CS 455: INTRODUCTION TO DISTRIBUTED SYSTEMS

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

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Related Work


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

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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

- 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()
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**
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

Server running at localhost:7777

- Data from time 0 to 1
- Data from time 1 to 2
- Data from time 2 to 3
- Data from time 3 to 4

- error lines from time 0 to 1
- error lines from time 1 to 2
- error lines from time 2 to 3
- error lines from time 3 to 4

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

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

- 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 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

  ```scala
  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)

Network Input

| t1 | Windowed Stream: Window: 3, Slide: 2 |
| t2 |
| t3 |
| t4 |
| t5 |
| t6 |

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()`

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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

- **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
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

- 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

1. What if you did not want to receive data with multiple input streams?
   - Explicitly **repartition** the input data stream

2. 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. Data received through receivers is stored with `StorageLevel.MEMORY_AND_DISK_SER_2`
   - Data that does not fit in memory spills over to disk

2. 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

- 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.

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**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

```java
SparkConf sparkConf = new SparkConf().setAppName("Spark-streaming-twitter-trends");
/*
Twitter authentication details ... [Not included here]
*/
//JavaStreamingContext
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

```java
//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**

```java
//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**

```java
//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 slide 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

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

```java
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 = "Trending hashtags:
        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

  [Chapter 10]

- Spark Streaming Programming Guide:

- Processing Twitter Streams using Spark: