Adding Spark To Your Hadoop

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Resources

This presentation, ETL code for email and all example code available at `https://github.com/medale/spark-mail/`.
Docker Image to run Spark 1.3.1 on Hadoop 2.6 with Enron email sample data set at https://registry.hub.docker.com/u/medale/spark-mail-docker/.

Talk Overview

- Hadoop - Spark Comparison
- Resilient Distributed Datasets (RDDs)
- Enron Email with Avro storage
- Analytic: Mail Folder Statistics in Hadoop and Spark
- Spark Installation, running on YARN, Spark Shell
- Spark Web UI
- RDD, PairRDDFunctions, DoubleRDDFunctions
- Resources

Speaker Background

Hadoop Ecosystem

- Based on Google GFS (2003)/MapReduce (2004) papers
- Extremely rich and robust
  - $\sim$ 2005 Nutch/2006 Yahoo - Doug Cutting/Mike Cafarella
- HDFS/Hadoop MapReduce batch
- YARN - allows other processing frameworks (like Spark)
- DSLs: Pig, Cascading/Scalding, Crunch, Hive (SQL)
- Graph processing: Giraph
- Real-time streaming: Storm
- Machine Learning: Apache Mahout ...

Hadoop Challenges

- With rich ecosystem: install, maintain, learn
- MapReduce is batch only - no interactive shell
- Must write out to disk between each iteration
- No general memory caching yet (Apache Tez?)
- Hadoop MapReduce programming is very low-level
  - map phase - (internal shuffle/sort) - reduce phase
  - Progammer expresses logic in map/reduce

Why Apache Spark?

- Different trade-offs
  - Improved hardware (faster processors, more memory)
- Programmer productivity
  - High-level, scalable processing framework
- Iterative algorithms/ML: Cache interim results
- Interactive data exploration (Spark shell)
- Can run on YARN (or standalone, Mesos)
- read/write HDFS (and many other data sources)

