Apache Kafka

for Java Developers

Consuming Records

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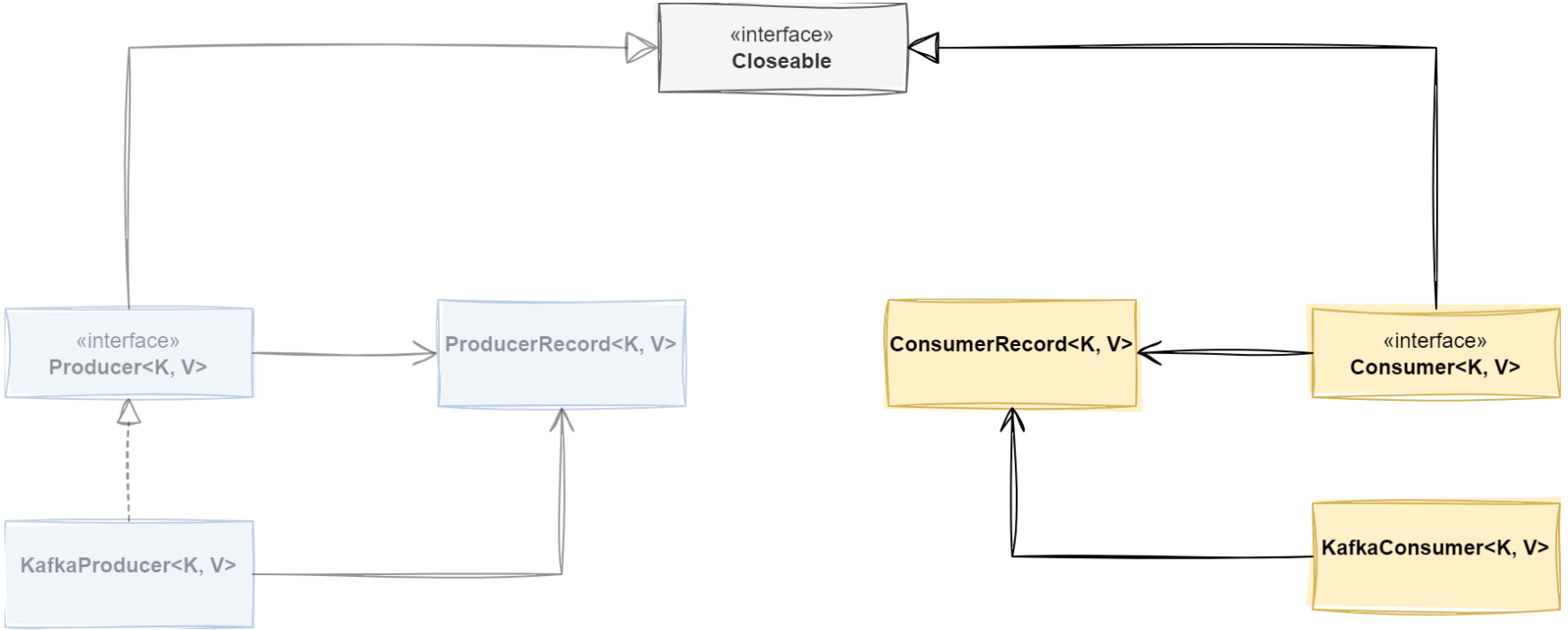
The Apache Kafka Clients SDK

A Consumer's Perspective

We are able to write a basic consumer by using just these few classes on the right.



- `Consumer<K,V>`: This is the public interface for a consuming client. It contains message signatures for controlling subscriptions and topic/partition assignment, fetching records, committing offsets, ...
- `KafkaConsumer<K,V>`: This is the implementation of the `Consumer` interface. Like its counterpart, it features rich documentation of its public API.
- `ConsumerRecord<K,V>`: This is a data structure that comprises all attributes of a Kafka record as perceived by a consumer. It is essentially a superset of the `ProducerRecord<K,V>`, as it contains additional metadata such as the record offset, a checksum, and some other attributes.

The parametric types `K` and `V` stand for the key resp. the value of of the record.

A Consumer<K,V> offers methods for managing subscriptions and consuming records.

```
public interface Consumer<K, V> extends Closeable {
  // subscription management
  void subscribe(Collection<String> topics);
  void subscribe(Collection<String> topics, ConsumerRebalanceListener callback);
  void subscribe(Pattern pattern);
  void subscribe(Pattern pattern, ConsumerRebalanceListener callback);
  void unsubscribe();
  void assign(Collection<TopicPartition> partitions);
  Set<TopicPartition> assignment();
  Set<String> subscription();

  // record consumption
  ConsumerRecords<K, V> poll(long timeout);
  ConsumerRecords<K, V> poll(Duration timeout);

  // offset committing (not showing overloaded methods)
  void commitSync();
  void commitAsync();

  // manage consumption order (not showing overloaded methods)
  void seek(TopicPartition partition, long offset);
  void seekToBeginning(Collection<TopicPartition> partitions);
  void seekToEnd(Collection<TopicPartition> partitions);
  // ... and a lot more ...
}
```

