Frequently asked questions from the previous class survey

- Do datanodes know about each other?
  - When you form a topology, how do they know about each other?
- If you do not receive an acknowledgement from one of the nodes, is it resent to the entire topology?
- Should you check to see if the compressed file is bigger than the original?
- Is it ever more efficient to send to multiple nodes (e.g. 2 or 4) than to only one node?
- HDFS aims for availability and partition-tolerance at the expense of consistency?
Topics covered in this lecture

- Spark
  - Software stack
  - Interactive shells in Spark
  - Core Spark concepts
  - Resilient Distributed Datasets
As distributed data analytics have grown common …

- Practitioners have sought easier tools for the task
- Apache Spark has emerged as one of the most popular
  - Extending and generalizing MapReduce

Spark: What is it?

- **Cluster computing platform**
  - Designed to be fast and general purpose
- **Speed**
  - Extends MapReduce to support more types of computations
    - Interactive queries, iterative tasks, and stream processing
- **Why is speed important?**
  - Difference between waiting for hours versus exploring data interactively
Spark: Influences and Innovations

- Spark has inherited parts of its API, design, and supported formats from other existing computational frameworks
  - Particularly DryadLINQ
- Spark’s internals, especially how it handles failures, differ from many traditional systems
- Spark’s ability to leverage lazy evaluation within memory computations makes it particularly unique

Where does Spark fit in the Analytics Ecosystem?

- Spark provides methods to process data in parallel that are generalizable
- On its own, Spark is not a data storage solution
  - Performs computations on Spark JVMs that last only for the duration of a Spark application
- Spark is used in tandem with:
  - A distributed storage system (e.g., HDFS, Cassandra, or S3)
    - To house the data processed with Spark
  - A cluster manager — to orchestrate the distribution of Spark applications across the cluster
Key enabling idea in Spark

- **Memory resident data**
- Spark loads data into the memory of worker nodes
  - Processing is performed on memory-resident data

A look at the memory hierarchy

<table>
<thead>
<tr>
<th>Item</th>
<th>time</th>
<th>Scaled time in human terms (2 billion times slower)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor cycle</td>
<td>0.5 ns (2 GHz)</td>
<td>1 second</td>
</tr>
<tr>
<td>Cache access</td>
<td>1 ns (1 GHz)</td>
<td>2 seconds</td>
</tr>
<tr>
<td>Memory access</td>
<td>70 ns</td>
<td>140 seconds</td>
</tr>
<tr>
<td>Context switch</td>
<td>5,000 ns (5 μs)</td>
<td>167 minutes</td>
</tr>
<tr>
<td>Disk access</td>
<td>7,000,000 ns (7 ms)</td>
<td>162 days</td>
</tr>
<tr>
<td>Quantum</td>
<td>100,000,000 ns (100 ms)</td>
<td>6.3 years</td>
</tr>
</tbody>
</table>

Spark covers a wide range of workloads

- Batch applications
- Iterative algorithms
- Queries
- Stream processing

This has previously required multiple, independent tools

APIs

- Java, Python, Scala, and SQL
- Integrates well with other tools
  - Can run in Hadoop clusters
  - Access Hadoop data sources, including Cassandra
At its core, Spark is a computational engine

- Spark is responsible for several aspects of applications that comprise
  - Many tasks across many machines (compute clusters)

- Responsibilities include:
  1. Scheduling
  2. Distributions
  3. Monitoring

THE SPARK SOFTWARE STACK
The Spark stack

- Spark SQL: structured data
- Spark Streaming: real-time
- Mlib & ML: machine learning
- GraphX: Graph processing

Spark Core

- Standalone Scheduler
- YARN
- Mesos

Benefits of tight integration [1/2]

- All libraries and higher-level components benefit from improvements at the lower layers
- E.g.: Spark’s core engine adds optimization? SQL and ML libraries automatically speed-up as well
Benefits of tight integration

- Biggest advantage is ability to build applications that **seamlessly combine different processing models**
- An application may use ML to classify data in real time as it is being ingested
  - Analysts can query this resulting data, also in real time, via SQL (e.g.: join data with unstructured log-files)

