CS 555: DISTRIBUTED SYSTEMS [SPARK]

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Frequently asked questions from the previous class survey

Topics covered in this lecture

- Transformations and Actions
  - RDDs
  - DataFrames

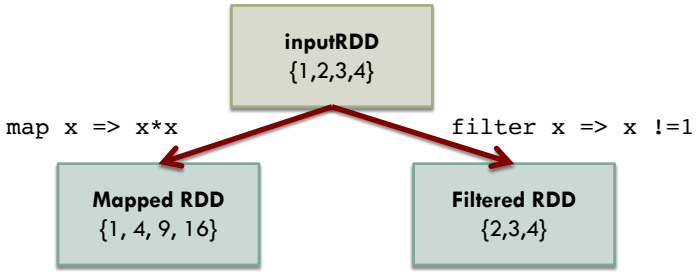
COMMON TRANSFORMATIONS AND ACTIONS

Element-wise transformations: `filter()`

- Takes in a function and returns an RDD that only has elements that pass the `filter()` function

Element-wise transformations: `map()`

- Takes in a function and applies it to each element in the RDD
- Result of the function is the new value of each element in the resulting RDD

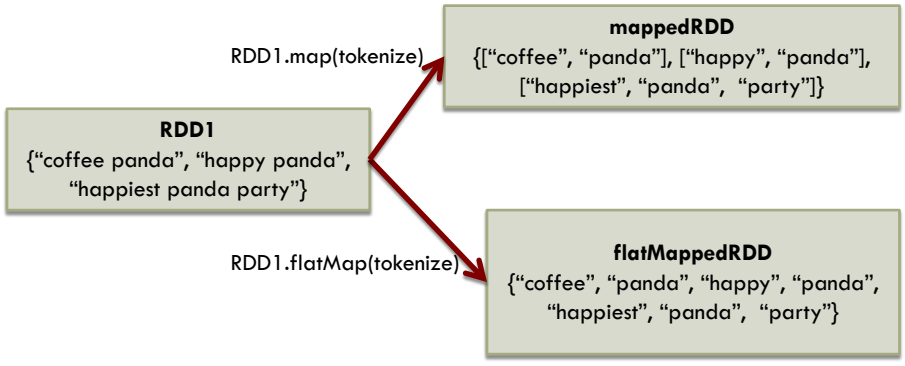


Things that can be done with `map()`

- Fetch website associated with each URL in collection to just squaring numbers
- `map()`'s return type does not have to be the same as its input type
- Multiple output elements for each input element?
  - Use `flatMap()`

```
lines=sc.parallelize(["hello world", "hi"])
words=lines.flatMap(lambda line: line.split(" ") )
words.first()   # returns hello
```

