CS 455: Introduction to Distributed Systems [Spark Streaming]

Drinking from a fire hose

A packet in isolation seems fine
Why then, do streams, strain systems design?

If processing lags the rate of arrival?
Imperil, you will, your process' survival

Shrideep Pallickara
Computer Science
Colorado State University

1

Related Work

Thilina Buddhika*, Sangmi Lee Pallickara, and Shrideep Pallickara. Pebbles: Leveraging Sketches for Processing Voluminous, High Velocity Data Streams. IEEE Transactions on Parallel and Distributed Systems. Vol 32 (8) pp 2005 - 2020. 2021.

Thilina Buddhika*, Ryan Stern*, Kira Lindburg*, Kathleen Ericson*, and Shrideep Pallickara. Online Scheduling and Interference Alleviation for Low-latency, High-throughput Processing of Data Streams. IEEE Transactions on Parallel and Distributed Systems. Vol. 28(12) pp 3553-3569. 2017.

Thilina Buddhika* and Shrideep Pallickara. Neptune: Real Time Stream Processing for Internet of Things and Sensing Environments. Proceedings of the 30th IEEE International Parallel & Distributed Processing Symposium. pp 1143-1152. Chicago, USA. 2016.

2

Topics covered in this lecture

- Spark Streaming
  - Architecture and Abstractions
  - Execution
  - Stateful and stateless transformations
  - Windowed operations
  - Performance considerations
  - Example

SPARK STREAMING

Spark Streaming

- Act on data **as soon as it arrives**
  - Track statistics of page views in real time, detect anomalies, etc.
- Spark streaming
  - Spark's module for dealing with streaming data
  - Uses an API very similar to what we have seen with batch jobs (centered around RDDs)
- Available in Java, Scala, and Python

Spark Streaming: Core concepts

- Provides an abstraction called **DStreams** (discretized streams)
- A DStream is a **sequence of data** arriving over time
- Internally, a DStream is represented as a **sequence of RDDs** arriving at each time step

DStreams

- DStreams can be created from various input sources
  - Flume, Kafka, or HDFS
- Once built, DStreams offer two types of operations:
  - **Transformations**: Yields a new DStream
  - **Output operations**: Writes data to an external system
- Provides many of the same operations available on RDDs
  - PLUS new operations related to time (e.g. sliding windows)

Simple Streaming Example [1/2]

- Start by creating a `StreamingContext`
  - Main entry point for streaming functionality
  - Specify batch interval, specifying **how often** to process new data
- We will use `socketTextStream()` to create a DStream based on text data received over a port
- Transform DStream with filter to get lines that contain "error"

Simple Streaming Example [1/2]

```
JavaStreamingContext jssc =
      new JavaStreamingContext(conf, Durations.seconds(1));

JavaDStream<String> lines =
      jssc.socketTextStream("localhost", 7777);

JavaDStream<String> errorLines =
      lines.filter(new Function<String, Boolean> () {
          public Boolean call(String line) {
             return line.contains("error");
          }
      };
```


Previous snippet only sets up the computation

- To start receiving the data?
  - Explicitly call `start()` on `StreamContext`
- SparkStreaming will start to schedule Spark jobs on the underlying SparkContext
  - Occurs in a **separate thread**
  - To keep application from terminating?
    - Also call `awaitTermination()`

```
jssc.start();
jssc.awaitTermination()
```

ARCHITECTURE & ABSTRACTION

COMPUTER SCIENCE DEPARTMENT

COLORADO STATE UNIVERSITY

11

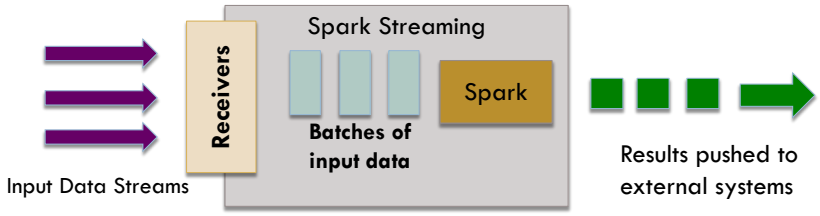
Spark Streaming Architecture

- Spark Streaming uses a **micro-batch** architecture
  - Streaming computation is treated as continuous series of batch computations on small **batches** of data
- Receives data from various input sources and groups into small batches
- New batches are **created at regular intervals**
  - At the start of each time interval, a new **batch** is created
    - Any data arriving in that interval is added to the batch
    - Size of batch is controlled by the *batch interval*

