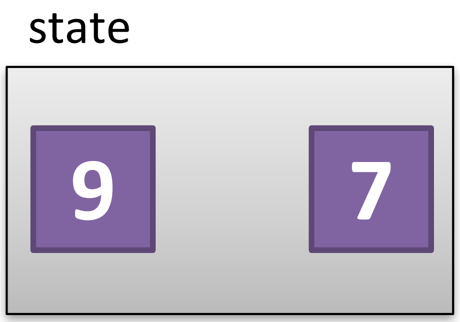
Aggregations on Windowed Streams

```
DataStream<SensorReading> input = …

input
  .keyBy(“key”)
  .timeWindow(Time.minutes(1))
  .apply(new MyWastefulMax());

public static class MyWastefulMax implements WindowFunction<
    SensorReading,                  // input type
    Tuple3<String, Long, Integer>,  // output type
    Tuple,                          // key type
    TimeWindow> {                   // window type

    @Override
    public void apply(
        Tuple key,
        TimeWindow window,
        Iterable<SensorReading> events,
        Collector<Tuple3<String, Long, Integer>> out) {

        int max = 0;
        for (SensorReading e : events) {
            if (e.f1 > max) max = e.f1;
        }
        out.collect(new Tuple3<>((Tuple1<String>)key).f0, window.getEnd(), max));
    }
}
```