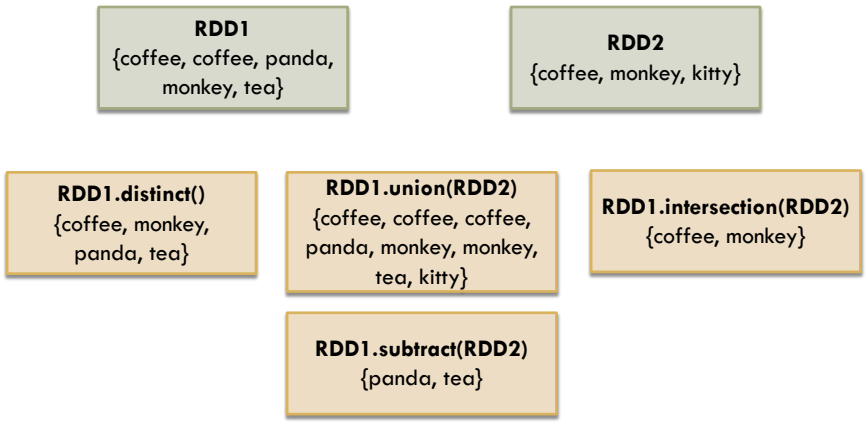

Difference between `map` and `flatMap`



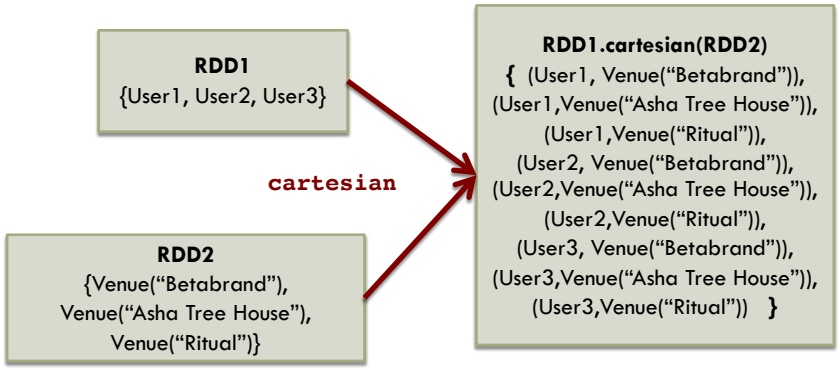
Psuedo set operations

- RDDs support many of the operations of mathematical sets such as union, intersection, etc.
  - Even when the RDDs themselves are not properly sets

Some simple set operations



Cartesian product between two RDDs



COMMON ACTIONS

Actions on Basic RDDs

- `reduce()`
  - Takes a function that operates on two elements in the RDD; returns an element of the same type
    - E.g. of such an operation? `+` sums the RDD

```
sum = rdd.reduce(lambda x, y: x+ y)
```

- `fold()` takes a function with the same signature as `reduce()`, but also takes a "zero value" for initial call
  - "Zero value" is the **identity element** for initial call
  - E.g., 0 for +, 1 for *, empty list for concatenation

Both `fold()` and `reduce()` require return type to be of the same type as the RDD elements

- The `aggregate()` removes that constraint
  - For e.g. when computing a running average, maintain both the count so far and the number of elements

EXAMPLES: BASIC ACTIONS ON RDDS

Examples: Basic actions on RDDs [1/7]

- Our RDD contains {1, 2, 3, 3}
- **`collect()`**
  - Return all elements from the RDD
  - Invocation: `rdd.collect()`
  - Result: {1, 2, 3, 3}

Examples: Basic actions on RDDs [2/7]

- Our RDD contains {1, 2, 3, 3}
- **`count()`**
  - Number of elements in the RDD
  - Invocation: `rdd.count()`
  - Result: 4

Examples: Basic actions on RDDs [3/7]

- Our RDD contains {1, 2, 3, 3}
- **`countByValue()`**
  - Number of times each element occurs in the RDD
  - Invocation: `rdd.countByValue()`
  - Result: { (1,1), (2,1), (3,2) }

Examples: Basic actions on RDDs [4/7]

- Our RDD contains {1, 2, 3, 3}
- **`take(num)`**
  - Return `num` elements from the RDD
  - Invocation: `rdd.take(2)`
  - Result: { 1, 2}

Examples: Basic actions on RDDs [5/7]

- Our RDD contains {1, 2, 3, 3}
- **`reduce(func)`**
  - Combine the elements of the RDD together in parallel
  - Invocation: `rdd.reduce( (x,y) => x + y )`
  - Result: 9

Examples: Basic actions on RDDs [6/7]

- Our RDD contains {1, 2, 3, 3}
- **`aggregate(zeroValue)(seqOp, combOp)`**
  - Similar to `reduce()` but used to return a different type
  - Invocation:
    - ```
      rdd.aggregate((0,0))
                   (x,y) => (x._1 + y, x._2 +1),
                   (x,y) => (x._1 + y._1, x._2 + y._2))
      ```
  - Result: (9, 4)

Examples: Basic actions on RDDs [7/7]

- Our RDD contains {1, 2, 3, 3}
- **`foreach(func)`**
  - Apply the provided function to each element of the RDD
  - Invocation: `rdd.foreach(func)`
  - Result: Nothing
      ```

PERISTENCE (CACHING)

Why persistence?

