CS 455: Introduction to Distributed Systems

Topics covered in this lecture

- Spark
  - Software stack
  - Interactive shells in Spark
  - Core Spark concepts

Professor: Shrideep Pallickara
Computer Science
Colorado State University

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

Apache Spark

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 in 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>
</tr>
</thead>
<tbody>
<tr>
<td>Processor cycle</td>
<td>0.5 ns (2 GHz)</td>
</tr>
<tr>
<td>Cache access</td>
<td>1 ns (1 GHz)</td>
</tr>
<tr>
<td>Memory access</td>
<td>78 ns</td>
</tr>
<tr>
<td>Context switch</td>
<td>8,000 ns (8 µs)</td>
</tr>
<tr>
<td>Disk access</td>
<td>7,000,000 ns (7 ms)</td>
</tr>
<tr>
<td>Quantum</td>
<td>100,000,000,000 ns (100 µs)</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.

Running Spark

- You can use Spark from Python, Java, Scala, R, or SQL.
- Spark itself is written in Scala, and runs on the Java Virtual Machine (JVM).
- You can Spark either on your laptop or a cluster, all you need is an installation of Java.
- If you want to use the Python API, you will also need a Python interpreter (version 2.7 or later).
- If you want to use R, you will need a version of R on your machine.

Spark 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 stack

- 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)

Benefits of tight integration

- 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 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

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 incorporates 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

Spark APIs
- Spark has two fundamental sets of APIs:
  - The low-level "unstructured" APIs, and
  - The higher-level structured APIs

Structured APIs
- Structured APIs are a tool for manipulating all sorts of data
  - From unstructured log files to semi-structured CSV files and highly structured Parquet files
- Refers to three core types of distributed collection APIs:
  - Datasets
  - DataFrames
  - SQL tables and views
- Majority of the Structured APIs apply to both batch and streaming computation

Spark’s Toolset
- Structured Streaming
- Advanced Analytics
- Libraries & Ecosystem
- Structured APIs
  - Datasets
  - DataFrames
  - SQLs
- Low Level APIs
  - RDDs
  - Distributed variables
Spark has two notions of structured collections: DataFrames and Datasets

- DataFrames and Datasets are (distributed) table-like collections with well-defined rows and columns.
- Each column:
  - Must have the same number of rows as all the other columns (although you can use null to specify the absence of a value).
  - Has type information that must be consistent for every row in the collection.

How does Spark view DataFrames and Datasets?

- To Spark, DataFrames and Datasets represent immutable, lazily evaluated plans that specify what operations to apply to data residing at a location to generate some output.
- When we perform an action on a DataFrame, we instruct Spark to perform the actual transformations and return the result.
- These represent plans of how to manipulate rows and columns to compute the user's desired result.

The DataFrame concept is not unique to Spark

- R and Python both have similar concepts.
- However, Python/R DataFrames (with some exceptions) exist on one machine rather than multiple machines.
- This limits what you can do with a given DataFrame to the resources that exist on that specific machine.
- A Spark DataFrame can span thousands of computers.

DataFrames versus Datasets

- DataFrames are considered "untyped".
- Datasets are considered "typed".

The DataFrame is the most common Structured API

- Simply represents a table of data with rows and columns.
- The list that defines the columns and the types within those columns is called the schema.

CORE SPARK CONCEPTS
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.

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

pythonLines = lines.filter(hasPython)
```

Also known as the lambda or => syntax:

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

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

```java
javaStr = "String"
pythonLines = lines.filter:
    return line.contains("Python")
```