Apache Spark Buzz

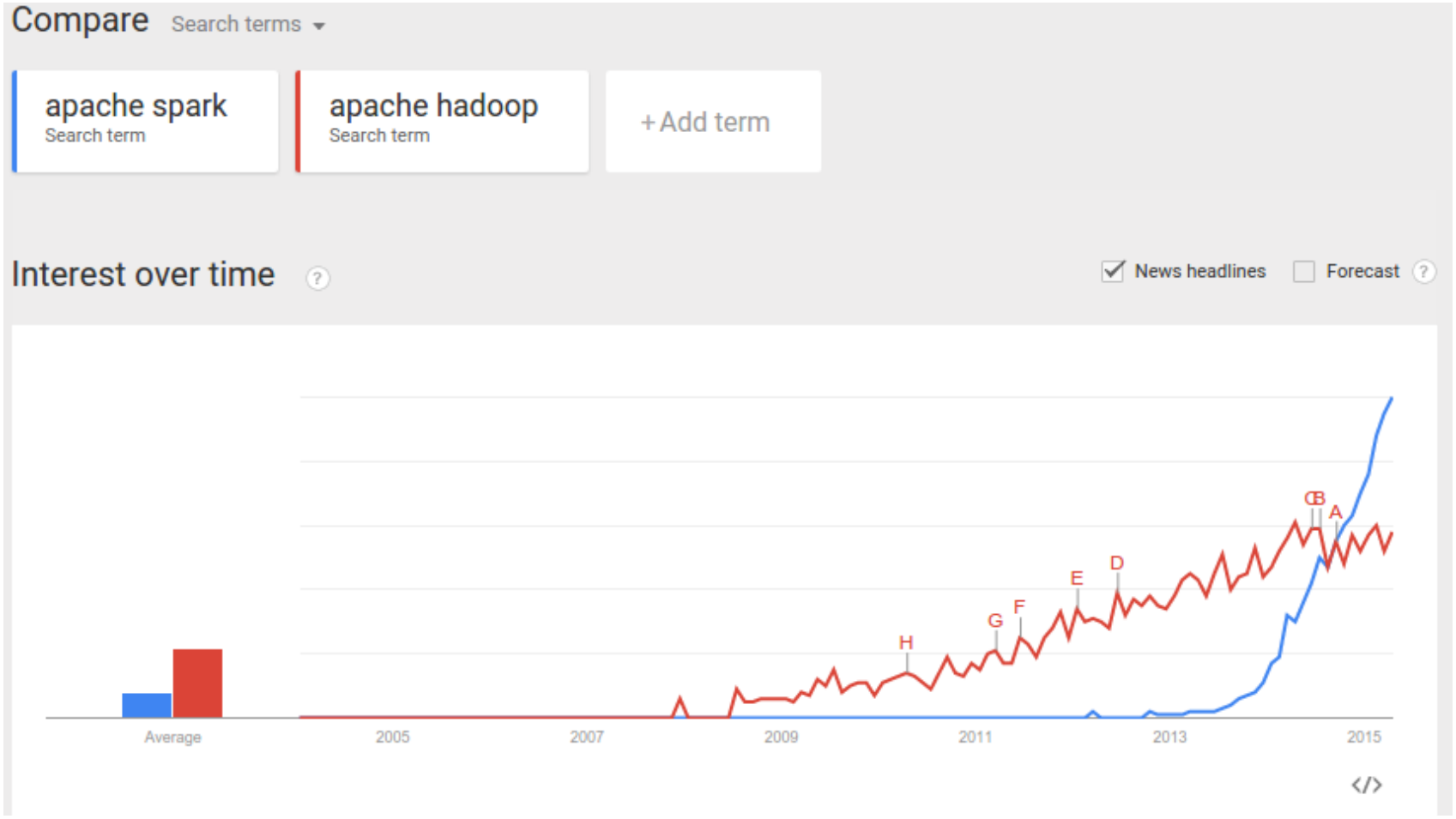

Figure : Google Trends Apache Spark/Apache Hadoop

Apache Spark Unified Large Scale Processing System

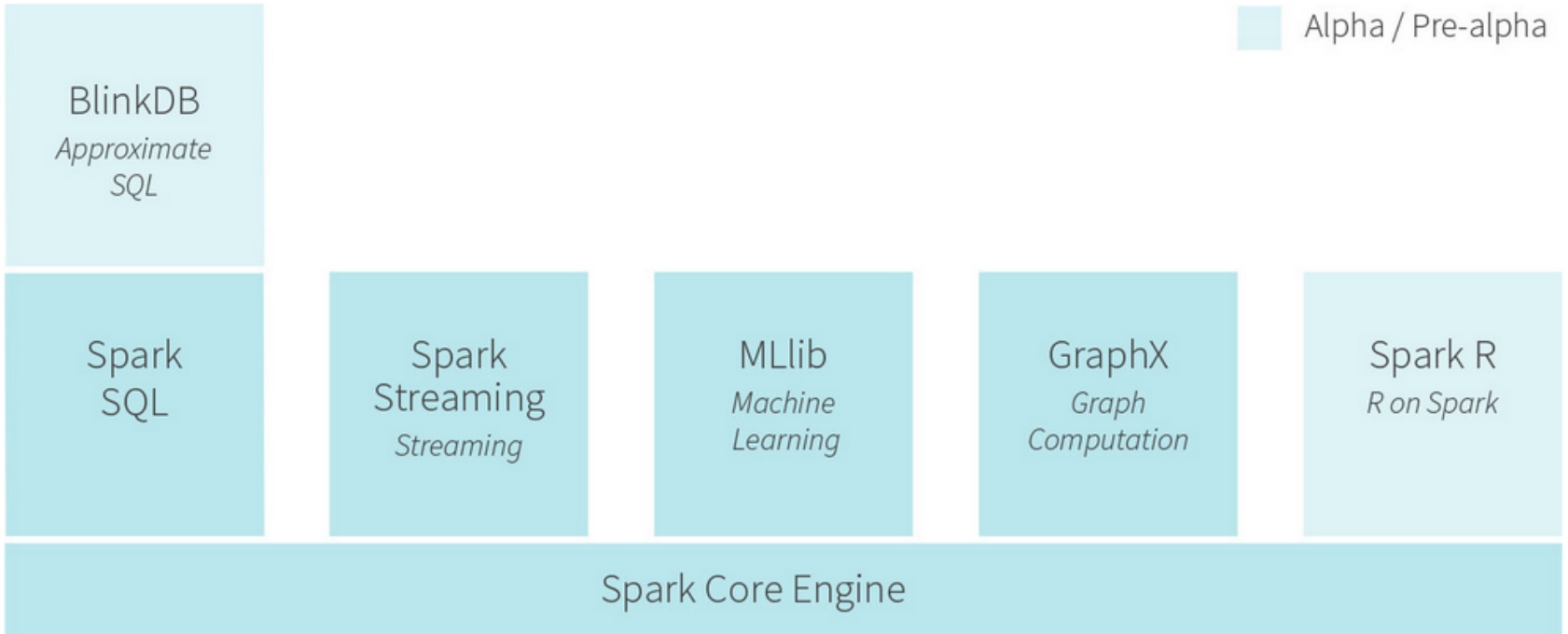

Figure : Databricks Spark Ecosystem (2015)