- Spark RDDs are lazily evaluated, and we may sometimes wish to use the same RDD multiple times
  - Naively, Spark will **recompute RDD and all of its dependencies** each time we call an action on the RDD
    - Super expensive for iterative algorithms
- To avoid recomputing RDD multiple times?
  - Ask Spark to **persist** the data
  - The nodes that compute the RDD, store the partitions

Coping with failures

- If a node that has data persisted on it fails?
  - Spark recomputes lost partitions of data when needed
- Also, replicate data on multiple nodes
  - To handle node failures without slowdowns

Persistence Levels for Spark

Level	Space Used	CPU time	In Memory	On disk	Comments
MEMORY_ONLY	High	Low	Y	N	
MEMORY_ONLY_SER	Low	High	Y	N	
MEMORY_AND_DISK	High	Medium	Some	Some	Spills to disk if there is too much data to fit in memory
MEMORY_AND_DISK_SER	Low	High	Some	Some	Spills to disk if there is too much data to fit in memory. Stores serialized representation in memory
DISK_ONLY	Low	High	N	Y	

What if you attempt to cache too much data to fit in memory?

- Spark will **evict old partitions** using a Least Recently Used Cache policy
  - For memory only storage partitions, it will be recomputed the next time they are accessed
  - For memory_and_disk ones? Write them out to disk
- RDDs also come with a method, `unpersist()`
  - Manually remove data elements from the cache

WORKING WITH KEY/VALUE PAIRS

RDDs of key/value pairs

- Key/value RDDs are commonly used to perform aggregations
  - Might have to do ETL (Extract, Transform, and Load) to get data into key/value formats
- Advanced feature to control layout of pair RDDs across nodes
  - **Partitioning**

RDDs containing key/value pairs

- Are called **pair RDDs**
- Useful *building block* in many programs
  - Expose operations that allow actions on each key in parallel or regroup data across network
  - `reduceByKey()` to aggregate data separately for each key
  - `join()` to merge two RDDs together by grouping elements of the same key

Pair RDDs

- RDDs that contain **key/value pairs**
- Expose partitions that allow you to act on each key in parallel or regroup data across the network

Creating Pair RDDs

- `pairs=lines.map(lambda x: (x.split(" ") )[0], x))`
  - Creates a pairRDD using the first word as the key
- Java does not have a built-in tuple type
  - `scala.Tuple2` class
    - `new Tuple2(elem1, elem2)`

TRANSFORMATIONS ON PAIR RDDS

Transformations on Pair RDDs [1/5]

- Pair RDD = {(1,2), (3,4), (3,6) }
- **`reduceByKey(func)`**
  - Combine values with the same key
  - Invocation: `rdd.reduceByKey((x, y) => x + y)`
  - Result: { (1, 2), (3,10) }

Transformations on Pair RDDs [2/5]

- Pair RDD = {(1,2), (3,4), (3,6) }
- **`groupByKey(func)`**
  - Group values with the same key
  - Invocation: `rdd.groupByKey()`
  - Result: { (1, [2]), (3, [4, 6]) }

Transformations on Pair RDDs [3/5]

- Pair RDD = {(1,2), (3,4), (3,6) }
- **`mapValues(func)`**
  - Apply function to each value of a pair RDD *without* changing the key
  - Invocation: `rdd.mapValues(x=> x+1)`
  - Result: { (1, 3), (3, 5), (3, 7) }

Transformations on Pair RDDs [4/5]

- Pair RDD = {(1,2), (3,4), (3,6) }
- **`values()`**
  - Return an RDD of just the values
  - Invocation: `rdd.values()`
  - Result: { 2, 4, 6 }

Transformations on Pair RDDs [5/5]

- Pair RDD = {(1,2), (3,4), (3,6) }
- **`sortByKey()`**
  - Return an RDD sorted by the key
  - Invocation: `rdd.sortByKey()`
  - Result: { (1,2), (3,4), (3,6 }