Window State during Aggregation



Window State during Aggregation

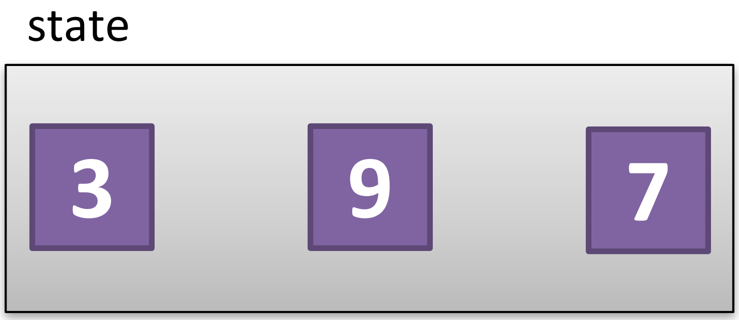


state

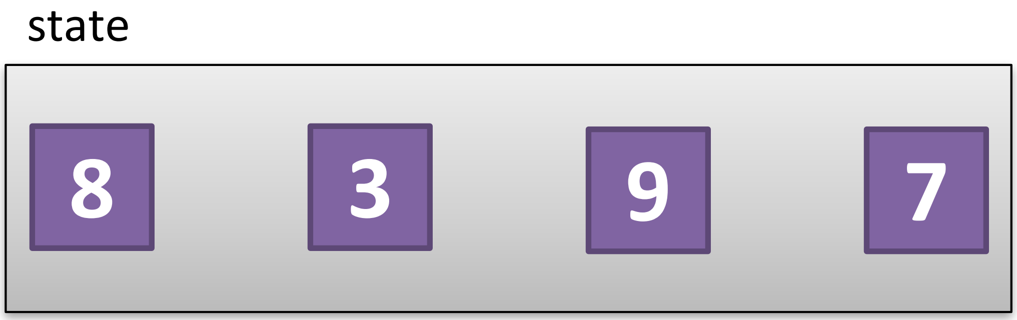
9

7

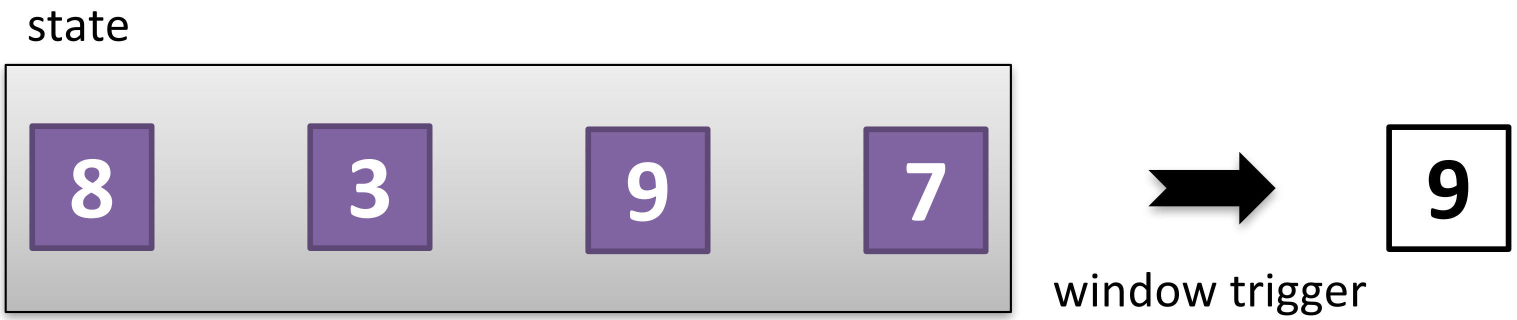
Window State during Aggregation



Window State during Aggregation



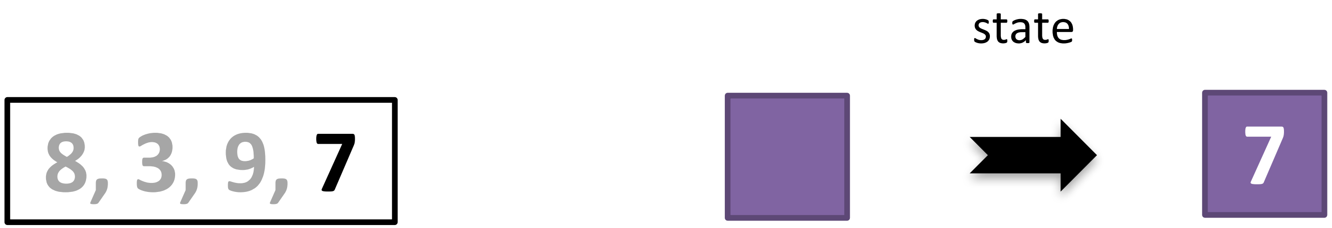
Window State during Aggregation



Incremental Window Aggregation

```
DataStream<SensorReading> input = …

input
  .keyBy(“key”)
  .timeWindow(Time.minutes(1))
  .reduce(new MyReducingMax(), new MyWindowFunction());

private static class MyReducingMax implements ReduceFunction<SensorReading> {
  public SensorReading reduce(SensorReading r1, SensorReading r2) {
      return r1.value() > r2.value() ? r1 : r2;
  }
}

private static class MyWindowFunction implements WindowFunction<
  SensorReading, Tuple2<Long, SensorReading>, String, TimeWindow> {
      public void apply(String key,
                    TimeWindow window,
                    Iterable<SensorReading> maxReadings,
                    Collector<Tuple2<Long, SensorReading>> out) {
          SensorReading max= maxReadings.iterator().next();
          out.collect(new Tuple2<Long, SensorReading>(window.getStart(), max));
      }
}
```

Incremental Aggregation

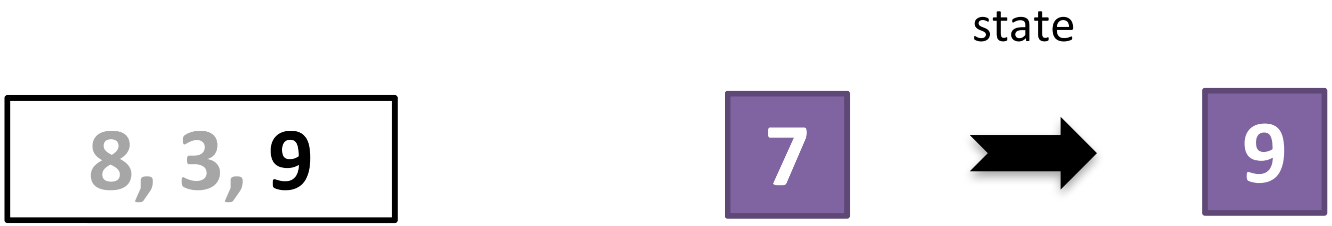


8, 3, 9, **7**

state

7

Incremental Aggregation



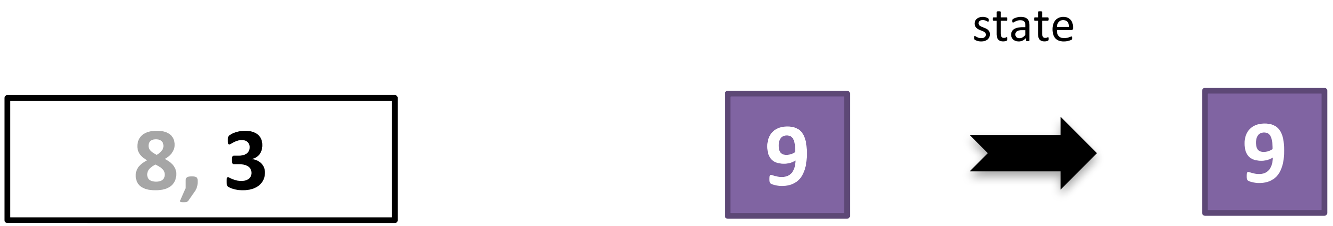
8, 3, 9

state

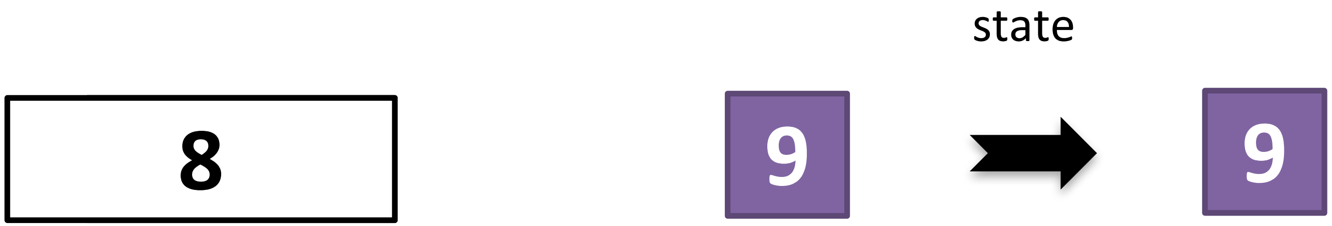
7

9

Incremental Aggregation



Incremental Aggregation



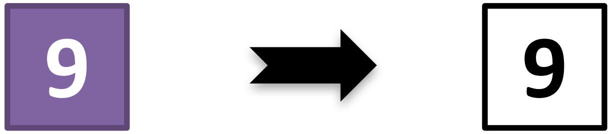
8

state

9

9

Incremental Aggregation



window trigger

Window Operations

- Passed an `Iterable` containing all elements of a `Window`:

