Scalable Stream Processing - Spark Streaming

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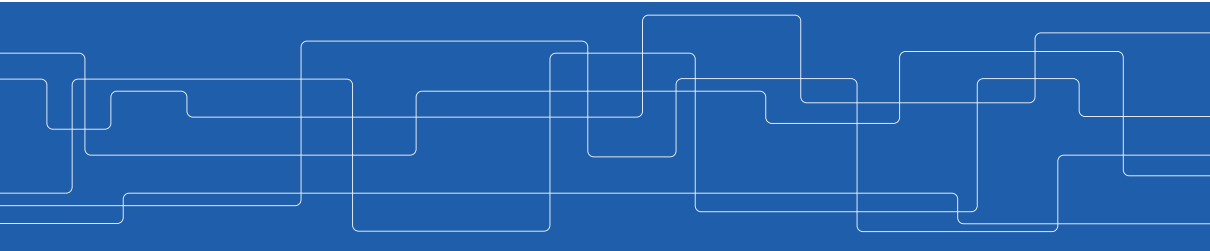
2023-09-25



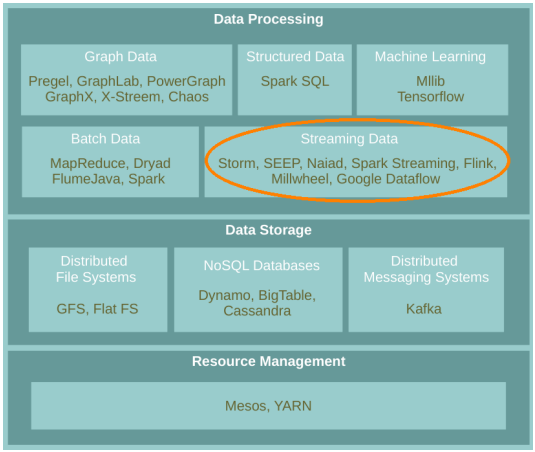
The Course Web Page

https://id2221kth.github.io

The Questions-Answers Page

https://tinyurl.com/hk7hzpw5

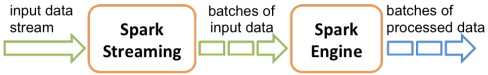
Where Are We?


Data Processing
Graph Data
Pregel, GraphLab, PowerGraph
GraphX, X-Streem, Chaos
Structured Data
Spark SQL
Machine Learning
Mllib
Tensorflow
Batch Data
MapReduce, Dryad
FlumeJava, Spark
Streaming Data
Storm, SEEP, Naiad, Spark Streaming, Flink,
Millwheel, Google Dataflow
Data Storage
Distributed
File Systems
GFS, Flat FS
NoSQL Databases
Dynamo, BigTable,
Cassandra
Distributed
Messaging Systems
Kafka
Resource Management
Mesos, YARN

Spark Streaming

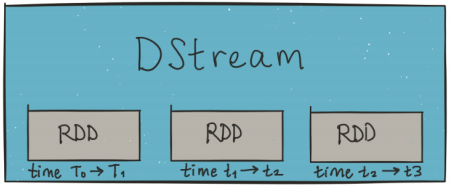
Spark Streaming

- Run a streaming computation as a series of very small, deterministic batch jobs.
  - Chops up the live stream into batches of X seconds.
  - Treats each batch as RDDs and processes them using RDD operations.
  - Discretized Stream Processing (DStream)



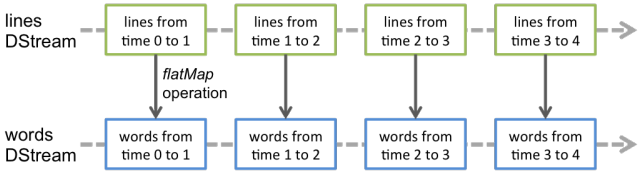
DStream (1/2)

- DStream: sequence of RDDs representing a stream of data.