TRANSFORMATIONS ON TWO PAIR RDDS

Transformations on two Pair RDDs [1/5]

- **rdd** = {(1,2), (3,4), (3,6) } **other** = {(3,9)}
- **subtractByKey()**
  - Remove elements with a key present in the `other` RDD
  - Invocation: `rdd.subtractByKey(other)`
  - Result: { (1,2) }

Transformations on two Pair RDDs [2/5]

- **rdd** = {(1,2), (3,4), (3,6) } **other** = {(3,9)}
- **join()**
  - Perform an **inner join** between two RDDs. Only keys that are present in both pair RDDs are output
  - Invocation: `rdd.join(other)`
  - Result: { (3, (4,9)) , (3, (6,9)) }

Transformations on two Pair RDDs [3/5]

- **rdd** = {(1,2), (3,4), (3,6) } **other** = {(3,9)}
- **leftOuterJoin()**
  - Perform a join between two RDDs where the key must be present in the first RDD.
  - Value associated with each key is a tuple of the value from the source and an Option for the value from the other pair RDD
    - In python if a value is not present, None is used.
  - Invocation: `rdd.leftOuterJoin(other)`
  - Result: { (1, (2,None)) , (3, (4, 9)) , (3, (6, 9)) }

Transformations on two Pair RDDs [4/5]

- **rdd** = {(1,2), (3,4), (3,6) } **other** = {(3,9)}
- **`rightOuterJoin()`**
  - Perform a join between two RDDs where the key must be present in the `other` RDD;
  - Tuple has an option for the source rather than `other` RDD
  - Invocation: `rdd.rightOuterJoin(other)`
  - Result: { (3, (4,9)) , (3, (6,9)) }

Transformations on two Pair RDDs [5/5]

- **rdd** = {(1,2), (3,4), (3,6) } **other** = {(3,9)}
- **`cogroup()`**
  - Group data from both RDDs using the same key
  - Invocation: `rdd.cogroup(other)`
  - Result: { (1, ([2],[])) , (3, ([4, 6], [9])) }

Example of chaining operations

key	value
panda	0
pink	3
pirate	3
panda	1
pink	4

mapValues

key	value
panda	(0, 1)
pink	(3, 1)
pirate	(3, 1)
panda	(1, 1)
pink	(4, 1)

reduceByKey

key	value
panda	(1, 2)
pink	(7, 2)
pirate	(3, 1)

```
rdd.mapValues(x=> (x, 1)).reduceByKey( (x,y) => (x._1 + y._1, x._2 + y._2))
```


A word count example

- We are using `flatMap()` to produce a pair RDD of words and the number 1

```
 rdd   = sc.textfile("s3://…")
words = rdd.flatMap(lambda x: x.split(" "))
result = words.map(lambda x: (x,1)).
              reduceByKey(lambda x, y: x+y)
```

DATAFRAMES

Dataframe Review

- Maintains features of RDD's
  - In-memory, resilient, distributed computing
  - Supports same transformations and actions
  - API's in a variety of languages
- Differs from RDD's by
  - Maintenance of data schema
  - Additional optimizations to query plan (Catalyst rules)

Dataframe sources

- Dataframes may be initialized from a variety of sources
  - Distributed File Systems (CSV, Json, XML, etc)
  - Databases (MySQL, Cassandra, Hive, Redis, etc)
  - RDD's
- Able to "inferSchema" of structured data

Example: Dataframe Initialization

```
val df1 = sqlContext.read.format("csv")
    .option("header", "true")
    .option("inferSchema", "true")

.load("hdfs://albany:56781/data/main/1987.csv")

  val df2 = sqlContext.read
    .format("org.apache.spark.sql.cassandra")
    .option("table", "students")
    .option("keyspace", "csu").load()
```

COMMON DATAFRAME OPERATIONS

Column Manipulations [1/4]

