CS555: DISTRIBUTED SYSTEMS [SPARK]

Shrideep Pallickara
Computer Science
Colorado State University

October 8, 2019
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Frequently asked questions from the previous class survey

- Why use Hadoop if Spark is so much faster?

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Topics covered in this lecture

- Orchestration Plans
- Transformations and Dependencies
- Spark Resilient Distributed Datasets

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A simple Scala word count example

```scala
def simpleWordCount( rdd: RDD[String]): RDD[(String, Int)] = {
  val words = rdd.flatMap(_.split(" "))
  val wordPairs = words.map((_, 1))
  val wordCounts = wordPairs.reduceByKey(_ + _)
  wordCounts
}
```

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Executing Spark code in clusters: Overview

- Write DataFrame/Dataset/SQL Code.
- If valid code, Spark converts this to a Logical Plan
- Spark transforms this Logical Plan to a Physical Plan, checking for optimizations along the way
- Spark then executes this Physical Plan (RDD manipulations) on the cluster

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Once you have the code ready

- Code is submitted either through the console or via a submitted job
- This code passes through the **Catalyst Optimizer**
  - Decides how the code should be executed
  - Lays out a plan for doing so before, finally, the code is run
  - And the result returned to the user

### The Catalyst Optimizer

- **SQL**
- **DataFrames**
- **Datasets**

### Logical Planning

- **The logical plan** only represents a set of abstract transformations
  - Does not refer to executors or drivers
  - Simply converts the user’s set of expressions into the most optimized version
- Converting user’s code into an **unresolved logical plan**
  - This plan is unresolved because although your code might be valid, the tables or columns that it refers to might or might not exist

### How are columns and tables resolved?

- Spark uses the **catalog**, a repository of all table and DataFrame information, to resolve columns and tables in the analyzer optimizations
- The analyzer might reject the unresolved logical plan if the required table or column name does not exist in the catalog
- If the analyzer can resolve it, the result is passed through the Catalyst Optimizer

### The Structured API Logical Planning Process

#### Catalyst Optimizer

- A collection of rules that attempt to optimize the logical plan by pushing down predicates or selections
- **Catalyst is extensible**
  - Users can include their own rules for domain-specific optimizations
Physical Planning [1/2]
- The physical plan specifies how the logical plan will execute on the cluster.
- Involves generating different physical execution strategies and comparing them through a cost model.
- An example of the cost comparison might be choosing how to perform a given join by looking at the physical attributes of a given table:
  - How big the table is or
  - How big its partitions are.

Physical Planning [2/2]
- Physical planning results in a series of RDDs and transformations.
- This is why Spark is also referred to as a compiler.
  - Takes queries in DataFrames, Datasets, and SQL and compiles them into RDD transformations.

The Physical Planning Process
- **Optimized Logical Plan** → **Physical Plan** → **Best Physical Plan** → **Executed on the cluster**

Execution
- Spark performs further optimizations at runtime.
- Generating native Java bytecode that can remove entire tasks or stages during execution.
- Finally, the result is returned to the user.

Transformations and Dependencies
- Two categories of dependencies:
  - **Narrow**: Each parent partition is used by at most one child partition.
  - **Wide**: Multiple child partitions may depend on a single parent partition.
- The narrow versus wide distinction has significant implications for the way Spark evaluates a transformation and, consequently, for its performance.

Wide and Narrow Transformations
Narrow Transformations

- Narrow transformations are those in which each input partition contributes to only one output partition.
- Can be determined at design time, irrespective of the values of the records in the parent partitions.
- Partitions in narrow transformations can either depend on:
  - One parent (such as in the map operator), or
  - A unique subset of the parent partitions that is known at design time (coalesce).
- Narrow transformations can be executed on an arbitrary subset of the data without any information about the other partitions.

Dependencies between partitions for narrow transformations

Wide Transformations

- A wide dependency (or wide transformation) style transformation will have input partitions contributing to many output partitions.
- Also referred to as a shuffle whereby Spark will exchange partitions across the cluster.

Dependencies between partitions for wide transformations

Wide dependencies cannot be known fully before the data is evaluated.
The dependency graph for any operations that cause a shuffle (such as groupByKey, reduceByKey, sort, and sortByKey) follows this pattern.

Other implications of narrow and wide transformations

- Narrow transformations:
  - Spark automatically performs pipelining.
  - If we specify multiple filters on DataFrames, they’ll all be performed in-memory.
- Wide transformations:
  - When we perform a shuffle Spark writes the results to disk.
One of the key optimizations that Spark performs is pipelining.