DStream (2/2)

- Any operation applied on a DStream translates to operations on the underlying RDDs.



StreamingContext

- `StreamingContext` is the main entry point of all Spark Streaming functionality.

```
val conf = new SparkConf().setAppName(appName).setMaster(master)
val ssc = new StreamingContext(conf, Seconds(1))
```

- The second parameter, `Seconds(1)`, represents the time interval at which streaming data will be divided into batches.

Input Operations

- Socket connection
  - Creates a DStream from text data received over a TCP socket connection.

```
ssc.socketTextStream("localhost", 9999)
```

- File stream
  - Reads data from files.

```
streamingContext.fileStream[KeyClass, ValueClass, InputFormatClass](dataDirectory)

streamingContext.textFileStream(dataDirectory)
```

- Connectors with external sources, e.g., Twitter, Kafka, Flume, Kinesis, ...

Transformations (1/2)

- Transformations on DStreams are still lazy!
- DStreams support many of the transformations available on normal Spark RDDs.
- Computation is kicked off explicitly by a call to the `start()` method.

Transformations (2/2)

- `map`: a new DStream by passing each element of the source DStream through a given function.
- `reduce`: a new DStream of single-element RDDs by aggregating the elements in each RDD using a given function.
- `reduceByKey`: a new DStream of (K, V) pairs where the values for each key are aggregated using the given reduce function.

Example - Word Count (1/6)

- First we create a `StreamingContex`

```
import org.apache.spark._
import org.apache.spark.streaming._

// Create a local StreamingContext with two working threads and batch interval of 1 second.
val conf = new SparkConf().setMaster("local[2]").setAppName("NetworkWordCount")
val ssc = new StreamingContext(conf, Seconds(1))
```

Example - Word Count (2/6)

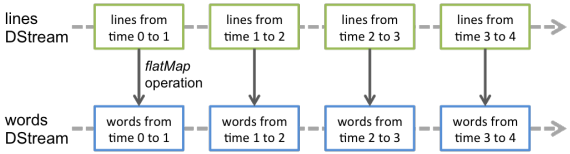
- Create a DStream that represents streaming data from a TCP source.
- Specified as hostname (e.g., localhost) and port (e.g., 9999).

```
val lines = ssc.socketTextStream("localhost", 9999)
```

Example - Word Count (3/6)

- Use `flatMap` on the stream to split the records text to words.
- It creates a new DStream.

```
val words = lines.flatMap(_.split(" "))
```



Example - Word Count (4/6)

- Map the `words` DStream to a DStream of `(word, 1)`.
- Get the frequency of words in each batch of data.
- Finally, print the result.

```
val pairs = words.map(word => (word, 1))

val wordCounts = pairs.reduceByKey(_ + _)

wordCounts.print()
```

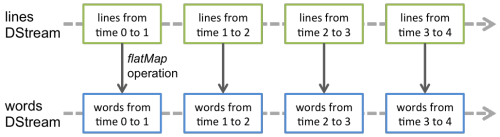
Example - Word Count (5/6)

- Start the computation and wait for it to terminate.

```
// Start the computation
ssc.start()

// Wait for the computation to terminate
ssc.awaitTermination()
```

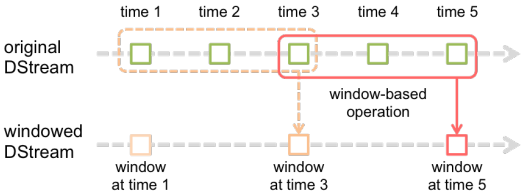
Example - Word Count (6/6)

```
val conf = new SparkConf().setMaster("local[2]").setAppName("NetworkWordCount")
val ssc = new StreamingContext(conf, Seconds(1))

val lines = ssc.socketTextStream("localhost", 9999)
val words = lines.flatMap(_.split(" "))
val pairs = words.map(word => (word, 1))
val wordCounts = pairs.reduceByKey(_ + _)
wordCounts.print()

ssc.start()
ssc.awaitTermination()
```