- **`withColumn(columnName, func)`**
  - Return an Dataframe with the additional column
  - Invocation: `df.withColumn("dogYears", df.age / 7)`
- **`dropColumn(columnName)`**
  - Return an Dataframe without the column
  - Invocation: `df.dropColumn("age")`

Column Manipulations [2/4]

- **`select(columnNames)`**
  - Return an Dataframe with the specified columns
  - Invocation: `df.select("firstName", "age")`
- **`describe(columnName)`**
  - Compute summary statistics over Dataframe columns
  - Invocation: `df.describe("age"), df.describe()`

Column Manipulations [3/4]

```
val df = Seq(
    ("Peterson", "Marcus", 54),
    ("Batey", "Edward", 36),
    ("Bruce", "Karen", 35)
  ).toDF("lastName", "firstName", "age")

  df.withColumn("dogYears", df.age / 7.0)
  df.describe("age", "dogYears")
```

Column Manipulations [4/4]

```
+-------+---------+---------+
|summary|      age| dogYears|
+-------+---------+---------+
|  count|        3|        3|
|   mean|  41.6667|  5.95238|
| stddev| 10.69268|  1.52753|
|    min|       35|        5|
|    max|       54| 7.714286|
+-------+---------+---------+
```


Dataframe joins

- **`join(other, <columnComparison>, <joinType>)`**
  - Performs a join between 2 Dataframes
  - Invocation: `df1.join(df2, Seq("id"))`

Join column comparison

- Supports a variety of criteria
  - Sequence of column names (ex. Seq("id", "age"))
  - Elaborate comparison definitions (ex. df1("age") >= df2("age"))

Join Type

- Dataframes may perform multiple styles of join
  - Inner: typical dataset join with key to key match
  - Outer, left-outer, right-outer: result contains all rows, filling in columns with 'null' values where data doesn't exist
  - Left-semi, right-semi: similar to outer join, but result only contains rows in specified source dataset

Example: Spark SQL

```
val df = Seq(
    (“Peterson”, “Marcus”, 54),
    (“Batey”, “Edward”, 36),
    (“Bruce”, "Karen", 35)
  ).toDF("lastName", “firstName”, "age”)

  df.createOrReplaceTempView(“people”)
  spark.sql(“SELECT firstName, age, age / 7.0
as dogYears
    FROM people where age < 50”)
```


TUNING THE LEVEL OF PARALLELISM

Tuning the level of parallelism

- Every RDD has a **fixed number of partitions**
  - Determine the degree of parallelism when executing operations
- During aggregations or grouping operations, you can ask Spark to use a specific number of partitions
  - This will override defaults that Spark uses

Example: Tuning the level of parallelism

```
data = [("a", 3), ("b", 4), ("a", 1)]

sc.parallelize(data).
       reduceByKey(lambda x, y: x+y) #default

sc.parallelize(data).
       reduceByKey(lambda x, y: x+y, 10) #Custom
```

What if you want to tune parallelism outside of grouping and aggregation operations?

- There is `repartition()`
  - **Shuffles data across the network** to create a new set of partitions
  - Very **expensive operation!**
- There is the `coalesce()` operation
  - Allow avoiding data movement
    - But only if you are decreasing the number of partitions
  - Check `rdd.getNumPartitions()` and make sure you are coalescing to fewer partitions

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

- *Holden Karau, Andy Konwinski, Patrick Wendell, and Matei Zaharia. Learning Spark: Lightning-Fast Big Data Analysis. 1st Edition. O'Reilly. 2015. ISBN-13: 978-1449358624.* [Chapters 1-4]
- Karau, Holden; Warren, Rachel. High Performance Spark. Best Practices for Scaling and Optimizing Apache Spark. O'Reilly Media. 2017. ISBN-13: 978-1491943205. [Chapter 2]
- Chambers, Bill, Zaharia, Matei. Spark: The Definitive Guide. Big Data Processing Made Simple. O'Reilly Media. ISBN-13: 978-1491912218. 2018. [Chapters 2, 3, 4, 15, and 16].