Building Kafka-based Microservices with Akka Streams and Kafka Streams

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Outline

• Overview of streaming architectures
  • Kafka, Spark, Flink, Akka Streams, Kafka Streams
• Running example: Serving machine learning models
• Streaming in a microservice context
  • Akka Streams
  • Kafka Streams
• Wrap up
About Streaming Architectures

Why Kafka, Spark, Flink, Akka Streams, and Kafka Streams?
• Dean wrote this report describing the whole fast data landscape.
• bit.ly/lightbend-fast-data
• Previous talks (“Stream All the Things!”) and webinars (such as this one, https://info.lightbend.com/webinar-moving-from-big-data-to-fast-data-heres-how-to-pick-the-right-streaming-engine-recording.html) have covered the whole architecture. This session dives into the next level of detail, using Akka Streams and Kafka Streams to build Kafka-based microservices
Kafka is the data backplane for high-volume data streams, which are organized by topics. Kafka has high scalability and resiliency, so it's an excellent integration tool between data producers and consumers.
What is Kafka?
Kafka is a distributed log, storing messages sequentially. Producers always write to the end of the log, consumers can read on the log offset that they want to read from (earliest, latest, ...)

Kafka can be used as either a queue or pub sub
The main differences are:
1. Log is persistent where queue is ephemeral (reads pop elements)
2. Traditional message brokers manage consumer offsets, while log systems allow users to manage offsets themselves

Alternatives to Kafka include Pravega (EMC) and Distributed Log/Pulsar (Apache)
Kafka cluster typically consists of multiple brokers to maintain load balance. One Kafka broker instance can handle hundreds of thousands of reads and writes per second and each broker can handle TB (based on the disk size and network performance) of messages without performance impact. Kafka broker leader election can be done by ZooKeeper.
Kafka data is organized by topic. A topic can be comprised of multiple partitions. A partition is a physical data storage artifact. Data in a partition can be replicated across multiple brokers. Data in a partition is guaranteed to be sequential. So, a topic is a logical aggregation of partitions. A topic doesn’t provide any sequential guarantee (except a one-partition topic, where it’s “accidental”). Partitioning is an important scalability mechanism - individual consumers can read dedicated partitions.

Partitioning mechanisms - round-robin, key (hash) based, custom. Consider the sequential property when designing partitioning.
Consumers label themselves with a consumer group name, and each record published to a topic is delivered to one consumer instance within each subscribing consumer group (compare to queue semantics in traditional messaging). Consumer instances can be in separate processes or on separate machines.
We'll walk through the whole project, to get the lay of the land, then look at the client piece. The embedded Kafka approach is suitable for non-production scenarios only, like learning ;}

Code time

1. Project overview
2. Explore and run the client project
   • Creates in-memory ("embedded") Kafka instance and our topics
   • Pumps data into them
We’re arguing that you should use Kafka as the data backplane in your architectures. Why?
First, point to point spaghetti integration quickly becomes unmanageable as the amount of services grows
Kafka can simplify the situation by providing a single backbone which is used by all services (there are of coarse topics, but they are more logical then physical connections). Additionally Kafka persistence provides robustness when a service crashes (data is captured safely, waiting for the service to be restarted) - see also temporal decoupling, and provide the simplicity of one “API” for communicating between services.
Why Kafka for Connectivity?

Kafka:

• Simplify dependencies between services
  • Improved data consistency
• Minimize data transmissions
• Reduce data loss when a service crashes

Kafka can significantly improve decoupling (no service specific endpoints, temporal decoupling). It minimize the amount of data send over network, each producer writes data to Kafka, instead of writing it to multiple consumers. This also improves data consistency - the same data is consumed by all consumers. Extensibility is greatly simplified - adding new consumers does not require any changes to producers, and provide the simplicity of one “API” for communicating between services.
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Streaming Engines:
Spark, Flink - services to which you submit work. Large scale, automatic data partitioning.

They support highly scalable jobs, where they manage all the issues of scheduling processes, etc. You submit jobs to run to these running daemons. They handle scalability, failover, load balancing, etc. for you.
Streaming Engines:

Spark, Flink - services to which you submit work. Large scale, automatic data partitioning.