  - `apply(windowFunction)`
  - `process(processWindowFunction)`
    - new in 1.3

ProcessWindowFunction()

```
public abstract class ProcessWindowFunction<IN, OUT, KEY, W extends Window> extends AbstractRichFunction {

 /**
   * Evaluates the window and outputs none or several elements.
   *
   * @param key The key for which this window is evaluated.
   * @param context The context in which the window is being evaluated.
   * @param elements The elements in the window being evaluated.
   * @param out A collector for emitting elements.
   *
   */
  public abstract void process(
    KEY key,
    Context context,
    Iterable<IN> elements,
    Collector<OUT> out) throws Exception;

  // The context holding window metadata.
  public abstract class Context implements java.io.Serializable {
    public abstract W window();
    public abstract long currentProcessingTime();
    public abstract long currentWatermark();
    public abstract KeyedStateStore windowState();   // per-key per-window state
    public abstract KeyedStateStore globalState();     // per-key global state
  }
}
```

Incremental Window Operations

- Passed each element of a window, which is aggregated into a single result:

  - `reduce(reduceFunction)`
  - ~~`fold(initialVal, foldFunction)`~~
  - `aggregate(aggregateFunction)`

Other Aggregations

- `sum`(*key*), `min`(*key*), `max`(*key*)
  - return the value

- `sumBy`(*key*), `minBy`(*key*), `maxBy`(*key*)
  - return an element with the value

- These are available on `KeyedStreams` as well as `WindowedStreams`

Custom window logic

- The DataStream API allows you to define very custom window logic

- GlobalWindows
  - a flexible, low-level window assignment scheme that can be used to implement custom windowing behaviors
  - only useful if you explicitly specify triggering, otherwise nothing will happen

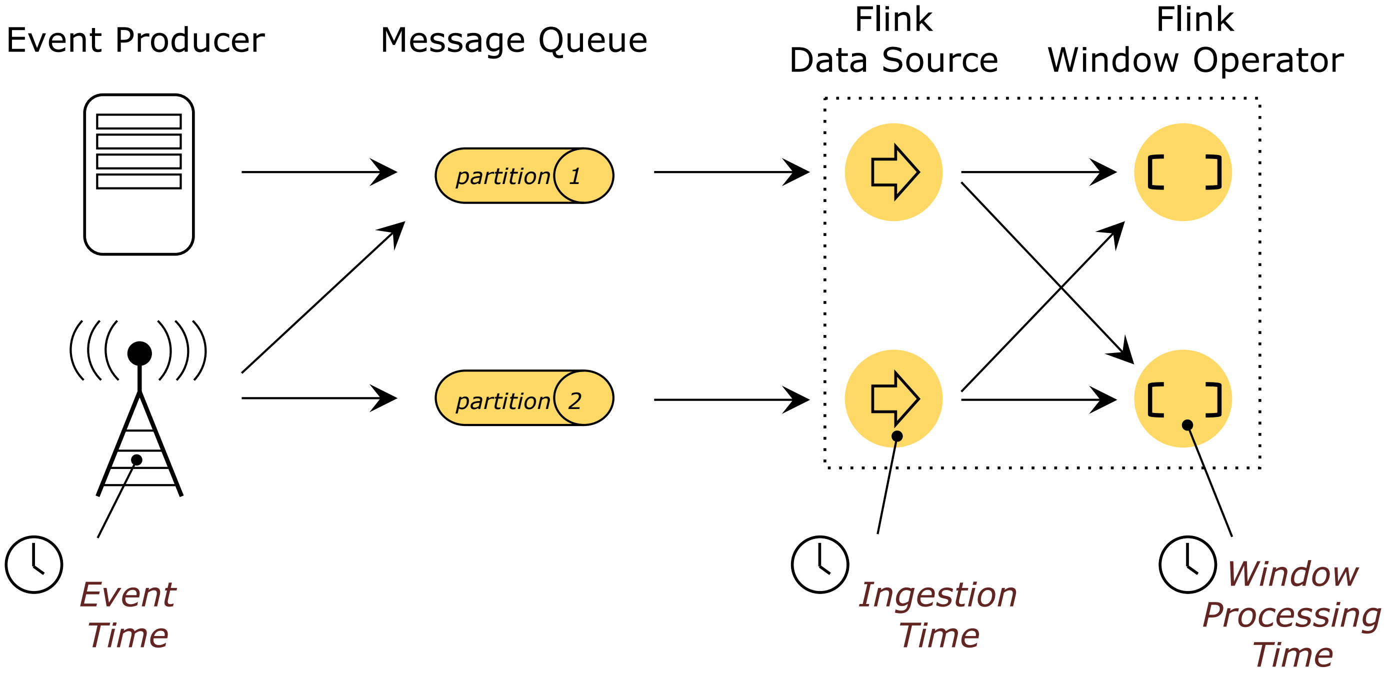
- Trigger
  - defines when to evaluate a window
  - whether to purge the window or not

- *Careful!* This part of the API requires a good understanding of the windowing mechanism!