With this knowledge in mind, we are able to write a first, yet simple, consumer!

```
public class BasicConsumer {
  public static void main(String[] args) {
    var topic = "getting-started";
    Map<String, Object> config = Map.of(
      ConsumerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092",
      ConsumerConfig.KEY_DESERIALIZER_CONFIG, StringDeserializer.class.getName(),
      ConsumerConfig.VALUE_DESERIALIZER_CONFIG, StringDeserializer.class.getName(),
      ConsumerConfig.GROUP_ID_CONFIG, "basic-consumer-group",
      ConsumerConfig.AUTO_OFFSET_RESET_CONFIG, "earliest",
      ConsumerConfig.ENABLE_AUTO_COMMIT_CONFIG, false);
    try (var consumer = new KafkaConsumer<String, String>(config)) {
      consumer.subscribe(Set.of(topic));
      while (true) {
        var records = consumer.poll(Duration.ofMillis(100));
        for (var record : records) {
          System.out.println("Received record with value %s%n", record.value());
        }
        consumer.commitAsync();
      }
    }
  }
}
```

Subscribing and Consuming

A `KafkaConsumer<K,V>` offers two ways for subscribing to the topics.

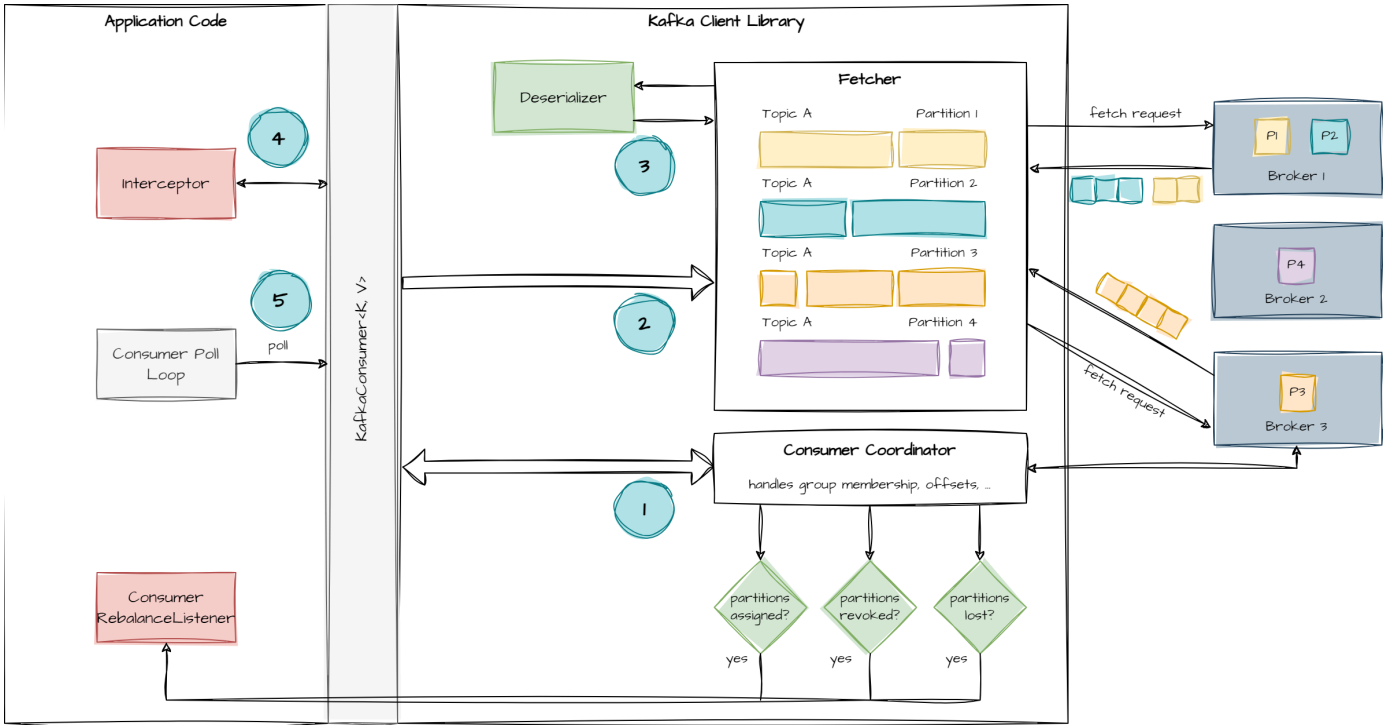
via `subscribe`

- subscribe to list of topics (regexp possible)
- group membership with failure detection
  - client-side
  - server-side
- dynamic partition assignment
- automatic or manual offset management
- single consumer per partition

