Big data: architectures and data analytics

Spark Streaming
What is Spark Streaming?

- Spark Streaming is a framework for large scale stream processing
  - Scales to 100s of nodes
  - Can achieve second scale latencies
  - Provides a simple batch-like API for implementing complex algorithm
  - Can absorb live data streams from Kafka, Flume, ZeroMQ, Twitter, ...
Motivation

- Many important applications must process large streams of live data and provide results in near-real-time
  - Social network trends
  - Website statistics
  - Intrusion detection systems
  - ...

Requirements

- Scalable to large clusters
- Second-scale latencies
- Simple programming model
- Efficient fault-tolerance in stateful computations
Other Existing Streaming Systems

- Storm
  - Replays record if not processed by a node
  - Processes each record at least once
  - May update mutable state twice
  - Mutable state can be lost due to failure
- Storm Trident
  - Uses transactions to update state
  - Processes each record exactly once
  - Per state transaction updates slow

Spark Streaming
Spark streaming runs a streaming computation as a series of very small, deterministic batch jobs. It splits each input stream in “portions” and processes one portion at a time (in the incoming order). The same computation is applied on each portion of the stream. Each portion is called batch.

Spark streaming splits the live stream into batches of X seconds. It treats each batch of data as RDDs and processes them using RDD operations. Finally, the processed results of the RDD operations are returned in batches.
Problem specification

- Input: a stream of sentences
- Split the input stream in batches of 10 seconds each and print on the standard output, for each batch, the occurrences of each word appearing in the batch
  - i.e., execute the word count problem for each batch of 10 seconds
Word count – Spark Streaming version

Input stream

Test Spark streaming

Stdout

Time (s)

0

10

20

30

Time (s)

0

10

20

30

Word count – Spark Streaming version

Input stream

Test Spark streaming
Second sentence Spark streaming

Stdout

Time (s)

0

10

20

30

Time (s)
Word count – Spark Streaming version

Input stream

Test Spark streaming
Second sentence Spark streaming

Stdout

(test,1), (spark,2), (streaming,2),
(second,1), (sentence,1)

Time (s)

Word count – Spark Streaming version

Input stream

Test Spark streaming
Second sentence Spark streaming

Stdout

Second Spark batch of 10 seconds
Batch size 10 seconds

(test,1), (spark,2), (streaming,2),
(second,1), (sentence,1)

Time (s)
**Word count – Spark Streaming version**

<table>
<thead>
<tr>
<th>Time (s)</th>
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</tr>
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<tbody>
<tr>
<td>0</td>
<td>Test Spark streaming</td>
<td>(test, 1), (spark, 2), (streaming, 2), (second, 1), (sentence, 1)</td>
</tr>
<tr>
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### Word count – Spark Streaming version

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### Key concepts

- **DStream**
  - Sequence of RDDs representing a discretized version of the input stream of data
    - Twitter, HDFS, Kafka, Flume, ZeroMQ, Akka Actor, TCP sockets, ..
  - One RDD for each batch of the input stream
- **PairDStream**
  - Sequence of PairRDDs representing a stream of pairs
Key concepts

- **Transformations**
  - Modify data from one DStream to another
  - Standard RDD operations
    - map, countByValue, reduce, join, ...
  - Window and Stateful operations
    - window, countByValueAndWindow, ...

- **Output Operations (actions)**
  - Send data to external entity
    - saveAsHadoopFiles, saveAsTextFile, ...

Fault-tolerance

- DStreams remember the sequence of operations that created them from the original fault-tolerant input data
- Batches of input data are replicated in memory of multiple worker nodes, therefore fault-tolerant
- Data lost due to worker failure, can be recomputed from input data
**Basic Structure of a Spark Streaming Program (1)**

- Define a Spark Streaming Context object
  - Define the size of the batches (in seconds) associated with the Streaming context
- Specify the input stream and define a DStream based on it
- Specify the operations to execute for each batch of data
  - Use transformations and actions similar to the ones available for “standard” RDDs