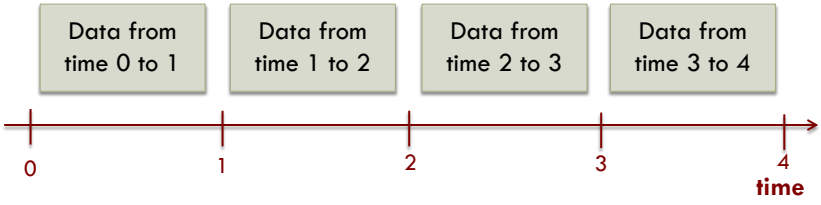
COLORADO STATE UNIVERSITY Professor: SHRIDEEP PALLICKARA COMPUTER SCIENCE DEPARTMENT SPARK L21.12

12

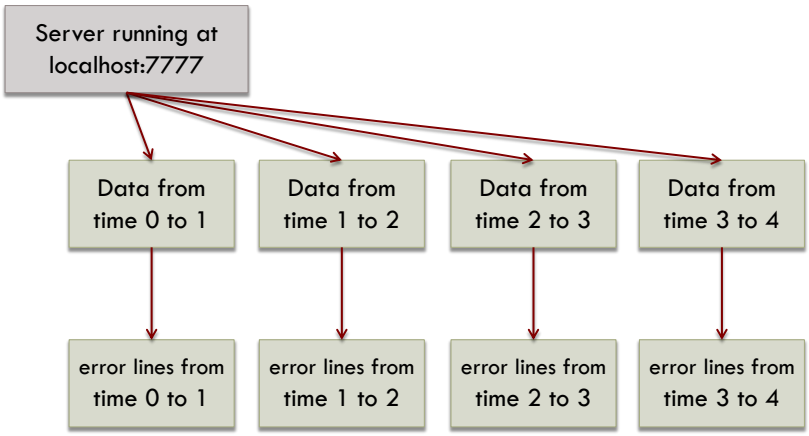
High-level architecture of Spark Streaming



DStream is a sequence of RDDs, where each RDD has one slice of data in stream



DStreams and the transformations in our example



DStreams support output operations, such as the `print()` used in our example.

- Output operations are similar to RDD actions in that they write data to an external system
- But in Spark Streaming they *run periodically* on each time step, producing **output in batches**

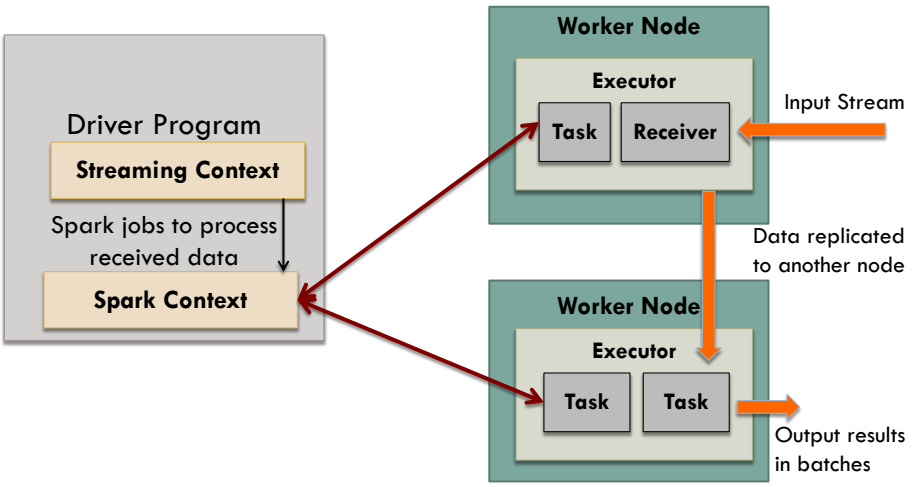
Spark Streaming: Execution

- For each input source, Spark Streaming launches receivers
  - Tasks running within the application's executors that collect data from source and save as RDDs
  - Receives input data and replicates it (by default) to another executor for fault tolerance
  - Data is **stored in memory of the executors** in the same way that RDDs are cached

Spark Streaming: Execution

- StreamingContext in the driver program then periodically runs Spark jobs to:
  - Process this data and …
  - Combine it with RDDs from previous time steps

Spark Streaming: Execution



Spark Streaming: Fault Tolerance [1/2]

- Spark Streaming offers the **same fault-tolerance** properties for DStreams as Spark has for RDDs
  - As long as a copy of the input data is still available, it can recompute any state derived from it using the lineage of the RDDs
    - By rerunning the operations used to process it