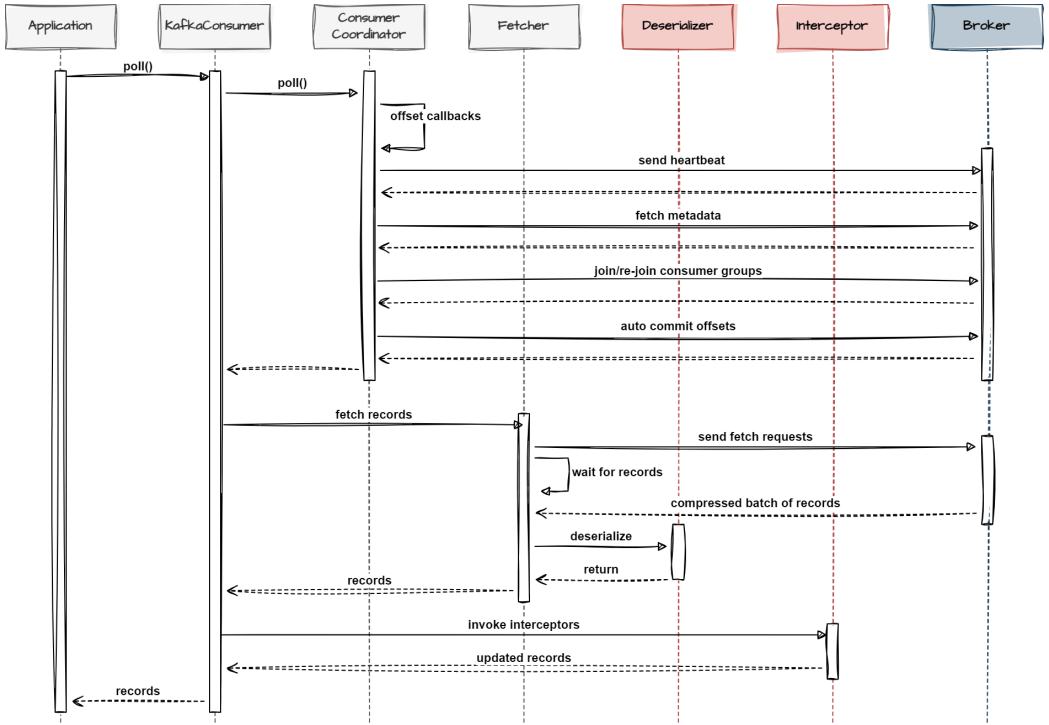
via `assign`

- finer control with topic-partition subscription
- manual offset management
- supports multiple consumers per partition

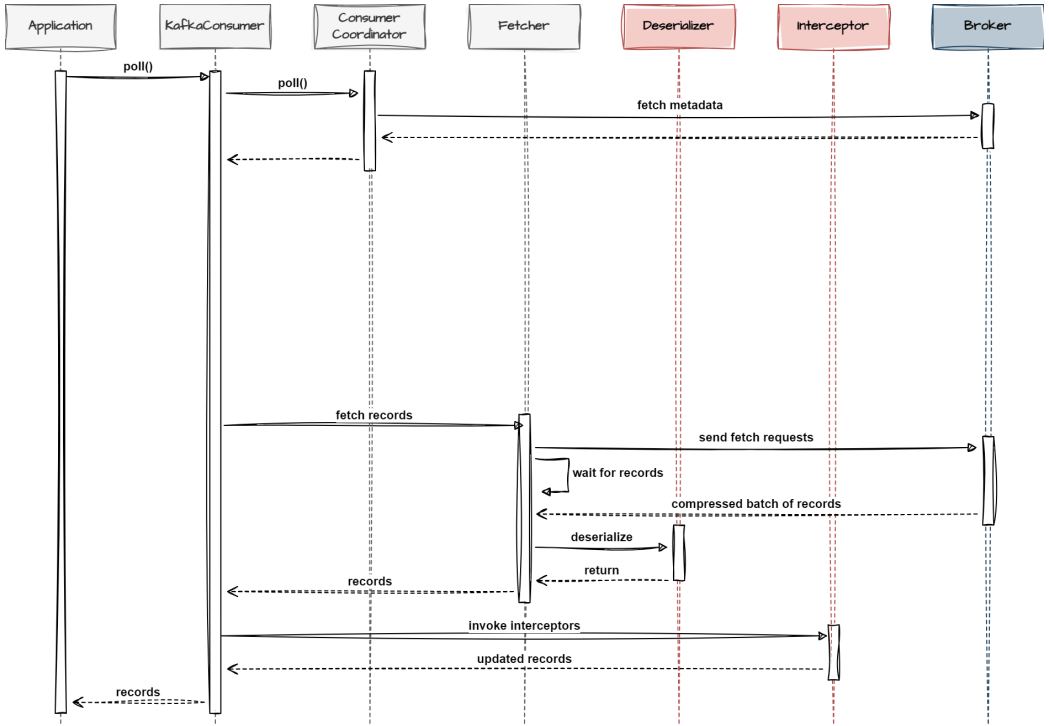
But what happens after subscribing and entering the poll-loop?



With `subscribe`, the consumer won't read records until it joins the consumer group.



With `assign`, the consumer won't invoke group membership functionality.



Offset Management

Partition offsets are part of the local consumer state, unless shared with the Kafka cluster.