You have to write jobs, using their APIs, that conform to their programming model. But if you do, Spark and Flink do a great deal of work under the hood for you!
Much more flexible deployment and configuration options, compared to Spark and Flink, but more effort is required by you to run them. They are “just libraries”, so there is a lot of flexibility and interoperability capabilities.
We’ll return to more details about AS and KS as we get into implementation details.
Our concrete examples are based on the content of this report by Boris, on different techniques for serving ML models in a streaming context.
ML Is Simple

Get a lot of data
Sprinkle some magic
And be happy with results
Not only the climb is steep, but you are not sure which peak to climb
Court of the Patriarchs at Zion National park
Even If There Are Instructions

Not only the climb is steep, but you are not sure which peak to climb
Court of the Patriarchs at Zion National park
The Reality

We will only discuss this.
What Is The Model?

A model is a function transforming inputs to outputs - \( y = f(x) \)

for example:

**Linear regression:** \( y = a_0 + a_1 x_1 + \ldots + a_n x_n \)

**Neural network:** \( f(x) = K(\sum w_i g_i(x)) \)

Such a definition of the model allows for an easy implementation of model’s composition. From the implementation point of view it is just function composition.
UC Berkeley AMPLab introduced machine learning pipelines as a graph defining the complete chain of data transformation. The advantage of such an approach is that it captures the whole processing pipeline including data preparation transformations, machine learning itself, and any required post-processing of the ML results. Although a single predictive model is shown on this picture, in reality, several models can be chained to gather or composed in any other way. See PMML documentation for a description of different model composition approaches. Definition of the complete model allows for optimization of the data processing. This notion of machine learning pipelines has been adopted by many applications including SparkML, Tensorflow, PMML, etc.
Traditional Approach to Model Serving

- Model is code
- This code has to be saved and then somehow imported into model serving

Why is this problematic?
In his talk at the last Flink Forward, Ted Dunning discussed the fact that with multiple tools available to Data scientists, they tend to use different tools for solving different problems and as a result they are not very keen on tools standardization. This creates a problem for software engineers trying to use “proprietary” model serving tools supporting specific machine learning technologies. As data scientists evaluate and introduce new technologies for machine learning, software engineers are forced to introduce new software packages supporting model scoring for these additional technologies.
In order to overcome these differences, Data Mining Group have introduced 2 standards - Predictive Model Markup Language (PMML) and Portable Format for Analytics (PFA), both suited for description of the models that need to be served. Introduction of these models led to creation of several software products dedicated to “generic” model serving, for example Openscoring, Open data group, etc.

Another de facto standard for machine learning is Tensorflow, which is widely used for both machine learning and model serving. Although it is a proprietary format, it is used so widely that it becomes a standard.

The result of this standardization is creation of the open source projects, supporting these formats - JPMML and Hadrian which are gaining more and more adoption for building model serving implementations, for example ING, R implementation, SparkML support, Flink support, etc. Tensorflow also released Tensorflow Java APIs, which are used in a Flink TensorFlow.
Exporting Model As Data With PMML

There are already a lot of export options

- Spark MLb: https://github.com/jpmml/jpmml-sparkml
- Scikit-learn: https://github.com/jpmml/jpmml-sklearn
- R: https://github.com/jpmml/jpmml-r
- TensorFlow: https://github.com/jpmml/jpmml-tensorflow
Evaluating PMML Model

There are also a few PMML evaluators

- **Java**: [https://github.com/jpmml/jpmml-evaluator](https://github.com/jpmml/jpmml-evaluator)

- **Python**: [https://github.com/opendatagroup/augustus](https://github.com/opendatagroup/augustus)
Exporting Model As Data With Tensorflow

- Tensorflow execution is based on Tensors and Graphs
- Tensors are defined as multilinear functions which consist of various vector variables
- A computational graph is a series of Tensorflow operations arranged into graph of nodes
- Tensorflow supports exporting graphs in the form of binary protocol buffers
- There are two different export format - optimized graph and a new format - saved model
Evaluating Tensorflow Model

- Tensorflow is implemented in C++ with a Python interface.
- In order to simplify Tensorflow usage from Java, in 2017 Google introduced Tensorflow Java API.
- Tensorflow Java API supports importing an exported model and allows to use it for scoring.