Handling Time Explicitly

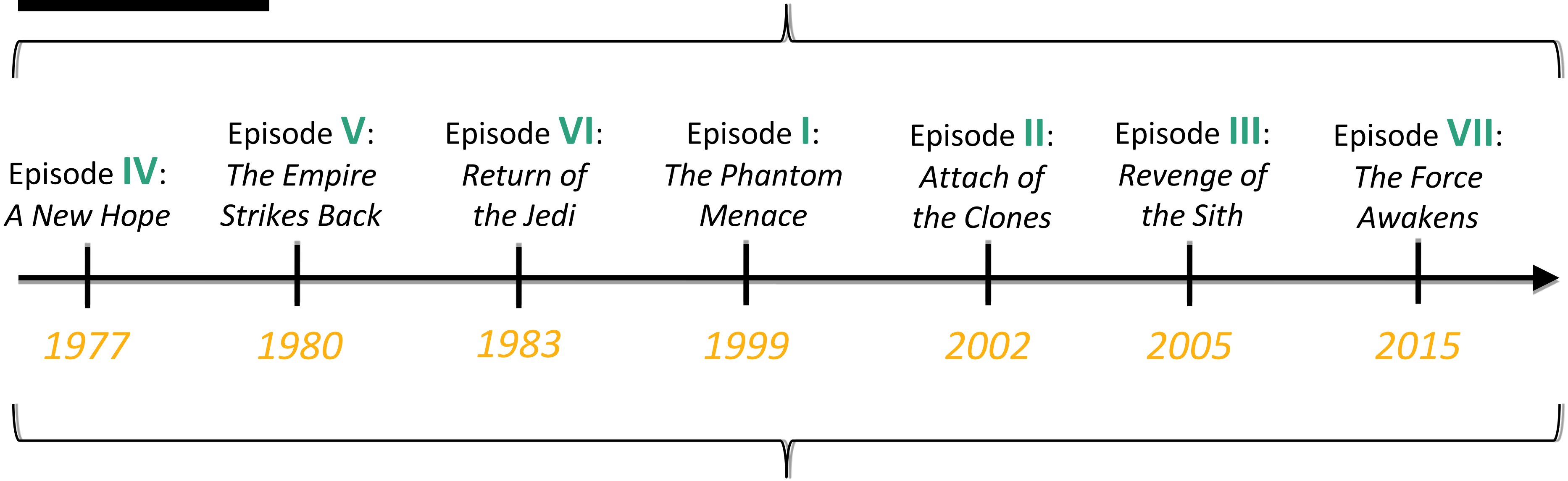
The **biggest change** in moving from batch to streaming is **handling time explicitly**

Different Notions of Time



Event Time vs Processing Time

This is called **event time**



Episode **IV**: *A New Hope* — *1977*

Episode **V**: *The Empire Strikes Back* — *1980*

Episode **VI**: *Return of the Jedi* — *1983*

Episode **I**: *The Phantom Menace* — *1999*

Episode **II**: *Attach of the Clones* — *2002*

Episode **III**: *Revenge of the Sith* — *2005*

Episode **VII**: *The Force Awakens* — *2015*

This is called *processing time*

Setting the StreamTimeCharacteristic

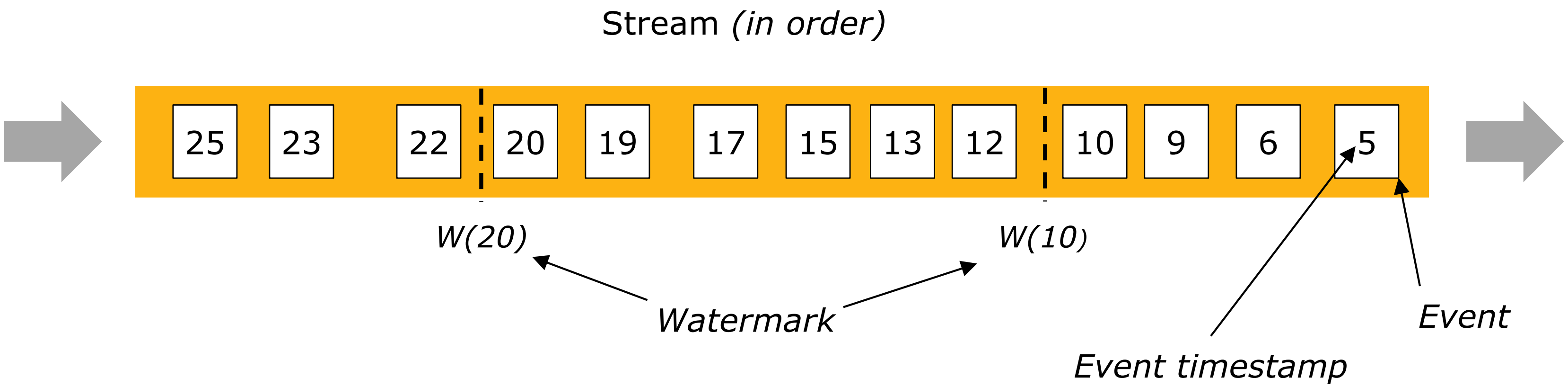
```java
final StreamExecutionEnvironment env =
  StreamExecutionEnvironment.getExecutionEnvironment();

env.setStreamTimeCharacteristic(TimeCharacteristic.EventTime);

// alternatively:
// env.setStreamTimeCharacteristic(TimeCharacteristic.IngestionTime);
// env.setStreamTimeCharacteristic(TimeCharacteristic.ProcessingTime);
```