- Use consumer offsets as **resumption point**
- Upon re-assigning a consumer, we need to know where to continue
- Skip over any records that have already been processed

Persisting the consumer state to the Kafka cluster is called committing an offset.

- Commit `offset of last record + 1`
  1. New consumer joins the consumer group and takes over.
  2. Starts off at the offset of the **last record** that has not been read
  3. This is `offset of last record + 1`

- Kafka employs a **recursive strategy** when managing offsets
  - Utilizes itself to persist and track offsets
  - cf. topic `__consumer_offsets`

The contents of the `__consumer_offsets` are compacted regularly to reduce the data progressively to only the last known committed offsets for every combination of `(consumer group, topic-partition)`.

Controlling when an offset is committed provides flexibility wrt. delivery guarantees.

- Move between *at-most-once* to *at-least-once* simply
  - by committing offsets **before** record processing (at-most-once)
  - by committing offsets **after** record processing completes (at-least-once)

> *A committed offset implies that the record **one below that offset** and **all prior records** have been processed by the consumer.*

- Last offset of a batch of records acknowledges the whole batch
- Built your error handling strategy around that fact

By default, a Kafka consumer will automatically commit offsets every five seconds.

- Adjusting frequency is done by setting `auto.commit.interval.ms`
- Setting `enable.auto.commit` to `false` disables this behavior
- API offers **synchronous** and **asynchronous** commit operations

```
public interface Consumer<K,V> {
  // only showing commit* methods
  // synchronous commits
  void commitSync();
  void commitSync(Duration timeout);
  void commitSync(Map<TopicPartition, OffsetAndMetadata> offsets);
  void commitSync(Map<TopicPartition, OffsetAndMetadata> offsets, Duration timeout);
  // asynchronous commits
  void commitAsync();
  void commitAsync(OffsetCommitCallback callback);
  void commitAsync(Map<TopicPartition, OffsetAndMetadata> offsets, OffsetCommitCallback callback);
}
```

- Setting `enable.auto.commit` to `false` disables the auto-commit-behavior. This means that you have to call one of the `commit*`-methods yourself. Make sure that this happens somewhere as part of your poll-and-process-records-loop.

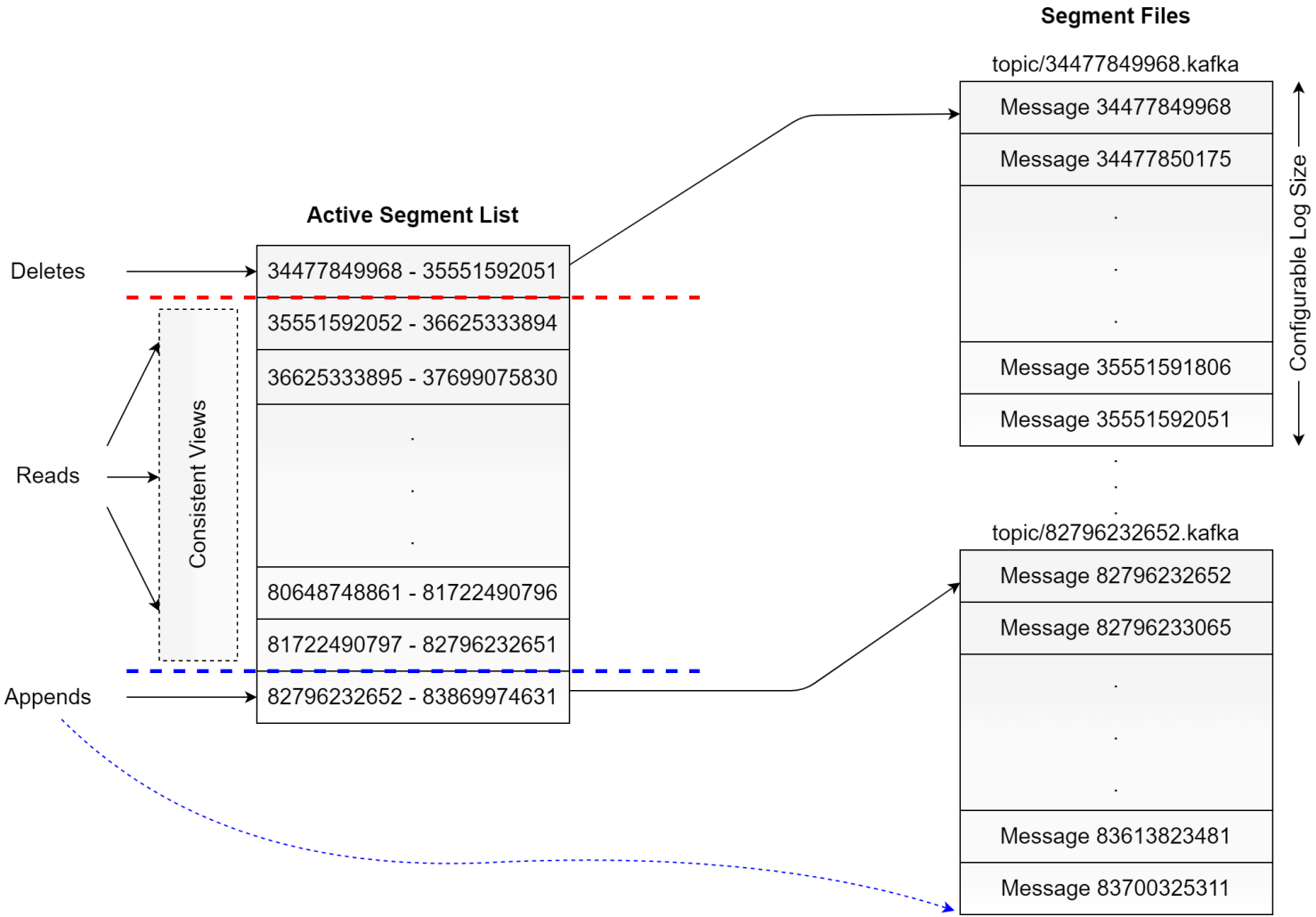
In case of no persisted offsets, `auto.offset.reset` controls where the consumer starts.