**Basic Structure of a Spark Streaming Program (2)**

- Invoke the start method
  - To start processing the input stream
- Wait until the application is killed or the timeout specified in the application expires
  - If the timeout is not set and the application is not killed, the application will run forever
Spark Streaming Context

- The Spark Streaming Context is defined by using the `JavaStreamingContext(SparkConf sparkConf, Duration batchDuration)` constructor of `JavaStreamingContext`
- The `batchDuration` parameter specifies the “size” of the batches
- Example
  ```java
  JavaStreamingContext jssc = 
  new JavaStreamingContext(conf, Durations.seconds(10));
  ```
  - The input streams associated with this context will be split in batches of 10 seconds

Input Streams

- The input Streams can be generate from different sources
  - TCP socket, Kafka, Flume, Kinesis, Twitter
  - Also an HDFS folder can be used as “input stream”
    - This option is usually used during the application development to perform a set of initial tests
Input Streams: TPC socket

- A DStream can be associated with the content emitted by a TCP socket
- `socketTextStream(String hostname, int port_number)` is used to create a DStream based on the textual content emitted by a TPC socket
- Example
  ```java
  JavaReceiverInputDStream<String> lines = jssc.socketTextStream("localhost", 9999);
  ```
  “Store” the content emitted by localhost:9999 in the lines DStream

Input Streams: (HDFS) folder

- A DStream can be associated with the content of an input (HDFS) folder
- Every time a new file is inserted in the folder, the content of the file is “stored” in the associated DStream and processed
- Pay attention that updating the content of a file does not trigger/change the content of the DStream
- `textFileStream(String folder)` is used to create a DStream based on the content of the input folder
Input Streams: (HDFS) folder

- Example
  
  JavaDStream<String> lines = 
  jssc.textFileStream(inputFolder);
  
  - “Store” the content of the files inserted in the
    input folder in the lines Dstream
  
  - Every time new files are inserted in the folder their
    content is “stored” in the current “batch” of the
    stream

Input Streams: other sources

- Usually DStream objects are defined on top
  of streams emitted by specific applications
  that emit real-time streaming data
  
  - E.g., Apache Kafka, Apache Flume, Kinesis, Twitter

- You can also write your own applications for
  generating streams of data
  
  - However, Kafka, Flume and similar tools are
    usually a more reliable and effective solutions for
    generating streaming data
Transformations

- Analogously to standard RDDs, also DStream are characterized by a set of transformations
  - When applied to DStream objects, transformations return a new DStream Object
  - The transformation is applied on one batch (RDD) of the input DStream at a time and returns a batch (RDD) of the new DStream
    - i.e., each batch (RDD) of the input DStream is associated with exactly one batch (RDD) of the returned DStream
  - Many of the available transformations are the same transformations available for standard RDDs

Basic Transformations on DStreams

- **map(func)**
  - Returns a new DStream by passing each element of the source DStream through a function `func`
- **flatMap(func)**
  - Each input item can be mapped to 0 or more output items. Returns a new DStream
- **filter(func)**
  - Returns a new DStream by selecting only the records of the source DStream on which `func` returns true
Basic Transformations on DStreams

- **reduce(func)**
  - Returns a new DStream of single-element RDDs by aggregating the elements in each RDD of the source DStream using a function `func`. The function should be associative so that it can be computed in parallel.

- **reduceByKey(func)**
  - When called on a PairDStream of (K, V) pairs, returns a new PairDStream of (K, V) pairs where the values for each key are aggregated using the given reduce function.

- **countByValue()**
  - When called on a DStream of elements of type K, returns a new PairDStream of (K, Long) pairs where the value of each key is its frequency in each batch of the source DStream.

- **count()**
  - Returns a new DStream of single-element RDDs by counting the number of elements in each batch (RDD) of the source Dstream.
    - i.e., it counts the number of elements in each input batch (RDD)

- **union(otherStream)**
  - Returns a new DStream that contains the union of the elements in the source DStream and otherDStream.