Window Operations (1/2)

- Spark provides a set of transformations that apply to a over a sliding window of data.
- A window is defined by two parameters: window length and slide interval.
- A tumbling window effect can be achieved by making slide interval = window length

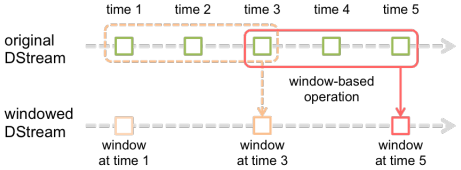


Window Operations (2/2)

- `reduceByWindow(func, windowLength, slideInterval)`
  - Returns a new single-element DStream, created by aggregating elements in the stream over a sliding interval using func.
- `reduceByKeyAndWindow(func, windowLength, slideInterval)`
  - Called on a DStream of (K, V) pairs.
  - Returns a new DStream of (K, V) pairs where the values for each key are aggregated using function func over batches in a sliding window.

Example - Word Count with Window

```
val conf = new SparkConf().setMaster("local[2]").setAppName("NetworkWordCount")
val ssc = new StreamingContext(conf, Seconds(1))

val lines = ssc.socketTextStream("localhost", 9999)
val words = lines.flatMap(_.split(" "))
val pairs = words.map(word => (word, 1))
val windowedWordCounts = pairs.reduceByKeyAndWindow(_ + _, Seconds(30), Seconds(10))
windowedWordCounts.print()

ssc.start()
ssc.awaitTermination()
```



What about States?

- Accumulate and aggregate the results from the start of the streaming job.
- Need to check the previous state of the RDD in order to do something with the current RDD.
- Spark supports stateful streams.

Checkpointing

- It is mandatory that you provide a checkpointing directory for stateful streams.

```
val ssc = new StreamingContext(conf, Seconds(1))
ssc.checkpoint("path/to/persistent/storage")
```

Stateful Stream Operations

- `mapWithState`
  - It is executed only on set of keys that are available in the last micro batch.

```
def mapWithState[StateType, MappedType](spec: StateSpec[K, V, StateType, MappedType]):
    DStream[MappedType]

StateSpec.function(updateFunc)
val updateFunc = (batch: Time, key: String, value: Option[Int], state: State[Int])
```

- Define the update function (partial updates) in `StateSpec`.

Example - Stateful Word Count (1/4)

```
val ssc = new StreamingContext(conf, Seconds(1))
ssc.checkpoint(".")

val lines = ssc.socketTextStream(IP, Port)
val words = lines.flatMap(_.split(" "))
val pairs = words.map(word => (word, 1))

val stateWordCount = pairs.mapWithState(StateSpec.function(updateFunc))

val updateFunc = (key: String, value: Option[Int], state: State[Int]) => {
  val newCount = value.getOrElse(0)
  val oldCount = state.getOption.getOrElse(0)
  val sum = newCount + oldCount
  state.update(sum)
  (key, sum)
}
```

Example - Stateful Word Count (2/4)

- The first micro batch contains a message a.
- `updateFunc = (key: String, value: Option[Int], state: State[Int]) => (key, sum)`
- Input: `key = a`, `value = Some(1)`, `state = 0`
- Output: `key = a`, `sum = 1`

Example - Stateful Word Count (3/4)

- The second micro batch contains messages `a` and `b`.
- `updateFunc = (key: String, value: Option[Int], state: State[Int]) => (key, sum)`
- Input: `key = a`, `value = Some(1)`, `state = 1`
- Input: `key = b`, `value = Some(1)`, `state = 0`
- Output: `key = a`, `sum = 2`
- Output: `key = b`, `sum = 1`