- Offers three different options
  - `earliest`: reset offset to the earliest offset (low watermark)
  - `latest`: reset offset to latest offset (high watermark)
  - `none`: throw exception if there are no offsets present

- `earliest`: Reset offset to the earliest offset. Consume from the beginning of the topic partition. This is the earliest offset of the *consistent view* onto a topic-partition and represents the **low watermark** (LWM) of the topic-partition.

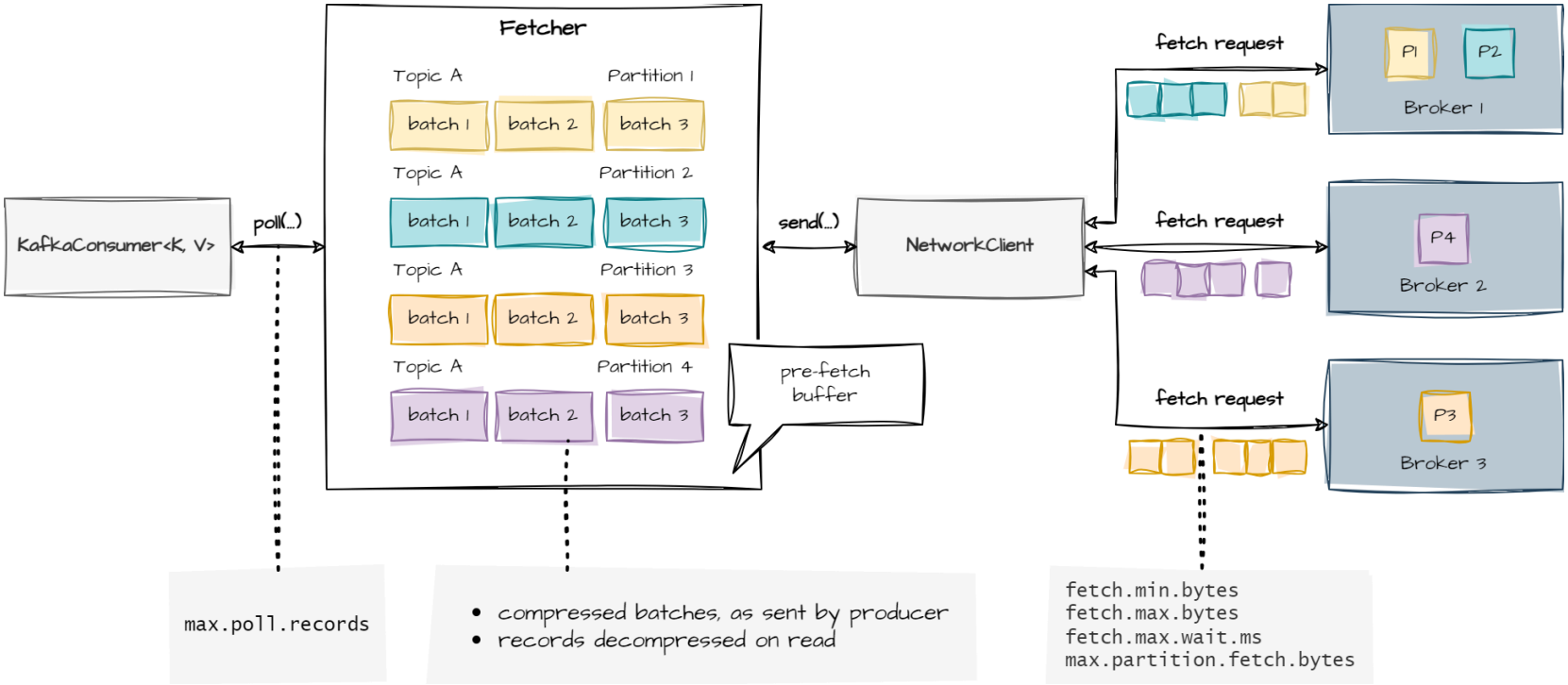
- `latest` (default): Reset offset to the latest offset. Consume from the end of the topic. This is the latest offset of the *consistent view* onto a topic-partition and represents the **high watermark** (HWM) of the topic-partition.