Working with Event Time

- With event time, Flink needs to know
  - the timestamp for each stream element
  - when results are ready to be emitted
    - e.g., have I received all events for 3 - 4 pm?

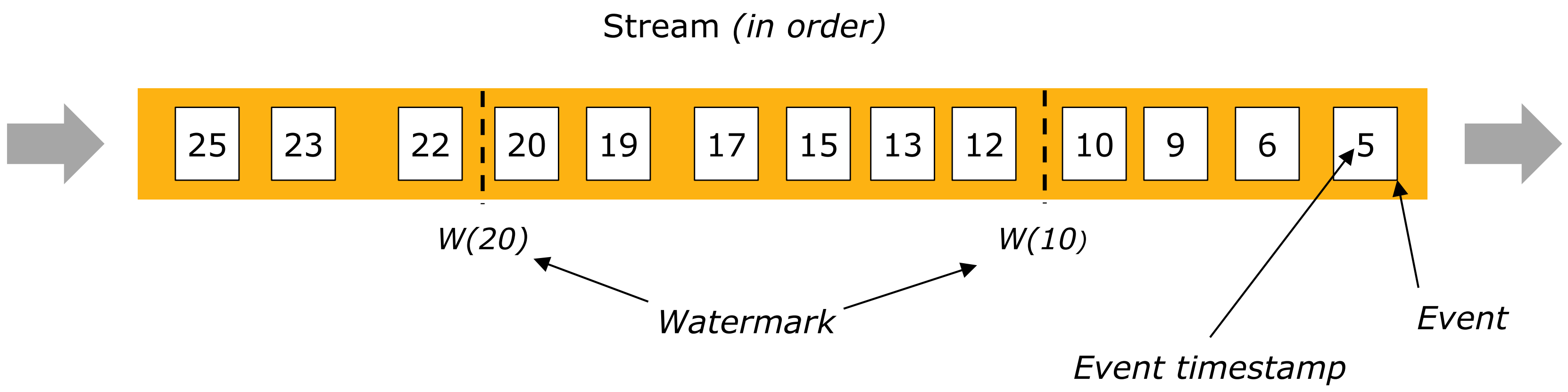
Watermarks

- Watermarks mark the progress of event time
- They flow with the data stream and carry a timestamp
- *Watermarks assert that all earlier events have (probably) arrived*



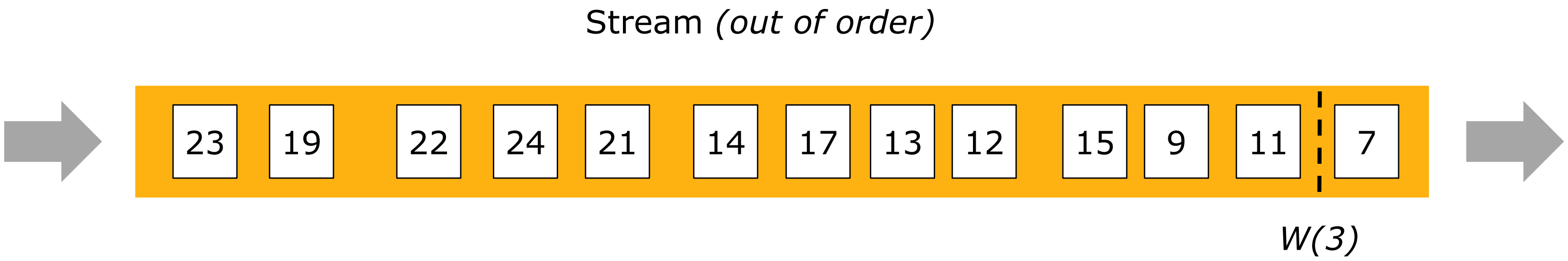
Perfect Watermarks

- When stream elements are in order (or in order by key), we can achieve perfect watermarking



Bounded out-of-orderness

- When events are out-of-order, we often assume there is some bound to how out-of-order they can be