Resilient Distributed Dataset (RDD)

- Treat distributed, immutable data set as a collection
- Resilient: Use RDD lineage to recompute failed partitions
- Two forms of RDD operations:
  - Transformations (applied lazily - optimized evaluation)
  - Actions (cause transformations to be executed)
- Scala, Java, Python APIs (Spark R coming)
  - Rich functions on RDD abstraction

Enron Email Dataset and Avro MailRecord

- Enron email dataset from Carnegie Mellon University
- Nested directories for each user/folder/subfolder
- Emails as text files with headers (To, From, Subject...)
- Over 500,000 files (= 500,000 splits for FileInputFormat)
- Don't want our analytic code to worry about parsing

Solution: Parse to Avro record format, store (MailRecord)

Why Apache Avro?

- JSON - need to encode binary data
- Hadoop Writable - Java centric

Apache Avro

- Binary serialization framework
- Doug Cutting 2009 (Hadoop, Lucene)
- Language bindings: Java, Scala, C, C++, C#, Python, Ruby
- Schema in file - can use generic or specific processing

(Apache Avro Cutting 2009)

Avro Container File

- Contains many individual Avro records ($\sim$ SequenceFile)
- Schema for each record at the beginning of file
- Supports compression
- Files can be split

Avro Schema for MailRecord

```
record MailRecord {
  string uuid;
  string from;
  union{null, array<string>} to = null;
  union{null, array<string>} cc = null;
  union{null, array<string>} bcc = null;
  long dateUtcEpoch;
  string subject;
  union{null, map<string>} mailFields = null;
  string body;
  union{null, array<Attachment>} attachments = null;
}
```

Analytic: Mail Folder Statistics

- What are the least/most/average number of folders per user?
- Each MailRecord has user name and folder name

```
lay-k/     <- mailFields(UserName)
business   <- mailFields(FolderName)
family
enron
inbox
...
```

Hadoop Mail Folder Stats - Mapper

- read each mail record
  - AvroKey(MailRecord), NullWritable
- emits key: Text(userName), value: Text(folderName)

Hadoop Mail Folder Stats - Reducer

- reduce method
  - create set from values for a given key (unique folder names per user)
  - set.size == folder count
  - keep adding up all set.size (totalNumberOfFolders)
  - one up counter for each key (totalUsers)
  - keep track of min/max count
- cleanup method
  - compute average for this partition: totalNumberOfFolders/totalUsers
  - write out min, max, totalNumberOfFolders, totalUsers, avgPerPartition

Hadoop Mail Folder Stats - Driver

- Set AvroKeyInputFormat, key schema
- Number of reducers
- OutputFormat
- See https://github.com/medale/spark-mail/blob/master/hadoop-example/src/main/java/com/uebercomputing/hadoop/FolderAnalyti

Spark Installation

- Download binary tgz from Apache Spark
  - match Hadoop version
  - or build from source
- Untar on edge node
- Need Java to run
- Set HADOOP_CONF_DIR environment variable
- or $SPARK_HOME/conf/spark-env.sh

Or

- Bundled with Cloudera, Hortonworks, MapR distros...

Running Spark on YARN

- https://spark.apache.org/docs/1.3.1/running-on-yarn.html
- Driver, Executors (SparkApplicationMaster)
- Submit jobs to YARN Resource Manager
  - spark-submit --master yarn-cluster/yarn-client
- Or run as interactive shell

Spark Interactive Shell

```
/usr/local/spark/bin/spark-shell \
  --master yarn-client --driver-memory 1G \
  --executor-memory 1G --num-executors 1 \
  --executor-cores 1 \
  ... (Kryo serialization/logging)
  --jars /root/mailrecord-utils-1.0.0-shaded.jar
```