Spark Streaming: Fault Tolerance [2/2]

- By default, data is replicated across two nodes
  - Can tolerate single worker failures
- Using lineage graphs to recompute any derived state? Impractical
- Spark Streaming relies on **checkpointing**
  - Saves state *periodically*
  - Checkpoint every 5-10 batches of data
  - When recovering, only go back to the last checkpoint

Spark Streaming: Transformations

- **Stateless** transformations
  - Each batch does not depend on data of its previous batches
- **Stateful** transformations
  - Use data or intermediate results from *previous batches* to compute results of the current batch

STATELESS TRANSFORMATIONS

Stateless transformations

- Stateless transformations are simple RDD transformations being applied on every batch — that is, every RDD in a DStream
- Many of the RDD transformations that we have looked at are also available on DStreams

Examples of stateless transformations [1/6]

- `map()`
- Apply a function to each element in the DStream and return a DStream of the result
- `ds.map (x => x + 1)`

Examples of stateless transformations [2/6]

- `flatMap()`
- Apply a function to each element in the DStream and return a DStream of the contents of the iterators returned
- `ds.flatMap (x => x.split(" ") )`

Examples of stateless transformations [3/6]

- `filter()`
- Return a DStream consisting of only elements that pass the condition passed to filter
- `ds.filter (x => x != 1 )`

Examples of stateless transformations [4/6]

- `repartition()`
- Change the number of partitions of the DStream
  - Distributes the received batches across the specified number of machines in the cluster before processing
    - The physical manifestation of the DStream is different in this case
- `ds.repartition(10)`

Examples of stateless transformations [5/6]

- `reduceByKey()`
- Combine values with the same key in each batch
- `ds.reduceByKey( (x, y) = > x + y) )`

Examples of stateless transformations [6/6]

- `groupByKey()`
- Group values with the same key in each batch
- `ds.groupByKey( )`

A note about stateless operations

- Although it may seem that they are being applied over the whole stream …
  - Each DStream has multiple RDDs (batches)
  - Stateless transformation applies ***separately*** to each RDD
  - E.g. `reduceByKey()` will reduce data for each timestep, but not across timesteps

STATEFUL TRANSFORMATIONS

Stateful transformations

- Operations on DStreams that track data across time
  - Data from previous batches used to generate results for a new batch
- Two types of windowed operations
  - Act over sliding window of time periods
  - `updateStateBykey()` track state across events for each key

Stateful transformations and fault tolerance

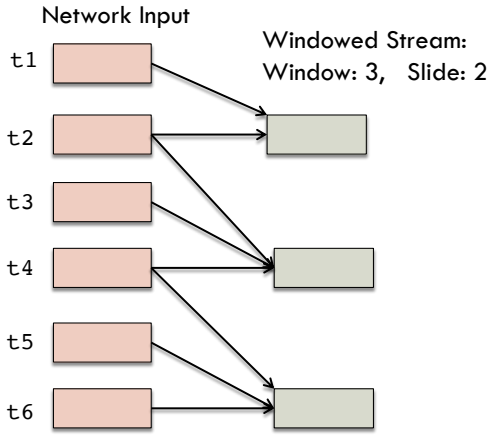
- Requires checkpointing to be enabled in `StreamingContext` for fault tolerance

```
ssc.checkpoint("hdfs:// …");
```

Windowed Transformations

- Compute results across a longer time period than the batch interval
- Two parameters: window and sliding durations
  - Both must be a *multiple* of the batch interval
- Window duration controls **how many** previous batches of data are considered
  - `window Duration/batchInterval`
  - If the batch interval is 10 seconds and the sliding window is 30 seconds … last 3 batches

A windowed stream: Window duration (3) & slide duration (2)