- **join(otherStream)**
  - When called on two PairDStreams of (K, V) and (K, W) pairs, return a new PairDStream of (K, (V, W)) pairs with all pairs of elements for each key.
Basic Transformations on DStreams

- **cogroup(otherStream)**
  - When called on a PairDStream of (K, V) and (K, W) pairs, return a new DStream of (K, Seq[V], Seq[W]) tuples

Advanced transformation on DStreams

- **transform(func)**
  - It is a specific transformation of DStreams
  - It returns a new DStream by applying an RDD-to-RDD function to every RDD of the source Dstream
    - This can be used to do arbitrary RDD operations on the DStream
  - For example, the functionality of joining every batch in a data stream with another dataset (a standard RDD) is not directly exposed in the DStream API
    - However, you can use transform to do that
Advanced transformation on DStreams

- **transformToPair(func)**
  - It is a specific transformation of PairDStreams
  - It returns a new PairDStream by applying a PairRDD-to-PairDD function to every PairRDD of the source PairDStream
  - It must be used instead of transform when working with PairDStreams/PairRDDs

Basic Output Operations (actions) on DStreams

- **print()**
  - Prints the first 10 elements of every batch of data in a DStream on the driver node running the streaming application
    - Useful for development and debugging
Basic Output Operations (actions) on DStreams

- `saveAsTextFiles(prefix, [suffix])`
  - Saves the content of the DStream on which it is invoked as text files
    - One folder for each batch
    - The folder name at each batch interval is generated based on prefix, time of the batch (and suffix): "prefix-TIME_IN_MS[.suffix]"
  - It is not directly available for JavaDStream objects
    - A Scala DStream object must be created from a JavaDStream by invoking the dstream() method.
    - `saveAsTextFiles` can be invoked on the returned Scala Dstream
  - Example
    - `Counts.dstream().saveAsTextFiles(outputPathPrefix, "")`;

Start and run the computation

- The `start()` method of the JavaSparkStreamingContext class is used to start the application on the input stream(s)
- The `awaitTerminationOrTimeout(long milliseconds)` method is used to specify how long the application will run
- The `awaitTerminationOrTimeout()` method is used to run the application forever
  - Until the application is explicitly killed
Example: Word count – Spark Streaming version

- Problem specification
  - Input: a stream of sentences retrieved from localhost:9999
  - Split the input stream in batches of 10 seconds each and print on the standard output, for each batch, the occurrences of each word appearing in the batch
    - i.e., execute the word count problem for each batch of 10 seconds
  - Store the results also in an HDFS folder

```java
package it.polito.bigdata.spark.StreamingWordCount;
import .....;

public class SparkDriver {

    public static void main(String[] args) {

        String outputPrefix = args[0];

        // Create a configuration object and set the name of the application
        SparkConf conf = new SparkConf()
            .setAppName("Spark Streaming word count");

        // Create a Spark Streaming Context object
        JavaStreamingContext jssc =
            new JavaStreamingContext(conf, Durations.seconds(10));

    }

```
Example: Word count – Spark Streaming version

// Create a (Receiver) DStream that will connect to localhost:9999
JavaReceiverInputDStream<String> lines =
    jssc.socketTextStream("localhost", 9999);

// Apply the "standard" transformations to perform the word count task
// However, the "returned" RDDs are DStream/PairDStream RDDs
JavaDStream<String> words = lines
    .flatMap(line -> Arrays.asList(line.split("\s+"))
        .iterator());

JavaPairDStream<String, Integer> wordsOnes = words
    .mapToPair(word ->
        new Tuple2<String, Integer>(word.toLowerCase(), 1));

JavaPairDStream<String, Integer> wordsCounts =
    wordsOnes.reduceByKey((i1, i2) -> i1 + i2);

wordsCounts.print();

wordsCounts.dstream().saveAsTextFiles(outputPathPrefix, "");

// Start the computation
jssc.start();

jssc.awaitTerminationOrTimeout(120000);

jssc.close();

Example: Word count – Spark Streaming version

wordsCounts.print();

wordsCounts.dstream().saveAsTextFiles(outputPathPrefix, "");