Brief Scala Background - map function on collections

- map: applies a given function to every element of a collection
- returns collection of output of that function
  - one per original element
- List[A]:
  - map(f: (A) => B): List[B]
  - Note: List[A].size == List[B].size

map - Scala

```
def computeLength(w: String): Int = w.length

val words = List("when", "shall", "we", "three",
  "meet", "again")
> words: List[String] = List(when, shall, we, three,
     meet, again)

val lengths = words.map(computeLength)
> lengths  : List[Int] = List(4, 5, 2, 5, 4, 5)
```

map - Scala syntactic sugar

```
//functions are first class objects
val f = (w: String) => w.length
val list1 = words.map(f)

//anonymous function (specifying input arg type)
val list2 = words.map((w: String) => w.length)

//let compiler infer arguments type
val list3 = words.map(w => w.length)

//use positionally matched argument
val list4 = words.map(_.length)
```

Option

- NPE - NullPointerException no more!
- Used instead of null
- If something declared as Option[T]
  - Some[T] or singleton object None
- Can be treated as a collection
- Option(null) == None

flatMap

```
For List[A]

flatMap[B](f: (A) =>
    GenTraversableOnce[B]): List[B]
```

- GenTraversableOnce - List, Array, Option...
- can be empty collection or None
- flatMap takes each element in the GenTraversableOnce and puts it in order to output List[B]
- removes inner nesting - flattens
- output list can be smaller or empty (if intermediates were empty)

flatMap Example

```
val macbeth = """When shall we three meet again?
|In thunder, lightning, or in rain?""".stripMargin
val macLines = macbeth.split("\n")
// macLines: Array[String] = Array(
  When shall we three meet again?,
  In thunder, lightning, or in rain?)

//Non-word character split
val macWordsNested: Array[Array[String]] =
      macLines.map{line => line.split("""\W+""")}
//Array(Array(When, shall, we, three, meet, again),
//      Array(In, thunder, lightning, or, in, rain))

val macWords: Array[String] =
     macLines.flatMap{line => line.split("""\W+""")}
//Array(When, shall, we, three, meet, again, In,
//      thunder, lightning, or, in, rain)
```

Scala Tuples - key/value pairs

```
> val tuple = ("key", "value")
tuple: (String, String) = (key,value)

> tuple._1
res0: String = key

> tuple._2
res2: String = value

> val (key,value) = tuple
key: String = key
value: String = value

> Some(tuple)
> None
```

Spark - SparkContext

- Automatically created by shell
  - In 1.3.1. variable names: sc, sqlContext
- Or created with SparkConf for submitting a job
- input from HDFS or local file system (Hadoop API, textFile...)
- accumulator and broadcast variables
  - $\sim$ Hadoop counters/distributed cache

Spark - RDD API

- RDD API
- Transforms - map, flatMap, filter, reduce, fold...
  - Lazy evaluation (not evaluated until action! Optimizations)
- Actions - count, collect, first, take, saveAsTextFile...
- Also PairRDDFunctions, DoubleRDDFunctions, OrderedRDDFunctions