We have a previously-trained TF model on the included “Wine Records” data. We’ll import that model to do scoring.
Additional Considerations – Model Lifecycle

• Models tend to change
• Update frequencies vary greatly – from hourly to quarterly/yearly
• Model version tracking
• Model release practices
• Model update process
The Solution

A streaming system allowing to update models without interruption of execution (dynamically controlled stream).

The majority of machine learning implementations are based on running model serving as a REST service, which might not be appropriate for high-volume data processing or streaming systems, since they require recoding/restarting systems for model updates. For example, Flink TensorFlow or Flink JPPML.
You need a neutral representation format that can be shared between different tools and over the wire. Protobufs (from Google) is one of the popular options. Recall that this is the format used for model export by TensorFlow. Here is an example.

```protobuf
// On the wire
syntax = "proto3";
// Description of the trained model.
message ModelDescriptor {
  string name = 1;   // Model name
  string description = 2;  // Human readable
  string dataType = 3; // Data type for which this model is applied.
  enum ModelType {   // Model type
    TENSORFLOW = 0;
    TENSORFLOWSAVED = 2;
    PMML = 2;
  }
  ModelType modeltype = 4;
  oneof MessageContent {
    // Byte array containing the model
    bytes data = 5;
    string location = 6;
  }
}
```
Model Representation (Scala)

trait Model {
    def score(input : Any) : Any
    def cleanup() : Unit
    def toBytes() : Array[Byte]
    def getType : Long
}

def ModelFactoryl {
    def create(input : ModelDescriptor) : Model
    def restore(bytes : Array[Byte]) : Model
}
Side Note: Monitoring

Model monitoring should provide information about usage, behavior, performance and lifecycle of the deployed models

case class ModelToServeStats(
  name: String,                    // Model name
  description: String,            // Model descriptor
  modelType: ModelDescriptor.ModelType,  // Model type
  since: Long,                    // Start time of model usage
  var usage : Long = 0,           // Number of servings
  var duration : Double = 0.0,    // Time spent on serving
  var min : Long = Long.MaxValue, // Min serving time
  var max : Long = Long.MinValue  // Max serving time
)
Queryable State

Queryable state: ad hoc query of the state in the stream. Different than the normal data flow.

Treats the stream processing layer as a lightweight embedded database. Directly query the current state of a stream processing application. No need to materialize that state to a database, etc. first.

Kafka Streams and Flink have built-in support for this and its being added to Spark Streaming. We’ll show how to use other Akka features to provide the same ability in a straightforward way for Akka Streams.
Microservice All the Things!
Microservices, for when your in-process methods have too little latency.

Dave Chaney @davechaney
Microservices, for when function calls are too reliable.

4:11 AM - 25 Feb 2018
207 Retweets 566 Likes
By event-driven microservices, I mean that each individual datum is treated as a specific event that triggers some activity, like steps in a shopping session. Each event requires individual handling, routing, responses, etc. REST, CQRS, and Event Sourcing are ideal for this.

Records are uniform (for a given stream), they typically represent instantiations of the same information type, for example time series; we can process them individually or as a group, for efficiency.

It's a spectrum because we might take those events and also route them through a data pipeline, like computing statistics or scoring against a machine learning model (as here), perhaps for fraud detection, recommendations, etc.
I think it's useful to reflect on the history of these toolkits, because their capabilities reflect their histories. Akka Actors emerged in the world of building Reactive microservices, those requiring high resiliency, scalability, responsiveness, CEP, and must be event driven. Akka is extremely lightweight and supports extreme parallelism, including across a cluster. However, the Akka Streams API is effectively a dataflow API, so it nicely supports many streaming data scenarios, allowing Akka to cover more of the spectrum than before.
Kafka reflects the heritage of moving and managing streams of data, first at LinkedIn. But from the beginning it has been used for event-driven microservices, where the “stream” contained events, rather than records. Kafka Streams fits squarely in the record-processing world, where you define dataflows for processing and even SQL. It can also be used for event processing scenarios.
Akka Streams
akka streams