Every 2 time steps, we compute a result over the previous 3 time steps

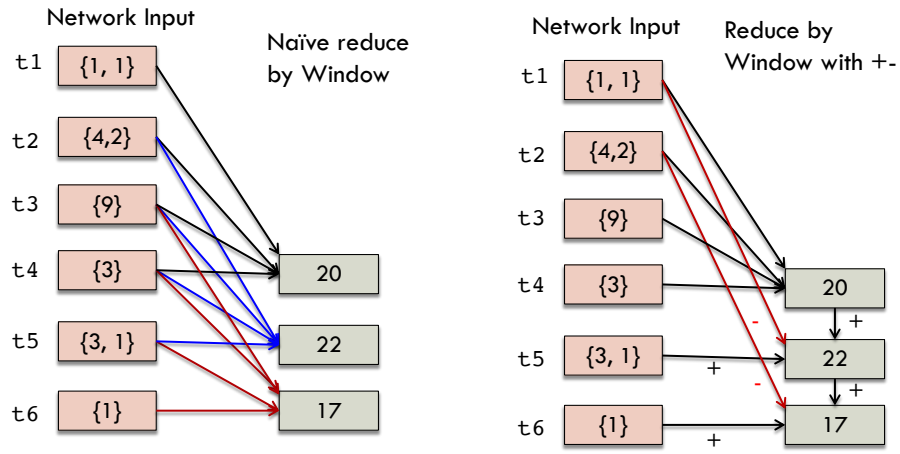
Simplest window operation on a DStream

- `window()`
- Returns new DStream with data from the requested window
- Each RDD in the DStream resulting from `window()`, will contain data from multiple batches

Other operations on top of `window()`

- `reduceByWindow` and `reduceByKeyAndWindow`
- Includes a special form that allows reduction to be performed **incrementally**
  - Considering only the data coming into the window and the data that is going out
  - Special form requires an **inverse** of the reduce function
    - Such as – for +
  - More efficient for large windows if your function has an inverse

Difference between naïve and incremental `reduceByWindow()`



Maintaining state across batches

- `updateStateByKey()`
  - Provides access to a state variable for DStreams of key/value pairs
  - Given a DStream of (key, value) pairs
    - Construct a new DStream of (key, state) pairs by taking a function that specifies how to update the state for each key, given new events

PERFORMANCE CONSIDERATIONS IN SPARK STREAMING

COMPUTER SCIENCE DEPARTMENT

COLORADO STATE UNIVERSITY

41

Performance considerations

- Batch size
  - **500 milliseconds** is considered a good minimum size
  - Start with a large batch size (~10 seconds) and work down to a smaller batch size
    - If processing times remain consistent, explore decreasing the batch size
    - If the processing times increase? You have reached the limit
- Window size
  - Has a great impact on performance
  - Consider increasing this for expensive operations

COLORADO STATE UNIVERSITY Professor: SHRIDEEP PALLICKARA COMPUTER SCIENCE DEPARTMENT SPARK L21.42

42

Garbage collections and memory usage

- Cache RDDs in serialized form
  - Using Kryo for serialization reduces this even more
    - Reduces space for in-memory representations
- By default, Spark uses an in-memory cache
  - Can also evict RDDs older than a certain time-period
    - spark.cleaner.ttl
    - This preemptive eviction of RDDs also reduces the garbage collection pressure

Levels of parallelism in data receiving [1/4]

- Each input DStream creates a single receiver that receives a single stream of data
  - Receiving multiple data streams possible by creating multiple input DStreams
    - Each Dstream must be configured to receive different partitions of the data stream from the source(s)
- For a Kafka DStream receiving data on two topics?
  - Split into two DStreams each receiving one topic
    - Two receivers would run and receive data in parallel

Levels of parallelism in data receiving [2/4]

- Another approach is to tune the receiver's **block interval**
  - Determined by `spark.streaming.blockInterval`
- For most receivers, received data is **coalesced** into blocks of data before storing in memory
- The number of blocks in each batch determines the number of tasks used to process the received data in a map-like transformation
- Number of tasks per batch?
  - Batch interval/block interval

Levels of parallelism in data receiving [3/4]

- Number of tasks per batch?
  - Batch interval/block interval
- Block interval of 200 ms will create 10 tasks per 2 second batches
- If the number of tasks is too low?
  - All available cores might not be available to use all the data
- To increase number of tasks for a given batch interval?
  - Reduce the block interval

Levels of parallelism in data receiving [4/4]

- What if you did not want to receive data with multiple input streams?
  - Explicitly **repartition** the input data stream
- Repartitioning is done using the `inputStream.repartition(<number of partitions>))`
  - Distributes the received batches of data across the specified number of machines in the cluster *before* further processing

Data serialization [1/2]

- Data received through receivers is stored with StorageLevel.MEMORY_AND_DISK_SER_2
  - Data that does not fit in memory spills over to disk
- Input data and persisted RDDs generated by DStream transformations are automatically cleared
  - If you are using a window operation of 10 minutes, then Spark Streaming will keep the last 10 minutes of data, and actively throw away older data
  - Data can be retained for a longer duration by setting `streamingContext.remember`

Data serialization [2/2]

- RDDs generated by streaming computations may be persisted in memory
  - Persisted RDDs generated by streaming computations are persisted with StorageLevel.MEMORY_ONLY_SER
- If you are using batch intervals of a few seconds and no window operations?
  - You can try disabling serialization in persisted data
    - Reduce CPU overheads due to serialization, without excessive GC overheads.