RDD Scaladocs

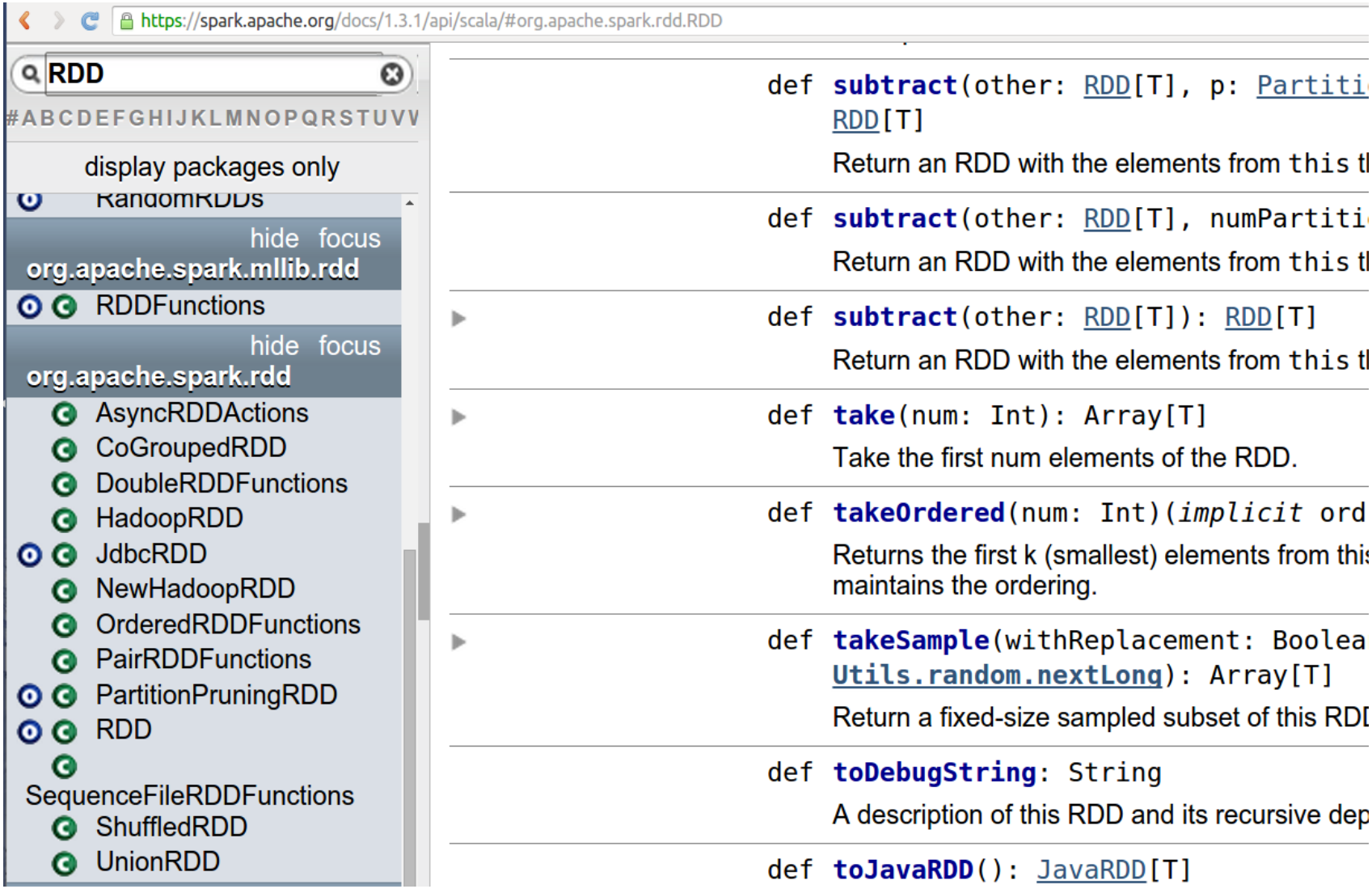

Figure : Spark RDD Scaladocs

Spark Shell - import required classes

```
scala> :paste
import org.apache.spark.rdd._
import org.apache.avro.mapred.AvroKey
import org.apache.avro.mapreduce.AvroKeyInputFormat
import org.apache.hadoop.io.NullWritable
import com.uebercomputing.mailrecord._
import com.uebercomputing.mailrecord.Implicits.mailRecordTo
import com.uebercomputing.mailparser.enronfiles.AvroMessage

Ctrl-D
```

Shell Command Completion, History, Exit

- $VAR_NAME. + TAB - shows available methods
- Up/down scroll through command history
- exit - to shut down Spark Shell

Reading enron.avro as MailRecord

```
val hadoopConf = sc.hadoopConfiguration

val mailRecordsAvroRdd =
  sc.newAPIHadoopFile("enron.avro",
  classOf[AvroKeyInputFormat[MailRecord]],
  classOf[AvroKey[MailRecord]],
  classOf[NullWritable], hadoopConf)
> RDD[(AvroKey[MailRecord], NullWritable)]
```

Convert to RDD with just MailRecords via map

```
val recordsRdd = mailRecordsAvroRdd.map {
     tuple => tuple._1.datum()
}

Or

val recordsRdd = mailRecordsAvroRdd.map {
    case(avroKey, _) => avroKey.datum()
}
> RDD[MailRecord]
```

Extract userName/folderName Tuples

```
val tupleRdd: RDD[(String,String)] =

 recordsRdd.flatMap { mailRecord =>
  val userNameOpt =
     mailRecord.getMailFieldOpt(
       AvroMessageProcessor.UserName)
  val folderNameOpt =
     mailRecord.getMailFieldOpt(
       AvroMessageProcessor.FolderName)

  if (userNameOpt.isDefined &&
    folderNameOpt.isDefined) {
    Some((userNameOpt.get,
      folderNameOpt.get))
    } else {
      None
    }
 }
```