- A library
- Implements Reactive Streams.
  - [http://www.reactive-streams.org/](http://www.reactive-streams.org/)
  - *Back pressure* for flow control

See this website for details on why *back pressure* is an important concept for reliable flow control, especially if you don’t use something like Kafka as your “near-infinite” buffer between services.
Bounded queues are the only sensible option (even Kafka topic partitions are bounded by disk sizes), but to prevent having to drop input when it’s full, consumers signal to producers to limit flow. Most implementations use a push model when flow is fine and switch to a pull model when flow control is needed.
And they compose so you get end-to-end back pressure.
Rich, mature tools for the full spectrum of microservice development.
• A very simple example to get the “gist”…
import akka.stream._
import akka.stream.scaladsl._
import akka.NotUsed
import akka.actor.ActorSystem
import scala.concurrent._
import scala.concurrent.duration._

implicit val system = ActorSystem("QuickStart")
implicit val materializer = ActorMaterializer()

val source: Source[Int, NotUsed] = Source(1 to 10)
val factorials = source.scan(BigInt(1)) ((acc, next) => acc * next)
factorials.runWith(Sink.foreach(printLn))
import akka.stream._
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import scala.concurrent.duration._

implicit val system = ActorSystem("QuickStart")
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val source: Source[Int, NotUsed] = Source(1 to 10)
val factorials = source.scan(BigInt(1)) ((acc, next) => acc * next)
factorials.runWith(Sink.foreach(printLine))
import akka.stream._
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import akka.NotUsed
import akka.actor.ActorSystem
import scala.concurrent._
import scala.concurrent.duration._

implicit val system = ActorSystem("QuickStart")
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This example is in akkaStreamsCustomStage/simple-akka-streams-example.sc
The core concepts are sources and sinks, connected by flows. There is the notion of a Graph for more complex dataflows, but we won’t discuss them further.
• This example is included in the project:
  • akkaStreamsCustomStage/simple-akka-streams-example.sc
• To run it (showing the different prompt!):

```
$ sbt
sbt:akkaKafkaTutorial> project akkaStreamsCustomStage
sbt:akkaStreamsCustomStage> console
scala> :load akkaStreamsCustomStage/simple-akka-streams-example.sc
```

The “.sc” extension is used so that the compiler doesn’t attempt to compile this Scala “script”. Using “.sc” is an informal convention for such files. We used yellow to indicate the prompts (3 different shells!)
Using Custom Stage

Create a custom stage, a fully type-safe way to encapsulate new functionality. Like adding a new “operator”.

Custom stage is an elegant implementation but doesn’t scale well to a large number of models. Although a stage can contain a hash map of models, all of the execution will be happening at the same place.
Using a Custom Stage

**Code time**

1. Run the *client* project (if not already running)
2. Explore and run *akkaStreamsCustomStage* project

Custom stage is an elegant implementation but not scale well to a large number of models. Although a stage can contain a hash map of models, all of the execution will be happening at the same place
Exercises!

We've prepared some exercises. We may not have time during the tutorial to work on them, but take a look at the exercise branch in the Git project (or the separate X.Y.Z_exercise download).

To find them, search for “// Exercise”. The master branch implements the solutions for most of them.
Other Production Concerns
Here's our streaming microservice example adapted for Akka Streams. We'll still use Kafka topics in some places and assume we're using the same implementation for the “Model Training” microservice. Alpakka provides the interface to Kafka, DBs, file systems, etc. We're showing two microservices as before, but this time running in Akka Cluster, with direct messaging between them. We'll explore this a bit more after looking at the example code.
We here create a routing layer: an actor that will implement model serving for specific model (based on key) and route messages appropriately. This way our system will serve models in parallel.
Custom stage is an elegant implementation but not scale well to a large number of models. Although a stage can contain a hash map of models, all of the execution will be happening at the same place.

1. While still running the client project…
2. Explore and run akkaActorsPersistent project
More Production Concerns
Using Akka Cluster

Two levels of scalability:
• Kafka partitioned topic allow to scale listeners according to the amount of partitions.
• Akka cluster sharing allows to split model serving actors across clusters.

Go Direct or Through Kafka?

- Extremely low latency
- Minimal I/O and memory overhead
- No marshaling overhead

vs.