Spark Core

- **Basic functionality** of Spark
  - Task scheduling, memory management, fault recovery, and interacting with storage systems
  - Also, the API that defines Resilient Distributed Datasets (RDDs)
    - Spark’s *main programming abstraction*
    - Represents collection of data items dispersed across many compute nodes
      - Can be manipulated concurrently (parallel)
Spark SQL

- Package for working with **structured data**
- Allows querying data using SQL and HQL (Hive Query Language)
  - Data sources: Hive tables, Parquet, and JSON
- Allows intermixing queries with programmatic data manipulations support by RDDs
  - Using Scala, Java, and Python

Semi-structured data and Spark SQL

- Spark SQL defines an interface for a semi-structured data type, called **DataFrames**
  - And as of Spark 1.6, a semi-structured, typed version of RDDs called **Datasets**
- Spark SQL is a very important component for Spark performance
- Much of what can be accomplished with Spark Core can be done by leveraging Spark SQL.
Spark Streaming

- Enables processing of **live streams** of data from sources such as:
  - Logfiles generated by production web servers
  - Messages containing web service status updates

- Uses the scheduling of the Spark Core for streaming analytics on **minibatches** of data

- Has a number of unique considerations, such as the **window sizes** used for batches

MLib

- Library that contains common machine learning functionality

- Algorithms include:
  - Classification, regression, clustering, and collaborative filtering

- Low-level primitives
  - Generic gradient descent optimization algorithm

- Alternatives?
  - Mahout, sci-kit learn, VW, WEKA, and R among others
What about Spark ML?

- Has existed since Spark 1.2
- Spark ML provides a higher-level API than MLlib
  - Goal is to allow users to more easily create practical machine learning pipelines
  - Spark MLlib is primarily built on top of RDDs and uses functions from Spark Core, while ML is built on top of Spark SQL DataFrames
- Eventually the Spark community plans to move over to ML and deprecate MLlib

Graph X

- Library for manipulating graphs
- Graph-parallel computations
- Extends Spark RDD API
  - Create a directed graph, with arbitrary properties attached to each vertex and edge
Cluster Managers

- Spark runs over a variety of cluster managers
- These include:
  - Hadoop YARN
  - Apache Mesos
  - Standalone Scheduler
    - Included within Spark

Storage Layers for Spark

- Spark can create distributed datasets from any file stored in HDFS
- Plus, other storage systems supported by the Hadoop API
  - Amazon S3, Cassandra, Hive, HBase, etc.
**Interactive Shells in Spark**

March 28, 2019

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**Spark Shells**

- **Interactive** [Python and Scala]
  - Similar to shells like Bash or Windows command prompt
- **Ad hoc** data analysis
- Traditional shells manipulate data using disk and memory on a single machine
  - Spark shells allow interaction with **data that is distributed** across many machines
  - Spark manages complexity of distributing processing
Several software were designed to run on the Java Virtual Machine

- Languages that compile to run on the JVM and can interact with Java software packages but are not actually Java
- There are a number of non-Java JVM languages
  - The two most popular ones used in real-time application development: Scala and Clojure

Scala

- Has spent most of its life as an academic language
  - Still largely developed at universities
  - Has a rich standard library that has made it appealing to developers of high-performance server applications
- Like Java, Scala is a strongly typed object-oriented language
  - Includes many features from functional programming languages that are not in standard Java
  - Interestingly, Java 8 incorporate several of the more useful features of Scala and other functional languages.
What is functional programming?

- When a method is compiled by Java, it is converted to instructions called byte code and ...
  - Then largely disappears from the Java environment
    - Except when it is called by other methods
- In a functional language, **functions are treated the same way as data**
  - Can be stored in objects similar to integers or strings, returned from functions, and passed to other functions

What about Clojure?