Caching and Action

```
tupleRdd.cache()

tupleRdd.count()
tupleRdd.count()
```

Spark Web UI - Resource Manager

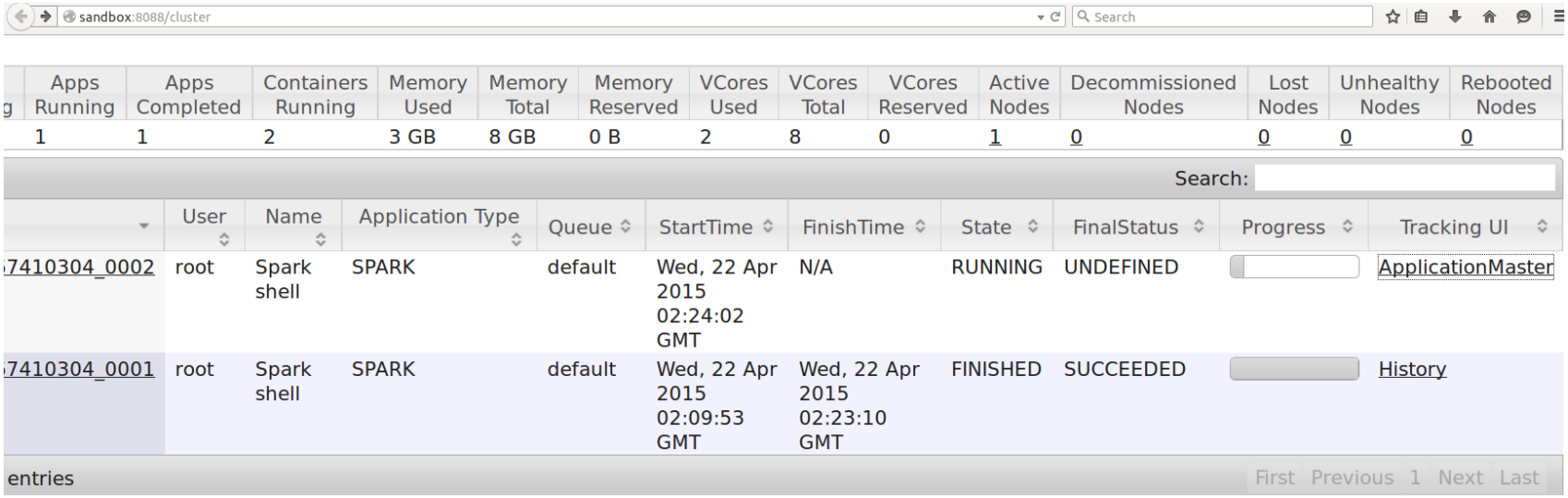

Figure : Yarn Resource Manager

Spark Web UI - Tour

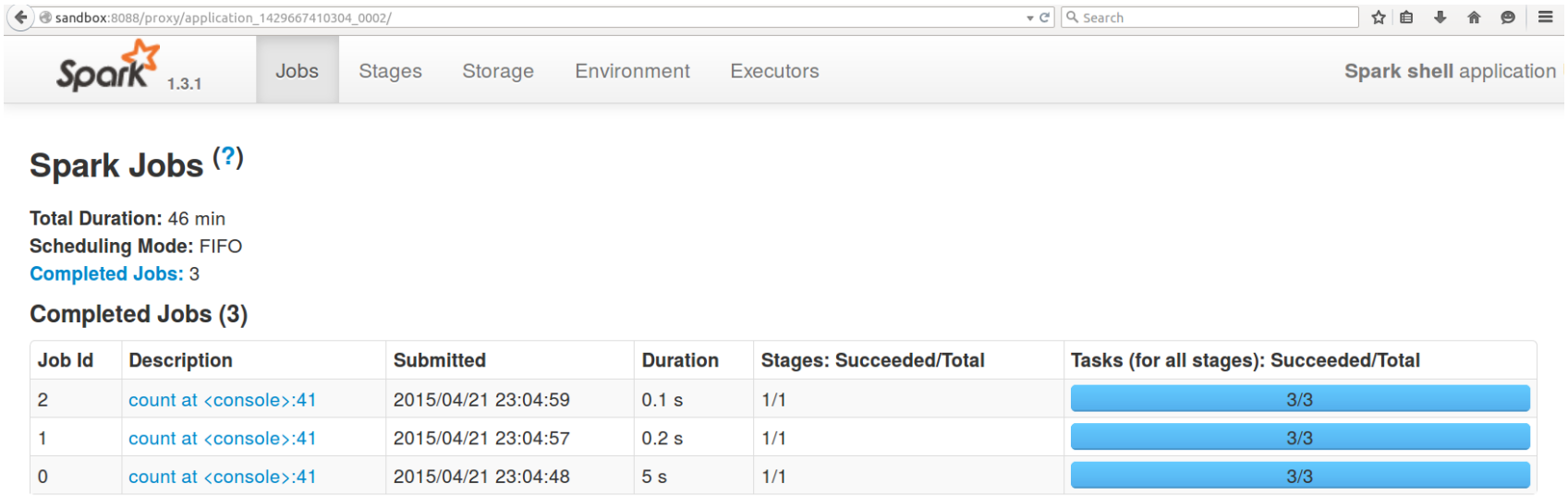

Figure : Spark Web UI

Spark - From RDD to PairRDDFunctions

- If an RDD contains tuples (K,V) - can apply PairRDDFunctions
- Uses implicit conversion of RDD to PairRDDFunctions
- In 1.3 conversion is defined in RDD singleton object
- In 1.2 and previous versions available by importing org.apache.spark.SparkContext._

From 1.3.0 org.apache.spark.rdd.RDD (object):

```
implicit def rddToPairRDDFunctions[K, V](rdd: RDD[(K, V)])
(implicit kt: ClassTag[K], vt: ClassTag[V],
  ord: Ordering[K] = null): PairRDDFunctions[K, V] = {
  new PairRDDFunctions(rdd)
}
```

PairRDDFunctions API

- keys, values - return RDD of keys/values
- mapValues - transform each value with a given function
- flatMapValues - flatMap each value (0, 1 or more output per value)
- groupByKey - RDD[(K, Iterable[V])]
  - Note: expensive for aggregation/sum - use reduce/aggregateByKey!
- reduceByKey - return same type as value type
- foldByKey - zero/neutral starting value
- aggregateByKey - can return different type
- lookup - retrieve all values for a given key