- `none`: Throw an exception if no offset is present for the consumer group.


Segment Files
topic/34477849968.kafka
Message 34477849968
Message 34477850175
Message 35551591806
Message 35551592051
Configurable Log Size
topic/82796232652.kafka
Message 82796232652
Message 82796233065
Message 83613823481
Message 83700325311
Active Segment List
Deletes
Reads
Appends
Consistent Views
34477849968 - 35551592051
35551592052 - 36625333894
36625333895 - 37699075830
80648748861 - 81722490796
81722490797 - 82796232651
82796232652 - 83869974631

Fetcher

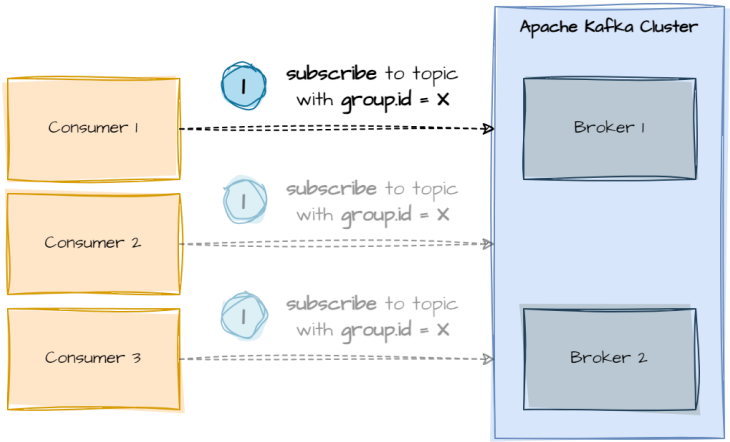
The Kafka consumer uses `Fetcher` as a buffer that retrieves batches from brokers.



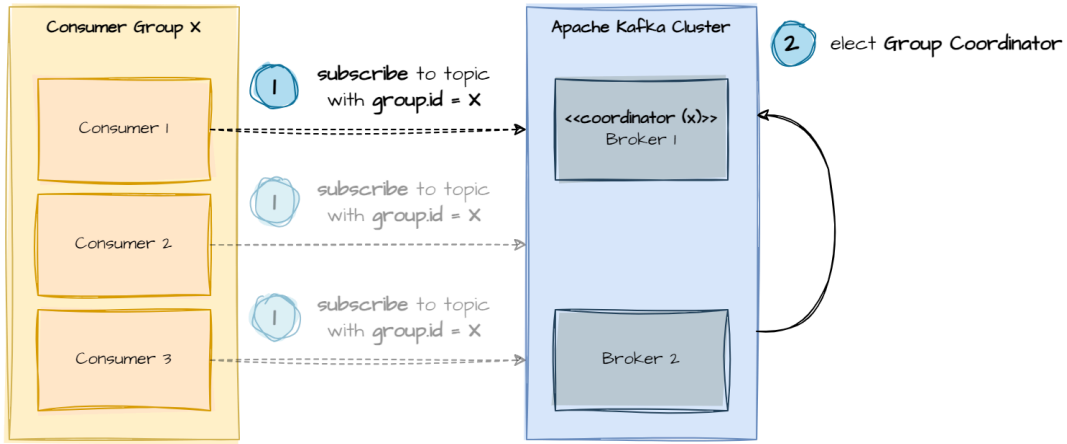
- `Fetcher` keeps compressed batches in-memory (as they are sent by the producer)
- `Fetcher` decompresses records on `poll()`
- Once a batch is completely consumed, it will be discarded from the buffer
- Key configurations:
  - `fetch.min.bytes`
  - `fetch.max.wait.ms`
- Increasing fetch size and wait time optimizes for **increased throughput**.
- Decreasing fetch size and wait time optimizes for **reduced latency**.

Consumer Groups

Consumers with the same `group.id` form a consumer group to cooperate.



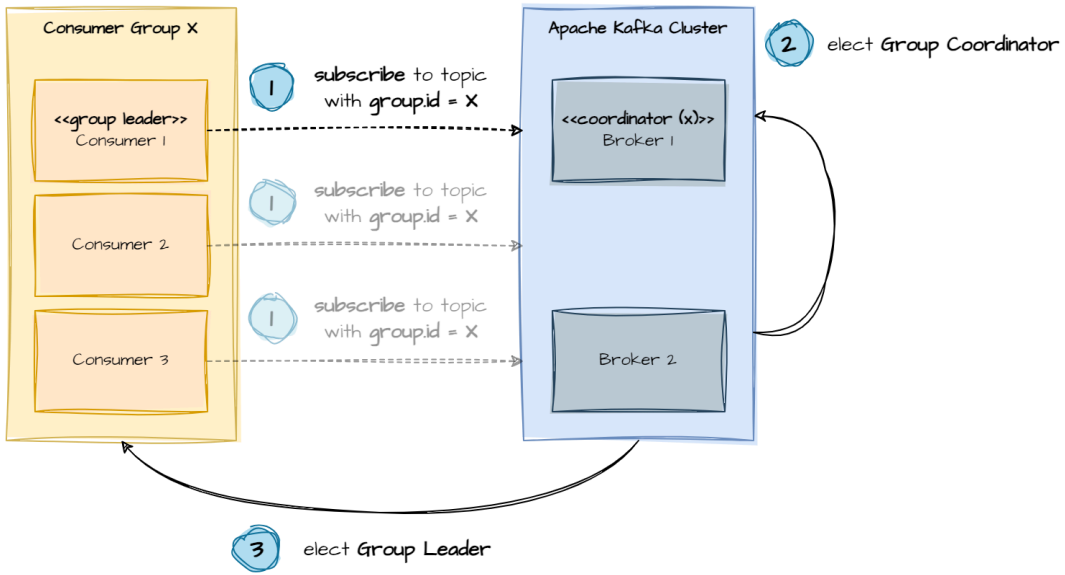
The Kafka cluster elects one of the brokers as *Group Coordinator*.