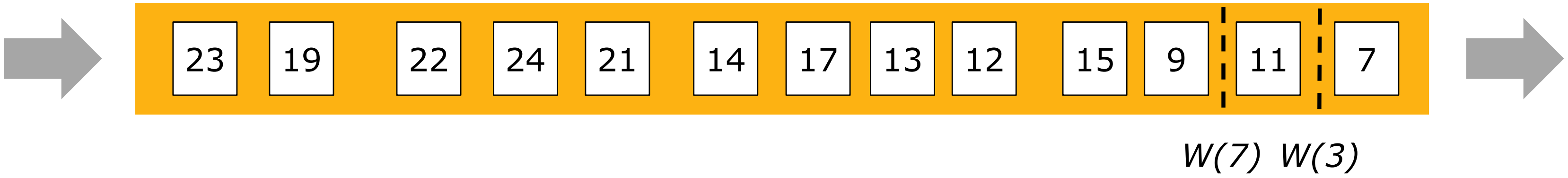


maxOutOfOrderness = 4

Bounded out-of-orderness

- Each time a new maximum timestamp arrives, we have enough info to emit a new Watermark

Stream *(out of order)*



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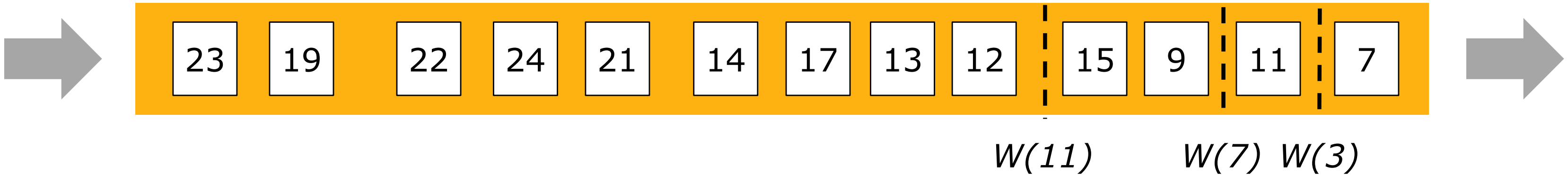

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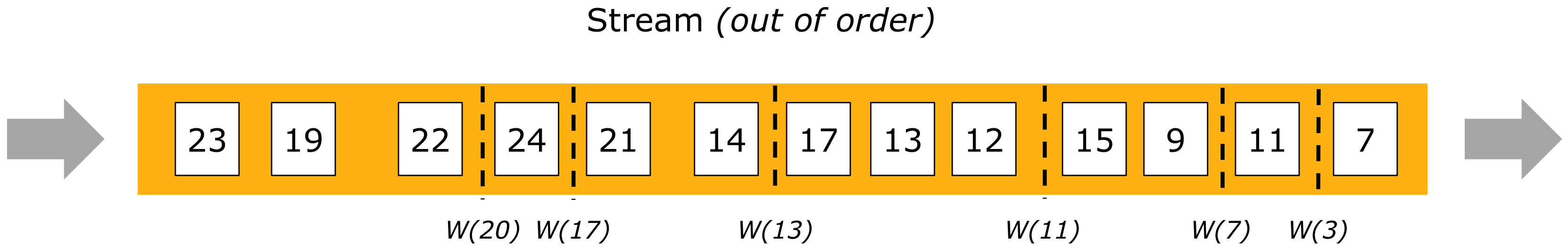
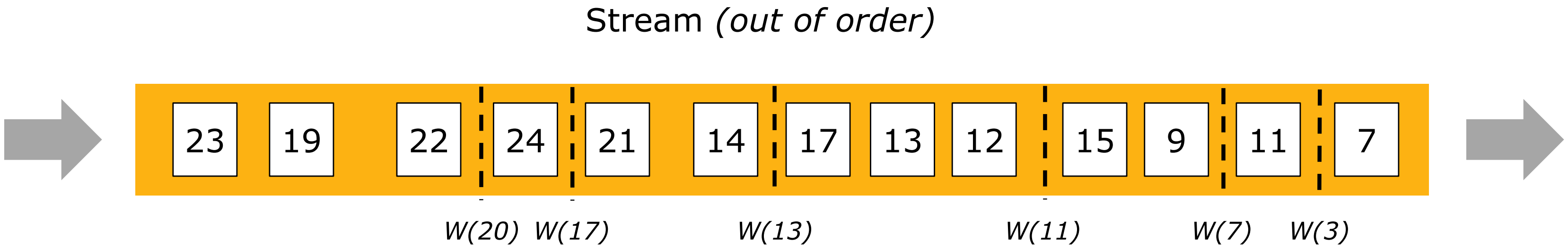


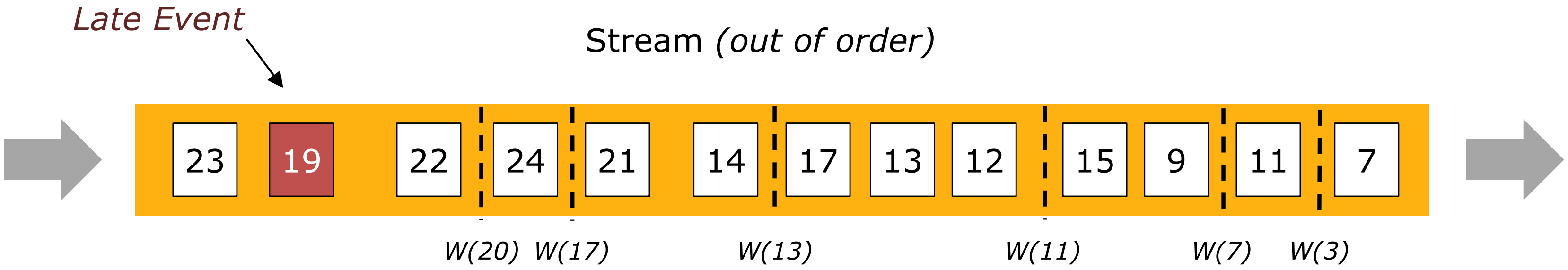
How often to emit Watermarks?