- Higher latency (including queue depth)
- Higher I/O and processing (marshaling) overhead
- Better potential reusability

Design choice: When is it better to use direct actor-to-actor (or service-to-service) messaging vs. going through a Kafka topic?
Design choice: When is it better to use direct actor-to-actor (or service-to-service) messaging vs. going through a Kafka topic?
Kafka Streams

Same sample use case, now with Kafka Streams
There’s a maturing body of thought about what streaming semantics should be, too much to discuss here. Dean’s book provides the next level of details. See Tyler’s work (from the Google Apache Beam team) for deep dives.
Kafka Streams

- KStream - per-record transformations
- KTable - key/value store of supplemental data
  - Efficient management of application state

There is a duality between streams and tables. Tables are the latest state snapshot, while streams record the history of state evolution. A common way to implement databases is to use an event (or change) log, then update the state from the log.
Kafka Streams

- Low overhead
- Read from and write to Kafka topics, memory
  - Could use Kafka Connect for other sources and sinks
- Load balance and scale based on partitioning of topics
- Built-in support for Queryable State
Kafka Streams

- Two types of APIs:
  - Process Topology
  - Compare to Apache Storm
- DSL based on collection transformations
  - Compare to Spark, Flink, Scala collections.
Kafka Streams

- Provides a Java API
- Lightbend donating a Scala API to Apache Kafka
  - [https://github.com/lightbend/kafka-streams-scala](https://github.com/lightbend/kafka-streams-scala)
  - See also our convenience tools for distributed, queryable state: [https://github.com/lightbend/kafka-streams-query](https://github.com/lightbend/kafka-streams-query)
- SQL - kind of, through a specialized application

The kafka-streams-query uses a KS API to find all the partitions across a cluster for a given topic, query their state, and aggregate the results, behind a web service. Otherwise, you have to query the partitions individually yourself.
Kafka Streams

- Ideally suited for:
  - ETL -> KStreams
  - State -> KTable
  - Joins, including Stream and Table joins
  - “Effectively once” semantics
  - Commercial support from Confluent, Lightbend, and others
Model Serving With Kafka Streams

Source 1 → Stream 1 → Process stream 1 record → Current state

Source 2 → Stream 2 → Process stream 2 record → Results stream

Result stream processing
We provide three example implementations, using three different ways of storing state. “Naive” - because in-memory state is lost if the process crashes; a restart can’t pick up where the previous instance left off.
Model Serving With Kafka Streams

**Code time**

1. Still running the *client* project…
2. Explore and run:  
   `kafkaStreamsModelServerInMemoryStore`  
   - The “naive” model  
   - Uses the processor topology API
The difference between ModelServer.scala and ModelServerFluent.scala is the KS API used. The 1st uses the KS Java API directly from Scala. It's hard to read, because of all the type signatures that can't be inferred by the Scala compiler. The 2nd uses the Lightbend Scala API, which supports Scala type inference better, resulting in cleaner, easier to read code.
Still running the *client* project…

2. Explore and run:
   `kafkaStreamsModelServerCustomStore`
   - Also uses the collections-like DSL
   - Uses a customer data store
   - `ModelServer.scala` - Uses the KS Java API
   - `ModelServerFluent.scala` - the LB Scala API
Akka Streams is a great choice if you are building full-spectrum microservices and you need lots of flexibility in your app architectures, connecting to different kinds of data sources and sinks, etc. Kafka Streams is a great choice if your use cases fit nicely in it’s “sweet spot”, you want SQL access, and you don’t need to full flexibility of something like Akka. Of course, you can use both! They are “just libraries”.
In Our Remaining Time Today…

1. Try the exercises in the exercise branch (or the X.Y.Z_exercise
   - Search for “// Exercise” in the code
2. Explore the code we didn’t discuss (a lot ;)
3. Ask us for help on anything now…
4. Visit lightbend.com/fast-data-platform
5. Profit!!
Thank you! Please check out the other Strata San Jose sessions by Boris, Dean, and our colleagues Debasish and Emre. Check out our Fast Data Platform for commercial options for building and running microservices with Kafka, Akka Streams, and Kafka Streams.