The *Group Coordinator* is responsible for

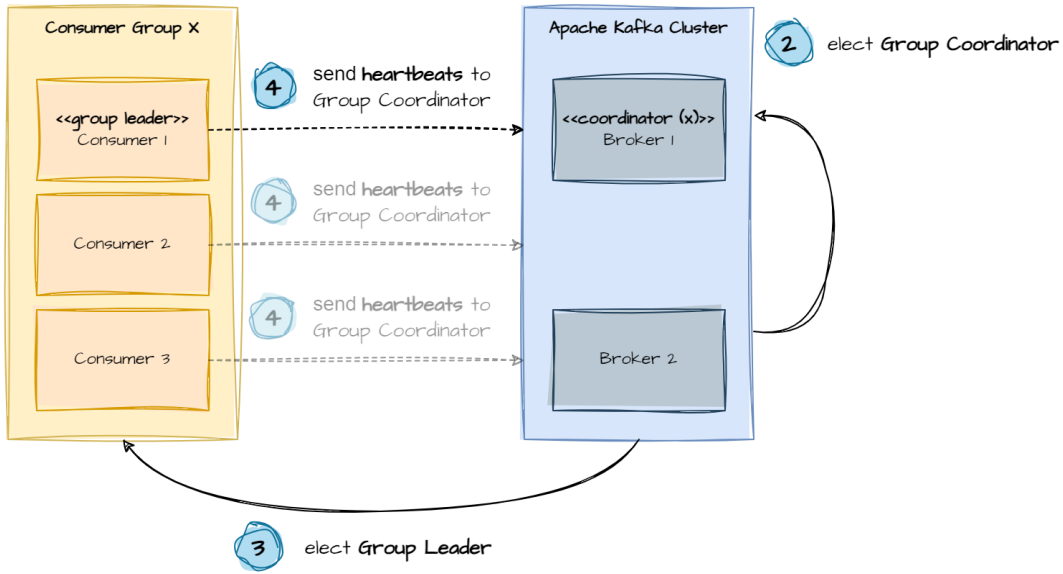
- managing group membership
- receiving heartbeats
- triggering rebalances
- ...

The *Group Coordinator* elects one consumer as *Group Leader*.

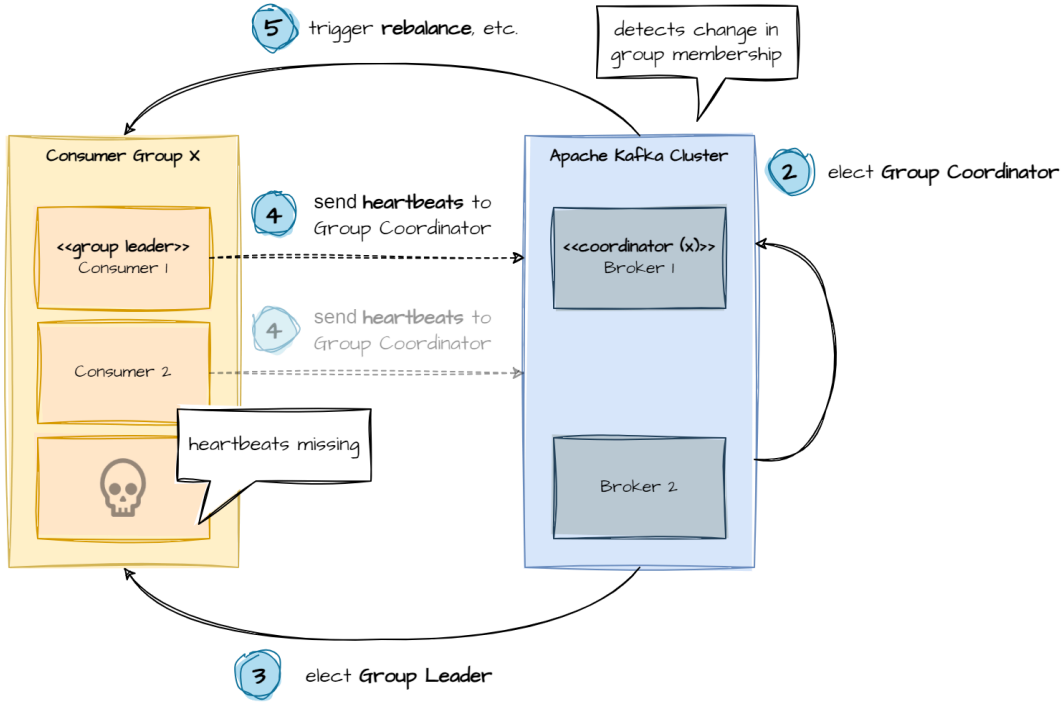


The *Group Leader* is responsible for partition assignments across consumers in the same group. Each partition will have only one consumer assigned.