- Here we are emitting an new Watermark as often as possible
- However, it is best to avoid generating too many Watermarks



Watermarks define Lateness

- Elements where *timestamp* < *currentWatermark* are late



Two Styles of Watermark Generation

- Periodic Watermarks
  - Based on a timer
  - `BoundedOutOfOrdernessGenerator` is an example
  - `ExecutionConfig.setAutoWatermarkInterval(msec)` controls the interval at which your periodic watermark generator is called
- Punctuated Watermarks
  - Based on something in the event stream

Pre-defined timestamp extractors / watermark emitters

- AscendingTimestampExtractor
  - For special case when timestamps are in ascending order

- BoundedOutOfOrdernessTimestampExtractor
  - Periodically emits watermarks that lag a fixed amount of time behind the max timestamp seen so far

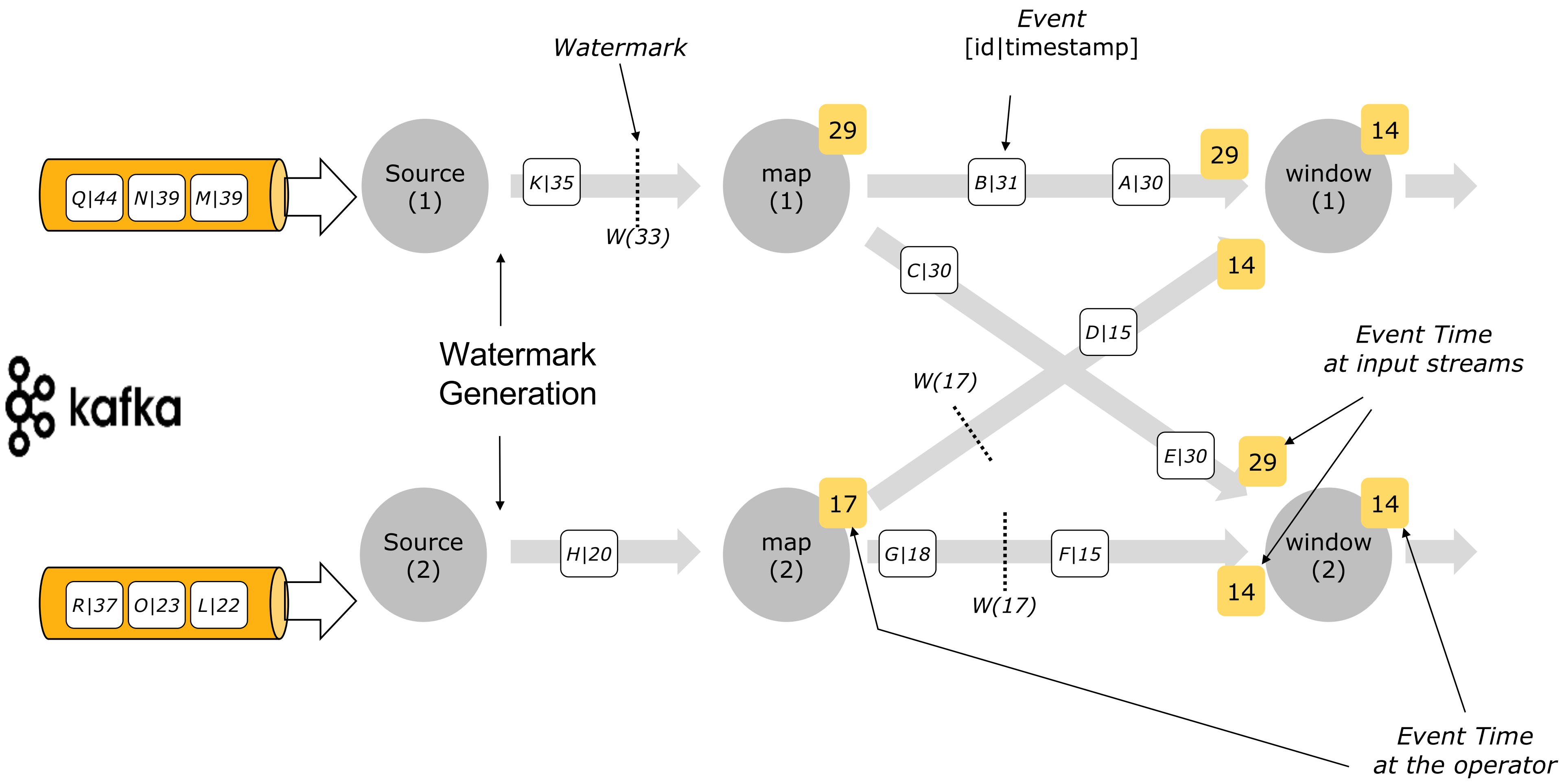
Example

```
stream
    .assignTimestampsAndWatermarks(new MyTSExtractor())
    .keyBy(...)
    .timeWindow(...)
    .addSink(...);

public static class MyTSExtractor extends
  BoundedOutOfOrdernessTimestampExtractor<TaxiRide> {

    public TaxiRideTSExtractor() {
        super(Time.seconds(MAX_EVENT_DELAY));
    }

    @Override
    public long extractTimestamp(TaxiRide ride) {
        return ride.startTime.getMillis();
    }
}
```