- join (left/rightOuterJoin), cogroup ...

Sets of folderNames per user

```
//pre Spark 1.3.0: import org.apache.spark.SparkContext._
import scala.collection.mutable.{ Set => MutableSet }

//mutable set - reduce object creation/garbage collection
val uniqueFoldersByUserRdd:
RDD[(String, MutableSet[String])] =
 tupleRdd.aggregateByKey(MutableSet[String]())(
    seqOp = (folderSet, folder) => folderSet + folder,
    combOp = (set1, set2) => set1 ++ set2)
> RDD[(String, Set[String])] = ShuffledRDD
```

Just the Set Size please

```
val foldersPerUserRdd: RDD[(String, Int)] =
  uniqueFoldersByUserRdd.mapValues { set => set.size }
> RDD[(String, Int)]
```

Exploring a data set

```
>foldersPerUserRdd.first()
res7: (String, Int) = (beck-s,135)

//WARNING: Brings it all back to driver!
>foldersPerUserRdd.collect()

>foldersPerUserRdd.count()
>foldersPerUserRdd.take(3)

>foldersPerUserRdd.max()(Ordering.by(_._2))
res11: (String, Int) = (kean-s,193)

>foldersPerUserRdd.min()(Ordering.by(_._2))
res12: (String, Int) = (harris-s,2)

> foldersPerUserRdd.sample(false, 0.1)
```

From RDD to DoubleRDDFunctions

- From API docs: "Extra functions available on RDDs of Doubles through an implicit conversion."
- mean, stddev, stats (count, mean, stddev, min, max)
- sum
- histogram ...