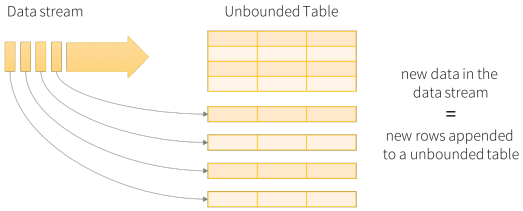
Example - Stateful Word Count (4/4)

- The third micro batch contains a message `b`.
- `updateFunc = (key: String, value: Option[Int], state: State[Int]) => (key, sum)`
- Input: `key = b`, `value = Some(1)`, `state = 1`
- Output: `key = b`, `sum = 2`

Structured Streaming

Structured Streaming

- Treating a live data stream as a table that is being continuously appended.

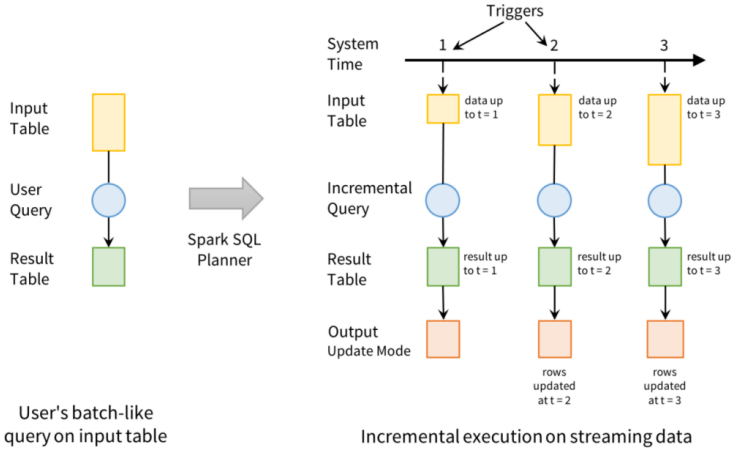


Data stream as an unbounded table

Programming Model (1/2)

- Defines a query on the input table, as a static table.
  - Spark automatically converts this batch-like query to a streaming execution plan.
- Specify triggers to control when to update the results.
  - Each time a trigger fires, Spark checks for new data (new row in the input table), and incrementally updates the result.

Programming Model (2/2)



Output Modes

- Three output modes:

1. Append: only the new rows appended to the result table since the last trigger will be written to the external storage.
2. Complete: the entire updated result table will be written to external storage.
3. Update: only the rows that were updated in the result table since the last trigger will be changed in the external storage.

Steps to Define a Streaming Query (1/4)

- Define input sources.
- Use spark.readStream to create a DataStreamReader.

```
val spark = SparkSession.builder.master("local[2]").appName("appname").getOrCreate()

val lines = spark.readStream.format("socket")
    .option("host", "localhost")
    .option("port", 9999)
    .load()
```

Steps to Define a Streaming Query (2/4)

- Transform data.
- E.g., below counts is a streaming DataFrame that represents the running word counts.

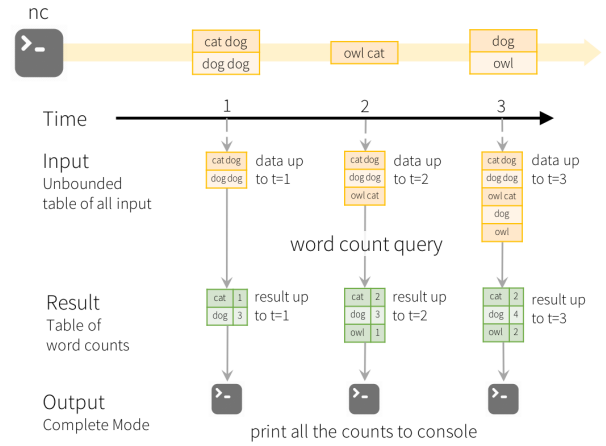
```
import org.apache.spark.sql.functions._

val words = lines.select(split(col("value"), " ").as("word"))

val wordCounts = words.groupBy("word").count()
```