PROCESSING TWITTER STREAMS USING SPARK

Spark-streaming example [1/5]

- Step-by-step approach to finding the top 10 hashtags from a stream of tweets using counts [Every second there is an output over data from the last 300 seconds]
- Step-1: Create a SparkStream context and Twitter credential setup

```
SparkConf sparkConf = new SparkConf().setAppName("Spark-
streaming-twitter-trends");

/*
Twitter authentication details … [Not included here]
*/
//JavaStreamigContext
JavaStreamingContext jssc =
      new JavaStreamingContext(sparkConf, new Duration(1000));

//Discretized stream of tweets
JavaDStream<Status> twitterStream = (JavaDStream<Status>)
TwitterUtils.createStream(jssc);
```


Spark-streaming example [2/5]

- Step-2: Map Input DStream of `Status` to `String`

```
//Discretized stream of Strings
JavaDStream<String> statuses = twitterStream.map(
    new Function<Status, String>() {
    public String call(Status status) {
        return status.getText();
    }
  }
);

statuses.print();

//trigger the execution of code
jssc.start();
jssc.awaitTermination();
```

Spark-streaming example [3/5]

- Step-3: Stream of hashtags from stream of tweets

```
//Tokenize words from status
JavaDStream<String> wordsFromStatuses = statuses.flatMap(
    new FlatMapFunction<String, String>() {
       public Iterable<String> call(String input) {
          return Arrays.asList(input.split(" "));
       }
    }
);

//Extract hashtags
JavaDStream<String> hashTags = wordsFromStatuses.filter(
    new Function<String, Boolean>() {
       public Boolean call(String word) {
          return word.startsWith("#");
       }
    }
);
```


Spark-streaming example [4/5]

- Step-4: Count the hashtag over 5 min window

```
//Mapping to tuple of (hashtag,1) in order to count
JavaPairDStream<String, Integer> hashtagtuples = hashTags.mapToPair(
new PairFunction<String, String, Integer>() {
   public Tuple2<String, Integer> call(String input) {
      return new Tuple2<String, Integer>(input, 1);
   }
});
//Aggregating over window of 5 min and silde of 1s
JavaPairDStream<String, Integer> counts =
hashtagtuples.reduceByKeyAndWindow(
   new Function2<Integer, Integer, Integer>() {
      public Integer call(Integer int1, Integer int2) {
         return int1 + int2;
      }
   },  new Function2<Integer, Integer, Integer>() {
         public Integer call(Integer int1, Integer int2) {
            return int1 - int2;
         }
   },  new Duration(60 * 5 * 1000), new Duration(1 * 1000));
```

Spark-streaming example [5/5]

- Step-5: Find top 10 hashtags according to counts

```
JavaPairDStream<Integer, String> swapCounts = counts.mapToPair(
new PairFunction<Tuple2<String, Integer>, Integer, String>() {
  public Tuple2<Integer, String> call(Tuple2<String, Integer> input)
    return input.swap();
  }});
JavaPairDStream<Integer, String> sortedCount = swapCounts.transformToPair(
new Function<JavaPairRDD<Integer, String>,JavaPairRDD<Integer, String>>(){
public JavaPairRDD<Integer, String> call(JavaPairRDD<Integer, String> input)
throws Exception {
  return input.sortByKey(false);
}});
sortedCount.foreach(new Function<JavaPairRDD<Integer, String>, Void> () {
  public Void call(JavaPairRDD<Integer, String> rdd) {
    String out = "\nTrending hashtags:\n";
    for (Tuple2<Integer, String> t: rdd.take(10)) {
      out = out + t.toString() + "\n";
}
System.out.println(out);
return null;}});
```


The contents of this slide-set are based on the following references

- *Learning Spark: Lightning-Fast Big Data Analysis. 1st Edition. Holden Karau, Andy Konwinski, Patrick Wendell, and Matei Zaharia. O'Reilly. 2015. ISBN-13: 978-1449358624.*
  [Chapter 10]
- Spark Streaming Programming Guide:
  http://spark.apache.org/docs/latest/streaming-programming-guide.html#memory-tuning
- Processing Twitter Streams using Spark:
  https://databricks-training.s3.amazonaws.com/realtime-processing-with-spark-streaming.html