DoubleRDDFunctions - Stats

```
val folderCounts: RDD[Int] =
   foldersPerUserRdd.values

val stats = folderCounts.stats()
> stats: org.apache.spark.util.StatCounter =
(count: 40, mean: 30.050000, stdev: 37.856935,
 max: 193.000000, min: 2.000000)

//buckets 0-25, 25-50 etc.
val buckets = Array(0.0,25,50,75,100,125,150,175,200)
folderCounts.histogram(buckets, evenBuckets=true)
res21: Array[Long] = Array(26, 5, 6, 1, 0, 1, 0, 1)
```

RDD Lineage - transformations

```
folderCounts.toDebugString
> res18: String =
(22) MappedRDD[27] at values at <console>:35 []
|   MappedValuesRDD[26] at mapValues at <console>:33 []
|   ShuffledRDD[25] at aggregateByKey at <console>:31 []
+-(22) FlatMappedRDD[2] at flatMap at <console>:26 []
|       CachedPartitions: 22; MemorySize: 76.3 MB;
         TachyonSize: 0.0 B; DiskSize: 0.0 B
|   MappedRDD[1] at map at MailRecordAnalytic.scala:48 []
|   NewHadoopRDD[0] at newAPIHadoopRDD at
         MailRecordAnalytic.scala:94 []
```

Hadoop InputFormats - Minimize object creation!

- WARNING: Hadoop InputFormats generally reuse the key/value objects
- Same with AvroKeyInputFormat
- Generally, not a problem if you just map out the fields you need (getFrom etc.)
- However, if you want to cache the whole MailRecord you need to copy the original:

```
val mailRecordsRdd = mailRecordsAvroRdd.map {
  case (mailRecordAvroKey, fileSplit) =>
    val mailRecord = mailRecordAvroKey.datum()
    //make a copy - MailRecord gets reused!!!
    MailRecord.newBuilder(mailRecord).build()
  }
```

Learning Resources

- https://github.com/medale/spark-mail
- https://github.com/medale/spark-mail-docker
- O'Reilly: Learning Spark, Advanced Analytics with Spark
- EdX: 2 Spark ML MOOCs summer 2015
- Coursera: 2 Scala MOOCs by Martin Odersky
- Databricks: https://databricks.com/spark/developer-resources

Questions?

Backup Slides

Hadoop Mapper

```
public void map(AvroKey<MailRecord> key,
NullWritable value,
Context context) throws ... {
  MailRecord mailRecord = key.datum();
  Map<String, String> mailFields =
  mailRecord.getMailFields();
  String userNameStr = mailFields.get("UserName");
  String folderNameStr = mailFields.get("FolderName");
  if (userNameStr != null && folderNameStr != null) {
    userName.set(userNameStr);
    folderName.set(folderNameStr);
    context.write(userName, folderName);
  }
}
```

Hadoop Reducer - reduce

```
public void reduce(Text userName,
Iterable<Text> folderNames,
Context context) throws ... {
  Set<String> uniqueFoldersPerUser = new HashSet<String>();
  for (Text folderName : folderNames) {
    uniqueFoldersPerUser.add(folderName.toString());
  }
  int count = uniqueFoldersPerUser.size();
  if (count > maxCount) {
    maxCount = count;
    maxUserName = userName.toString();
  }
  if (count < minCount) {
    minCount = count;
  }
  totalNumberOfFolders += count;
  totalUsers++;
}
```

Hadoop Reducer - cleanup

```
@Override
public void cleanup(Context context) throws ... {
  double avgFolderCountPerPartition =
  totalNumberOfFolders / totalUsers;

  String resultStr = "AvgPerPart=" +
  avgFolderCountPerPartition +
  "\tTotalFolders=" +
  totalNumberOfFolders +
  + "\tTotalUsers=" +
  totalUsers +
  "\tMaxCount=" +
  maxCount +
  "\tMaxUser=" + maxUserName +
  "\tMinCount=" + minCount;
  Text resultKey = new Text(resultStr);
  context.write(resultKey, NullWritable.get());
}
```

Hadoop Driver

```
FileInputFormat.addInputPath(job, new Path("enron.avro"));
FileOutputFormat.setOutputPath(job,
  new Path("folderAnalytics"));

job.setInputFormatClass(AvroKeyInputFormat.class);
job.setMapperClass(FolderAnalyticsMapper.class);
job.setReducerClass(FolderAnalyticsReducer.class);

job.setNumReduceTasks(1);
AvroJob.setInputKeySchema(job,
MailRecord.getClassSchema());

job.setMapOutputKeyClass(Text.class);
job.setMapOutputValueClass(Text.class);

job.setOutputFormatClass(TextOutputFormat.class);
```

References I

Cutting, Doug. 2009. “Apache Avro.” `http://avro.apache.org/`.

Ecosystem. 2015. “Databricks Spark Ecosystem.” `https://databricks.com/spark/about`.