// Start the computation
jssc.start();

jssc.awaitTerminationOrTimeout(120000);

jssc.close();
Spark Streaming also provides windowed computations

- It allows you to apply transformations over a sliding window of data
  - Each window contains a set of batches of the input stream
  - Windows can be overlapped
    - i.e., the same batch can be included in many consecutive windows

Graphical example

- Every time the window slides over a source DStream, the source RDDs that fall within the window are combined and operated upon to produce the RDDs of the windowed DStream
In the graphical example, the operation
  - is applied over the last 3 time units of data (i.e., the last 3 batches of the input DStream)
    - Each window contains the data of 3 batches
    - slides by 2 time units

Any window operation needs to specify two parameters:
  - Window length
    - The duration of the window (3 in the example)
  - Sliding interval
    - The interval at which the window operation is performed (2 in the example)
  - These two parameters must be multiples of the batch interval of the source DStream
Word count and Window

- Problem specification
  - Input: a stream of sentences
  - Split the input stream in batches of 10 seconds
  - Define widows with the following characteristics
    ▪ Window length: 20 seconds (i.e., 2 batches)
    ▪ Sliding interval: 10 seconds (i.e., 1 batch)
  - Print on the standard output, for each window, the occurrences of each word appearing in the window
    ▪ i.e., execute the word count problem for each window

Word count and Window

<table>
<thead>
<tr>
<th>Input stream</th>
<th>Stdout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Spark streaming</td>
<td></td>
</tr>
<tr>
<td>Second sentence Spark streaming</td>
<td></td>
</tr>
</tbody>
</table>

Time (s) 0 10 20 30 40

Time (s) 0 10 20 30 40
Word count and Window

Input stream

0
Test Spark streaming
Second sentence Spark streaming
10
Second Spark batch of 10 seconds
Batch size 10 seconds
20
30
Time (s)

Stdout

0
10
20
30
Time (s)

(test, 1), (spark, 3), (streaming, 2),
(second, 2), (sentence, 1),
(batch, 2), (of, 1), (size, 1), (10, 2),
(seconds, 2)
Word count and Window

Basic Window Transformations

- `window(windowLength, slideInterval)`
  - Returns a new DStream which is computed based on windowed batches of the source DStream.
- `countByWindow(windowLength, slideInterval)`
  - Returns a new single-element stream containing the number of elements of each window
    - The returned object is a JavaDStream<Long>. However, it contains only one value for each window (the number of elements of the last analyzed window)
Basic Window Transformations

- **reduceByWindow(func, windowLength, slideInterval)**
  - Returns a new single-element stream, created by aggregating elements in the stream over a sliding interval using `func`. The function should be associative so that it can be computed correctly in parallel

- **countByValueAndWindow(windowLength, slideInterval)**
  - When it is called on a PairDStream of (K, V) pairs, returns a new PairDStream of (K, Long) pairs where the value of each key is its frequency within a sliding window

- **reduceByKeyAndWindow(func, windowLength, slideInterval)**
  - When called on a PairDStream of (K, V) pairs, returns a new PairDStream of (K, V) pairs where the values for each key are aggregated using the given reduce function over batches in a sliding window
    - The window length and the sliding window step are specified as parameters of this invocation
Checkpoints

- A streaming application must operate 24/7 and hence must be resilient to failures unrelated to the application logic (e.g., system failures, JVM crashes, etc.)
- For this to be possible, Spark Streaming needs to checkpoint enough information to a fault-tolerant storage system such that it can recover from failures
- This result is achieved by means of checkpoints
  - Operations that store the data and metadata needed to restart the computation if failures happen
  - Checkpointing is necessary even for some window transformations and stateful transformations

Checkpoints

- Checkpointing is enabled by using the `checkpoint(String folder)` method of JavaSparkStreamingContext
  - The parameter is the folder that is used to store temporary data
Example: Word count and Windows