Steps to Define a Streaming Query (3/4)

- Define output sink and output mode.
- Use DataFrame.writeStream to define how to write the processed output data.
- Start the query.

```
val query = wordCounts.writeStream.format("console").outputMode("complete").start()

query.awaitTermination()
```

Steps to Define a Streaming Query (4/4)



[https://spark.apache.org/docs/latest/structured-streaming-programming-guide.html]

Streaming Data Sources and Sinks - Files (1/2)

- Reading from files.

```
import org.apache.spark.sql.types._

val inputDirectoryOfJsonFiles = ...

val fileSchema = new StructType()
    .add("key", IntegerType)
    .add("value", IntegerType)

val inputDF = spark.readStream
    .format("json")
    .schema(fileSchema)
    .load(inputDirectoryOfJsonFiles)
```

Streaming Data Sources and Sinks - Files (2/2)

- Writing to files.

```
val outputDir = ...
val checkpointDir = ...
val resultDF = ...

val streamingQuery = resultDF
    .writeStream
    .format("parquet")
    .option("path", outputDir)
    .option("checkpointLocation", checkpointDir)
    .start()
```

Basic Operations (1/2)

- Most of operations on DataFrame/Dataset are supported for streaming.

```
case class Call(action: String, time: Timestamp, id: Int)

val df: DataFrame = spark.readStream.json("s3://logs")
val ds: Dataset[Call] = df.as[Call]
```

- Selection and projection

```
df.select("action").where("id > 10") // using untyped APIs
ds.filter(_.id > 10).map(_.action) // using typed APIs
```

Basic Operations (2/2)

- Aggregation

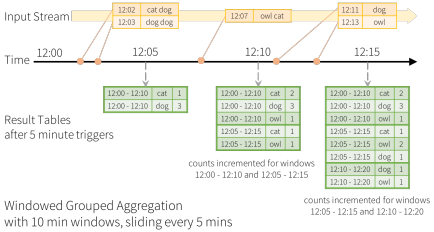
```
df.groupBy("action") // using untyped API
ds.groupByKey(_.action) // using typed API
```

- SQL commands

```
df.createOrReplaceTempView("dfView")
spark.sql("select count(*) from dfView") // returns another streaming DF
```

Window Operation

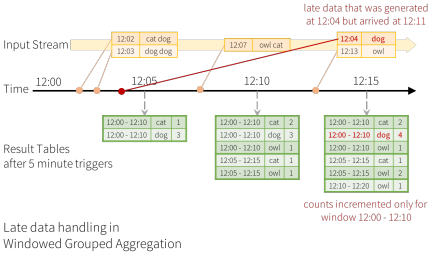
- Computing counts corresponding to 10-minute windows sliding every five minutes.




```
words = ...  // streaming DataFrame of schema { timestamp: Timestamp, word: String }

windowedCounts = words.groupBy( \
    window($"timestamp", "10 minutes", "5 minutes"), $"word").count()
```

Handling Late Data

- The watermark delay defines how long the engine will wait for late data to arrive.




```
words = ...  # streaming DataFrame of schema { timestamp: Timestamp, word: String }

windowedCounts = words.withWatermark("timestamp", "10 minutes") \
    .groupBy( \
    window($"timestamp", "10 minutes", "5 minutes"), $"word").count()
```

Summary

- Mini-batch processing
- DStream: sequence of RDDs
- RDD and window operations
- Structured streaming

References

- M. Zaharia et al., “Spark: The Definitive Guide”, O’Reilly Media, 2018 - Chapters 20-23.
- M. Zaharia et al., “Discretized Streams: An Efficient and Fault-Tolerant Model for Stream Processing on Large Clusters”, HotCloud’12.
- The world beyond batch: Streaming 102
  `https://www.oreilly.com/ideas/the-world-beyond-batch-streaming-102`

Questions?