Every consumer of the group sends regular heartbeats to the *Group Coordinator*.



The *Group Coordinator* detects a change in membership due to missing heartbeats.



Any change in group membership triggers consumer group rebalances.

Rebalance is triggered when

- consumer joins the group
- consumer leaves the group
- client-side failure detected via `max.poll.interval.ms`
- server-side failure detected via `session.timeout.ms`

There are many probable causes for rebalancing.

- Service is scaling up or down
- `poll()` and long message processing occur in the same thread
- Heartbeats do not reach the *Group Coordinator*
- Long JVM garbage collection pauses (stop-the-world)
- Kubernetes pods become CPU-throttled
- Pod evictions due to Kubernetes cluster upgrades
- Networking issues (latency, packet drop, ...)
- ...

The *Group Leader* uses a configurable partition assignment strategy.

- **Range** (default)
  - stop-the-world strategy
  - works on a per-topic basis
  - can generate imbalanced assignments
- **Round Robin**
  - stop-the-world strategy
  - uniformly distributes partitions

The strategy can be set using parameter `partition.assignment.strategy`.

Range (`org.apache.kafka.clients.consumer.RangeAssignor`)

For each topic, we lay out the available partitions in numeric order and the consumers in lexicographic order. We then divide the number of partitions by the total number of consumers to determine the number of partitions to assign to each consumer. If it does not evenly divide, then the first few consumers will have one extra partition.

Round Robin (`org.apache.kafka.clients.consumer.RoundRobinAssignor`)

The round robin assignor lays out all the available partitions and all the available consumers. It then proceeds to do a round robin assignment from partition to consumer. If the subscriptions of all consumer instances are identical, then the partitions will be uniformly distributed.

The *Group Leader* uses a configurable partition assignment strategy.

- **Range** (default)
  - stop-the-world strategy
  - works on a per-topic basis
  - can generate imbalanced assignments
- **Round Robin**
  - stop-the-world strategy
  - uniformly distributes partitions
- **Sticky**
  - stop-the-world strategy
  - initial distribution close to *Round Robin*
  - tries to minimize effect of a rebalance
  - can generate imbalanced assignments
- **Cooperative Sticky** (prefer for newer clusters)
  - incremental rebalance
  - does not stop consumption
  - same logic as *Sticky*

The strategy can be set using parameter `partition.assignment.strategy`.

Sticky (`org.apache.kafka.clients.consumer.StickyAssignor`)

Guarantees an assignment that is as balanced as possible, meaning that the numbers of topic partitions assigned to consumers differ by at most one and each consumer that has 2+ fewer topic partitions than some other consumer cannot get any of those topic partitions transferred to it. It preserves as many existing assignments as possible when a reassignment occurs, thus reducing overhead processing when topic partitions move from one consumer to another.

Cooperative Sticky (`org.apache.kafka.clients.consumer.CooperativeStickyAssignor`)

Follows the same logic as *Sticky*, but allows for cooperative rebalancing while *Sticky* follows the eager rebalancing protocol. Users should prefer this strategy for newer clusters. To enable it properly, all consumers must be configured using this strategy. Important: If you upgrade from 2.3 or earlier, please make sure to follow the Confluent recommendations on switching to this strategy.

A `ConsumerRebalanceListener` enables us to react on altered partition assignments.

```
public interface ConsumerRebalanceListener {

  void onPartitionsRevoked(Collection<TopicPartition> partitions);

  void onPartitionsAssigned(Collection<TopicPartition> partitions);

  default onPartitionsLost(Collection<TopicPartition> partitions) {
    onPartitionsRevoked(partitions);
  }
}
```

- Use it to save / restore offsets to / from external storage
- Use it to make sure that outstanding offsets are committed
- Instance is passed to `subscribe` when subscribing to a topic
- **Important: Different semantics for eager and incremental assignors!**

Summary

What did we learn?

- Client SDK Essentials
- Subscriptions vs. Assignments
- Offset Management
- The `poll()` loop
- Pre-Fetch Buffer
- Consumer Group
- Partition Assignment & Re-Balancing

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- Client SDK Essentials
- Subscriptions vs. Assignments
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What's to follow?

- *Deserialization*
- Interceptors
- Consumer Coordinator
- Consumer Designs
- Transactions

Questions?

assignment is available at

bit.ly/kafka-workshop-exchanging-records