- Problem specification
  - Input: a stream of sentences retrieved from localhost:9999
  - Split the input stream in batches of 10 seconds
  - Define widows with the following characteristics
    - Window length: 30 seconds (i.e., 3 batches)
    - Sliding interval: 10 seconds (i.e., 1 batch)
  - Print on the standard output, for each window, the occurrences of each word appearing in the window
    - i.e., execute the word count problem for each window
  - Store the results also in an HDFS folder

```
package it.polito.bigdata.spark.StreamingWordCount;
import ....

public class SparkDriver {
    public static void main(String[] args) {
        String outputPathPrefix=args[0];

        // Create a configuration object and set the name of the application
        SparkConf conf = new SparkConf()
            .setAppName("Spark Streaming word count");

        // Create a Spark Streaming Context object
        JavaStreamingContext jssc =
            new JavaStreamingContext(conf, Durations.seconds(10));

        // Set the checkpoint folder (it is needed by some window transformations)
        jssc.checkpoint("checkpointfolder");
    }
}
```
Example: Word count and Windows

// Create a (Receiver) DStream that will connect to localhost:9999
JavaReceiverInputDStream<String> lines =
    jssc.socketTextStream("localhost", 9999);

// Apply the "standard" transformations to perform the word count task
// However, the "returned" RDDs are DStream/PairDStream RDDs
JavaDStream<String> words =
    lines.flatMap(line -> Arrays.asList(line.split("\s+"))).iterator();

// Count the occurrence of each word in the current window
JavaPairDStream<String, Integer> wordsOnes =
    words.mapToPair(word -> new Tuple2<String, Integer>(
        word.toLowerCase(), 1));

// reduceByKeyAndWindow is used instead of reduceByKey
// The characteristics of the window is also specified
JavaPairDStream<String, Integer> wordsCounts = wordsOnes
    .reduceByKeyAndWindow((i1, i2) -> i1 + i2,
        Durations.seconds(30),
        Durations.seconds(10));

// Print the num. of occurrences of each word of the current window
// (only 10 of them)
wordsCounts.print();

// Store the output of the computation in the folders with prefix
// outputPathPrefix
wordsCounts.dstream().saveAsTextFiles(outputPathPrefix, "");
// Start the computation
jssc.start();

jssc.awaitTerminationOrTimeout(120000);

jssc.close();
}
}

---

**Example: Word count and Windows**

**UpdateStateByKey Transformation**

- The updateStateByKey transformation allows maintaining a state
  - The value of the state is continuously updated every time a new batch is analyzed
UpdateStateByKey Transformation

- The use of updateStateByKey is based on two steps
  - Define the state
    - The data type of the state can be an arbitrary data type
  - Define the state update function
    - Specify with a function how to update the state using the previous state and the new values from an input stream

- In every batch, Spark will apply the state update function for all existing keys
- For each key, the update function is used to update the value associated with a key by combining the former value and the new values associated with that key
  - For each key, the call method of the “function” is invoked on the list of new values and the former state value and returns the new aggregated value for the considered key
Word count example (Stateful version)

- By using the UpdateStateByKey, the application can continuously update the number of occurrences of each word
  - The number of occurrences stored in the PairDStream returned by this transformation is computed over the union of all the batches (for the first one to current one)
    - For efficiency reasons, the new value is computed by combining the last value with the values of the current batch

Example: Word count (stateful version)

- Problem specification
  - Input: a stream of sentences retrieved from localhost:9999
  - Split the input stream in batches of 10 seconds
  - Print on the standard output, every 10 seconds, the occurrences of each word appearing in the stream (from time 0 to the current time)
    - i.e., execute the word count problem from the beginning of the stream to current time
  - Store the results also in an HDFS folder
package it.polito.bigdata.spark.StreamingWordCount;
import .....;

public class SparkDriver {
    public static void main(String[] args) {
        String outputPathPrefix=args[0];

        // Create a configuration object and set the name of the application
        SparkConf conf = new SparkConf()
            .setAppName("Spark Streaming word count");

        //Create a Spark Streaming Context object
        JavaStreamingContext jssc =
            new JavaStreamingContext(conf, Durations.seconds(10));

        // Set the checkpoint folder (it is needed by some window transformations)
        jssc.checkpoint("checkpointfolder");