- Based on Lisp
- Javascript?
  - Name was a marketing gimmick
  - Closer to Clojure and Scala than it is to Java
Core Spark Concepts

- Drivers
- SparkContext
- Executors
Spark in a nutshell

- Spark allows users to write a program for the driver (or master node) on a cluster computing system that can perform operations on data in parallel.
- Spark represents large datasets as RDDs which are stored in the executors (or worker nodes).
- The objects that comprise RDDs are called partitions and may be (but do not need to be) computed on different nodes of a distributed system.
- The Spark cluster manager handles starting and distributing the Spark executors across a distributed system.

Drivers

- Every Spark application consists of a driver program.
- Driver launches various parallel operations on the cluster.
- Constituent elements:
  - Application's main function
  - Defines distributed datasets on the clusters
  - Applies operations to these datasets
SparkContext

- Driver programs access Spark through a SparkContext object
  - Represents a connection to a computing cluster
- Within the shell?
  - Created as the variable `sc`
    - You can even print out `sc` to see the type
- Once you have a SparkContext, you can use it to build RDDs
  - And then run operations on the data ...

Executors

- Driver programs manage a number of nodes, called executors
- Executors are responsible for running operations
- For example:
  - If we were running a `count()` operation on cluster
    - Different machines might count lines in different ranges of the file
Components for distributed execution in Spark

Lot of Spark’s API revolves around passing functions to its operators

```python
def hasPython(line):
    return "Python" in line

pythonLines =
    lines.filter(hasPython)

pythonLines =
    lines.filter(line => line.contains("Python"))

Also known as the lambda or => syntax
```
Lot of Spark’s API revolves around passing functions to its operators.

```java
JavaRDD<String> pythonLines = lines.filter(new Function<String, Boolean>() {
    public Boolean call(String line) {
        return line.contains("Python");
    }
});

JavaRDD<String> pythonLines = lines.filter(line -> line.contains("Python"));
```

**Resilient Distributed Dataset**

**[RDD]**

March 28, 2019

CS455: Introduction to Distributed Systems  [Spring 2019]
Dept. Of Computer Science, Colorado State University
Resilient Distributed Dataset (RDD)

- RDD is an **immutable distributed collection** of objects
- Each RDD is split into *multiple partitions*
  - Maybe computed on different nodes in the cluster
- Can contain any type of Java, Scala, or Python objects
  - Including user-defined classes

Creation of RDDs

1. Loading an external dataset
2. Distributing a collection of objects via the driver program

```python
>>> lines = sc.textFile("README.md")
```
Once created, RDDs offer two types of operations

- **Transformations**
  - Construct a new RDD from a previous one
  - E.g.: Filtering data that matches a predicate

- **Actions**
  - Compute a result based on an RDD
  - Return result to the driver program or save it in external storage system (HDFS)

Some more about RDDs

- Although you can define new RDDs anytime
  - Spark computes them in a **lazy fashion**
  - When?
    - The first time they are used in an action

- Loading lazily allows transformations to be performed **before** the action
Lazy loading allows Spark to see the whole chain of transformations

- Allows it to **compute just the data needed** for the result
- Example:
  ```python
  lines = sc.textFile("README.md")
  pythonLines = lines.filter(lambda line: "Python" in line)
  ```
- If Spark were to load and store all lines in the file, as soon as we wrote `lines=sc.textFile()`?
  - Would waste a lot of storage space, since we immediately filter out a lot of lines

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RDD and actions

- **RDDs are recomputed** (by default) every time you run an action on them
- If you wanted to **reuse** an RDD?
  - Ask Spark to **persist** it using `RDD.persist()`
  - After computing it the first time, Spark will store RDD contents in memory (**partitioned** across cluster machines)
  - Persisted RDD is used in future actions
Every Spark program and shell works as follows

1. **Create** some input RDD from external data
2. **Transform** them to define new RDDs using transformations like `filter()`
3. Ask Spark to `persist()` any intermediate RDDs that needs to be reused
4. **Launch actions** such as `count()`, etc. to kickoff a parallel computation
   - Computing is optimized and executed by Spark

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

- *Real-Time Analytics: Techniques to Analyze and Visualize Streaming Data*. Byron Ellis. Wiley. [Chapter 2]