- Occurs at and below the RDD level
- Any sequence of operations that feed data directly into each other, without needing to move it across nodes?
  - This sequence is collapsed into a single stage of tasks that do all the operations together

An example of pipelining

- If you write an RDD-based program that does a map, then a filter, then another map?
  - These will result in a single stage of tasks that will immediately read each input record, pass it through the first map, pass it through the filter, and pass it through the last map function if needed
  - This pipelined version of the computation is much faster than writing the intermediate results to memory or disk after each step
  - The same kind of pipelining happens for a DataFrame or SQL computation that does a select, filter, and select

Let’s look at a case when pipelining is infeasible

- When Spark needs to run an operation that has to move data across nodes, such as a reduce-by-key operation
  - Where input data for each key needs to first be brought together from many nodes
  - The engine can’t perform pipelining anymore
  - Instead it performs a cross-network shuffle

How shuffles work

- Spark executes shuffles by first having the “source” tasks (those sending data) write shuffle files to their local disks during their execution stage
- Then, the stage that does the grouping and reduction launches and runs tasks
  - E.g., fetches and processes the data for a specific range of keys

How writing the shuffle to disk helps

- Saving the shuffle files to disk lets Spark run this stage later in time than the source stage
  - E.g., if there are not enough executors to run both at the same time
  - Also lets the engine re-launch reduce tasks on failure without rerunning all the input tasks

Other benefits of shuffle persistence

- Running a new job over data that’s already been shuffled does not rerun the “source” side of the shuffle
  - Because the shuffle files were already written to disk earlier
  - Spark knows that it can use them to run the later stages of the job
  - It need not re-run the earlier ones
  - In the Spark UI and logs, you will see the pre-shuffle stages marked as “skipped”
  - This automatic optimization can save time in a workload that runs multiple jobs over the same data
  - For even better performance?
  - You can perform your own caching with the DataFrame or RDD cache method
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Resilient Distributed Dataset (RDD)

- RDD is an immutable, distributed collection of objects
  - Lazyly evaluated, statically typed
- 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

RDDs: memory residency and immutability implications

- Spark can keep an RDD loaded in-memory on the executor nodes throughout the life of a Spark application for faster access in repeated computations
- RDDs are immutable, so transforming an RDD returns a new RDD rather than the existing one
- Cross-cutting implications?
  - Lazy evaluation, in-memory storage, and immutability allows Spark to be easy-to-use, fault-tolerant, scalable, and efficient

RESILIENT DISTRIBUTED DATASET

[ RDD ]

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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:
  - 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

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

RDDs support two types of operations

- Transformations
  - Operations that return a new RDD. E.g.: filter()

- Actions
  - Operations that return a result to the driver program or write to storage
    - Kicks of a computation. E.g.: count()

  - Distinguishing aspect
    - Transformations return RDDs
    - Actions return some other data type
Transformations

- Many transformations are element-wise
  - Work on only one element at a time

- Some transformations are not element-wise
  - E.g.: We have a log file, log.txt, with several messages, but we only want to select error messages
    ```
    inputRDD = sc.textFile("log.txt")
    errorsRDD = inputRDD.filter(lambda x: "error" in x)
    ```

In our previous example ...

- filter does not mutate inputRDD
  - Returns a pointer to an entirely new RDD
  - inputRDD can still be reused later in the program

  - We could use inputRDD to search for lines with the word “warning”

    ```
    warningsRDD = inputRDD.filter(lambda x: "warning" in x)
    ```

  - While we are at it, we will use another transformation, union(), to print number of lines that contained either errors or warnings

    ```
    badlinesRDD = errorsRDD.union(warningsRDD)
    ```

RDD lineage graphs

- As new RDDs are derived from each other using transformations, Spark tracks dependencies
  - Lineage graph

- Uses lineage graph to
  - Compute each RDD on demand
  - Recover lost data if part of persistent RDD is lost

RDD lineage graph for our example

Actions

- We can create RDDs from each other using transformations

  - At some point, we need to actually do something with the dataset
    
    - Actions

  - Forces evaluations of the transformations required for the RDD they were called on
Each Spark program must contain an **action**

- Actions either:
  - Bring information back to the driver or
  - Write the data to stable storage
- Actions are what force evaluation of a Spark program
- Persist calls also force evaluation, but usually do not mark the end of a Spark job
- Actions that bring data back to the driver include `collect`, `count`, `collectAsMap`, `sample`, `reduce`, and `take`.

Let's try to print information about `badlinesRDD`

```
print "Input had " + badLinesRDD.count() + " concerning lines"
print "Here are 10 examples:
for line in badLinesRDD.take(10):
    print line
```

RDDs also have a **collect** to retrieve the entire RDD

- Useful if program filters RDD to a very small size and you want to deal locally
  - Your entire dataset must fit in memory on a single machine to use `collect()` on it
  - Should NOT be used on large datasets
- In most cases, RDDs **cannot be** `collect()`ed to the driver
  - Common to write data out to a distributed storage system ... HDFS or S3

A caveat about actions and scaling

- Some of these actions do not scale well, since they can cause memory errors in the driver
- In general, it is best to use actions like `take`, `count`, and `reduce`, which bring back a fixed amount of data to the driver, rather than `collect` or `sample`.

Lazy Evaluation

- Transformations on RDDs are **lazily evaluated**
  - Spark will not begin to execute until it sees an action
- Uses this to **reduce the number of passes** it has to take over data by grouping operations together
- What does this mean?
  - When you call a transformation on an RDD (for e.g. `map`) the operation is not immediately performed
  - Spark internally records metadata that operation is requested

How you should think of RDDs

- Rather than thinking of it as containing specific data
  - Best to think of it as containing instructions on how to compute the data that we build through transformations
- Loading data into a RDD is lazily evaluated just as transformations are
The contents of this slide-set are based on the following references