        // Create a (Receiver) DStream that will connect to localhost:9999
        JavaReceiverInputDStream<String> lines =
            jssc.socketTextStream("localhost", 9999);

        // Apply the "standard" transformations to perform the word count task
        // However, the "returned" RDDs are DStream/PairDstream RDDs
        JavaDStream<String> words =
            lines.flatMap(line -> Arrays.asList(line.split("\s+"))).iterator();

        JavaPairDStream<String, Integer> wordsOnes = words
            .mapToPair(word -> new Tuple2<String, Integer>(word.toLowerCase(), 1));
Example: Word count (stateful version)

// DStream made of get cumulative counts that get updated in every batch
JavaPairDStream<String, Integer> totalWordsCounts =
wordsCounts.updateStateByKey((newValues, state) -> {
    // state.or(o) returns the value of State
    // or the default value o if state is not defined
    Integer newSum = state.or(0);

    // Iterates over the new values and sum them to the previous state
    for (Integer value : newValues) {
        newSum += value;
    }
    return Optional.of(newSum);
});

It is invoked one time for each key

// DStream made of get cumulative counts that get updated in every batch
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    // Iterates over the new values and sum them to the previous state
    for (Integer value : newValues) {
      newSum += value;
    }

    return Optional.of(newSum);
  });

Example: Word count (stateful version)

Current “state” of the current key,
  i.e., number of occurrences in the previous part of the stream

JavaPairDStream<String, Integer> totalWordsCounts =
  wordsCounts.updateStateByKey((newValues, state) -> {
    // state.or(o) returns the value of State
    // or the default value o if state is not defined
    Integer newSum = state.or(0);

    // Iterates over the new values and sum them to the previous state
    for (Integer value : newValues) {
      newSum += value;
    }

    return Optional.of(newSum);
  });
Example: Word count (stateful version)

totalWordsCounts.print();
totalWordsCounts.dstream().saveAsTextFiles(outputPathPrefix, "");

// Start the computation
jssc.start();
jssc.awaitTerminationOrTimeout(120000);
jssc.close();

Example: Word count – use of transformPair

- Problem specification
  - Input: a stream of sentences retrieved from localhost:9999
  - Split the input stream in batches of 10 seconds each and print on the standard output, for each batch, the occurrences of each word appearing in the batch
    - The pairs must be returned/displayed sorted by key
  - Store the results also in an HDFS folder
Example: Word count – use of `transformPair`

```java
package it.polito.bigdata.spark.StreamingWordCount;
import ....

public class SparkDriver {

    public static void main(String[] args) {
        String outputPathPrefix=args[0];

        // Create a configuration object and set the name of the application
        SparkConf conf = new SparkConf()
            .setAppName("Spark Streaming word count");

        // Create a Spark Streaming Context object
        JavaStreamingContext jssc =
            new JavaStreamingContext(conf, Durations.seconds(10));

        // Create a (Receiver) DStream that will connect to localhost:9999
        JavaReceiverInputDStream<String> lines =
            jssc.socketTextStream("localhost", 9999);

        // Apply the "standard" transformations to perform the word count task
        // However, the "returned" RDDs are DStream/PairDStream RDDs
        JavaDStream<String> words = lines
            .flatMap(line -> Arrays.asList(line.split("\s+"))).iterator();

        JavaPairDStream<String, Integer> wordsOnes = words
            .mapToPair(word -> new Tuple2<String, Integer>(word.toLowerCase(), 1));

        JavaPairDStream<String, Integer> wordsCounts =
            wordsOnes.reduceByKey((i1, i2) -> i1 + i2);
    }
}
```
Example: Word count – use of transformPair

```java
// Sort the content/the pairs by key
JavaPairDStream<String, Integer> wordsCountsSortByKey = wordsCounts
    .transformToPair((JavaPairRDD<String, Integer> rdd) -> rdd.sortByKey());

wordsCountsSortByKey.print();

wordsCountsSortByKey.dstream().saveAsTextFiles(outputPathPrefix, "");

// Start the computation
jssc.start();

jssc.awaitTerminationOrTimeout(120000);

jssc.close();
```