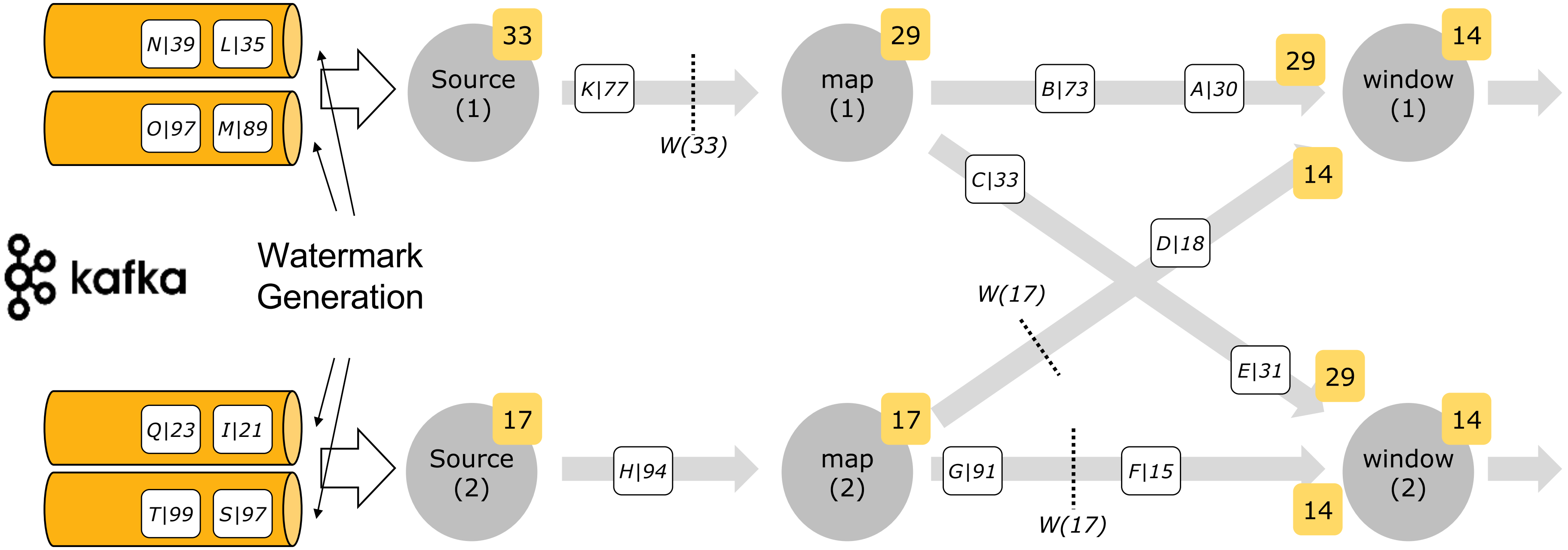
```
public class BoundedOutOfOrdernessGenerator extends
  AssignerWithPeriodicWatermarks<MyEvent> {

    private final long maxOutOfOrderness = 3500; // 3.5 seconds

    private long currentMaxTimestamp;

    @Override
    public long extractTimestamp(MyEvent element, long previousElementTimestamp) {
        long timestamp = element.getCreationTime();
        currentMaxTimestamp = Math.max(timestamp, currentMaxTimestamp);
        return timestamp;
  }

    @Override
    public Watermark getCurrentWatermark() {
        // watermark is current highest timestamp minus the out-of-orderness bound
        return new Watermark(currentMaxTimestamp - maxOutOfOrderness);
  }
}
```

```
public class PunctuatedAssigner extends AssignerWithPunctuatedWatermarks<MyEvent> {

  @Override
  public long extractTimestamp(MyEvent element, long previousElementTimestamp) {
    return element.getCreationTime();
  }

  @Override
  public Watermark checkAndGetNextWatermark(MyEvent lastElement,
                                            long extractedTimestamp) {

    return lastElement.hasWatermarkMarker() ?
      new Watermark(extractedTimestamp) : null;
  }
}
```

Watermarks in Parallel



Per-Kafka-Partition Watermarks



Watermarking

- Perfect
- (Un)comfortably bounded by fixed delay
  - too slow: results are delayed
  - too fast: some data is late
- Heuristic
  - allow windows to produce results as soon as meaningfully possible, and then continue with updates during the allowed lateness interval